INDIA

Third National Communication

and

Initial Adaptation Communication

to The United Nations Framework Convention on Climate Change

सत्यमेव जयते

India

Third National Communication
and
Initial Adaptation Communication

प्रकृतिः रक्षति रक्षिता

Nature Protects if She is Protected

Ministry of Environment, Forest and Climate Change
Government of India

India

Third National Communication and Initial Adaptation Communication

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भारत सरकार

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR & EMPLOYMENT
GOVERNMENT OF INDIA

सत्यमेव जयते

स्वच्छ भारत
एक कदम स्वच्छता की ओर

भूपेन्द्र यादव
BHUPENDER YADAV

आज़ादी का अमृत महोत्सव

MESSAGE

India is pleased to submit its Third National Communication (TNC) to the United Nations Framework Convention on Climate Change (UNFCCC). This onerous task has been accomplished on account of the considerable efforts of our Scientists, Scholars and officials from the Ministry of Environment, Forest and Climate Change (MoEFCC) as well as from the other Central Ministries, Organizations and Departments. The TNC is testimony of our commitment to the responsibilities under the Convention and its agreements and protocols.

The striking feature of India's national circumstances, as indeed for most of the developing world, is that the remaining carbon budget is only one-fifths of the total carbon budget for 1.5 degrees and one-third of the total carbon budget for 2°C. On the other hand, India has consumed less than 4 per cent of the four-fifths of the global carbon budget that has been already consumed so far.

Nevertheless, India is committed to doing its utmost to combat the challenge of global warming. The facts, data, and analysis assembled by our Scientists and Officials in this Report present in detail our efforts in this direction. The information and analysis presented here provides to the global community the scientific foundations and rigorous assessment of our climate policies. The TNC demonstrates why India is a leader in climate action and one of the few nations on track to achieve its Nationally Determined Contribution (NDC) targets submitted as part of the fulfillment of its obligations under the Paris Agreement.

As a megadiverse country, with a variety of landscapes and ecosystems, spanning different climatic zones, India is already witnessing the impact of climate change, impacts that are described in some detail in this report. These impacts are the consequence of global warming due to historical cumulative emissions. The average global temperature has already risen to more than two-thirds of the way to 1.5°C to 1.1°C. The burden of adaptation is an immense one, falling disproportionately on the vast majority in our country, and on the developing world, who have contributed far less to the problem than the developed nations.

It is in this context that India has always called for equitable access to and sharing of global carbon space. To enable this equitable sharing, the developed countries, having disproportionately consumed the carbon budget, need to vastly increase their ambition in emissions reduction, and reach net zero well before their current target years and in fact,

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achieve negative emissions so as to provide the requisite carbon space to the developing countries including India.

The TNC spells out how India is sparing no effort for the upscaling of renewable energy resources. Relative to its responsibility and relative to what equity demands, India is contributing far more than its fair share in emission reduction. Further, in international cooperation, apart from championing and safeguarding the tenets of multilateralism, India is hosting, supporting and nurturing the International Solar Alliance (ISA) and the Coalition for Disaster Resilient Infrastructure (CDRI) as a part of its commitment towards reducing emissions and towards strengthening its adaptation efforts. This international partnership of National Governments, UN agencies, Multilateral Development Banks, the Private Sector, and Knowledge Institutions will promote the resilience of new and existing infrastructure systems to growing climate risks and disasters.

India's achievements in climate action have been largely through its own financial and human resources, that can certainly be enlarged in scope and extended further if financial assistance, technology transfer and capacity building needs are met. The developed countries must walk their talk and live up to their responsibilities and commitments under the Convention reiterated from time to time, even as developing countries are doing their utmost to cope with the challenges that global warming has thrust on them. As has been very aptly stated by Hon'ble Prime Minister, Shri Narendra Modi while launching Mission LiFE (Lifestyle for Environment) that there is a need to move away from the path of mindless and destructive consumption and production towards mindful and deliberate utilization of resources. We have to involve each and every citizen in combating climate change if we have to turn LiFE into a successful Global Mass Movement. As part of our International obligation and following the procedure laid down in Article 711 of the Paris Agreement, TNC also carries a special Annexure on India's Adaptation Communication which gives details of Adaptation measures undertaken by India.

I compliment all the Scientists and officials from the different Institutions and Ministries, Departments and Organizations who have put together this Third National Communication and Initial Adaptation Communication.

Date: 25 11.2023

(Bhupender Yadav)

अश्विनी कुमार चौबे
Ashwini Kumar Choubey

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
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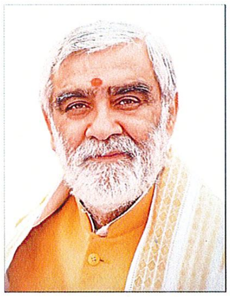

Message

At the 26th Conference of Parties (COP26) of the UNFCCC held at Glasgow, UK; The Hon'ble Prime Minister Shri Narendra Modi ji expounded India's 'Panchamrit' or Five Nectar Elements of Climate Action.' The Panchamrit envisaged, inter-alia, India to achieve Net Zero Emissions by 2070. Alongside these five elements, India also announced LiFE – Lifestyle for the Environment as Global Pro-Planet-People (P3) Movement that calls for a paradigm shift from mindless and destructive consumption to mindful and deliberate utilisation.

India's Third National Communication (TNC) and First Adaptation Communication (AdCom) to the United Nations Framework Convention on Climate Change (UNFCCC) enumerates as series of significant and pivotal developments in India's climate policy. The looming dangers of climate change and its repercussions has precipitated primarily due to excessive consumption pattern of the developed nations who have been devouring disproportionate share of historical carbon budget. It has become imperative that these countries follow, in letter and spirit, the message of LiFE – a Global Mass Movement led by India, at the very individual level.

India's efforts towards greening its various sectors of economy has been notable and palpably impactful. The nation is working towards increasing the ratio of the bio-fuel blend in petrol and diesel, which 'National Hydrogen Mission' has been launched to contribute to clean transport, as well as for providing substitute for fossil fuels in a plethora of other economic activities. Out commendable efforts has stabilised, protected and enhanced our forest cover and tree covers while increasing our carbon stock. Further, our Forests and Tree Cover offsets approximately 20% of the country's total CO_2 emissions.

However, to effectively deal with this mammoth challenge, a collaborative and profoundly synchronised effort of the entire globe is necessary. Without the developed countries making aggressive and sincere efforts for accelerating their emissions reduction, which falls short since

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1990, the world cannot attain the Paris Agreement goals. Further, Technological and financial support, which was promised, must be delivered to the developing countries, especially the much-looked-forward to first stage of USD 100 billion of climate finance annually.

India's response to the challenge of global warming has always been based on the principles of equity and common but differentiated responsibilities and respective capabilities and the need for enhanced means of implementation, including climate finance, technology transfer and capacity-building support, from developed countries in accordance with their obligations and commitments under the UNFCCC and its Paris Agreement.

The TNC provides a detailed view of the plethora of initiatives which India has been undertaking with profuse enthusiasm and a crystal-clear vision to tackle this extremely sensitive issue of climate change – a problem which has been in its genesis, a heavily disproportionate emissions of a few developed countries. It also underlines the perils of climate change which India is already experiencing, despite its minimal contribution to the 1.1-degree rise in Global Average Temperature above pre-industrial times. I extend my heartiest congratulations to the dedicated team of Scientists, Experts and Officials on preparing such an exhaustive and meticulous document which serves so well in fulfilling our international obligations.

(Ashwini Kumar Choubey)

लीना नन्दन
LEENA NANDAN

सत्यमेव जयते

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SECRETARY
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& CLIMATE CHANGE

Foreword

It is indeed a pleasure to present India's Third National Communication (TNC) and First Adaptation Communication (AdCom) to the United Nations Framework Convention on Climate Change (UNFCCC)

Climate change is a challenge that all of humanity and, in fact, Planet Earth, are facing today. Despite not being part of the problem, India has undertaken consistent and meaningful steps to combat climate change. These impactful initiatives encompass both mitigation and adaptation measures.

India's TNC is an organic continuation of the earlier declarations and submissions on climate policy. This volume is a comprehensive document that covers climate initiatives, with the foundational chapter being the greenhouse gas emissions inventory. India is committed to the principles of climate justice and equity, specifically, access to its fair share of the global carbon budget.

The Adaptation communication submitted as an Annexure to the TNC captures the essential aspects of adaptation and the linkages between adaptation and mitigation. As has been brought out, substantial access to the means of implementation are key for decisive climate action. The country's adaptation burden is high, with the vast majority of those rendered vulnerable by climate change having contributed next to nothing by way of cumulative emissions. The AdCom will provide useful inputs for researchers and policymakers in developing an enhanced understanding of India's adaptation priorities and challenges.

The TNC clearly demonstrates how India has progressively continued decoupling of its economic growth from greenhouse gas emissions. We are a nation mindful of our global responsibilities, and this document underscores the fact that the country's focus is on growth, which is both responsible and sustainable.

I compliment the efforts of all those involved in the preparation of India's Third National Communication and First Adaptation Communication to the UNFCCC, for their diligent and painstaking endeavours.

Date: Nov.28,2023

(Leena Nandan)

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GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE

Preface

India, as a Party to the United Nations Framework Convention on Climate Change (UNFCCC), is required to periodically communicate relevant information on the implementation of the Convention as part of its International Obligation.

Accordingly, India has submitted to the UNFCCC its Initial National Communication in 2004, the Second National Communication in 2012, the first Biennial Update Report in 2016, the Second Biennial Update Report in 2018, and the Third Biennial Update Report in 2021. In continuation of these and based on the policy vision of India's Long-Term Low-Carbon Development Strategy submitted at the 27th Conference of Parties (COP27) and inspired by Hon'ble Prime Minister Narendra Modi's vision of Mission LiFE-Lifestyle for Environment, the Third National Communication or TNC has been prepared.

TNC comprises information provided through six chapters: i) National Circumstances, ii) National Greenhouse Gas (GHG) Inventory, iii) Mitigation actions, iv) Impacts, Vulnerability and Adaptation, v) Research and Systematic Observation, and vi) Finance, Technology and Capacity Building Needs and Support Received, together with an initial chapter on the institutional arrangements for the preparation of the TNC. The TNC also includes India's First Adaptation Communication (AdCom) as an Annexure.

The contributions of more than 100 Scientists from a number of institutions, with more than 100 studies and contributions from 28 Ministries/ Departments have underpinned the preparation of this TNC. Additionally, distinguished experts from Institutions, both in Government and private sector, including academic and research institutions, civil society organizations have peer-reviewed the output.

It may be seen from the chapter on GHG inventory that India emitted 3,132 million tonne CO2e (excluding LULUCF) and 2,647 million tonne CO2e (including LULUCF) in 2019. However, India's per capita GHG emission is of the order of only 2 tonnes CO2e, which is considerably lower than the world average of 6.5 tonnes CO2e and the emissions of many other countries, both developed and developing. Our forest and tree cover removed about 20 per cent of total CO2 emissions.

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India has been conscious of its responsibilities while moving ahead on the path of growth and development. The emissions intensity of India's Gross Domestic Product (GDP) has reduced by 33 per cent over the period of 2005 – 2019 due to its continued effort in decoupling its economic growth from GHG emissions. This has been made possible by a strong political determination for climate action leading to a wide range of initiatives, policies, programmes and measures for mitigation and their implementation. The entire range of efforts for mitigation are aptly captured in the chapter on mitigation actions. It is this scale of efforts that has enabled India to update its Nationally Determined Contribution (NDC) in 2022 and make it more ambitious.

To fulfil its obligations under the Paris Agreement, to overcome the lack of access to physical carbon space and to meet the needs of growing ambition in mitigation and adaptation due to the lack of commitment of the developed countries; India requires enhanced new, additional, and climate specific finance, alongside requisite technology transfer and capacity building support. Climate change is a global action problem. Enhanced action and support is the way forward to address the challenges of increasing warming, which is now affecting each one of us. The sixth chapter presents an account of the support received and the needs and gaps in climate finance and technology transfer.

I take this opportunity to express our gratitude to Hon'ble Minister as well as to Minister of State for Environment, Forest and Climate Change, and specially to Secretary, Environment, Forest and Climate Change for providing continued guidance and support to the entire team in the preparation and finalization of this communication. I would also like to compliment the entire team of Scientists, experts, and institutions and the officials for their involvement and painstaking efforts in preparing this informative communication which is an important milestone in fulfilling our international commitment.

Date: 30.11.2023

(Tanmay Kumar)

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EXECUTIVE SUMMARY

1. Background

1.1 India is a Party to the UNFCCC (United Nations Framework Convention on Climate Change). The objective of the Convention is to achieve, in accordance with the relevant provisions of the Convention, stabilization of Greenhouse Gas (GHG) concentration in the atmosphere at a level that would prevent alarming anthropogenic interference with the climate system. The Convention came into force on 21st March, 1994.The Convention, in accordance with its Articles 4.1 and 12.1, enjoins upon all Parties, both developed Country Parties and developing Country Parties, to furnish information, in the form of a National Communication regarding the implementation of the Convention. The Communications are furnished in accordance with the decisions and guidelines adopted by the Conference of Parties (COP) – the supreme body of the Convention.

1.2 Similarly, paragraph 10 of Article 7 of the Paris Agreement calls for submission and periodic updation of an Adaptation Communication which may be submitted as a component of a National Communication mentioned in paragraph 11 of the Paris Agreement. Accordingly, the TNC also includes National Adaptation Communication as an Annexure.

1.3 The scope of the contents of the Third National Communication (TNC) is circumscribed by Article 12 of the UNFCCC which provides for communication of information related to implementation of reporting requirements.

1.4 India submitted its initial National Communication to UNFCCC on 22nd June, 2004 after approval by the Cabinet in June, 2004 which contained the GHG inventory of 1994. The second National Communication was submitted to the UNFCCC on 4th May, 2012, consequent upon the approval of the Cabinet on 12thApril 2012 which contained the GHG inventory of 2000. Further, pursuant to the decision 1 of 16th Session of COP, India submitted its first Biennial Update Report (BUR) to the UNFCCC on the 22nd January, 2016 consequent upon the approval of the Cabinet on 22ndDecember, 2015, which contained the GHG inventory of 2010. The second BUR was submitted to the UNFCCC on the 31stDecember, 2018 consequent upon the approval of the Cabinet on 27th December, 2018 and this contained the GHG inventory of 2014.The third BUR was submitted to the UNFCCC on the 20th February 2021consequent upon the approval of the Cabinet on 27th January, 2021 and which contained the GHG inventory of 2016. Now, India is furnishing its third National Communication (TNC) to UNFCCC which includes a chapter on the GHG inventory of 2019.

2. Introduction

2.1 The area of India is almost 2.3% of the world's land area. It is the 7th largest country in the world and it is home to one-sixth of the world's humanity. To meet the needs of one-sixth of the humanity is the foremost priority of the Government of India. This poses its own challenges before the Nation to be able to maintain a sustainable development pathway and to harness its resources efficiently.

2.2 India played an active part in the drafting and signing of the UNFCCC, the Climate Convention and India is a Party to the United Nations Framework Convention on Climate Change (UNFCCC). The Convention aims at stabilizing the Greenhouse Gas (GHG) concentrations in the atmosphere at safer levels that would prevent alarming anthropogenic interference with the climate system. Eradication of poverty, ensuring that the food production is not threatened, and sustainable development are three integrated principles deeply embedded in the Convention. Information provided in the present national communication is according to the guidelines stipulated for Parties not included in Annex I to the UNFCCC. India, situated below the Himalayas and lying in the sub-tropical terrain, is adorned with a largely diverse topography, climate and biosphere, spanning a geographical area of 3.28 million km^2. India shelters over 1.4 billion people representing various socio-cultural groups that collectively constitute the world's largest democracy.

3. Institutional Arrangement and structure for Preparation of TNC

3.1 The Ministry of Environment, Forest and Climate Change (MoEFCC) is the executing and implementing agency for the preparation of the National Communication. The Communication has been prepared in association with several expert/research organizations and with inputs from concerned Ministries/Departments of Government of India.

3.2 The Third National Communication (TNC) is based on the outputs of the different studies assigned to various institutes and extensive inputs from various Government Departments and Ministries. It contains information on seven major components namely, (i) National Circumstances, (ii) National Greenhouse Gas Inventory, (iii) Mitigation Actions, (iv) Impacts, Vulnerability and Adaptation (v) Research and Systematic Observations, and (vi) Finance, Technology and Capacity Building Needs and Support received for the same, and includes National Adaptation Strategies, Policies and Programmes as an Annexure.

4. National Circumstances

This section covers description of national and regional development priorities, objectives and circumstances on the basis of which India will address climate change and its adverse impacts.

4.1 The mainland of India extends between 68°7′E to 97°25′E and 8°4′N to 37°6′N. With a total land area of over 3.28 million square kilometres, it is the seventh-largest country in the world. Population growth and higher population density can exacerbate the challenges of ensuring that future development is sustainable and inclusive.

4.2 As a consequence of such diverse geographic and climatic conditions, there are at present 15 agro-climatic zones in India- Western Himalayan, Eastern Himalayan, Lower Gangetic plains, Middle Gangetic Plains, Upper Gangetic Plains, Trans Gangetic Plains, Eastern Plateau and Hills, Western Plateau and Hills, Central Plateau and Hills, Southern Plateau and Hills, East Coast Plains and Hills, Gujarat Plains and Hills, West Coast Plains and Hills, Western Dry Region, and Islands.

4.3 As described above, a wide range of spatial and seasonal variations of weather and climatic patterns exist in India. Extreme conditions of heat waves, thunderstorms, and cold waves are also experienced across different regions in the Country.

4.4 **Salient features:**

4.4.1 Annual mean temperature of India has increased between 1901-2022. The increasing trend is more significant for maximum temperatures (1.0°C/ 100 years) than minimum temperatures. The past 10 years (2012-2021/ 2013-2022) were the warmest decade on record since 1901; with temperature anomalies being 0.37°C/ 41°C above average. Out of the past 15 years (2008-2022), 11 were the warmest years in India on record since 1901.

4.4.2 The IMD report on Observed Monsoon Rainfall Variability and Changes indicates that, between 1989-2018, there was a significant decreasing trend in the Southwest Monsoon rainfall for the states of Uttar Pradesh, Bihar, West Bengal, Meghalaya and Nagaland. Consequently, annual rainfall over these States have declined. Several Districts in the Country show significant changes in southwest monsoon and annual rainfall patterns in this period. Heavy rainfall days have increased in parts of Gujarat (Kutch and Saurashtra), Rajasthan (South eastern parts), Tamil Nadu (Northern parts), Andhra Pradesh (Northern), Odisha (southwest), and parts of West Bengal, Manipur & Mizoram, Konkan & Goa and Uttarakhand.

4.4.3 Extreme precipitation and flooding events have affected several parts of India in recent years (2020 and 2021). These floods were caused by heavy precipitation, as well as events such as glacier breaks and flash floods, and avalanches. These events caused the loss of lives, massive damage to crops, public infrastructure, and private property across several districts in India. As per study by NRSC/ISRO, over the last 4 years, the number of States affected by major floods has increased from 8 States in 2017 to 15 States in 2021.

4.4.4 Existing analysis of trends in heavy rainfall and flooding indicate that their frequency is increasing in some parts of India that include the peninsular, east, north-east, and some parts of central India. Apart from the extreme events mentioned above, various regions experienced shocks due to snowfall, lightning, thunderstorms, hailstorms and dust storms between 2019 and 2021.

4.4.5 In terms of monitoring and adapting to these events, several key capacity building measures have been implemented. These include the development of spatial flood early warning models using very high-resolution Digital Terrain Models, and the Rapid Response and Emergency Services/Decision Support Centre (RRES/DSC) at NRSC/ISRO. In terms of analysing vulnerability across different regions of India, a unified framework for assessment was developed as a part of the report on "Climate Vulnerability Assessment for Adaptation Planning in India". The report indicates high vulnerability of southern and Eastern zones of India to extreme cyclonic events, floods, and droughts combined. Further, the report identifies the western and southern regions of India as being extremely vulnerable to agricultural droughts and indicates that northern, eastern, and central zones are moderately vulnerable to both meteorological and agricultural droughts.

4.4.6 India recognizes the fact that adaptation is imperative for its development process and has been undertaking several efforts to increasingly mainstream adaptation efforts while furthering developmental requirements through a range of schemes/ projects/ programmes of several Ministries.

4.4.7 The objective of achieving a sustainable transition to improve the living and working conditions of all its citizens guides India's policies. These goals are sought to be achieved by striking a balance between ecological and environmental conservation and protection on the one hand and sustainable economic growth and development on the other. India's international efforts to combat climate change, inter alia, include formation of International Solar Alliance (ISA), Coalition of Disaster Resilient Infrastructure (CDRI), creation of LeadIT, Big Cat Alliance and such other initiatives as well as roll out of programmes and policies related to affordable housing, waste management and circular economy, conservation of water as well as providing adequate infrastructure are some examples of such a holistic approach.

4.4.8 India's energy consumption is well below developed countries. Energy consumption in India is characterized by low per capita level and a large disparity between urban and rural areas. Energy intensity in India (energy consumed per unit of GDP (2011-12 prices)) decreased to 0.2245 Mega Joules / Rupee (MJ/Rupee) in 2021-22 from 0.2801 MJ/Rupee in 2012-13. In 2021-22 primary energy supply added up to 739.386 million tonne of oil equivalent (Mtoe). India's per capita energy consumption in 2021-22 stood provisional outlay at 24,453 MJ/person.

4.4.9 The installed capacity of electricity generation stood at 4,16,058.89 MW as of 31st March 2023. India's growing energy needs are undeniable. The country is making strong efforts to increase the share of installed electric power capacity from non-fossil sources and an environmentally sustainable and low carbon mining operations of energy minerals.

4.4.10 India's emissions are likely to increase in line with growing energy demand and overall development, eventually reaching the envisioned goal of net-zero emissions in 2070. It is very clear that India's energy needs for development, which are substantial, cannot be deferred.

4.4.11 India has abundant coal reserves which meets most of its requirement for energy in infrastructure, housing, transport sectors whereas more than 80% requirement for oil and natural gas is met through imports. India's reliance on coal is critical to its energy security in the background of the relative paucity of oil and natural gas of domestic origin.

4.4.12 The transportation sector consisting of infrastructure for transport as well as its effective and sustainable management are key to building capacities for improved sustainable development and long-term adaptation strategies. This sector is also a significant source of emissions. In relation to climate change, transportation by road and air are the most significant segments of this sector.

4.4.13 Road transport is the dominant mode of goods and passenger transport in India. The total length of highways in the country has more than doubled from 57,737 Km in 2001 to 1,44, 955 Km in 2022; the total number of registered vehicles has increased by about 6 times within the last two decades. The Total Fuel Consumption (TFC) by the transport sector in India has more than doubled in ten years, more than tripled since 2000 and stands at 94 Mtoe or 17% of TFC in 2017. With a view to addressing this challenge, and to abate vehicular emission, the GoI has subscribed to BS-VI emissions standards for new vehicles. India has leapfrogged one stage of emission norms, moving from BS-IV to BS-VI displaying its commitment of protecting the environment.

4.4.14 India's Long-Term Low-Emissions Development Strategy (LT-LEDs), as per Article 4, Para 19 of the Paris Agreement, was submitted to the UNFCCC in COP 27 at Sharm-El-Sheikh in November 2022 and by doing so, India joined a select group of 68 out of 198 countries, who have submitted their LT-LEDs. It is to be noted that agriculture is not included in LT-LEDs, given its predominantly adaptation-related character; especially in the context of India's agriculture which has predominance of small and marginal farmers. The absence of large-scale or "industrial agriculture" in India indicates that the burden of mitigating GHG emissions from other sectors cannot be passed on to the agricultural sector.

4.4.15 The TNC brings out the efforts undertaken by different sectors of the economy in reducing the emission intensity and in decoupling the economic growth from GHG emissions through the use of modern technologies and innovative techniques and by pursuing policies that promote efficiency, equity and resilience which form the core values of 'Atmanirbhar Bharat'. Shift towards cleaner fuels and behavioral changes to move towards sustainable production and consumption are also helping in reducing emission intensity.

4.5 Third National Communication (TNC), while listing what has been achieved so far, also indicates the direction in which India's efforts are aimed for the future in the climate change arena. The Communication illustrates how these efforts can be fully aligned to the five pillars of the Atmanirbhar Bharat Abhiyan.

5. National GHG Inventory

This section provides an overview of national inventory of anthropogenic emissions by sources and removals by sinks of all Greenhouse Gases (GHGs)

5.1 The national GHG inventory has been proposed in accordance with the updated guidelines 17/CP.8 intended for reporting National Communications (NCs) from Non-Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC), as required by UNFCCC guidelines for NCs preparation. The update is in line with reporting capacities, deadlines, data accessibility, and reporting support levels.

5.2 The chapter on National GHG Inventory provides a thorough explanation of the Greenhouse Gas inventory for the year 2019, which includes information on the sources and sinks of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) emissions. Energy, Industrial Processes and Product Use (IPPU), agriculture, Land use, Land-Use Change and Forestry (LULUCF), and waste are among the sectors covered.

5.3 **Salient Features**

5.3.1 In 2019, India's total GHG emissions excluding LULUCF amounted to 3,132 $MtCO_2e$ and including LULUCF amounted to 2,647 $MtCO_2e$. Total national emissions (including LULUCF) have increased by 4.56 percent with respect to 2016 and by 115.42 percent since 1994.

5.3.2 The energy sector contributed the most to the overall emissions with 75.81 per cent, followed by agriculture sector 13.44 percent, Industrial Processes and Product Use (IPPU) by 8.41 percent and Waste by 2.34 per cent.

5.3.3 In 2019, total anthropogenic emissions were estimated for GHGs (as mentioned in Decision 17/CP.8 of UNFCCC) – Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbon (HFC), Perfluorocarbons which include Carbon Tetrafluoride (CF_4), Hexafluoroethane (C_2F_6) and Sulfur hexafluoride (SF_6). For the same year, emissions of CO_2 accounted for 24,89,043 Gg (79 per cent); CH_4 emissions accounted for 4,09,127 $GgCO_2e$ (13.06 per cent) and N_2O emissions accounted for 1,61,841 $GgCO_2e$ (5.17 per cent). In the case of fluorinated gases, emissions of HFC was 27,949 $GgCO_2e$ (0.89 per cent), CF_4 emissions 31,749 $GgCO_2e$ (1 per cent), C_2F_6 emissions 12,219 $GgCO_2e$ (0.39 per cent) and SF_6 emissions 100 $GgCO_2$. Emissions by gas as mentioned above total up to 31,320,28 $GgCO_2e$ which is the gross GHG emissions for India for the year 2019.

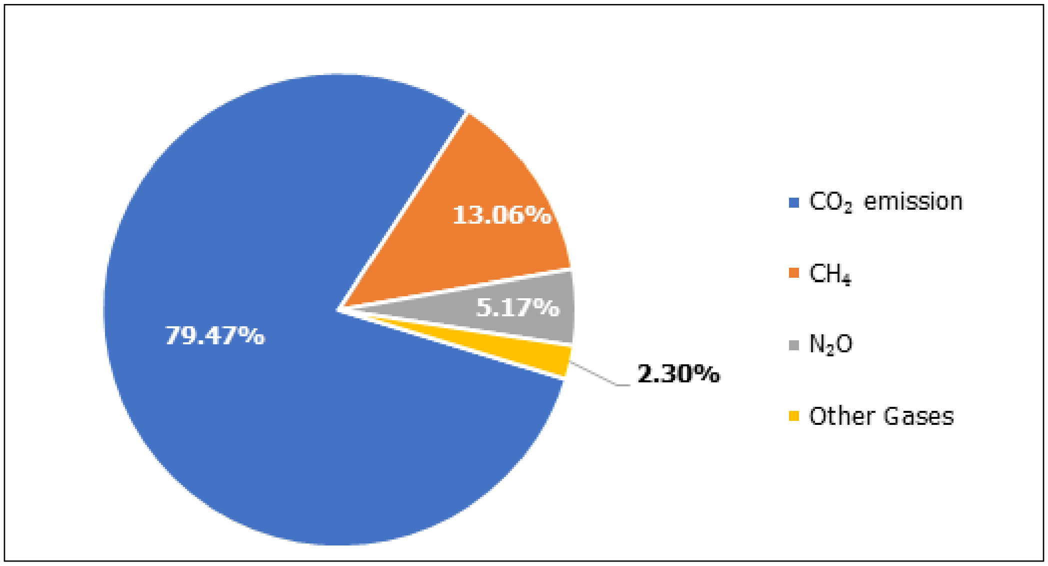

Figure 1: Gas-wise emissions for the year 2019

5.3.4 As mentioned in the preceding paragraph, 31,320,28 Gigagram (Gg) of CO_2e (Carbon dioxide equivalent) (or 3.1 billion tonnes of CO_2e) of GHGs emission was contributed by sectors such as from Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste. Land use, Land-Use Change and Forestry (LULUCF) sector remained a net sink in 2019, accounting for the removal of 4,85,472 GgCO_2e of emissions. Considering total emissions and removals, net national emissions in 2019 was 26,46,556 GgCO_2e (or 2.6 billion tonnes of CO_2e). The status of GHG emissions since 1994 is indicated in the table below:

Table 1: Status of GHG emissions from 1994-2019

BUR/National Communication (Year of Submission)	Inventory Year	Gross Emissions (without LULUCF) (Million tonnes of CO_2 equivalent)	Net Emissions (With LULUCF) (Million tonnes of CO_2 equivalent)
Initial National Communication (2004)	1994	1214	1229
Second National Communication (2012)	2000	1524	1301
First Biennial Update Report (2016)	2010	2137	1884
Second Biennial Update Report (2018)	2014	2607	2306
Third Biennial Update Report (2021)	2016	2839	2531
Third National Communication	2019	3132	2647

5.3.5 The Energy sector, which includes the consumption of fossil fuels in the Country and their associated fugitive emissions, is the main GHG emitting sector in the Country, contributing to 75.81 per cent of the total GHG emissions in 2019 (excluding LULUCF). The total emissions from the energy sector were 23,74,330 Gg CO_2e in 2019, increasing by 11.5 per cent since 2016, mainly due to the steady increase in the Country's energy consumption, including the consumption of coal and natural gas for power generation and the consumption of liquid fuels for transportation.

5.3.6 Consistent time series information of the GHG inventory starting from the last (second) national communication (inventory year 2000) to 2019 has been presented in the form of a bar chart:

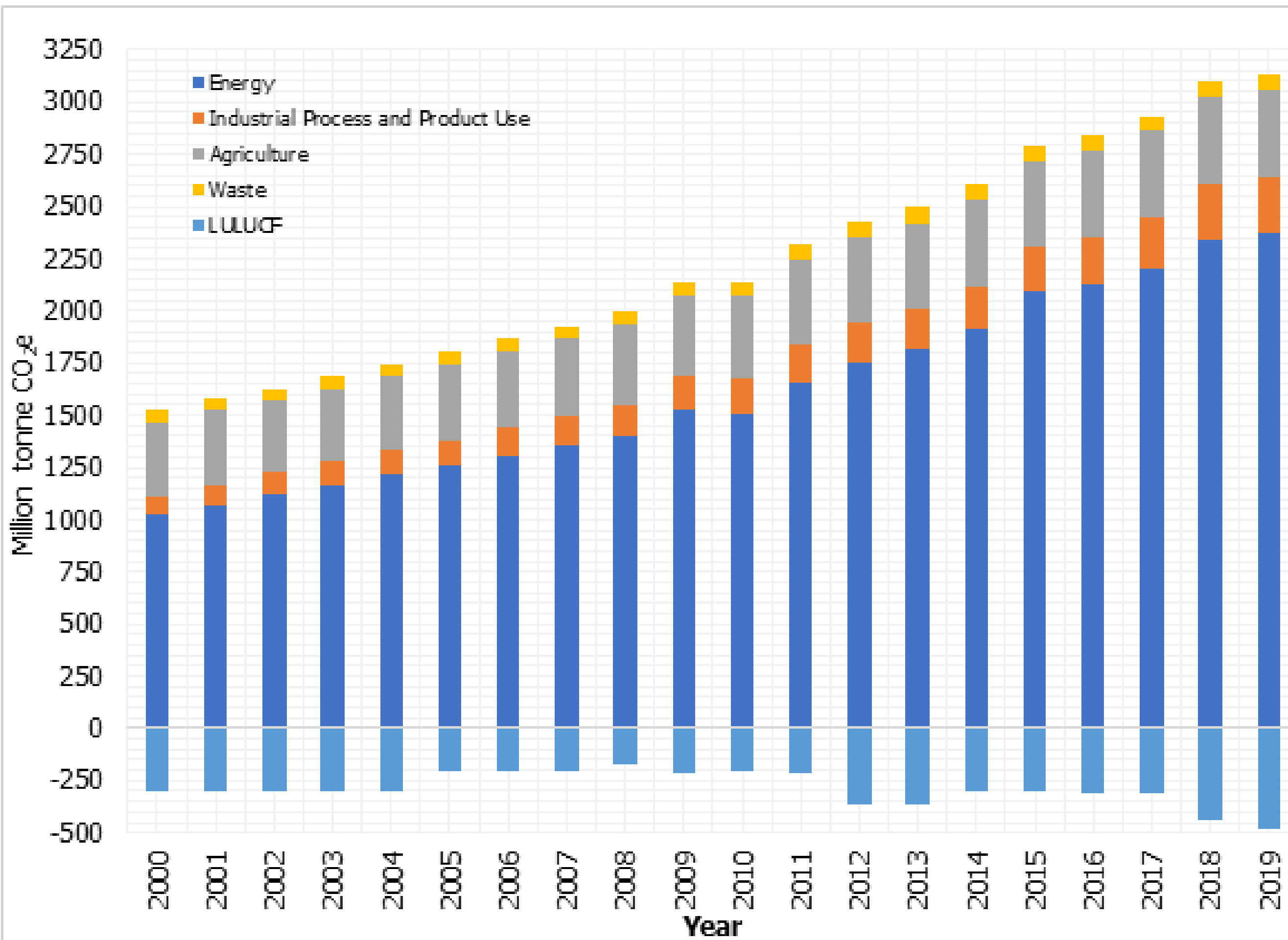

Figure 2: Time series information of GHG emissions (2000-2019)

5.3.7 The IPPU sector, which includes GHG emissions produced by a variety of industrial activities that transform raw materials by chemical or physical means, represented 8.41 percent of GHG emissions (without LULUCF) in 2019. The same year, their emissions reached 2,63,540 GgCO_2e, increasing by 16 per cent since 2016 mainly due to the increase in the production of cement, aluminum, and lime.

5.3.8 The main GHG emissions from the agriculture sector are methane from livestock's enteric fermentation and rice cultivation and nitrous oxide from manure management and agriculture soil. The agriculture sector represented 13.44 percent of the total GHG emissions (4,20,968 GgCO_2e) in 2019, a decrease of 1 percent compared to 2016. Even though in absolute terms, the emissions from agriculture sector increased by 3.22 percent over 2016, the share of emissions from agriculture sector is progressively reducing over the years.

5.3.9 Land Use and Land-Use Change and Forestry Sector removed 20 per cent of the Country's carbon dioxide emissions in 2019. In the same year, its emissions reached -4,85,472 GgCO_2e, increasing its status as a sink by 58 per cent since 2016.

5.3.10 In 2019, the waste sector, which includes GHG emissions accounted for only 2.34 per cent of total GHG emissions. In the same year, its emissions were 73,189 GgCO_2e, decreasing by 2.72 per cent since 2016.

6. Mitigation

This chapter provides description of a number of Mitigation actions/Schemes undertaken by different Ministries/Departments and States to combat climate change including their mitigation potential.

6.1 Recognizing that climate change is a global collective action problem, India is committed to addressing the challenge with firm adherence to multilateralism keeping in mind the National Circumstances and based on equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC), as enshrined in the United Nations Framework Convention on Climate Change (UNFCCC). India maintains that operationalizing the principle of equity and climate justice requires that the global carbon budget be equitably shared among all countries and used responsibly. Historical and future responsibility of countries needs to be framed in terms of limiting their cumulative emissions within their fair share of this budget. The key principle that informs India's climate policy, therefore, is to pursue its development goals according to national circumstances while keeping within its fair share of the global carbon budget.

6.2 **Salient features:**

6.2.1 One of the important features of the growth and development of the country is the continuous reduction in the emission intensity of the economy which is the total amount of greenhouse gas emissions emitted for every unit increase of GDP. India has successfully continued to decouple its economic growth from Greenhouse Gas emissions, resulting in the reduction of the emission intensity of its Gross Domestic Product (GDP) as the following table indicates.

Table 2: Reduction in Emission Intensity (2005-2019)

Period	GHG Inventory year	Reduction in Emission Intensity
2005-2010	2010	12%
2005-2014	2014	21%
2005-2016	2016	24%
2005-2019	2019	33%

6.2.2 Thus, as per current National GHG Inventory, the emission intensity has further reduced by 33% between 2005 and 2019 indicating decoupling of India's GDP from GHG emissions. India submitted its Intended NDC to UNFCCC on October 2, 2015 as per decision 1CP/20 of the 20th session of Conference of Parties (COP 20) held in Lima in December 2014. India has communicated its NDC, for the period 2021-2030, which *inter alia*, include tangible contributions such as reduction of emission intensity of its GDP by 33 to 35 percent by 2030 from 2005 level; achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF); create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2e through additional forest and tree cover by 2030.

6.2.3 India's emissions intensity of gross domestic product (GDP) has reduced by 33 per cent between 2005 and 2019. India's current share of non-fossil sources based installed capacity of electricity generation is more than 41%. India achieved its NDC of 40 percent cumulative electrical power installed capacity from non-fossil fuel-based energy sources in 2021 – nine years in advance of the target date of 2030. During 2005 to 2021, additional carbon sink of 1.97 billion tonnes of CO_2 equivalent has been created.

6.2.4 Further, India submitted updated NDC in August, 2022 as follows:

6.2.4.1 To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for 'LIFE'– 'Lifestyle for Environment' as a key to combating climate change.

6.2.4.2 To reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level.

6.2.4.3 To achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF).

6.2.5 Installed capacity of solar energy in India has increased by more than 25 times from 2.63 GW in March 2014 to 66.78 GW in March 2023.

6.2.6 LPG connections given to 96 million households under Pradhan Mantri Ujjwala Yojana (PMUY) has led to an increase in LPG coverage from 62% on 1st May 2016 to near saturation in March 2023.

6.2.7 For the year 2021-22, implementation of Perform, Achieve and Trade (PAT) scheme has resulted in energy savings of about 24.34 Mtoe translating into avoiding of about 105 million tonnes of CO_2 emissions.

6.2.8 During the financial year 2021 – 22, Energy Efficiency Services Limited (EESL) distributed 10.50 lakh LED bulbs, where cumulative achievement as on 31st March 2022 is 36.79 crore. Total energy savings of 47.78 billion kWh per year with avoided peak demand of 9567 MW and estimated GHG emission reduction of 38.70 million tCO_2 per year.

6.2.9 During the financial year 2021 – 22, EESL distributed 52,451 LED Tube Lights, where cumulative achievement as on 31st March 2022 is 72.18 Lakh. Total energy savings of 316.17 million kWh per year with avoided peak demand of 144 MW and estimated GHG emission reduction of 259.26 kilotons CO_2 per year.

6.2.10 During the financial year 2021 – 22, EESL distributed 56,574 Energy Efficient Fans, where cumulative achievement as on 31st March 2022 is 23.59 Lakh. Total energy savings of 219.40 million kWh per year with avoided peak demand of 59 MW and estimated GHG emission reduction of 179.91 kilotonnes CO_2 per year.

6.2.11 Emission avoidance of 57 MtCO2e (2021-22) under the Standards and Labelling program; avoidance of 125 $MtCO_2e$ (2021-22) under the Prime Minister's Ujala scheme and initiative such as Energy Conservation Building Code (ECBC) and Eco Niwas Samhita.

6.2.12 Energy is the most important sector for adaptation as it is responsible for 75-80 % of the emissions. India has emerged as a world leader in energy transition. India's energy efficiency measures including PAT for industries, star labelling programme for appliances, the Ujala program for LEDs, the Energy Conservation Building Code (ECBC) and Eco Niwas Samhita for buildings have together resulted in the equivalent reduction of CO_2 emissions by 280 million tonnes per annum (2021-22).

6.2.13 Solar energy contributes to more than 50% in the total RE segment, making it the largest contributor amongst all RE sources (excluding large hydro projects).

6.2.14 International Solar Alliance (ISA), launched by India and France, is a dedicated platform for cooperation between Governments, multilateral organizations, and industry to strengthen global cooperation on solar energy.

6.2.15 India is committed to minimizing the impact of the Iron and Steel Sector on global warming. The average emissions intensity of the steel industry was projected to reduce from 3.1 T/tcs (tonne of CO_2/tonne of crude steel) in 2005 to 2.64 T/tcs in 2020 and subsequently to 2.4 T/tcs by 2030. The steel sector has achieved its 2020 targets, showing a decreasing trend in emissions intensity from 3.1 T/tcs in 2005 to 2.65 T/tcs in 2015 to 2.5 T/tcs in 2020.

6.2.16 The Government of India announced the National Hydrogen Mission with the objective of meeting our mitigation targets as well as making India an export hub for Green Hydrogen and Green Ammonia. The policy is aimed at meeting a targeted production of 5 million tonnes per annum of Green Hydrogen by 2030 and the related development of renewable energy capacity required for it.

6.2.17 The Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) scheme has been launched since 2019, for the "de-dieselisation of the farm sector and enhancing farmers' incomes by providing energy and water security across India.

6.2.18 India recognizes that climate change is a significant global problem. India's participation in the global climate discourse has been shaped by a scientific understanding of its domestic vulnerabilities to climate change and its adverse impact on the country's environment, economy, and society. India believes that each citizen can contribute positively in combating climate change. With this unique perspective in mind, Hon'ble Prime Minister Shri Narendra Modi at COP26 at Glasgow stated that 'Lifestyle for Environment' (LiFE) can become a mass movement of Environmental Conscious Life Style. He mentioned that 'What is needed today is Mindful and Deliberate Utilization of resources, instead of Mindless and Destructive Consumption'. LiFE has been included in the updated non-quantifiable targets under Nationally Determined Contributions under the Paris Agreement to the UNFCCC.

6.2.19 Traditional and local knowledge systems are a way of life in India. The immense potential of traditional knowledge systems that have supported local societies in organizing lifestyles successfully in remote and fragile areas of the country has been acknowledged and appreciated by integrating them into the formal sector policies and practices. On 20th October, 2022, Hon'ble Prime Minister Shri Narendra Modi launched Mission LiFE at Kevadia, Gujarat. LiFE is a global mass movement to nudge human behaviour towards adopting sustainable lifestyles and contribute towards achievement of climate goals.

6.2.20 Further, in his address at the Spring Meeting of the World Bank in 2023, Prime Minister Shri Narendra Modi spoke on LiFE, stating that "Mission LiFE is about democratising the battle against climate change".

6.2.21 The MoEFCC has been mobilising Central Ministries, State Governments, Departments, Institutions, Private Organizations, and Individual Citizens to join the LiFE initiative by organising and partaking in both action and awareness events regarding LiFE. As of June 2023, the LiFE movement witnessed participation from 76 Central Ministries and all States and UTs in conducting more than 1.6 million events with involvement of more than 25 million persons.

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7. Impacts, Vulnerability and Adaptation

This section provides information on India's vulnerability to the adverse effects of climate change, and on adaptation measures being taken to meet their specific needs and concerns arising from these adverse effects.

7.1 India is experiencing the full range of climate change impacts, ranging from floods and droughts to heat waves and glacier melt. This section elaborates on the climate change impacts India is facing, and extent of vulnerability and adaptation measures undertaken by the Government of India to combat the impacts of climate change.

7.2 **Salient features:**

7.2.1 There is emerging scientific evidence of the impact of climate change on ecosystems and landscapes in India, with the observed changes in species composition, productivity and biodiversity.

7.2.2 Climate change is an additional threat to the Indian agricultural system that is stressed by several factors such as reduced availability of land, water, deteriorating soil health in many regions, yield stagnation, and the attack of pests and diseases, apart from several socio-economic stressors.

7.2.3 The alarming rate of groundwater depletion, the variability of precipitation coupled with the uncertainty brought in by climate change, inefficient irrigation water usage and deteriorating water quality on the one hand and burgeoning water demand on the other side highlights the need for appropriate mitigation and adaptation measures in water sector.

7.2.4 The coastal ecosystems in their entirety are highly vulnerable to climate change. Many of these ecosystems are also under severe anthropogenic stress and hence the vulnerability to climate change.

7.2.5 India's blueprint on climate action, the National Action Plan on Climate Change (NAPCC), encompasses nine National Missions, both on adaptation and mitigation, and covers various climate-vulnerable sectors. Of these nine Missions, three pertain to developing energy sources and improving energy efficiency to reduce the emission of Greenhouse Gases into the atmosphere. These constitute mitigation efforts. The remaining six have specific components of adaptation incorporated into their Mission objectives. All the Missions are highly interconnected and include measures to facilitate action across sectors.

7.2.6 State-level Action Plans on Climate Change (SAPCCs) have also been formulated with a higher focus on adaptation and afforestation than on mitigation. Agriculture, water, health, forests, and coasts are the major sectors which have been covered for addressing State-specific climate impacts.

7.2.7 The Plans and Policies thus formulated are implemented at the sub-National level through the State Government's line Departments and District authorities to achieve the desired goal of enhancing resilience and improving the adaptive capacities of the communities and ecosystems. Further, localized climate actions facilitate community engagement by enabling the participation of local stakeholders in adaptation process. The approach enhances the effectiveness and sustainability of climate action by ensuring that local needs, priorities, and knowledge are integrated into a combined action plan. Civil society and private sector organizations also support these implementation efforts at the local level.

7.2.8 Consistent with the NAPCC, all the States and UTs in the Country have developed SAPCCs with some inbuilt Monitoring and Evaluation (M&E) arrangements to ensure better measurement of adaptation impacts and to promote accountability and effective learning. However, the mainstreaming of the climate change agenda into the State level planning through sectoral line departments has just been initiated and capacity building of all the stakeholders for M&E of SAPCC activities is also making a beginning in the country.

7.2.9 Apart from NAPCC and SAPCCs, India has been implementing a series of schemes to maintain a high economic growth rate to improve the living standards of its people, to strengthen the adaptive capacities of the vulnerable communities and to reduce their vulnerability to the impacts of climate change. Thus, India has been pursuing a two-pronged policy approach by mainstreaming adaptation into its developmental planning through a qualitative shift in its growth trajectory and by drawing adaptation benefits from the ongoing schemes. Various Ministries of the Government of India have been consistently developing and implementing relevant climate adaptation programmes to protect the natural environment and also to reduce social and economic vulnerabilities and build adaptive capacities to withstand both current and future climate change impacts.

7.2.10 Agriculture is a significant sector for adaptation. One of the major programmes is the National Mission for Sustainable Agriculture (NMSA). Considering significant risks of climate extreme and disasters in agriculture sector, the Ministry of Agriculture and Farmers Welfare has also come up with a comprehensive National Agriculture Disaster Management Plan (NADMP).

7.2.11 Water is recognized as vital to India's economic growth, the well-being of its people and the sustainability of its ecosystems. Over the last few years, the Government of India as well as State Governments have been implementing a range of projects and programmes focused on groundwater recharge, and efficient use of water for agriculture, through the use of specialised technologies. The National Water Mission is implemented to address the impacts of climate change on the hydrological cycle by-compiling and maintaining a comprehensive water database in the public domain and assessing the impacts of climate change on water resources. Programmes have been taken up to increase storage, both in large and local reservoirs, as well as under the ground. The terminal mine voids are being developed into mine pit lakes which act as infrastructure for storage and conservation of mine water.

7.2.12 Government of India launched Pradhan Mantri Awas Yojana in 2015 to provide safe housing to the poor. This Scheme has helped poor families and has reduced their exposure to climatic extremes by providing climate-proof housing leading to increased resilience and improved quality of life.

7.2.13 India launched the Coalition for Disaster Resilient Infrastructure (CDRI) at the 2019 Climate Summit. This international partnership of National Governments, UN agencies, Multilateral Development Banks, the private sector, and knowledge Institutions will promote the resilience of new and existing infrastructure systems to growing climate risks and disasters. Government of India has allocated Rs.480 crore (58 million USD) to support the work of the CDRI over a period of five years from 2019 to 2023-24.

7.2.14 Information on various programmes and initiatives to mitigate climate change and measures to facilitate adequate adaptation to climate change have been included. The initiatives referred to include, inter alia, increase in renewable energy deployment, the Perform Achieve and Trade (PAT) Scheme, the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY), the Street Lighting National Programme, Atal Mission for Rejuvenation and Urban Transformation(AMRUT),Swachh Bharat Mission (SBM), the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National Policy on Biofuels, National Electric Mobility Mission Plan (NEMMP), Sustainable Alternative Towards Affordable Transportation (SATAT), Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME-India), and Unnat Jyoti by Affordable LEDs for All (UJALA).

7.3 **Salient features from Adaptation Communication**

7.3.1 India is among a few countries in the world where, despite ongoing developmental efforts, forest and tree cover are increasing considerably. The Government of India has taken several steps for the conservation of country's biodiversity which include survey, inventorization, taxonomic validation and threat assessment of floral and faunal resources; assessment to develop an accurate database for planning and monitoring as well as conservation and protection of forests; establishment of a protected area network of national parks, wildlife sanctuaries, conservation and community reserves; designating biosphere reserves for conservation of representative ecosystems; undertaking of species oriented programmes, such as Project Tiger and Project Elephant; complemented with ex-situ conservation efforts. India is committed to ambitious afforestation programmes, a flagship program being the National Mission for a Green India (GIM), besides providing opportunities to the forest dependent communities through various schemes, such as the Pradhan Mantri Van DhanYojna, and Green Skill Development Programme (GSDP). Reclamation of mine degraded lands to convert them into productive land usage or re-purposing in line with the commitment under UNCCD (UN Convention to Combat Desertification).

7.3.2 With a view of conserving and protecting India's unique coasts and marine environments and promoting development in a sustainable manner, the Government of India places a strong emphasis on adaptation to the impacts of climate change on coastal communities and the fragile and vulnerable coastal ecosystems. Indian National Centre for Ocean Information Services (INCOIS) has carried out Coastal Vulnerability Index (CVI) mapping to assess the probable implications of sea-level rise along the Indian coast. India Meteorological Department (IMD) has prepared a map of the cyclone hazard proneness of the coastal districts of India based on the frequency of cyclones, their intensity, actual/estimated maximum wind strength, Probable Maximum Storm Surge (PMSS) associated with the cyclones and Probable Maximum Precipitation (PMP) for all the districts along the coastline.

7.3.3 Climate change concerns in the Himalayas are multifaceted, encompassing floods, droughts, landslides, human health, biodiversity, endangered species, agriculture, livelihoods and food security. The National Mission for Sustaining the Himalayan Ecosystem contributes to the sustainable development of the country by enhancing the understanding of climate change, its likely impacts and adaptation actions required for the Himalayas. The mission intends to evolve suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem.

7.3.4 India has been able to establish a holistic disaster risk reduction and response mechanism at the National, State and District levels with the aim of reducing existing levels of vulnerability, prevention, and mitigation of disasters and providing appropriate response, rehabilitation and reconstruction measures. The programmes and schemes include early warning system and communications, the construction and sustainable maintenance of multi-purpose cyclone shelters, improved access and evacuation, enhanced capacity, and capability of local communities to respond to disaster and strengthening disaster risk mitigation capacity at the Central, State and local levels.

7.3.5 India's Health sector, in preparedness for climate change, has put in place the National Plan on Climate Change and Human Health. The Ministry of Health and Family Welfare has also taken steps to increase public awareness on the subject of health impacts of climate change including heat waves. IMD in collaboration with local health departments have started heat action plans in many parts of the country to forewarn about heat waves and also advising action to be taken. In addition, the Government is also implementing various other programs and schemes that contribute, inter-alia to climate action in the health Sector. Some of the flagship programs are Pradhan Mantri Swasthya Suraksha Nidhi, Ayushman Bharat Pradhan Mantri Jan AarogyaYojna, National Digital Health Mission, Pradhan Mantri Swasthya Suraksha Yojna, Intensified Mission Indradhanush 3.0, Janani Shishu Suraksha Karyakram. Rashtriya Bal SwasthyaKaryakram (RBSK), etc.

7.3.6 The impacts of climate change and disasters affect weaker socio-economic groups with much higher intensity. Women, especially those from lower economic backgrounds, face some of the most severe effects of climate change. Climate change may result in a consequent shrinkage of work opportunities, and may, thereby, inflict a severe blow to the socio-economic edifice of the rural womenfolk, adversely affecting their traditional source of occupation and income. Government to take stock of impact arising out of climate change and transition towards clean energy through just transition measures.

7.3.7 Several initiatives have been taken by Government of India to improve gender parity and women's participation in the workforce, thereby enabling greater access to as well as ownership of resources. Gender has been made an integral component of developmental planning in the Country, with key schemes of the Government of India highlighting the priorities of women. In order to address the heightened vulnerabilities faced by the women in the rural parts of the country, schemes such as Mahila Shakti Kendra, Mahila E-Haat and STEP (Support to Training and Employment Programmme for Women) have been undertaken. Thus, women related issues are being mainstreamed in developmental programmes of the Government of India. Recognizing that national budgets benefit women and men differently, India formally adopted Gender Responsive Budgeting (GRB) in 2005-2006. GRB does not merely involve the earmarking of funds for women; it is an exercise that scrutinizes the budget through a gender lens.

8. Research and Systematic Observation

This section provides information on climate change research and systematic observation, including India's participation in and contribution to activities and programmes, as appropriate, of National, Regional and Global Research Networks and observing systems.

8.1 Climate research has become a major focus of scientific query since the latter half of the 20th century, especially after the identification of the impact of Greenhouse Gases and global warming on the Earth's climate system. This chapter details the vast institutional setup at the backdrop of India's climate change research, supported by systematic observation networks – atmosphere, weather and climate forecasting, satellite-based observation networks and oceanic observations. It also describes India's efforts in monitoring the terrestrial surface – cryosphere, mountain meteorology, ecosystems and hydrology.

8.2 **Salient features**

8.2.1 India Meteorological Department (IMD) operates weather and climate monitoring, detection and warning services for various sectors of economy.

8.2.2 The weather and climate observing system comprises multitude of individual surface- and space-based observing systems.

8.2.3 The main long-term objectives of India's Observing Systems are to improve and optimize systems for observing the state of the atmosphere to meet the requirements, in the most effective and efficient manner, for the preparation of increasingly accurate weather analyses, forecasts and warnings, and for climate and environmental monitoring.

8.2.4 IMD now has 33 Doppler Weather Radars (DWR) in the Country. Eight Doppler Weather Radars are in operation along the east coast of India including DWR at Kolkata, Paradip, Gopalpur, Visakhapatnam, Machhilipatnam, Sriharikota, Chennai and Karaikal and 5 along the west coast at Thiruvananthapuram, Kochi, Goa, Mumbai and Bhuj.

8.2.5 At present, IMD maintains 206 Surface Observatories, 735 Automatic Weather Stations and 1350 Automatic Rain Gauge Network.

8.2.6 IMD also conducts monitoring and research related to Environment Monitoring and has a strong Agrometeorology Observation Network.

8.2.7 The scientific rationale of all the ocean observing programmes is to support the greater goal of sustainable development and ecosystem restoration, expanding biological observing networks and marine biodiversity observations, innovation and using advanced technologies for low-cost, multidisciplinary observations, and improving global ocean observation networks.

8.2.8 Several of India's ocean observing networks form integral part of the Global Ocean Observing System (GOOS) programme of the Inter-Governmental Oceanographic Commission (IOC/UNESCO).

8.2.9 Government of India launched an ambitious "Deep Ocean Mission" programme to grow our marine and maritime economy, tackle climate change and pollution, and improve our sustainable use of resources. This mission is led by the Ministry of Earth Science, Government of India.

9. Finance, Technology and Capacity Building Needs and Support Received

This section provides a snapshot of India's financial and technological needs for low-carbon development and for adapting to the impacts of climate change. It also notes the context of International/Multilateral climate finance as relevant to India and the barriers to the flow and adequacy of funds in meeting India's financial needs for transitioning to a low carbon emission pathway. It is important to note that the coverage in this section is not a complete or final statement of India's finance and technology needs and requirements for low-carbon transition both in the short and long term.

9.1 **Salient features:**

9.1.1 The developed countries have been lagging in providing finance in terms of scale, speed and scope. The 26th session of Conference of Parties (COP26) to the UNFCCC passed an unprecedented resolution of "regret" at the failure to achieve this objective of meeting the financial needs of the developing countries. This "regret" has been recorded in the cover decision of COP26.

9.1.2 India considers that the current climate finance mechanisms are contrary to the letter and spirit of the Convention, hugely dominated by loans and not grants or loans on adequately concessional terms, with an overwhelming emphasis on mitigation to the neglect of adaptation.

9.1.3 The UNEP Adaptation Gap Report 2022 states that international adaptation finance flows to developing countries are 5-10 times below estimated needs and the gap is widening. With projected climate change impacts, India's adaptation needs will intensify leading to an increase in adaptation costs. India has been spending significant amount of resources for adaptation, despite the competing demands. India's total adaptation relevant expenditure was 5.60 per cent of the GDP in 2021-2022, growing from a share of 3.7 per cent in 2015-16. India looks forward to climate specific grants and/or concessional loans, predominantly from public sources of funding, with appropriate balance between mitigation and adaptation and based on India's articulation of its needs and development aspirations.

9.1.4 India's climate action is largely financed by domestic resources as climate finance flows from developed countries are falling far short of what is needed to mitigate and adapt to climate change. Preliminary estimate suggests that trillions of dollars will be required for meeting India's climate change actions; however, climate finance needs of developing countries are yet to be adequately addressed by developed nations. The cumulative expenditure needed for adaptation in a Business as Usual (BAU) scenario, without any additionality, is estimated to be INR 56.68 trillion till 2030, assuming 2023-24 as the base year of analysis. Climate induced damages could lead to an incremental cost of INR 15.5 trillion by 2030, and the requirements for building adaptation capital stock could be as high as INR 72 trillion after accounting for the country's developmental needs and climate-induced pressures. Urgently increasing adaptation finance flows to India is a crucial requirement for India to be able to meet its long-term sustainable development and economic growth objectives.

9.1.5 According to the GCF India dashboard, there are 7 GCF projects in India with a total GCF financing of USD 528.9 million. India has received a total financing commitment (including co-financing) of USD 500.49 million from GEF Trust Fund (GTF) spread over 51 national projects with a co-financing ratio of 11.55. India has also received a commitment of USD 17.36 million spread over 3 regional projects from GTF with a co-financing ratio of 4.17. From the Special Climate Change Fund (SCCF), India has received a commitment of USD 10.8 million spread over 2 projects, with a co-financing ratio of 10.85. Four projects with a total outlay of $10 Million were funded through Adaptation Fund.

9.1.6 Data, and its modelling and interpretation, have been identified as an important constraint in planning and implementation of adaptation interventions. It has been observed that there is a lack of uniformity and synchronization of available data within sectors. It was identified that similar indicators and data points could not be homogenized across sectors. Methodologies for the integration of numerical predictions of climate change impacts with socio-economic vulnerability are limited in their scope and applicability.

9.1.7 One of the major gaps in adaptation action is that the risk assessment studies in India are hazard-specific and often consider only hazards. Scientific and technical studies depict areas prone to climate related hazards without establishing their impacts on society. Thus, an integration of the socio-economic, as well as cultural aspects of communities and societies is needed while assessing specific impacts of climate risks and hazards as they play a crucial role in adaptation planning. Even where vulnerability assessments are available, the social and economic inequalities, differential access to information and technologies, and capacities of stakeholders need to be adequately captured for adaptation planning purposes.

9.1.8 While India has established an extensive knowledge network of national and international Institutions on climate adaptation, there remains a considerable gap in adaptation technologies available to India. Challenges around technology transfer, technology co-creation and intellectual property rights reflect the larger debate on the responsibility of developed Nations to support climate action in developing Nations. The other pertinent issue for India is the need to assess technological requirements across sectors and sub-national levels to understand the scale of deployment, levels of risk (present and future) that adaptation options can address, temporal dimensions for implementation (short, medium and long term), and associated costs and benefits.

9.1.9 India recognizes the need to improve the R&D base for green technologies and climate change mitigation and adaptation, while also focusing on its developmental vision for mid-century, including self-reliance and reduced dependence on imports.

9.1.10 There is a need to build capacity at all levels, and particularly at the local level. There is a lack of trained personnel on the ground to operate technical tools and devices. Capacity building and skill development of all stakeholders, across sectors and levels is imperative to enable the effective implementation of adaptation strategies on the ground and the collection of relevant data through appropriate processes.

9.1.11 A wide range of estimates exist regarding the economic losses and damages caused by climate impacts to the Indian economy. Isolating the climate component of total losses due to extreme weather events continues to remain a challenge. It is critical for developed countries to fulfil their commitment in providing adaptation finance to minimize further losses, and to provide adequate compensation for unavoidable loss and damage.

BACKGROUND INFORMATION AND INSTITUTIONAL ARRANGEMENTS

BACKGROUND

Ministry of Environment, Forest and Climate Change (MoEFCC) is the Nodal Ministry in the Government of India dealing with collection and collating of information related to climate change-related programmes, actions and reporting information under Article 4.1 of the Convention. According to the Article, all Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall develop, periodically update, publish and make available to the Conference of the Parties (COPs), the information following Article 12 of the Convention and decisions of the COPs and related guidelines[1]. Accordingly, Parties communicate information on national inventories of greenhouse gases (GHGs) not controlled by the Montreal Protocol, steps taken or envisaged for implementing the decisions taken under the Convention and any other information that the Party considers relevant for the achievement of the objective of the Convention and suitable for inclusion in its communication. As per decision 12/CP.4[2] of the COPs to the United Nations Framework Convention on Climate Change (UNFCCC), Non-Annex I Parties are required to submit their first National Communication (NC) within three years of entering the Convention, and every four years thereafter. The NCs shall be prepared in accordance with the guidelines contained in decision 17/CP.8[3].

In fulfillment of the aforesaid requirements, MoEFCC, with its cross-ministerial and institutional network, is implementing and executing the matters related to the National Communication (NCs) and Biennial Update Reports (BURs).

Previous Submissions

Towards the fulfillment of reporting obligations under the UNFCCC, India has so far furnished two National Communications (NCs) and three BURs to the UNFCCC:

i. Initial National Communication (INC) in June 2004, comprising national GHG inventory of 1994.

ii. Second National Communication (SNC) in May 2012, comprising national GHG inventory for the year 2000.

1 United Nations Framework Convention on Climate Change - https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

2 https://unfccc.int/sites/default/files/dec12-cp4.pdf

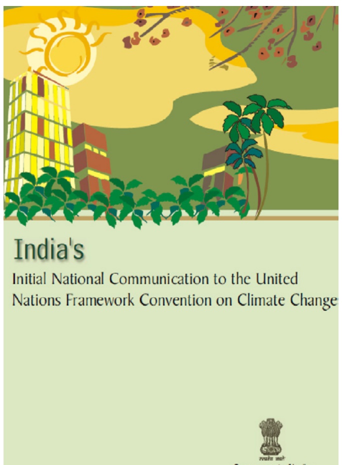
3 https://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/dec17-cp.pdf

iii. First Biennial Update Report (BUR-1) in January 2016, containing national GHG inventory for the year 2010.

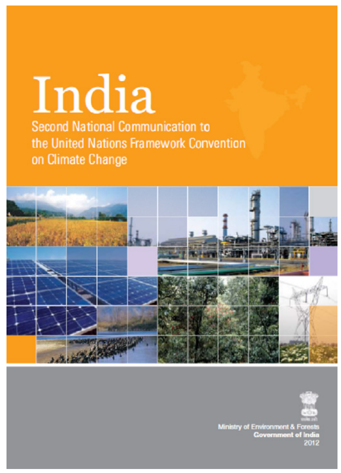
iv. Second Biennial Update Report (BUR-2) in December 2018, containing national GHG inventory for the year 2014.

v. Third Biennial Update Report (BUR-3) in February 2021, containing national GHG inventory for the year 2016.

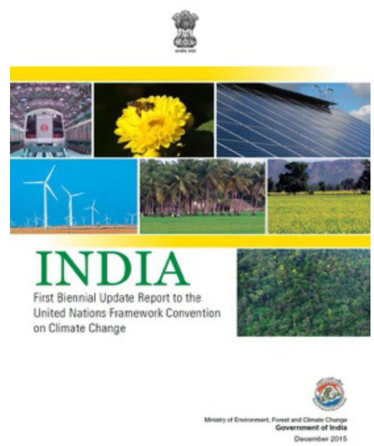
As a fulfillment of the requirement of enhanced reporting and updating of information, India's Third National Communication (TNC) is being presented to the UNFCCC.



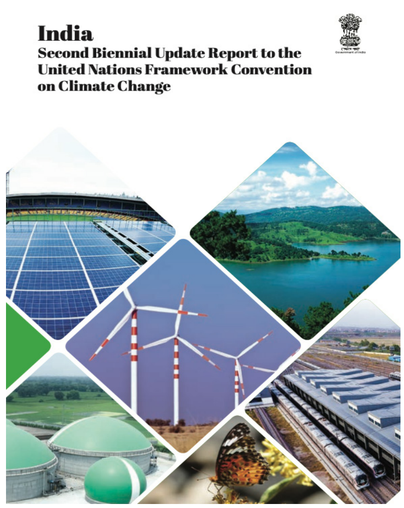
Initial NC



Second NC



BUR-1



BUR-2

BUR-3

Figure IA1: India's National Communications and BURs

The TNC presents updated information on the National GHG Inventory, Mitigation Actions, Adaptation measures, Research and Systematic Observations, and Financial, Technology and Capacity Building needs. It also addresses the suggestions made during the International Consultation and Analysis (ICA) process for BUR-1, BUR-2 and BUR-3, wherever relevant, and within the scope of present capacity in order to enhance the transparency of mitigation actions and their effects. This would be without engaging in discussion on the appropriateness of India's mitigation actions and their effects and enhancing the consistency of the methods used for preparing GHG inventories (as per IPCC 2006 Guidelines for National GHG Inventories).

Institutional Arrangements

The Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India (GoI), is the executing and implementing agency for preparation of NCs. National Communications (NATCOM) Project Management Unit headed by National Project Director, under GEF-UNDP-GoI Project has been established in MoEFCC for the preparation of National Communications including BURs. The PMU coordinates with the line Ministries, Organizations and Departments of GoI, network of Scientific and Research Organisations including data providers. The activities are supervised by National Steering Committee (NSC), comprising representatives from various line Ministries and Departments, under the technical guidance of Technical Advisory Committee (TAC), comprising representatives from various Scientific and Research Organisations of the country. The schematic diagram in Figure IA2 depicts the implementation arrangement for TNC.

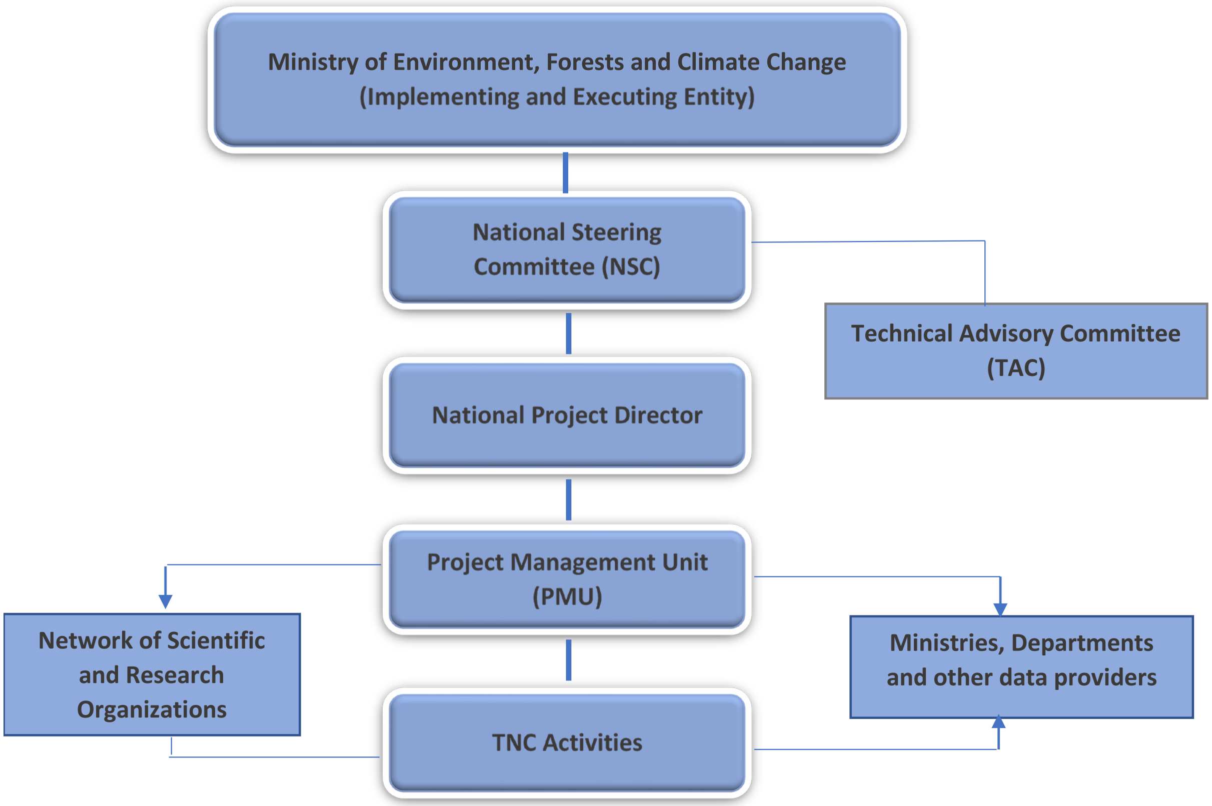


Figure IA2: Implementation Arrangement for the Third National Communication

For the preparation of National Communication on a continuous basis, GoI has taken steps and made efforts towards creating a sustainable institutional structure. Preparation of the TNC required a comprehensive study, and technical as well as administrative arrangements, in addition to stakeholder's participation in various tasks and activities. To ensure adequate attention and participation, elaborate implementation arrangements have been formulated. NSC under the Chairmanship of the Secretary, MoEFCC is in place to oversee the preparation and implementation of the work programme of the TNC. Various line Ministries and Government Departments that are concerned with providing different types of information required for the compilation of this report have representation in the NSC. Composition of NSC is provided in Annexure II.

Technical consultations on multiple and multidisciplinary aspects of information related to the compilation of GHG inventory and mitigation actions were held during the process. Considering the range of requirements, it was found practical to have a Technical Advisory Committee (TAC) to provide technical guidance to the preparation of NC. This committee has members from the Government, Academia and Society. Composition of TAC is provided in Annexure II.

This report encompasses information on National Circumstances, National GHG Inventory, Mitigation Actions, Impacts, Vulnerability and Adaptation, Research and Systematic Observations, and an analysis of the Finance, Technology and Capacity Building needs, and support received, including information on domestic MRV (Monitoring, Review and Verification). Several studies were launched to accommodate the requisites of the TNC. These studies were carried out by Scientific and Research Institutions having sector-specific expertise. Besides, various Ministries, Government Departments, and Public-Sector Units (PSUs) and industrial associations provided inputs for preparation of this TNC (Figure IA3).

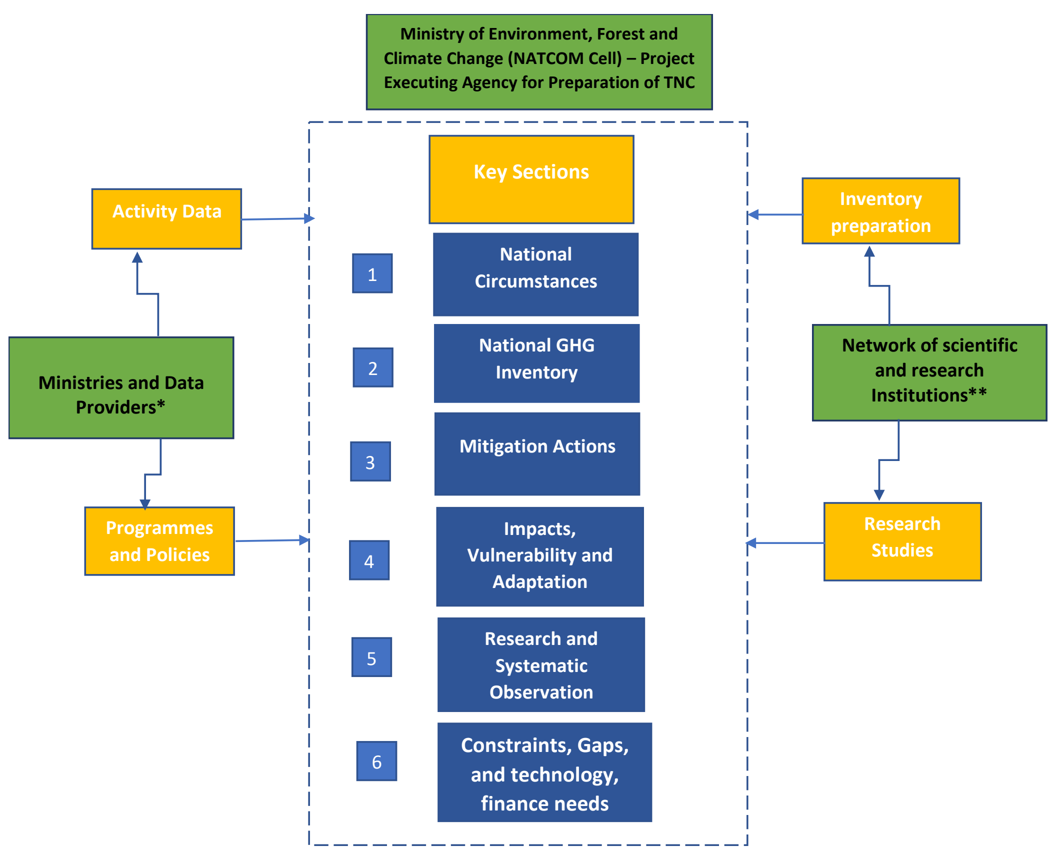


Figure IA3: Institutional Arrangements for the Third National Communication

S. No.	* Ministries and Data Providers
1.	Bureau of Energy Efficiency
2.	Central Electricity Authority
3.	Department of Agricultural Research and Education
4.	Department of Economic Affairs
5.	Department of Heavy Industry
6.	Department of Space
7.	Department of Science and Technology
8.	India Meteorological Department
9.	Indian Space Research Organisation
10.	Ministry of Agriculture and Farmers Welfare
11.	Ministry of Coal
12.	Ministry of Chemicals and Fertilizers
13.	Ministry of Civil Aviation
14.	Ministry of Earth Sciences
15.	Ministry of Health and Family Welfare
16.	Ministry of Housing and Urban Affairs
17.	Ministry of Power
18.	Ministry of Petroleum and Natural Gas
19.	Ministry of Railways
20.	Ministry of Road Transport and Highways
21.	Ministry of Steel
22.	Ministry of Statistics and Programme Implementation
23.	Ministry of Science and Technology
24.	Department of Water resources, River Development & Ganga Rejuvenation
25.	Ministry of New and Renewable Energy
26.	National Institute of Solar Energy
27.	National Institution for Transforming India
28.	Petroleum Conservation Research Association
29.	Petroleum Planning and Analysis Cell
30.	Space Application Centre, ISRO, Hyderabad

S. No.	** Network Institutions
1.	Council on Energy, Environment and Water, New Delhi
2.	Confederation of Indian Industry, New Delhi
3.	Central Institute of Mining and Fuel Research, Dhanbad
4.	Central Research Institute of Dryland Agriculture, Hyderabad
5.	Forest Survey of India, Dehradun
6.	Indian Agricultural Research Institute, New Delhi
7.	Indian Council of Forestry Research and Education, Dehradun
8.	Indian Institute of Management, Ahmedabad
9.	Indian Institute of Petroleum, Dehradun
10.	Indian Institute of Science, Bengaluru
11.	IORA Ecological Solutions, New Delhi
12.	National Dairy Research Institute, Karnal
13.	National Environmental Engineering Research Institute, Nagpur
14.	National Remote Sensing Institute, New Delhi
15.	The Energy and Resources Institute, New Delhi
16.	Technology Information, Forecasting and Assessment Council, New Delhi
17.	M.S. Swaminathan Research Foundation, Chennai
18.	National Institute of Advanced Studies, Bengaluru
19.	Birla Institute of Technology and Science, Goa

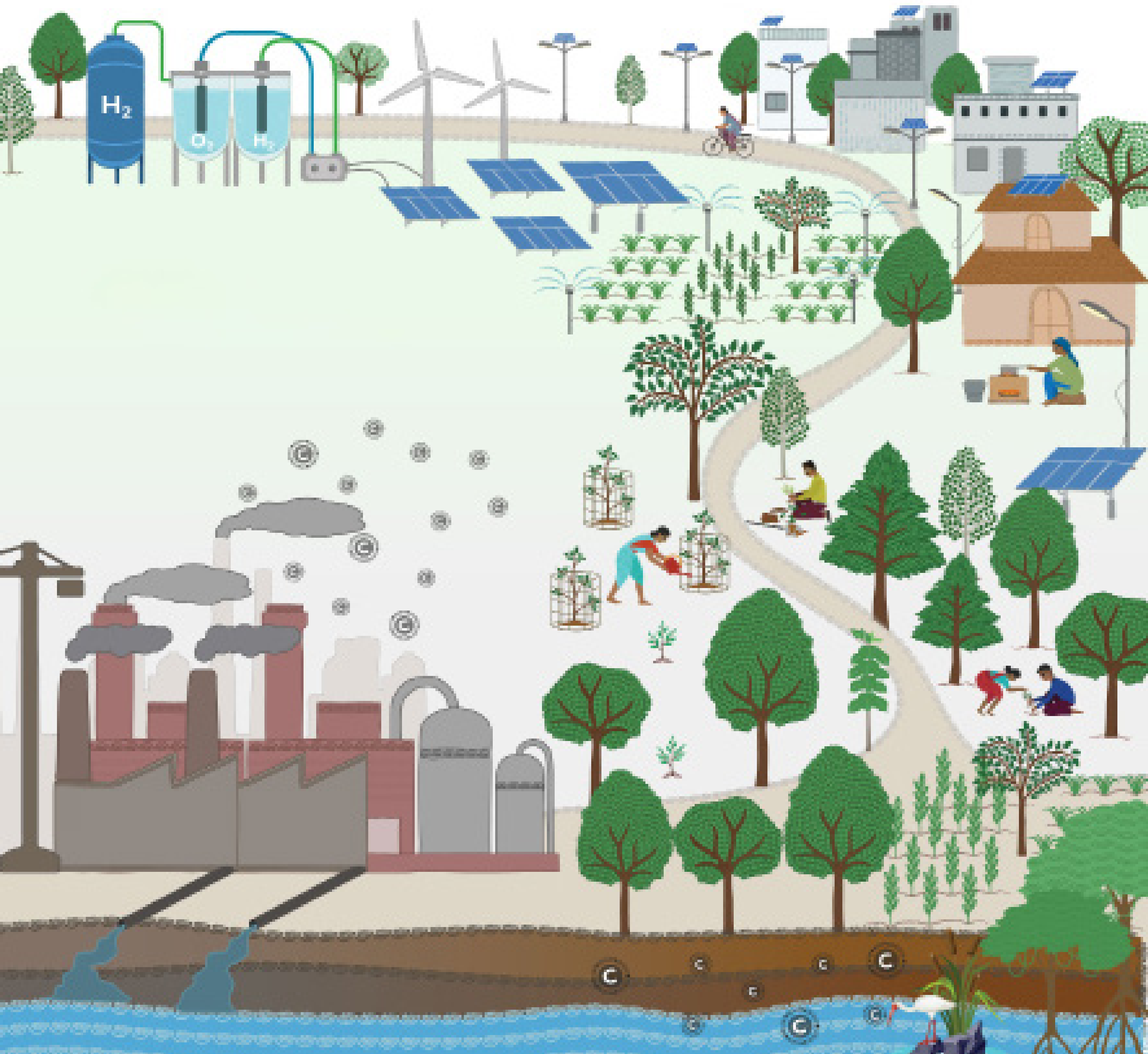
Institutional Network

The Ministry of Environment, Forests and Climate Change, being the implementing and executing entity assigns several research and scientific studies and conducts activities including workshops and national consultations for the preparation of National Communication. This National Communication includes information from several studies carried out under the Impacts, Vulnerability and Adaptation component.

A large number of independent experts and think tanks also provided their inputs, comments and feedback for preparation of TNC.

Quality Assurance and Quality Control (QA/QC) and uncertainty analysis are performed at appropriate stages, including at the time of data collection and inventory preparation by the concerned institutions. The expert institutions, relevant Ministries and NGOs together have supported the preparation of National Communication. These coordinating institutions and supporting network institutions are in the process of developing the required technical capacity, especially for the GHG inventory preparation, which India envisages as a continuous process. India is currently in the process of developing a National Inventory Management System (NIMS) that will coordinate consistently with the data providers and supporting institutions with adequate capacity for the preparation of National Communications and BURs on a continuous basis. Formalizing such an institutional arrangement requires financial, technological and capacity-building support from international institutions and Annex-I Parties on a continuous basis.

National Circumstances



NATIONAL CIRCUMSTANCES

Chapter 01

INTRODUCTION

India is an ancient civilization but one of the youngest democracies on the planet. As the country celebrates the 75th anniversary of independence it is embarking on a series of historic and unprecedented transformation that is touching every aspect of society, economy and polity.

India, the world's largest democratic nation, is uniquely placed as a major economy, a leader among emerging economies, home to more than a sixth of the global population, and yet a nation whose global carbon footprint is strikingly lower than the global average both in cumulative and per-capita terms.

India's recognition of the significance of climate change, based on the best available science as it has evolved over the last thirty years, goes alongside its deep-rooted tradition of respect for frugality and respect for Nature.

Indeed, it would be fair to say that India's deep spiritual traditions and civilizational ethos form the basis for a society that values sustainable lifestyles, mindful consumption and harmony with nature and is against mindless and destructive consumption as lucidly enunciated by Hon'ble Prime Minister when he spoke about LiFE – Lifestyle for Environment at the 26th Conference of Parties (COP26) in Glasgow in 2021. Regenerative practices in agriculture, growing use of renewable energy, creative use of traditional building materials for habitat and community-based natural resource management are all examples of elements of a unique developmental pathway rooted in sustainability.

India has been a prompt signatory, providing timely ratification, to the United Nations Framework Convention on Climate Change (UNFCCC) and all the agreements, protocols and decisions under it that are the foundation of the international climate regime today. India discharges its obligations, commitments and responsibilities under the international climate regime in a timely fashion with full transparency. Having submitted its Third Biennial Update Report (BUR-3) in 2021 and India's Long-Term Low-Emission Development Strategy (LT-LEDS) in 2022, the submission of this Third National Communication (TNC) marks an important milestone. It is to be noted that subsequently India will be submitting its Fourth Biennial Update Report, and its first Biennial Transparency Report (BTR) and the Fourth National Communication in accordance with its international obligations.

India firmly believes in multilateralism and has been proactive in helping other vulnerable Nations. This is evident from the recent launch of 'Infrastructure for Resilient Island States (IRIS)' by India, UK, Australia, Fiji, Jamaica and Mauritius at 'The World Leaders Summit' at COP26. IRIS will provide technical support on the multifaceted issues posed by infrastructure systems and promote disaster and climate resilience of infrastructure assets in Small Island Developing States. India launched the Coalition for Disaster Resilient Infrastructure (CDRI) in 2019 to promote resilience of new and existing infrastructure systems to climate and disaster risk. The International Solar Alliance (ISA), launched in 2015, is a prime example of how constructive global climate action can be taken forward through global partnership. Hon'ble Prime Minister of India, at COP26, launched the Green Grids Initiative — One Sun, One World One Grid (GGI-OSOWOG) the first international network of global interconnected solar power grids, jointly with the United Kingdom. India has also partnered with Sweden on the Leadership Group on Industry Transition (LeadIT) initiative to find innovative solutions for hard-to-abate sectors with a view to promoting voluntary action for low carbon transition.

These collaborations reflect the continuation of India's longstanding commitments to the global climate cooperation under the UNFCCC. Reflecting this commitment, India is also signatory to numerous international agreements, conventions, protocols, and treaties on climate and environmental issues.

India's Nationally Determined Contributions (NDCs)

India submitted its Intended Nationally Determined Contributions (INDCs) to UNFCCC for the very first time on October 2, 2015 as per Decision 1/CP.20 of the 20th session of Conference of Parties (COP20) held in Lima in December 2014. India has communicated its NDCs for the period 2021-2030 as below:

i. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation.

ii. To adopt a climate-friendly and a cleaner path than the one followed hitherto by others at corresponding level of economic development.

iii. To reduce the emissions intensity of its GDP by 33 to 35 per cent by 2030 from 2005 level.

iv. To achieve about 40 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of transfer of technology and low cost international finance, including from Green Climate Fund.

v. To create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030.

vi. To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management.

vii. To mobilize domestic and new and additional funds from developed countries to implement the above mitigation and adaptation actions in view of the resource required and the resource gap.

viii. To build capacities, create domestic framework and international architecture for quick diffusion of cutting edge climate technology in India and for joint collaborative R&D for such future technologies.

India's emission intensity of Gross Domestic Product (GDP) has reduced by 33% between 2005 and 2019. India's current share for non-fossil fuel sources-based installation capacity of electricity generation is more than 41%. During 2005 to 2019, an additional carbon sink of 1.97 billion tonnes of CO_2 equivalent has been created.

Panchamrit and updated NDCs

Further at COP26, the Hon'ble Prime Minister, Shri Narendra Modi, introduced the Panchamrit or five nectar elements of key climate actions by India as its contribution to the global challenge of climate change. The high point of the Panchamrit was the announcement that India would reach the target of net zero by 2070. Subsequently, three key elements of the Panchamrit and the National Statement were incorporated in the updated NDCs submitted to the UNFCCC in August 2022. The updated NDCs consisted the following:

1. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for 'LiFE'– 'Lifestyle for Environment' as a key to combating climate change [UPDATED].
2. To reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level [UPDATED].
3. To achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF) [UPDATED].

While the second and third in the list above, enhanced the targets set in the original NDC, the first of the NDCs underwent significant modification by the inclusion of LiFE – Lifestyle for Environment, that was first introduced in the National Statement.

It is to be noted that two other elements of the Panchamrit remain outside the updated NDCs, viz.

- India will reach its non-fossil energy capacity to 500 GW by 2030.
- India will reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030.

The latter refers to the cumulative emissions from 2021 to 2030, which were to be reduced by one billion tonnes from the projected values.

India's Long-Term Low-Emission Development Strategy (LT-LEDS)

India's long-term low-emissions development strategy (LT-LEDS), titled India's "Long-term Low-Carbon Development Strategy" as per Article 4, Para 19 of the Paris Agreement, was submitted to the UNFCCC in November 2022 during the 27th Conference of Parties (COP27) at Sharm-El-Sheikh in Egypt. This document elaborates the vision and overall strategy of India's long-term climate policies. The document emphasizes that India's long-term strategy is underpinned by the following four key considerations:

1. India has only minimal historical contribution to the consumption of the global carbon budget and its annual per capita emissions remain modest.

2. India is a developing country with low per capita energy use, and with considerable energy needs for development.

3. Mindful of the need to combat climate change and the potential for continued technological and competitive opportunities from a low-carbon development pathway, India will pursue low-carbon development strategies within its fair share of the global carbon budget, aimed at meeting India's 2070 net-zero pledge, on the basis of equity and in accordance with the principle of CBDR-RC and national assessments of its development futures.

4. India's growth and development are also essential to build climate resilience and mitigate the climate risk and vulnerability that India will face with increasing global warming.

The elements of India's long-term low-carbon development strategy are further elaborated in the document across transitions in seven key sectors and issues. These are – i) Low-carbon electricity systems consistent with development; ii) Develop an integrated, efficient and inclusive low-carbon transport system; iii) Promote adaptation in urban design, energy and material-efficiency in buildings, and sustainable urbanisation; iv) Promote economy-wide decoupling of growth from emissions and development of an efficient, innovative low-emission Industrial System; v) CO_2 removal and related engineering solutions; vi) Enhancing forest and vegetation cover consistent with socio-economic and ecological considerations and; vii) Economic and financial aspects of low-carbon development.

It is to be noted that agriculture is not included in these considerations given its predominantly adaptation-related character, especially in the context of India's agriculture sector being dominated by small and marginal farmers whose lives and livelihoods will be severely impacted by climate change. Another aspect to note is that transitions in the Indian context refer to low-carbon development and not de-carbonization. Further, it will entail rational use of India's fossil fuel resources, keeping in view the need for development and energy security. India's low-carbon development strategy will undergo further evolution and as noted will need to accommodate new developments in technology, global economy and international cooperation, while being mindful of the risks that such a long-term strategy inevitably entails.

Challenges of COVID-19 Pandemic

The challenge of COVID-19 pandemic that the world faced and continues to face even today, was also a global collective action problem that served to illustrate, in real time, many aspects of the challenge of climate action. In many ways, the inequalities that the world faces were mirrored in the global response to the pandemic. At the same time, India responded to global pandemic with an approach similar to tackling the climate challenge – mindful of its global responsibilities and ready to act as a responsible global power while being aware of and responding to its development challenges and imperatives. In this regard, India contributed in the innovation and technology development aspect of tackling the pandemic, with its own vaccine development, and extended its support to the world. However, many developed countries were reluctant to endorse India's call, along with other developing countries, to modify the international property rights regime in order to enable rapid and affordable vaccine development. The COVID-19 response and the way the world addressed the challenge, illustrates the gap yet to be bridged to arrive at meaningful and effective climate action.

Finance and economic stimulus and Production Linked Incentives (PLI)

India's efforts at sustainable development, keeping in view the need to build climate resilience, are significantly hampered by the lack of finance. The poor state of the flow of climate finance hampers all developing countries. Climate finance suffers from the lack of scale, scope and speed, is highly skewed towards mitigation and not adaptation, fails to be new and additional to development assistance (often substituting for it) and significantly fails to be dominated by grants and concessional loans. In this background, it is necessary for India to mobilise its own resources to undertake progress in climate mitigation and adaptation. India's mitigation schemes are funded through loans, and even where scarce climate grants are made, India has to supplement the same with domestic co-financing.

The pandemic also created new economic challenges and economic stimulus during the pandemic had a significant impact on available finance for development and climate related activities. In the absence of large-scale technology transfer on concessional terms, India has had to invest in production-linked incentives to stimulate production in key areas such as manufacture of solar panels and in battery development. Similarly, the ethanol blending in fuel program as well as the national hydrogen initiatives have had to be driven by purely domestic resource mobilisation.

India's policies are framed in the background of India's recognition of global warming as a global collective action problem, that can be solved only through international cooperation. India emphasizes the foundational importance of the principles of the UNFCCC, namely equity and the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), alongside the recognition of the importance of the best available science. At the same time, the aspirations for growth and development of the citizens of India have to be respected, with the focus on social and economic development being the key to building climate resilience to the inevitable consequences that the profligate emissions of the developed countries have thrust on the world.

India's resolute climate actions and its efforts in all aspects of meeting the challenge of global warming span all aspects of the economy, drawing in all Ministries and Departments of Government, Institutions, and entities, both at the Centre and in the State level, inclusive of the local governments, private sector and civil society. India has also reached out in various dimensions of climate action in the international arena through several targeted initiatives in collaboration with other nations, going beyond a purely domestic agenda.

India's Third National Communication (TNC) is formulated as per Decision 17/CP.8 of the UNFCCC, keeping in view India's status as a non-Annex-I Party to the Convention.

The TNC begins with a chapter on India's national circumstances. This Chapter is divided into eight sections and provides an overview of the current circumstances of climate and weather in India, important ecosystems and economic sectors, as well as important initiatives taken at various levels of governance to address these concerns. The first two sections provide an overview of climatic and weather patterns of India, including an overview of temperature and precipitation patterns. Sections 3 and 4 cover extreme events and existing capacities to monitor and adapt to these events. Sections 5 and 6 link the concerns of vulnerability and development in the context of disaster, extreme events, climate variability, and capacities to address long term climate change impacts. Section 7 provides an overview of India's energy profile. Section 8 emphasizes the interlinkages between important developmental goals at the national level and sustainability concerns at the global level. It also describes the current policy measures undertaken to address questions of sustainability in relation to poverty eradication, urbanisation, waste management, transport, and sustainability.

1.1 Key Points

i. According to the IMD (2022), annual mean temperature has increased between 1901-2021. The increasing trend is more significant for maximum temperatures (1°C/100 years) than minimum temperatures. The past 10 years (2012-2021/2013-2022) was the warmest decade on record since 1901; with temperature anomalies of 0.37°C/ 0.41°C above average. Eleven out of the 15 warmest years were during the recent fifteen years (2008-2022).

ii. The IMD (2020c) report, titled 'Observed Monsoon Rainfall Variability and Changes during Recent 30 years', indicates that, between 1989-2018, there was a significant decreasing trend in the southwest monsoon rainfall for the states of Uttar Pradesh, Bihar, West Bengal, Meghalaya and Nagaland. Consequently, annual rainfall in these States have declined. Several districts in the country show significant changes in southwest monsoon and annual rainfall patterns in this period. Heavy rainfall days have increased in parts of Gujarat (Kutch and Saurashtra), Rajasthan (South eastern parts), Tamil Nadu (Northern parts), Andhra Pradesh (Northern), Odisha (southwest), and parts of West Bengal, Manipur & Mizoram, Konkan & Goa and Uttarakhand.

iii. Extreme precipitation and flooding events have affected several parts of India in recent years (2020 and 2021) (IMD 2020a; 2020b; 2021a; 2021b). These floods were caused by heavy precipitation, as well as events such as glacier breaks and flash floods, and avalanches. These events caused the loss of lives, massive damage to crops, public infrastructure, and private property across several districts in India. As per study by NRSC/ISRO, over the last 4 years, the number of States affected by major floods has increased from 8 States in 2017 to 15 states in 2021. Existing analysis of trends in heavy rainfall and flooding indicate that their frequency is increasing in some parts of India that include the peninsular, east, north-east, and some parts of central India. Apart from the extreme events mentioned above, shocks were faced by various regions due to snowfall, lightning, thunderstorms, hailstorms and dust storms between 2019 and 2021.

iv. In terms of monitoring and adapting to these events, several key capacity building measures have been implemented. These include the development of spatial flood early warning models using very high-resolution Digital Terrain Models, and the Rapid Response and Emergency Services/ Decision Support Centre (RRES/DSC) at NRSC/ISRO. Other important monitoring systems include the Indian National Centre for Ocean Information Services (INCOIS), and the Indian Tsunami Early

Warning Centre (ITEWC). Development of spatial flood early warning models using very high-resolution Digital Terrain Models now provide alarms for spatial flooding in flood prone regions of India. Spatial flood early warning models for major floodplains of Godavari and Mahanadi rivers are developed using high resolution digital terrain models.

v. In terms of analysing vulnerability across different regions of India, a unified framework for assessment was developed as a part of the report on "Climate Vulnerability Assessment for Adaptation Planning in India" (DST, 2020). The report indicates high vulnerability of southern and eastern zones of India to extreme cyclonic events, floods, and droughts combined. Further, the report identifies the western and southern regions of India as being extremely vulnerable to agricultural droughts and indicates that most northern, eastern, and central zones are moderately vulnerable to both meteorological and agricultural droughts.

vi. To improve capacity building and scientific knowledge on the impacts of climate variability and climate change on Indian agriculture, several adaptation and capacity building programmes have been implemented –

   a. National Innovations on Climate Resilient Agriculture (NICRA), Policies on soil health, extension, and agriculture, livestock health and resilience.

   b. The GoI is currently issuing location and crop specific weather-based advisories for the benefit of farming community of eastern Uttar Pradesh region on every Tuesday and Friday under Gramin Krishi MausmSeva (GKMS). An India Centric Climate Model (ICCM) being developed for reliable future climate projections at district level to assess the impacts of climate change on agriculture, health, water resources, and the energy sectors.

vii. Climate change impacts have direct consequences for water security. The various important schemes implemented in India to address these include –

   a. Namami Gange Programme
   b. National Water Mission
   c. Jal Jeevan Mission
   d. Jal Shakti Abhiyan
   e. Atal Bhujal Yojana (ATAL JAL)
   f. Pradhan Mantri Krishi Sinchayi Yojana (PMKSY)
   g. Swachh Bharat Mission
   h. Dam Rehabilitation and Improvement Programme (DRIP)
   i. Flood Management

viii. India is undergoing multiple transitions – a demographic transition that leads to demands for job creation, an agrarian and urbanisation transition, and rapid infrastructure growth. All three are energy intensive. As with Human Development Index (HDI), historical evidence clearly shows that energy use per capita grows strongly during the early years of per capita GDP growth, and India is only beginning to exploit the positive linkages between energy consumption and GDP. The limited extent of decoupling emissions from growth seen in developed countries is still insufficient and their emissions continue to remain at high levels indicative of significantly higher consumption compared to developing countries. In contrast, India's trajectory reflects its low energy consumption and low emissions even currently, as well as the impact of its significant mitigation efforts, with its decoupling beginning at much lower emission levels.

ix. Energy is essential to meet the development needs and erasing India's development deficits while building for a prosperous future. Social development, as measured by the HDI, is closely correlated with growing per capita energy consumption. India is well short of the threshold of per capita energy consumption required to reach an acceptable national level HDI. India's primary energy consumption per capita in 2021-22 was 24.45 gigajoules (GJ), considerably lower than both developed country peers (e.g., 282.2 GJ for the United States, 340.4 GJ for Canada, 106.8 GJ for the United Kingdom) and comparative developing countries (e.g., 58.2 GJ for Brazil, 100.1 GJ for South Africa, 101.3 GJ for China). Meeting the development needs will require steep increases in overall and per capita energy use even as India implements an effective programme to enhance energy efficiency.

x. India's energy consumption is well below developed countries. Energy consumption in India is characterized by low per capita level and a large disparity between urban and rural areas. The energy intensity of the economy has come down and will continue to decrease over the coming years. This has been possible due to a number of initiatives taken by the government. Energy intensity in India (energy consumed per unit of GDP (2011-12 prices) decreased to 0.2245 MJ/rupee in 2021-22 from 0.2801 MJ/rupee in 2012-13 (MoSPI, 2023a). In 2021-22 primary energy supply added up to 739.386 million tonne of oil equivalent (Mtoe). India's per capita energy consumption in 2021-22(P) stood at 24,453 MJ/person. The installed capacity of electricity generation stood at 4,16,058.89 MW as of 31st March 2023.

xi. It is expected that the energy basket would shift with an increase in income. India's energy and electricity consumption is well below developed countries. Energy consumption in India is characterized by low per capita levels and a large disparity between urban and rural areas.

xii. The objective of achieving a sustainable transition to improve the living and working conditions of all its citizens, guides India's policies. These goals are sought to be achieved through policies of affordable housing, waste management and circular economy, as well as providing adequate infrastructure. Some of the important schemes and policies include:

    a. The Anganwadi Services Scheme (ASS) (earlier named The Integrated Child Development Scheme (ICDS), covered under POSHAN ABHIYAN, 2018

    b. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), 2005

    c. Pradhan Mantri Awas Yojana-Urban (PMAY-U), 2005- more than 123 lakh houses were sanctioned.

d. Affordable Rental Housing Complexes (ARHCs), 2020

e. The Swachh Bharat Mission (SBM), 2014 – Clean India Mission

f. National Urban Livelihood Mission (NULM), 2013.

g. Circular economy principle-based policies-including plastic waste management and ban on identified single use plastics.

h. Achieving universal access to electricity under the Saubhagya scheme

xiii. The transportation sector consisting of infrastructure for transport as well as its effective and sustainable management are key to building capacities for improved sustainable development and long-term adaptation strategies. This sector is also a significant source of emissions. In relation to climate change, transportation by road and air are the most significant segments of this sector.

xiv. Road transport is the dominant mode of goods and passenger transport in India- total length of the highways in the country has more than doubled from 57,737 Km in 2001 to 1,44,955 Km in 2022; the total number of registered vehicles has increased by about 6 times within the last two decades (MoRTH, 2023). The Total Fuel Consumption (TFC) by the transport sector in India has more than doubled in ten years, more than tripled since 2000 and stands at 94 Mtoe or 17% of TFC in 2017. With a view to addressing this challenge, and to abate vehicular emission, the GoI has subscribed to BS-VI emissions standards for new vehicles. India has leapfrogged one stage of emission norms, moving from BS-IV to BS-VI. Ministry of Road Transport and Highways has issued guidelines on use of new and alternative materials and technology such as fly ash, waste plastic, polymer modified bitumen, steel slag, soil stabilizers, solid municipal waste etc. to promote sustainable practices in the construction of highways.

xv. India represents a growing aviation market with more than 80 operational airports and carried more than 201.9 million passengers in 2019-20. With an aim to reduce the contribution of emissions from the aviation sector, several measures such as promotion of sustainable aviation fuel are being adopted in India in the recent past.

1.2 Climate and weather overview

The mainland of India extends between 68°7'E to 97°25'E and 8°4'N to 37°6'N. With a total land area of over 3.28 million square kilometres, it is the seventh-largest country in the world. The country also borders Pakistan, Bhutan, Bangladesh, and Myanmar. India shelters over 1.4 billion people representing various socio-cultural groups that collectively make up the world's largest democracy. India occupies almost 2.3% of the world's land area with 18% of the world's population. Population growth and higher population density can exacerbate the challenge of ensuring that future development is sustainable and inclusive.

An overview of India's climatic conditions includes – i) the presence of various climate regimes, including extremes of heat or cold, aridity and negligible rainfall to excessive humidity and torrential rainfall. ii) Northern parts are characterised by severe summer and cold winters, iii) coastal climatic conditions and

iv) Southeast and western regions witness moderate precipitation and temperature across some parts of the country.

As a consequence of such diverse geographic and climatic conditions, there are 15 agroclimatic zones in India- Western Himalayan, Eastern Himalayan, Lower Gangetic Plains, Middle Gangetic Plains, Upper Gangetic Plains, Trans Gangetic Plains, Eastern Plateau and Hills, Western Plateau and Hills, Central Plateau and Hills, Southern Plateau and Hills East Coast Plains and Hills, Gujarat Plains and Hills, West Coast Plains and Hills, Western Dry Region, and Islands.

As described above, a wide range of spatial and seasonal variations of weather and climatic patterns exist in India. Extreme conditions of heat waves, thunderstorms, and cold waves are also experienced across different regions in the country.

The Oceans, Himalayas and the Thar Desert strongly influence the climate of India. The Arabian Sea, the Indian Ocean and the Bay of Bengal surround southern peninsular India. Hence the climate of coastal regions of India is equable or maritime. The Himalayan and adjoining mountain ranges extend from Kashmir in the Northwest to Arunachal Pradesh in the Northeast. These mountain ranges protect India from the extremely cold and dry winds of Central Asia during winter. Furthermore, they act as an effective physical barrier for the rain-bearing southwest monsoon winds to cross the northern frontiers of India. Land areas in the country's north have a continental climate, with severe summer heat that alternates with extremely cold winters.

In India, four principal seasons have been defined in a year as follows:

The months of January and February constitute the winter season, however, in most parts of northern India, winter starts in December and extends till early March. Clear skies, fine weather, light northerly winds, low humidity and temperature, and significant daytime temperature variations are the typical features of the weather in India from December to February. The coldest months of the year are December and January, when the mean maximum temperature ranges from 0.5^{o}C to 29^{o}C, whereas the mean minimum temperature ranges from -7.7^{o}C to 13.6^{o}C in the northwest region. Temperatures rise as one proceeds towards the equator when the mean maximum temperature ranges from 17.3^{o}C to 33.9^{0}C, whereas the mean minimum temperature ranges from 6.2^{o}C to 29.8^{o}C in the peninsular region. The relative humidity is 70% or more in extreme north-western parts and the eastern coast of India. During the winter, extreme northern subdivisions and Arunachal Pradesh receive the highest rainfall in the range of 120-225 mm due to the western disturbances. In contrast, Western parts receive the lowest rainfall (less than 15mm). All of India's winter season (Jan-Feb) rainfall (39.8 mm) contributes around 3.4% to the annual rainfall over India.

The pre-monsoon or summer season is the period from March to May. Apart from cyclonic storms that form over the Indian sea areas, the other weather phenomenon during this season is the convective type of weather (thunderstorms, dust storms, hailstorms and their associated features). For the Northeast region, May and June are generally the hottest months when the mean maximum temperature ranges from 19.3^{o}C (May)/19.8^{o}C (June) to 42.6^{0}C; whereas the mean minimum temperature ranges from

10.6^{0}C to 27.4^{0}C. May is generally the hottest month for the Northwest region, with a mean maximum temperature ranging from 15.4^{0}C to 43.1^{0}C, whereas a minimum temperature ranges from 5.6^{0}C to 29.9^{0}C. In Central India, May is generally the hottest month when the mean maximum temperature ranges from 30.1^{0}C to 42.9^{0}C, whereas the mean minimum temperature ranges from 18.1^{0}C to 28.1^{0}C. For the Peninsular region, April and May are the hottest months, where the mean maximum temperature ranges from 21.1^{0}C to 41.9^{0}C whereas the mean minimum temperature ranges from 11.2^{0}C to 34.8^{0}C. The change in the climatic conditions in summer results in the formation of many natural hazards. Thunderstorms associated with rain and sometimes hail the predominant phenomenon of this season. Over the dry and hot plains of northwest India, dust storms, accompanied by dust-laden solid winds, occur frequently. Violent thunderstorms with strong winds and rain lasting for a short duration also occur over the eastern and northeastern regions in Bihar, Odisha, West Bengal, and Assam). In the pre-monsoon season (March-May), North-eastern India receives the highest rainfall, followed by Kerala in the range of 350-758mm. India's pre-monsoon season (March-May) rainfall (130.6mm) contributes around 11% to the annual rainfall in India.

The southwest monsoon season from June to September is the primary rainy season in India. Although the southwest monsoon (also known as the summer monsoon) period over the country is generally four months (June–September), its actual period at a specific place differs, depending on the date of its onset and withdrawal. Usually, the southwest monsoon sets in over the Kerala coast, the southern tip of the country, by 1st June and then advances in early June and extends over the entire country by the end of July. On islands in the Bay of Bengal, the onset occurs about a week earlier. The duration of the monsoon varies from less than 75 days in western Rajasthan to more than 120 days over the southwestern regions of peninsular India. The season is dominated by the humid southwest summer monsoon, which slowly sweeps across the country in late May or early June. Winds are south-westerly over the Bay of Bengal and the Arabian Sea in July compared to north-easterly in January. The monsoon air mass is maritime and moist in great depth against the winter dry continental air. The relative humidity is 80% or more in the eastern, north-eastern and western coastal regions. These regions are also experiencing high southwest monsoon rainfall. Monsoon rains begin to retreat from North India at the start of October. The southwest monsoon rains exhibit a striking regularity in their seasonal onset and distribution within the country but are variable both within the season and from year to year. Within a season, the monsoon rainfall oscillates between active spells associated with widespread rains over most parts of the country and "breaks" with little rainfall activity over the plains and heavy rains across the foothills of the Himalayas. Heavy rainfall in the mountainous catchments under "break" conditions leads to floods over the plains. Breaks are also associated with very uncomfortable weather due to high humidity and temperature.

The post-monsoon or northeast monsoon season, during October, November and December, is the major period of rainfall in the south Peninsula, particularly the coastal Andhra Pradesh, Rayalaseema and Tamil Nadu. In northwestern India, October and November are mostly cloud-free. The term 'Northeast Monsoon' is often used to describe the period from October to December. However, according to the Indian Meteorological Department (IMD) classification of the year into seasons, these three months constitute the 'post-monsoon season', also known as the 'Retreating Southwest Monsoon season'. During post-monsoon season, Tamil Nadu and Kerala receive more than 350mm of rainfall, while adjacent subdivisions receive 150-350mm. All India post-monsoon season rainfall (121.0mm) contributes around 10% respectively to the annual rainfall over India.

The following sub-sections summarise the natural circumstances in India regarding temperature trends, precipitation, climatic variations, extreme events and adaptive action taken in response to the same. The information for this section was obtained from various reports published by the Indian Meteorological Department, Ministry of Earth Sciences, the Department of Science and Technology, and the Ministry of Environment and Forestry and Climate Change. In particular, information on climatic patterns and other events are based on the Annual Climate Summary 2022 (IMD, 2022), Annual Report of India Meteorological Department (IMD) for the year 2020 and 2021 (IMD, 2020a; 2021a) and the Annual Statement on Climate of India 2020 and 2021 (IMD 2020b; 2021b), and the IMD (2020c) report on "Observed Monsoon Rainfall Variability and Changes".

1.2.1 Temperature in recent years: trends and variation

The country averaged annual mean temperature during 1901-2022 showed a significant increasing trend of 0.64°C/ 100 years, while a significant increasing trend was observed in maximum temperature (1.0°C/ 100 years) and a relatively lower increasing trend (0.28°C / 100 years) in minimum temperature.

The annual mean land surface air temperature for the country during the year 2022 was +0.51°C above the 1981-2010 average, thus making the year 2022 the fifth warmest year on record since 1901. The five warmest years on record, in descending order were 2016 (+0.71°C), 2009 (+0.55°C), 2017 (+0.541°C), 2010 (+0.539°C) and 2022 (+0.51°C).

It may be mentioned that 11 out of the 15 warmest years were during the recent fifteen years (2008-2022). The past decade (2012- 2021 / 2013-2022) was also the warmest decade on record with the decadal averaged annual mean temperature anomaly (Actual-Long Period Average) of +0.37°C / +0.41°C.

Figure 1.2 (a-e) describes spatial warming trends for 1901-2022. They are based on mean annual temperature anomalies. These trends indicate a significant positive trend for most parts of the country. The exceptions to these trends are found in Rajasthan, Gujarat, Uttar Pradesh and Bihar (IMD, 2022).

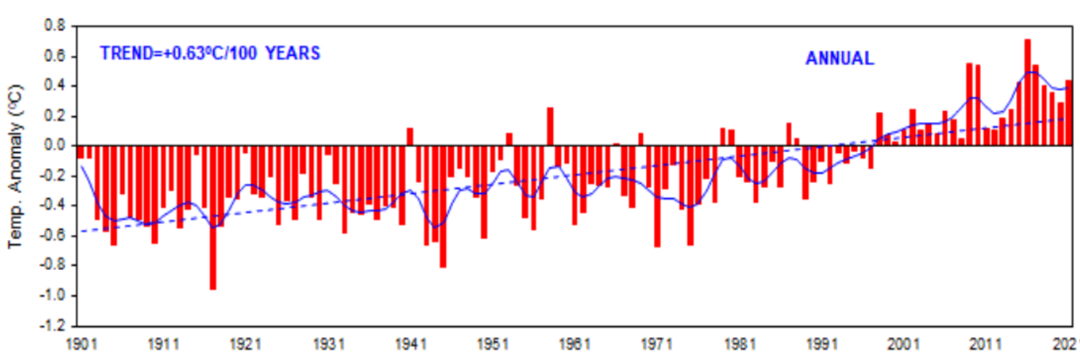


Figure. 1.1: Annual mean land surface air temperature anomalies averaged over India (1901-2021).

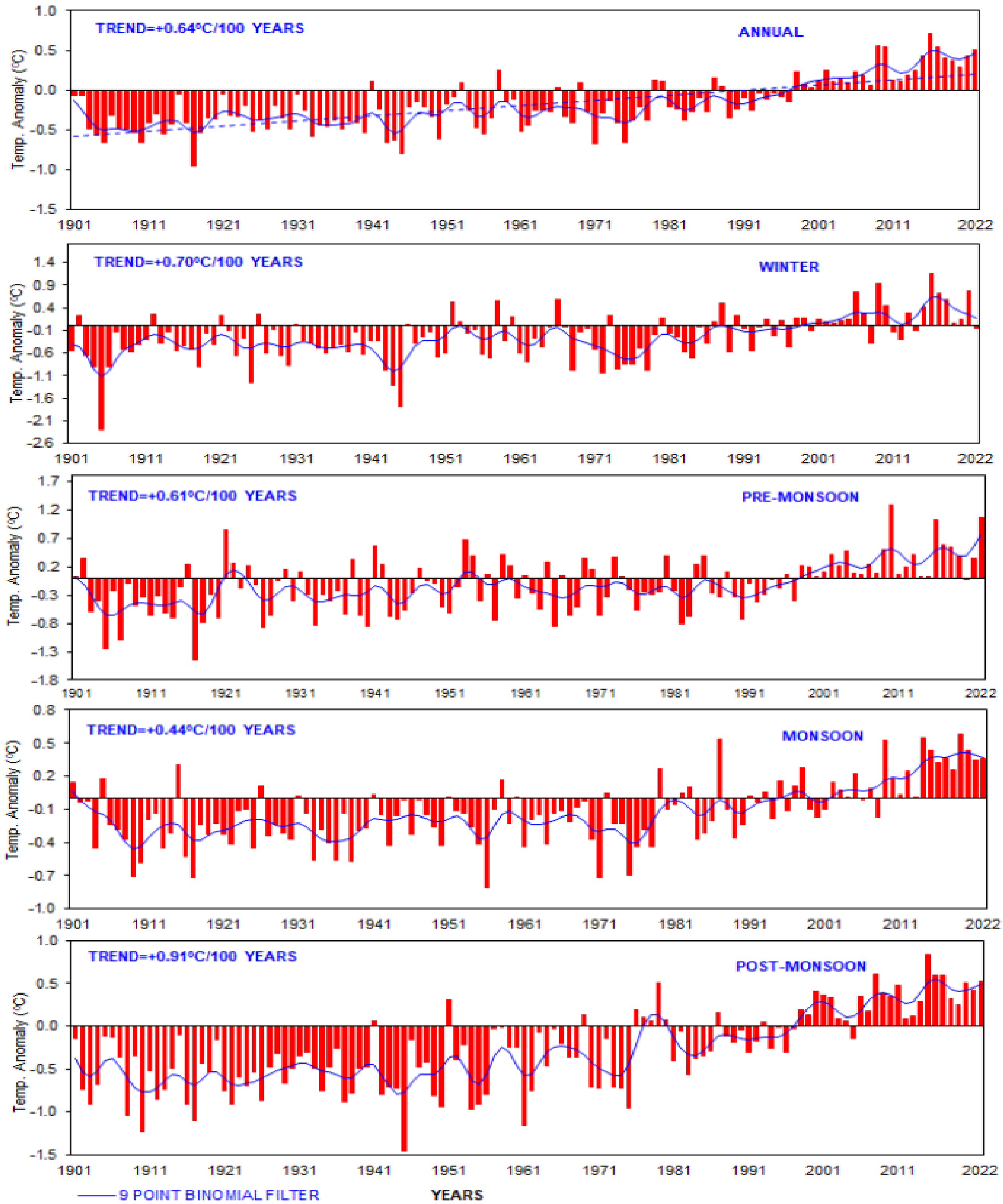


Figure. 1.2 All India mean temperature anomalies (a) Annual (b) Winter (c) Pre-monsoon (d) SW-monsoon (e) Post-monsoon for the period 1901 - 2022 shown as vertical bars. The solid blue curve had sub-decadal time scale variations smoothed with a Binomial Filter (Departures from the 1981 - 2010 average)

[Source: IMD, 2022]

Anomalies computed for a base period of 1901- 2022. The dotted line indicates the linear trend in the time series. A solid blue curve represents sub-decadal time scale variation smoothed with a binomial filter.

1.2.2 Precipitation and rainfall: patterns and variations

The Indian monsoon is one of the most prominent features of the world's monsoon systems, which blows from the southwest during the warmest months of the year and reverses direction to blow from the Northeast during cooler months. This process brings large amounts of rainfall to the region from June to September and is regarded as the principal rainy season. Overall, there is a large inter-annual variability in its onset and withdrawal dates over different parts of the country. Rainfall distribution and intensity significantly impact different socioeconomic sectors, especially agriculture and hydrology, besides their impact on other ecosystems.

The IMD report on 'Observed Monsoon Rainfall Variability and Changes' indicates that between 1989-2018, there was a significant decreasing trend in the southwest monsoon rainfall for the states of Uttar Pradesh, Bihar, West Bengal, Meghalaya and Nagaland (IMD, 2020a). Consequently, annual rainfall in these States has declined. Several districts in the country show significant changes in southwest monsoon and annual rainfall patterns in this period. Heavy rainfall days have increased in parts of Gujarat (Kutch and Saurashtra), Rajasthan (Southeastern), Tamil Nadu (Northern), Andhra Pradesh (Northern), Odisha (Southwest), and parts of West Bengal, Manipur, Mizoram, Konkan, Goa and Uttarakhand (ibid.). The time series of the percentage departure of annual rainfall over the country since 1901 is shown in Figure 1.3.

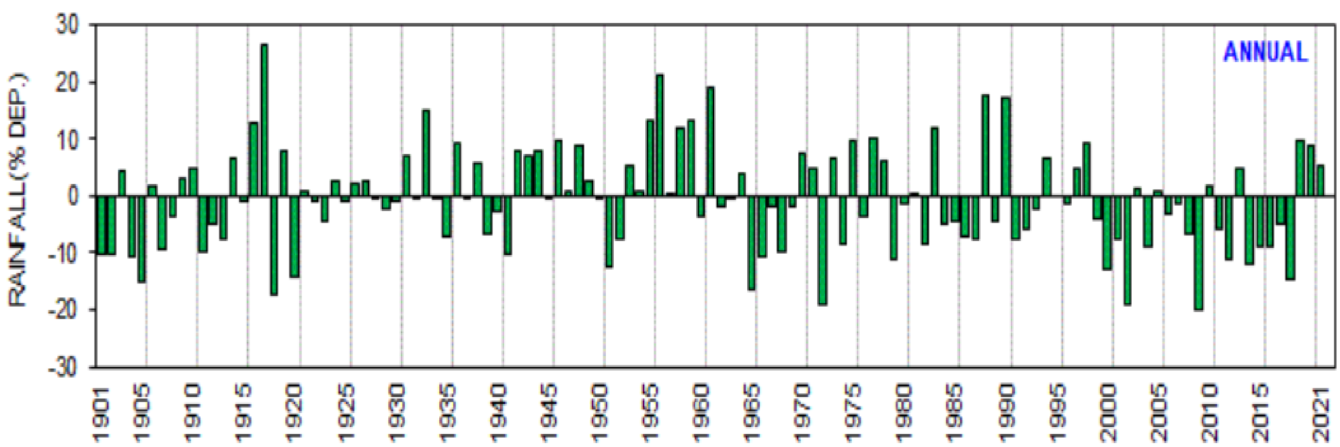


Figure 1.3: All India Annual Rainfall Percentage Departure from LPA during 1901-2021.
Source: IMD (2021b). Note: The percentage of departures was computed for the base period of 1961-2010

Other important features to note (IMD, 2020a; IMD 2021b) are as follows:

i. India receives about 868.6 mm of rainfall during the southwest monsoon season, which is about 74.9% of the country's annual rainfall (1160.1mm). June, July, August, and September contribute 19.1%, 32.3%, 29.4%, and 19.3% to the total monsoon season rainfall, respectively. Out of twelve months, July receives the maximum rainfall of 280.4 mm, followed by August (254.9mm). The monsoon rainfall shows a large spatial variability in its distribution. The meteorological sub-division of Konkan and Goa receive the highest rainfall of more than 300 cm annually, followed by sub-divisions in northeastern India which have annual rainfall normal between 200 to 280 cm. The normal rainfall for the Southwest monsoon season is highest over the states of Assam and Meghalaya, followed by western coastal subdivisions with a value of more than 1600mm. West Rajasthan receives the lowest annual rainfall of about 33 cm, including about 28 cm during the southwest monsoon season.

ii. Based on data between 1989 and 2018 period, the mean pattern of dry days (no rainfall for a day), rainy days (rainfall between 2.5mm-6.5cm), and heavy rainfall days (above 6.5cm) for the monsoon season (June to September) are shown in Figures 1.4 (a, b, c). Dry days are significantly found in the regions of northwest India and the southeastern and coastal regions. The rainy days are highest over the western coast and northeastern states. The number of heavy rainfall days is high over the states of Uttar Pradesh, Bihar, Madhya Pradesh, West Bengal, Jharkhand, and Odisha.

iii. In this same period, significant changes have been recorded across several districts regarding the frequency of these days. This change in frequency is shown in Figures 1.5 (a, b, c). The frequency of dry days during the monsoon season has significantly increased in the states of Andhra Pradesh, Tamil Nadu, Odisha, Jharkhand, Madhya Pradesh, Chhattisgarh, West Bengal, and Uttar Pradesh. Regarding rainy days, there is a significant decreasing trend in the states of Uttar Pradesh, Bihar, Jharkhand, Punjab and northeastern states. The frequency of rainy days shows a significantly increasing trend for the states of Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, Odisha, and Chhattisgarh. Heavy rainfall days are significantly increasing (in frequency) over parts of Gujarat (Saurashtra and Kutch), Rajasthan (southeastern), Tamil Nadu, Andhra Pradesh, Odisha, Chhattisgarh, Madhya Pradesh, Uttarakhand, West Bengal, Manipur, Mizoram, and Goa.

iv. The spatial distribution of long-term average cumulative rainfall (cm) is depicted in Figure 1.6. Separate panels for the four major seasons are displayed (Winter, Pre-monsoon, Southwest Monsoon and Post-Monsoon).

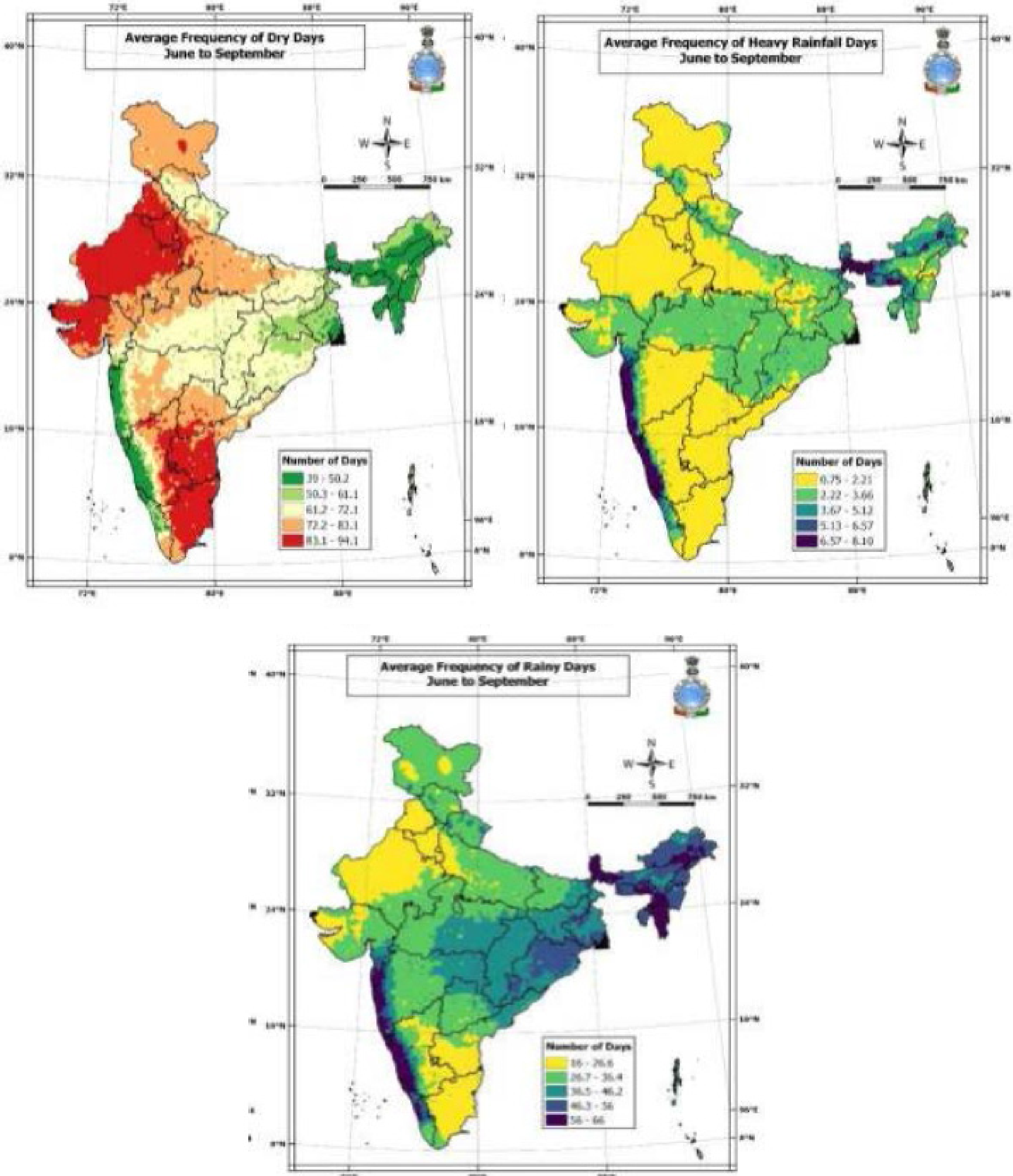


Figure 1.4 Mean patterns of (a) dry days (No rain in a day), (b) rainy days (rainfall between 2.5mm-6.5cm) and heavy rainfall (above 6.5 cm)

Source: IMD (2020a) based on IMD data between 1989-2018

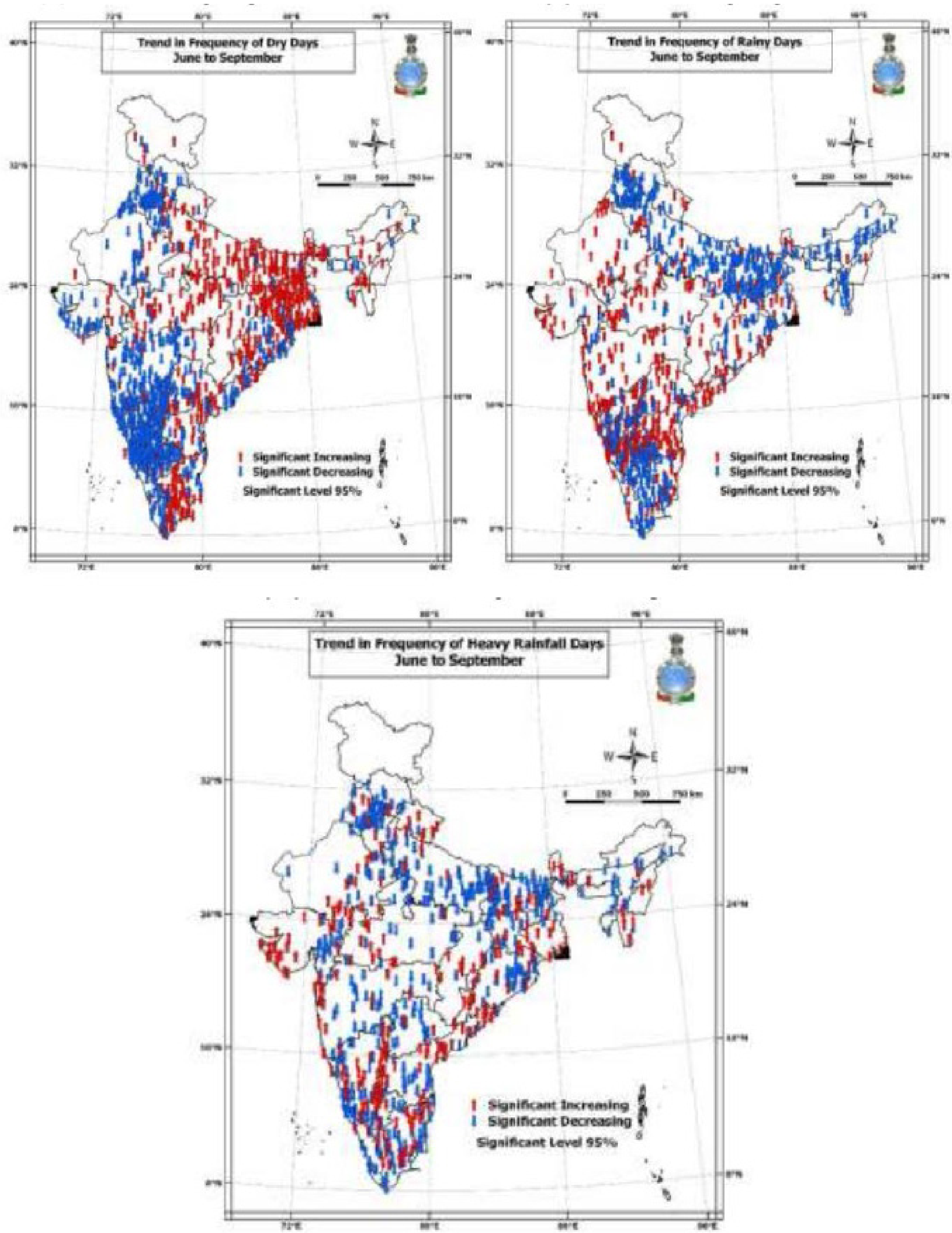


Figure. 1.5 Trends in the frequency of (a) dry days (No rain in a day), (b) rainy days (rainfall between 2.5mm-6.5cm) and heavy rainfall (above 6.5 cm)

Source: IMD (2020a) based on IMD data between 1989-2018

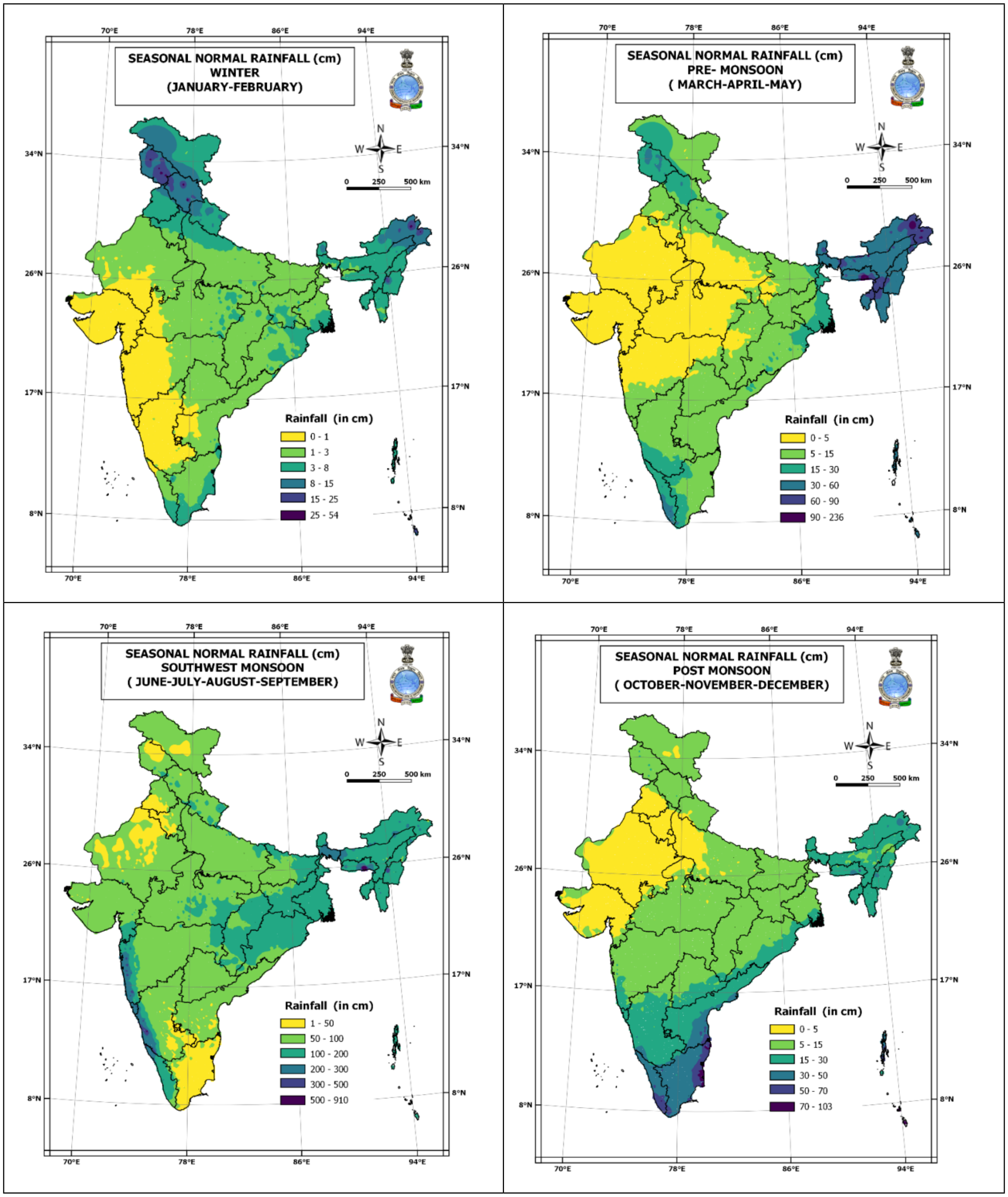


Figure. 1.6 Average cumulative rainfall (cm) over India during four seasons (Winter, Pre-monsoon, Southwest Monsoon and Post-Monsoon).

Source: IMD

1.3 Extreme events

Along with the climatic variations and long-term trends in precipitation and temperature, various parts of the country have experienced extreme events. These events include cyclonic storms, droughts, floods, lightning, thunderstorms, snowfall, cold waves, and heat waves. The subsequent sections provide an overview of these extreme events.

1.3.1 Cyclones

India experiences various types of natural hydro-meteorological hazards. Cyclones over the North Indian Ocean pose a potential threat to the coastal population as well as the marine community of the region. Tropical cyclones are sizeable synoptic-scale weather systems that originate over the world's warm oceans and develop into massive vortices composed of swirling winds, intense clouds and torrential rains by drawing energy from the oceans. While moving over land, they cause large-scale destruction to life and property over the world's coastal areas. India's east and west coasts are prone to the destructive features of Tropical Cyclone (TC) activity (Mohapatra et al., 2012) over the North Indian Ocean (NIO) comprising the Bay of Bengal (BoB) and the Arabian Sea (AS). Mohapatra et al. (2021) analysed the characteristics of genesis and intensification of cyclonic disturbances of different categories developing over the North Indian Ocean and crossing different coastal regions based on the data of the satellite era (1965-2020). About ten Cyclonic Disturbances (CD) and five Tropical Cyclones develop over the North Indian Ocean during a year. About eight Cyclonic Disturbances develop over the Bay of Bengal in a year, out of which 3–4 (45%) become Tropical Cyclones (maximum sustained wind speed ≥ 34 knots).

The storms forming over the Bay of Bengal are more frequent than the ones originating over the Arabian Sea. Mohapatra et al. (2021) analysed data from 1965-2020 to find different categories of tropical cyclones making landfall over different coasts in the NIO region. About average annually, 7.6 CDs and 3.3 tropical cyclones (cyclonic storm & above) make landfall over the NIO. Basin-wise, the average frequency of landfall is about 6.7 for CDs and 2.8 for TCs over the BoB and 0.9 and 0.5, respectively, over the AS. The frequency of landfalling TCs is higher post-monsoon (2.2) than in the pre-monsoon (1.0) season over the NIO. It is about 1.9 (0.3) and 0.7 (0.3) over the BoB (AS) during the post-monsoon and pre-monsoon seasons, respectively.

The development of Tropical Cyclones is generally seasonal in nature, with most tropical ocean basins having a maximum frequency of formation during the late summer-to-early autumn period. However, unlike other ocean basins, the Tropical Cyclones' frequency over the North Indian Ocean shows a bimodal character with a primary peak during the post-monsoon season followed by a secondary peak during the pre-monsoon season (Li et al., 2013). About 5–6 Cyclonic Disturbances, including about one Tropical Cyclone, form over the North Indian Ocean during the monsoon season. The Tropical Cyclones in monsoon season usually occur during the onset phase (month of June) and withdrawal phase (month of September) of the southwest monsoon (Rao, 1976). Over the past several years, there have been significant improvements in the skill of track and intensity of tropical cyclones forecast by the India Meteorological Department.

A methodology (Pseudo Global Warming Method) has been developed to simulate the effect of climate change on the behaviour of a cyclone or extreme rainfall event in future and studied various cyclonic events like 'Vardah' (2016), 'Hudhud' (2014), 'Phailin' (2013) and 'Madi' (2013) and the 2015 Chennai extreme rainfall event. A coupled ocean-atmospheric model has been developed to capture the ocean-atmospheric interaction during the progress of cyclones and used to study cyclone Titli (2018).

1.3.2 Heatwaves

Heatwaves are also among the most significant natural hazards affecting India. A heatwave is a period of abnormally high temperatures, more than the normal maximum temperature, that occurs during the summer. The IMD criteria for declaring heat waves and cold waves are described in IMD Forecasting Circular No. 5/2015 (3.7). The heatwaves typically occur between March and June and sometimes even extend till July in India. Heatwaves are more frequent over the Indo-Gangetic plains of India. On average, 5-6 heat wave events occur every year over the northern parts of the country. Temperatures in excess of 46°C have been recorded in many parts of the country, especially north and central India. Higher daily peak temperatures and longer, more intense heat waves are becoming increasingly frequent globally due to climate change. The climatology of heat wave days over the country based on data from an observational network of IMD point out that except over northeast India and large parts of the Peninsula (South of ~21°N & west of 80°E), most areas of the country have experienced an average ≥ 2 heatwave day. Many areas of Rajasthan, Punjab, Haryana, northern parts of East Rajasthan, Madhya Pradesh, Chhattisgarh, Vidarbha, western Uttaranchal, East Uttar Pradesh, western parts of Jharkhand and Bihar, Gangetic West Bengal, northern parts of Odisha, Telangana, Coastal Andhra Pradesh, eastern parts of Rayalaseema and north Tamil Nadu on an average have experienced ≥8 heat wave Days.

Studies conducted by the Department of Science and Technology (DST) indicate a shift in the spatial-temporal occurrence of heat waves and severe heat waves in India from the eastern region to northwestern and central India to south-central India, with an overall increase in heat waves during the last three decades (Singh et al., 2021). These are described in Figure 1.7. Similarly, India has observed a western shift and a significantly increasing trend in extreme rainfall events over the past 119 years, indicating a greater vulnerability in the western region due to floods. A significant decrease in the Diurnal Temperature Range (DTR) in India was observed in the last three decades owing to much increase in minimum temperature and a decline in solar radiation that is much more prominent over northwest India, parts of Gangetic plain, north-east, and central India and might have serious repercussions on human health and agricultural production.

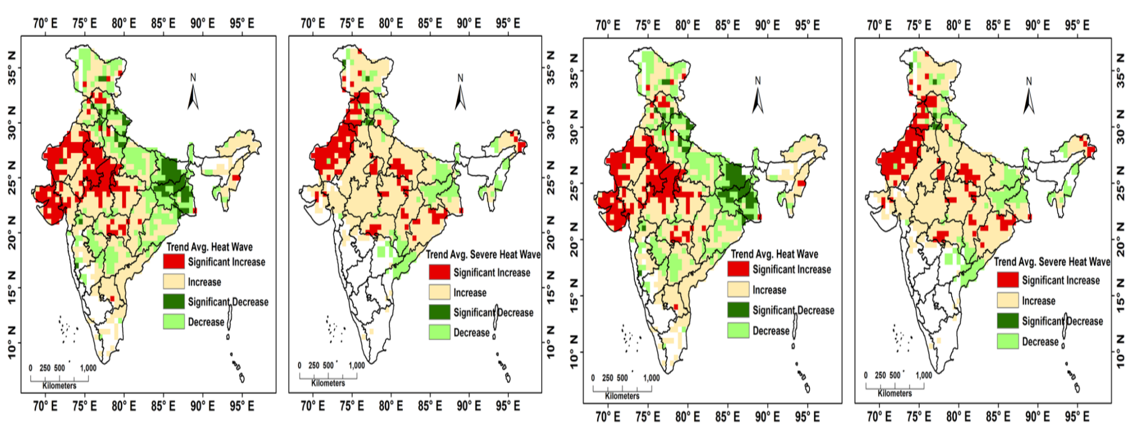


Figure 1.7: Heatwave hotspots in India
Source: PIB, 2021

1.3.3 Droughts and Floods

Variations in the monsoons make the Indian sub-continent more susceptible to the impacts of events such as droughts and floods. Precipitation over India and drought conditions are analysed using the 'Standardised Precipitation Index' (SPI). The SPI is used for monitoring drought conditions and is based on precipitation. This index is negative for dry and positive for wet conditions. The index becomes more negative or positive as the dry or wet conditions become more severe. This index for the period of January to December 2021 is displayed in Figure 1.8.

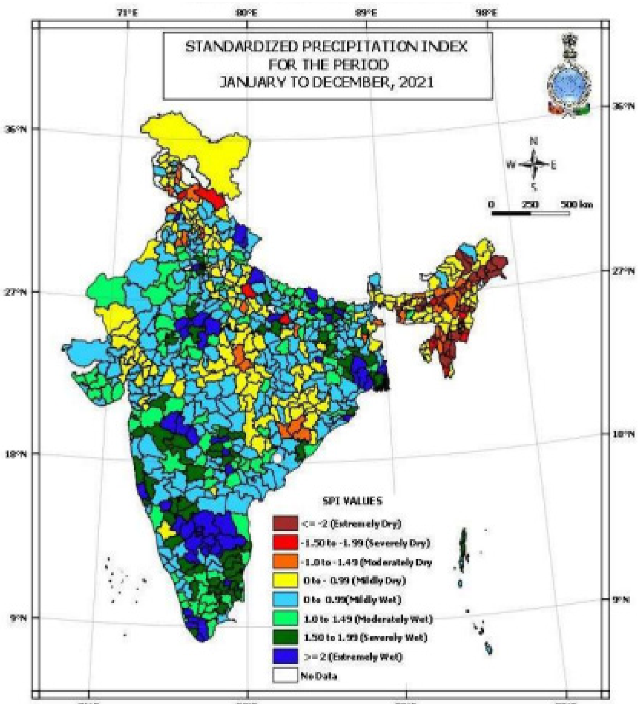


Figure. 1.8 Standardised Precipitation Index for the period January to December 2021
Source: IMD 2021b

It indicates extremely wet-severely wet conditions over parts of Andaman & Nicobar Islands, Odisha, Gangetic West Bengal, Jharkhand, Bihar, eastern Uttar Pradesh, Chandigarh & Delhi, Uttarakhand, Haryana, Punjab, East Rajasthan, Gujarat Region, West Madhya Pradesh, Konkan & Goa, Madhya Maharashtra, Marathwada, Andhra Pradesh, Telangana, Tamil Nadu, north interior Karnataka, south interior Karnataka and Kerala. However, extremely dry and severely dry conditions were observed over parts of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Sub Himalayan West Bengal, Sikkim, eastern Uttar Pradesh, Himachal Pradesh and Jammu & Kashmir.

Extreme precipitation and flooding have affected several parts of India in recent years (2020 and 2021). These floods were caused by heavy precipitation and events such as glacier breaks, flash floods, and avalanches. These incidents occurred during the winter, pre-monsoon, monsoon and post-monsoon seasons. These events caused the loss of lives and massive damage to crops, public infrastructure, and private property across several districts in India.

As per study by NRSC/ISRO, over the last four years, the number of states affected by major floods has increased from 8 states in 2017 to 15 in 2021 (Figure 1.9). Existing analysis of trends in heavy rainfall and flooding indicate that their frequency is increasing in some parts of India, including the peninsular, east, north-east, and some parts of central India (Guhathakurta et al., 2011; Hirabayashi et al., 2013; Roxy, et al. 2017; Ali, et al., 2019; Lutz et al. 2019). Various parts of North India, including the Indo-Gangetic plain, remain prone to flood risk events.

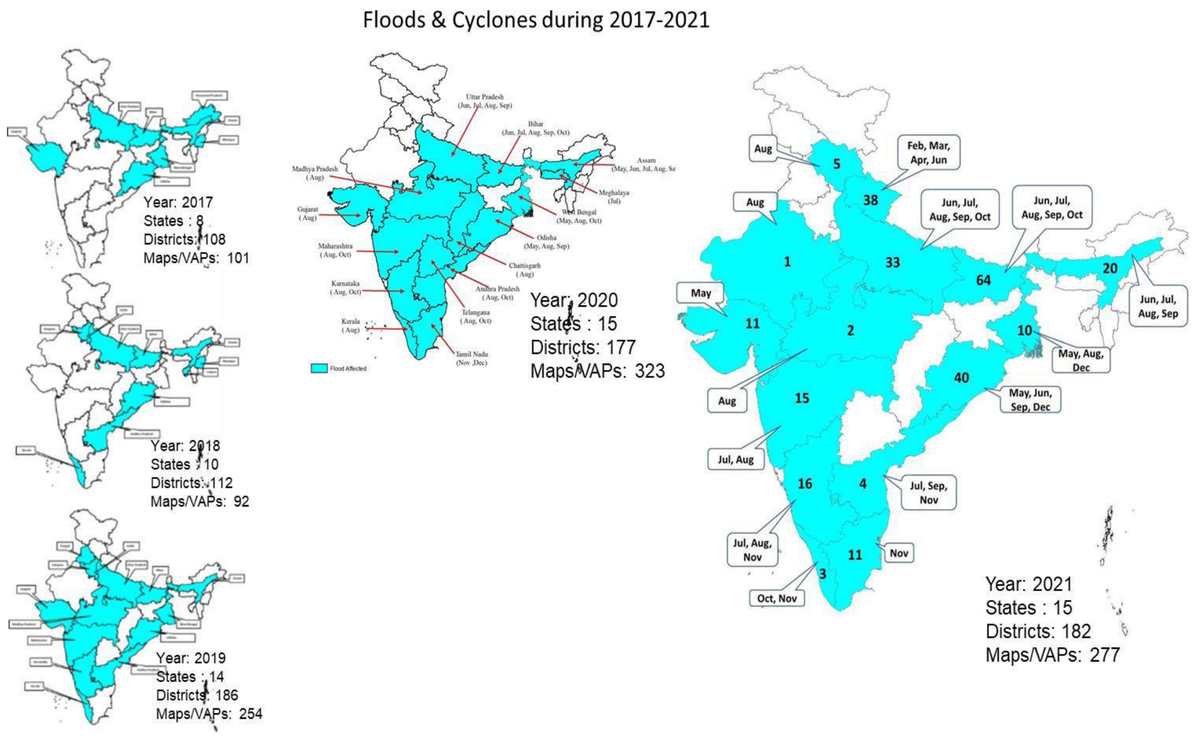


Figure 1.9: Floods & Cyclones in India monitored & mapped during 2017-2021

Source: ISRO

1.3.4 Other extreme weather events

Apart from the extreme events mentioned above, shocks were faced by various regions due to snowfall, lightning, thunderstorms, hailstorms and duststorms between 2019 and 2021. Some of the highest death tolls were caused by lightning and thunderstorms, particularly in the states of Odisha, Madhya Pradesh, Maharashtra, Rajasthan, Bihar, and Jharkhand. Loss of life and severe crop damage was caused by hailstorms in the states of Jammu Kashmir, Uttar Pradesh, Maharashtra, Uttarakhand, and Himachal Pradesh.

1.4 Monitoring events and disaster risk reduction

Various Ministries at the Central and State level governments in India and specific departments work together to improve capacities and knowledge of information systems for extreme events and disasters in India. Developing knowledge and capacities to monitor and forecast extreme events to inform disaster risk management and its reduction is a broad goal that informs the working of such institutions in India. It is also important to note that based on these disaster management and disaster risk reduction strategies implemented in India, the Disaster Management Support Programme also helps in disaster management globally by sharing data and information for specific events through International Charter and Sentinel Asia projects. An overview of some of these important institutions dealing with disasters in India and their work is provided below.

1.4.1 Weather monitoring and warning systems for extreme events

The IMD provides regular and ongoing assessments of the seasonal outlook for the hot weather season and daily temperature forecasts over India at different temporal and spatial scales. They are used as a prompt early warning of extreme heat by city officials. The number of heat-related deaths and illnesses in the past few years has significantly reduced on account of timely release of updates, effective implementation of the National Guidelines on heatwaves, preparation of Heat Action Plans (HAP) by vulnerable States and cities, regular follow-up and monitoring by National Disaster Management Authority (NDMA), extensive awareness generation campaigns, preparedness workshops.

The development of spatial flood early warning models using very high-resolution Digital Terrain Models now provide alarms for spatial flooding in flood-prone regions of India. Spatial flood early warning models for floodplains of Godavari and Mahanadi rivers are developed using high-resolution digital terrain models. A web-enabled semi-automated spatial early warning system is being run in the operational mode in real-time with data support from Central Water Commission (CWC) and India Meteorology Department (IMD), and results are disseminated through Geo-portals.

For assessing floods and other extreme events, the Rapid Response and Emergency Services/Decision Support Centre (RRES/DSC) has been established under Indian Space Research Organisation (ISRO) - Disaster Management Support (DMS) programme. The RRES/DSC provides space and aerial-based disaster-specific information in near real-time to support disaster management in India. Major flood events were monitored and mapped in near real-time mode using multi-sensor and multi-temporal satellite datasets in about 182 districts spread across 15 states by riverine floods or floods induced due to cyclone-induced rainfall during 2021. Very Severe Cyclone 'Tauktae' struck the coasts of Gujarat, and 'Yaas' struck the coasts of Odisha and West Bengal. The cyclones caused severe damage to standing crops, infrastructure and property. Subsequently, Andhra Pradesh and Odisha states suffered inundation due to cyclones Gulab and Jawad during September and December 2021. However, due to accurate early warning issued by IMD and the preventive measures taken by disaster management agencies at central and state level, the death toll due to cyclones has reduced. As part of the Flood Mitigation initiative under Disaster Risk Reduction, Disaster Management Support Group (DMSG) has generated the flood hazard zonation atlases for the frequently food-affected states of Andhra Pradesh, Assam, Bihar, Odisha, Uttar Pradesh and West Bengal by utilising the inundation layers derived from the multi-temporal satellite datasets of the last two decades.

An array of numerical models is used by for IMD for the early detection of tropical cyclogenesis in the North Indian Ocean region prior to satellite detection. The developed multi-model ensemble technique is quite promising for early detection of the development or strengthening of tropical cyclones in the atmospheric column prior to satellite detection over the ocean surface in North Indian Ocean region.

The method identifies the genesis, area of genesis and possible intensification and track thereafter, with a minimum of five days (~ 120h) lead-time for cyclones developed during pre- and post-monsoon seasons. In context to the impact of sea level rise, a comprehensive study was carried out on the Lakshadweep archipelago in a climate change scenario. Studies identified the best-performing models for sea level rise and made projections for different Islands in the Lakshadweep region. The study estimated that smaller islands Chetlat and Amini, are expected to have a major land loss. Projection mapping indicated that about 60%-70% of the existing shoreline would experience land loss in Amini and about 70%-80% in Chetlat.

Climate change limits the predictability of weather, despite that weather forecast accuracy of IMD has improved by about 40% for different types of severe weather events in recent years (2018-2022). It has been possible due to timely intervention by Government of India through augmentation of meteorological observation network, data communication system and better numerical weather prediction modelling system.

1.4.2 Ocean State Forecast (OSF) services from INCOIS

The Indian National Centre for Ocean Information Services (INCOIS) provides operational ocean information, forecast and advisory services. Ocean State Forecast (OSF) services are one of the major services rendered by INCOIS. Among the Indian Ocean rim countries, India has a long coastline of over 8,000 km (including Andaman, Nicobar and Lakshadweep Islands). A wide range of marine activities dominate the maritime zone of India. Prior information on the state of the seas surrounding the Indian subcontinent is vital for the smooth operational activities of those who are venturing out into the sea and those at the seashore. The users can make informed decisions based on forecast of sea conditions for saving life and property.

At present, under the Ocean State Forecast services, INCOIS provides forecasts of wave height, direction and period (of both wind waves and swell waves), sea surface currents, sea surface temperature, mixed layer depth (the well-mixed upper layer of the sea), depth of the 20-degree isotherm (a measure of the depth of the thermocline), astronomical tides, wind speed and direction and oil-spill trajectory. The forecast is available separately for the following regions: Arabian Sea, Bay of Bengal, Northern Indian Ocean, Southern Indian Ocean, Red Sea, Persian Gulf and South China Sea. Further, it provides more detailed forecast information for specific locations like fish landing centres, small fishing harbours, commercial ports, etc., as well as for the coastal waters of the maritime states, Union Territories and island regions of India. The various user categories are sea-faring communities like the fishermen, Indian Navy, Indian Coast Guard, Port and Harbour authorities, Maritime Boards, Merchant and passenger shipping agencies, Offshore oil & gas exploration industries, Pollution control boards, Energy sectors, Research organisations, Disaster Management Authorities, Non-Governmental Organisations and any other coastal communities.

The forecasts are generated by a suite of state-of-the-art numerical models, which are evaluated extensively using observations, especially using indigenously developed real-time observational systems, and are customised to simulate and predict the Indian Ocean features accurately. Warnings on swell surges related to rough sea conditions are issued when there is a chance of high-period swells hitting the Indian coastline. The bulletins are disseminated to the coastal population through various modes.

These forecasts are generated operationally on High-Performance Computers and disseminated in local languages by different modes- including the latest Information and Computational Technology tools-like Mobile phones (SMS & voice message), Radio (AIR & FM), TV, Electronic Display Boards, e-mails, Website, Fax and social media platforms. ESSO-INCOIS also collaborates with non-governmental agents and civil society organisations working with the fishing community to disseminate the advisories on a daily operational basis.

Water quality now-casts and forecasts, impact-based forecast systems based on ensembles and probabilistic forecasting, coastal erosion advisories, specialised forecasts and services for the tourism department, and climate service (advisories on future sea level, wave surge, and productivity) are being developed. They would be operational in the near future.

During extreme weather conditions, the INCOIS-IMD joint bulletins consisting of meteorological and oceanic information, forecasts and advisories, and high sea state warnings, are issued. Storm surge and related inundation warnings are also included in these bulletins. The storm surge and wave surge conditions or rough sea conditions due to the combined/isolated effects of swells (long period ocean surface waves) and/or tides in the form of warnings and advisories are also included in these bulletins.

The Indian Tsunami Early Warning Centre (ITEWC) was established in 2006 at INCOIS, Hyderabad, as an autonomous body under the Ministry of Earth Sciences. It came into operation on 15 October 2007 after the deadly boxing day Tsunami that hit India during the year 2004. The centre functions 24X7 to monitor tsunamis and provide timely tsunami advisories to Indian coastal regions and countries in the Indian Ocean. A Decision Support System (DSS) is the heart of entire tsunami warning centre operations, designed based on a unique Standard Operating Procedure (SOP) and made operational to provide timely information on the tsunami threat. Since 2007, INCOIS has monitored about 582 tsunami-genic earthquakes around the globe and issued timely advisories to different stake holders with its state of art UPSTREAM components of an End-to-End early warning system. As a Tsunami Service Provider (TSP) for the Indian Ocean under IOC-UNESCO Indian Ocean Tsunami Warning and Mitigation System (IOTWMS), India is providing tsunami advisories to 25 Indian Ocean Rim countries, i.e., Australia, Bangladesh, Comoros, France (La Réunion), India, Indonesia, Iran, Kenya, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Myanmar, Oman, Pakistan, Seychelles, Singapore, South Africa, Sri Lanka, Tanzania, Thailand, Timor Leste, UAE and Yemen.

1.5 Vulnerability, adaptation, and development challenges

Climate Change Adaptation is “the adjustment process to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities” (IPCC, 2022). One of the important advances made within the study of adaptation is its linkages with the concept of vulnerability. Therefore, policies that seek to achieve adaptation refer to the concept of adaptive capacity or the “ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages take advantage of opportunities, or cope with the consequences." (IPCC, 2001). One of the major gaps in adaptation action is that the risk assessment studies in India are hazard-specific and often consider only hazards. Scientific and technical studies depict areas prone to climate related hazards without establishing their impacts on society. Thus, an integration of the socio-economic, as well as cultural aspects of communities and societies is needed while assessing specific impacts of climate risks and hazards as they play a crucial role in adaptation planning. Even where vulnerability assessments are available, the social and economic inequalities, differential access to information and technologies, and capacities of stakeholders are not adequately captured. One of the important advances made within the study of adaptation is the recognition that adaptation is tied closely to the concept of both bio-physical risks and socioeconomic capacities. At the same time, it is also widely recognised that the short and long-term impacts of climatic events act upon and exacerbate existing socioeconomic vulnerabilities of a population in a given region. The IPCC defines vulnerability as "the propensity or predisposition to be adversely affected, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." (IPCC, 2022).

In emphasising the relation between vulnerability and adaptation, the 6th Assessment Report (AR6) indicates that impacts of climate change will be experienced most by vulnerable countries and regions (IPCC, 2022). These impacts of climate change include 1) economic losses in the sectors of agriculture, forestry, fishery, and energy, 2) biodiversity loss and degradation, 3) access to water availability and water supply, 4) and increased stress on food production and access, including food security and nutrition. Vulnerability assessments and adaptation policies seeking to address the adaptation challenges must be linked to macro-economic factors and social processes. In particular, inequalities and deprivations within a population are reflected in their material well-being. In the Indian context, the inequalities and deprivations created by caste and gender are particularly important to be included in any assessment of vulnerability and adaptation. Therefore, in addition to bio-physical risks and human development indicators, it is also important in the case of climate adaptation policies to examine questions of unequal access and availability of resources and entitlements.

The various missions that are a part of the National Action Plan on Climate Change (NAPCC) launched by the Government of India in 2008 indicate the importance of such broad interventions.

An integral aspect of India's climate change policy are the nine national missions that are part of the NAPCC. The National Mission on Strategic Knowledge for Climate Change (NMSKCC) focuses on building national Science & Technology (S&T) capacities in climate change. NMSKCC focuses on building human and institutional S&T capacities in climate change and developing strategic knowledge in the key areas of climate change science, adaptation and mitigation. In addition to national-level capacity building, a network of resources for state-level capacity building exists. Twenty-Eight State Climate Change Centres/ Cells (SCCCs) have been established in India since 2012. The Institutions/Departments in States & UTs that have been closely involved in formulating State Action Plans for Climate Change (SAPCCs) were invited for their initiation. These are expected to carry out several activities that connect their State Action Plan on Climate change (SAPCC) with NMSKCC per a standard national framework. These SCCCs are entrusted with assessing risk and vulnerability at district and sub-district levels in detail, establishing human capacity-building programmes such as training for various stakeholders, including policymakers, legislatures, officials, educationists and researchers, conducting public awareness programmes, and building institutional, infrastructural capacity in climate change research. These 28 SCCC are actively working towards capacity-building initiatives and awareness programmes to popularize climate change science concepts. An important initiative under this policy is to also spread sensitization and awareness amongst school students in the country. Over the past two years, capacity building of more than 5 lakh school students has also been undertaken.

In more recent times, the Government of India, in its Nationally Determined Contributions made towards the Paris Agreement of 2015 and its commitment to national and international sustainability, has emphasized the role of climate change adaptation that recognizes the vulnerability faced by different regions within India. The Economic Survey of India in 2018-19 summarized this approach by stating that India's climate change action plans were "meant to focus on key adaptation requirements and creation of scientific knowledge and preparedness for dealing with climate change" (Ministry of Finance, 2019).

Under the aegis of the Department of Science and Technology (DST), an assessment of the vulnerability of India's districts was carried out in 2020. The report titled "Climate Vulnerability Assessment for Adaptation Planning in India Using a Common Framework" comments that vulnerability assessment is the "first step towards adaptation planning" (DST, 2020). The report emphasises that all regions in India are vulnerable to the impacts of climatic events, but some regions and states are identified as particularly vulnerable. The report indicates the high vulnerability of India's southern and eastern zones to extreme cyclonic events, floods, and droughts combined. Further, the report identifies India's western and southern regions as extremely vulnerable to agricultural droughts. It indicates that northern, eastern, and central zones are moderately vulnerable to meteorological and agricultural droughts.

The findings identify the most vulnerable States and Districts in India. The states with a relatively high vulnerability are Jharkhand, Mizoram, Orissa, Chhattisgarh, Assam, Bihar, Arunachal Pradesh, and West Bengal, mostly in the eastern part of the country, requiring prioritisation of adaptation interventions. Figure 1.10 (a) and (b) present the main summary of this vulnerability assessment across various states and districts of India, respectively.

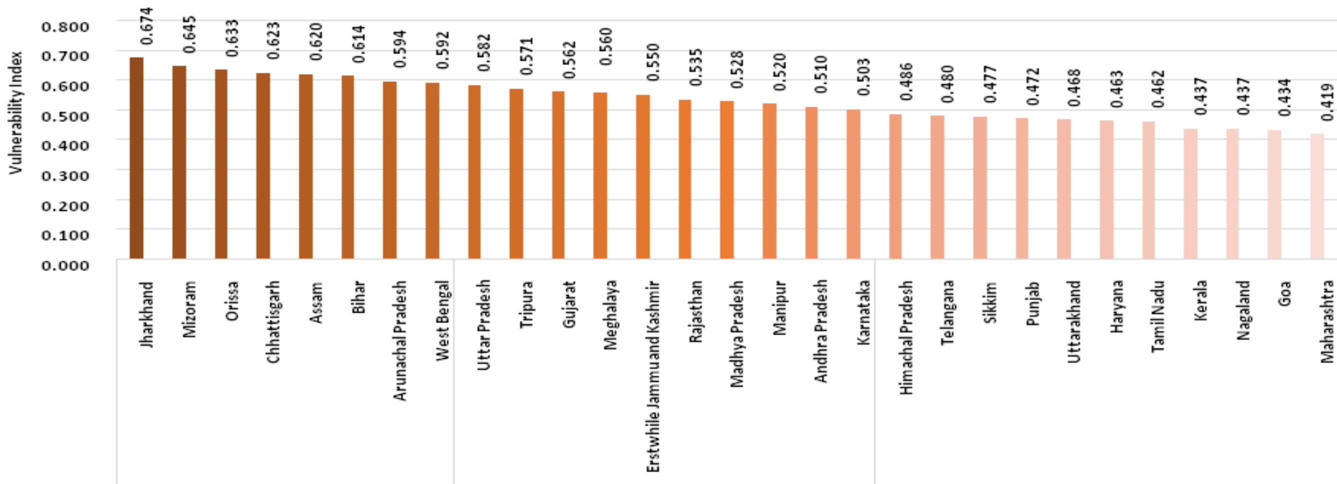


Figure. 1.10- a: Vulnerability indices of the Indian states, their categorisation, and corresponding ranks
Source: DST (2020)

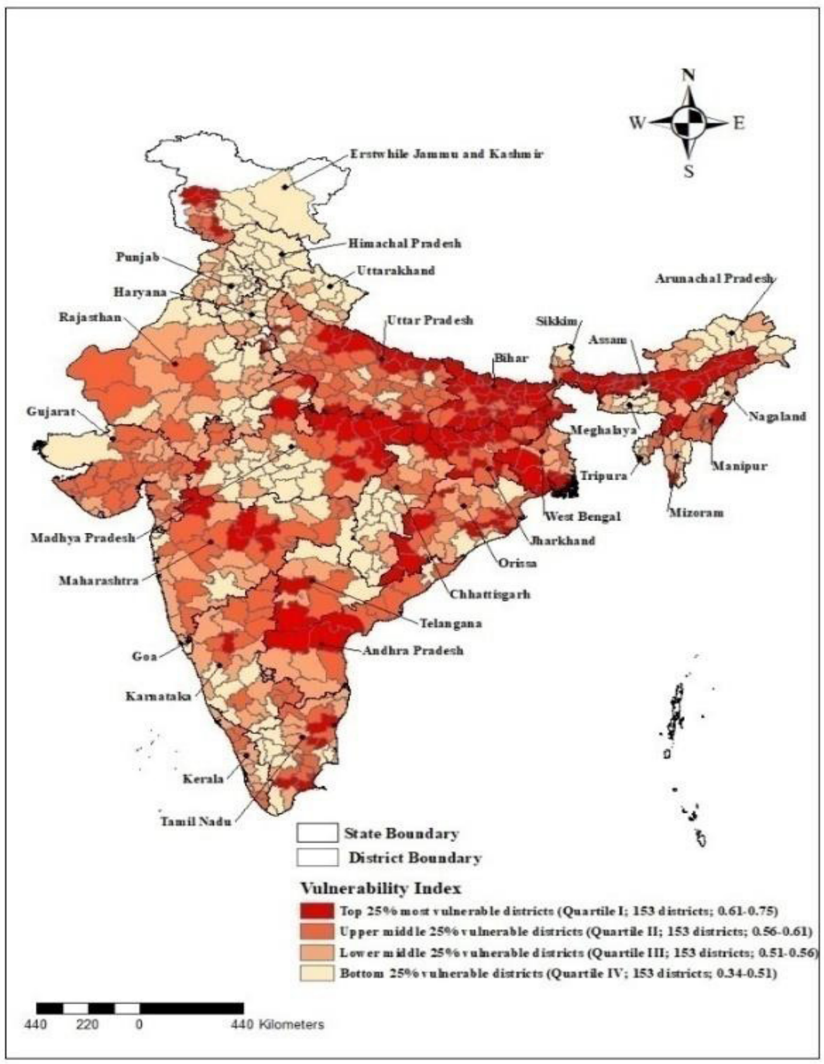


Figure. 1.10-b: District-level vulnerability profile of India based on four Quartiles (Quartile I include the top 25% of most vulnerable districts, and Quartile IV includes the bottom 25% of vulnerable districts)
Source: DST (2020)

1.6 Important ecosystems and sectors

Apart from the overview of climatic and weather events mentioned above, several important ecosystems are present within India. These include glaciers in the Himalayan cryosphere, the coasts of the Indian Peninsula, coral reefs in India's maritime waters, wetlands within the country, and water systems across India. Apart from these ecosystems, the sectors of agriculture and the forests of India are important economic systems that are most vulnerable to climatic shocks and stresses. This section provides an assessment of the current state of vulnerability of these ecosystems and sectors regarding existing and future shocks and stresses.

1.6.1 State of Glaciers in the Himalayan cryosphere

Climate change is likely to enhance the retreat of glaciers, which may further increase the number of glacial lakes and expand the size of existing ones. The Indian Himalayan Region (IHR) is facing critical challenges while coping with the adverse effects of climate change. IHR lies in Seismic Zones IV and V, making the region highly prone to earthquakes. As a consequence, the glacial lakes are vulnerable to breaches, unleashing sudden, potentially disastrous floods in the nearby communities. Monitoring of glacial lakes/ water bodies in the Indian Himalayan region using satellite remote sensing has been taken up by Central Water Commission (CWC) to assess changes in their size over time.

The CWC monitored 477 glacial lakes/ water bodies of more than 50 ha in the IHR starting from 2014 (monthly basis) every year from June to October.[1] During every month of the monsoon season, the boundaries of glacial lakes and water bodies are digitized, and the change in the water spread area is monitored. Monitoring glacial lakes is a continuous activity and are proposed to be further expanded.

In terms of the Himalayan glacier systems, an inventory of glacial lakes and avalanches for the Bhagirathi basin has been prepared under the Task Force (TF) study on 'Geo- resources and impact assessment of geological (exogenic) processes in northwest Himalayan Ecosystem'. This inventory was created using high-resolution remote sensing data (ResourceSat-2-LISS IV, Resolution 5.8m, 20 September 2013), ASTER data (Resolution 30m) and Google Earth image.[2] A total of 15 avalanche sites and 135 glacial lakes (area >500 m^2) have been identified. Out of 135 glacier lakes, 130 have been classified as ice-dammed lakes (supra-glacial lakes), and only 5 are moraine-dammed lakes which are very small. The research indicates that overall, the glacier tongues (snout) recession has accelerated in the last few decades. In general, Himalayan glaciers are under thinning (mass loss) and reduction in length and area in the present climate conditions. However, the recession rate and the amount of mass loss of Himalayan glaciers vary from glacier to glacier depending on the geographical location and climatic regime. In addition, the landslides and related phenomena are ubiquitous in the Himalayan region, though their magnitude and frequency have recently increased.

The rate of recession of glaciers is important as it controls the hydrological regime and related hazards (Allen et al. 2016). The glacial retreat varies across the Hindu Kush Himalayan (HKH) region with a mean

1 http://www.cwc.gov.in/sites/default/files/monitoring-glacial-lakes-water-bodies-himalayan-region-indian-river-bodies-oct-2020.pdf

2 ttps://dst.gov.in/sites/default/files/DST_Status%20of%20health%20of%20ecosystem%20in%20IHR%202.pdf

retreat rate of -14.9 ± 15.1 metre per annum (m/a). The highest retreat was observed in Brahmaputra basin (-20.2 ± 19.7 m/a) followed by Ganga basin (-15.5 ± 14.4 m/a), Indus basin (-12.7 ± 13.2 m/a) and the least witnessed in Karakoram region (-1.37 ± 22.8 m/a). Rapid recession of glaciers (Barry, 2006; Kamp et al. 2011) and its consequences have been studied using ground and satellite-based observations (Kumar & Dobhal, 1994; Kuniyal, 2002; Kumar et al. 2009; Kulkarni et al. 2007; Dumka et al. 2013; Kulkarni & Karyakarte, 2014; Rashid & Majeed, 2018; Bisht et al. 2020; Majeed et al. 2020; Romshood et al. 2020, etc.) and the results show that glaciers are retreating with an average rate of 18 to 20 m/yr.

A new technique based on surface velocity was developed to estimate glacier depth. This method was used to estimate glacier-stored water and hence the influence of climate change on the water security of small mountain communities in the Himalayas.[3] The simulation by a coupled ocean-atmosphere model has shown that an increase in solar radiation by 15% after the last glacial maximum led to an increase in Indian rainfall by 100% on account of the role played by the large increase in water vapour during deglaciation.

The National Mission for Sustaining Himalayan Ecosystem (NMSHE) was designed to develop the capacity to scientifically assess the vulnerability of the Himalayan region to climate change and continuously assess the health status of the Himalayan Ecosystem (HE). The broad objectives of the NMSHE include - understanding the ecosystem and evolving suitable management and policy measures for sustaining and safeguarding the HE, creating and building capacities in different domains, networking of knowledge institutions engaged in research and development of knowledge for the ecosystem of Indian Himalayan Region (IHR).

SECURE Himalaya Project

The objective of SECURE Himalaya is to promote the sustainable management of alpine pastures and forests in the high range Himalayan ecosystems that secures conservation of globally significant wildlife, including vulnerable snow leopard and their habitats, ensures sustainable livelihoods and community socioeconomic benefits. The project is being implemented in the State of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Sikkim.

The four outcomes of SECURE Himalaya Project are:

1. Conservation of key biodiversity areas and their effective management to secure long-term ecosystem resilience, habitat connectivity and conservation of snow leopard and other endangered species and their habitats.
2. Securing sustainable community livelihoods and natural resource management in high range Himalayan ecosystems.
3. Enhancing enforcement, monitoring and cooperation to reduce wildlife crime and related threats.
4. Gender Mainstreaming, Monitoring, evaluation and knowledge management.

3 https://library.wmo.int/index.php?lvl=notice_display&id=13153

National Mission on Himalayan Studies

Recognizing that the Himalaya is important for ecological security of the country, the Government of India attaches highest priority to protect unique but highly fragile Himalayan ecosystem. The National Mission on Himalayan Studies (NMHS), a Central Sector Grant-in-aid Scheme, therefore, targets to provide much needed focus, through holistic understanding of system's components and their linkages, in addressing the key issues relating to conservation and sustainable management of natural resources in Indian Himalayan Region (IHR). The ultimate goal is to improve quality of life and maintain ecosystem health of the region to ensure long- term ecological security to the country.

As the Mission specifically targets the Indian Himalayan Region (IHR), the jurisdiction of NMHS includes 10 Himalayan states fully (i.e., Arunachal Pradesh, Himachal Pradesh, Jammu & Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and Uttarakhand) and two states partially (i.e., hill districts of Assam and West Bengal).

With a broad Vision to support the sustenance and enhancement of the ecological, natural, cultural, and socio-economic capital assets and values of the IHR, the mission is to launch and support innovative studies and related knowledge interventions. The NMHS envisages to work towards a set of linked and complementary goals to:

- Foster conservation and sustainable management of natural resources;
- Enhance supplementary and/or alternative livelihoods and overall economic well-being of the region;
- Control and prevent pollution in the region;
- Foster increased/augmented human and institutional capacities and the knowledge and policy environment in the region; and
- Strengthen, greening, and fostering development of climate-resilient core infrastructure and basic services assets.

1.6.2 Coastal regions, sea level rise, coral reefs

The Indian coast, along with various ecosystems within India's maritime waters, is an important natural resource. The impacts of climate variability and extreme events on these systems affect India's coastal community and strategically important infrastructures. An additional threat that must be monitored in this regard is climate change-induced sea level rise. This section assesses current capacities to monitor these concerns relating to the Indian coast and existing policies to provide short- and long-term adaptation measures for local populations.

Recent efforts have also been made to map risk for the entire coastline of India, resulting in a new cartographic product at a district scale. Such assessments and maps have implications for environmental and risk managers as they can help identify the regions needing adaptive interventions. One such assessment map is shown in Figure 1.11.

Studies on the impact of climate change on five major coral reef regions of India found that Indian coral reef regions have different regional, thermal and bleaching thresholds corresponding to their individual warmest months and warmest quarters.[4] A prototype coral bleaching alert system based on these regional thresholds has also been developed and hosted by ISRO.

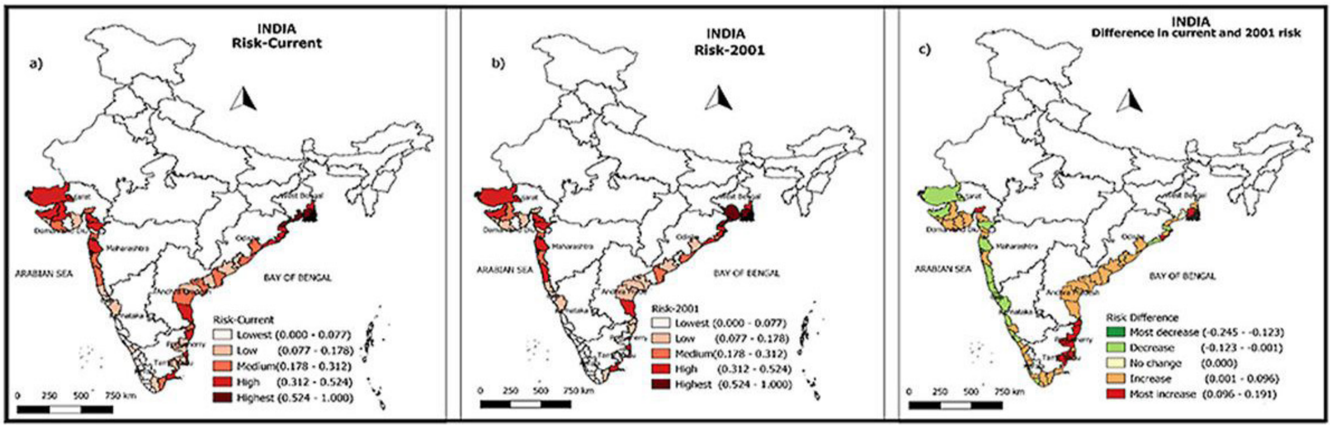


Figure 1.11: Map showing the risk index of the coastal districts (a) currently, (b) in 2001 and (c) their change/difference

1.6.3 Land use change, wetland areas, and desertification

Recently, various departments in India have strengthened their capacity to monitor land use and land cover based on remote sensing satellite imagery. Under the Natural Resources Census program of ISRO, a project was taken up to monitor land use land cover along with a net sown area of the country annually. This project envisages the annual generation of monthly and seasonal cropped areas and integrated Land Use & Land Cover (LULC). This project has been carried out from 2004-05 onwards using multi-temporal Indian Remote Sensing (IRS) satellite data. The following figure depicts the temporal changes in the extent of major land cover groups. During the 14 years, there is an increase in the country's net sown area with a corresponding decrease in the fallow area (Figure 1.12).

4 The study was conducted by ISRO and was based on modelled and satellite-derived Sea Surface Temperatures (SST) for the last three decades (1982-2018), More information in this GoI press release here https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1810572

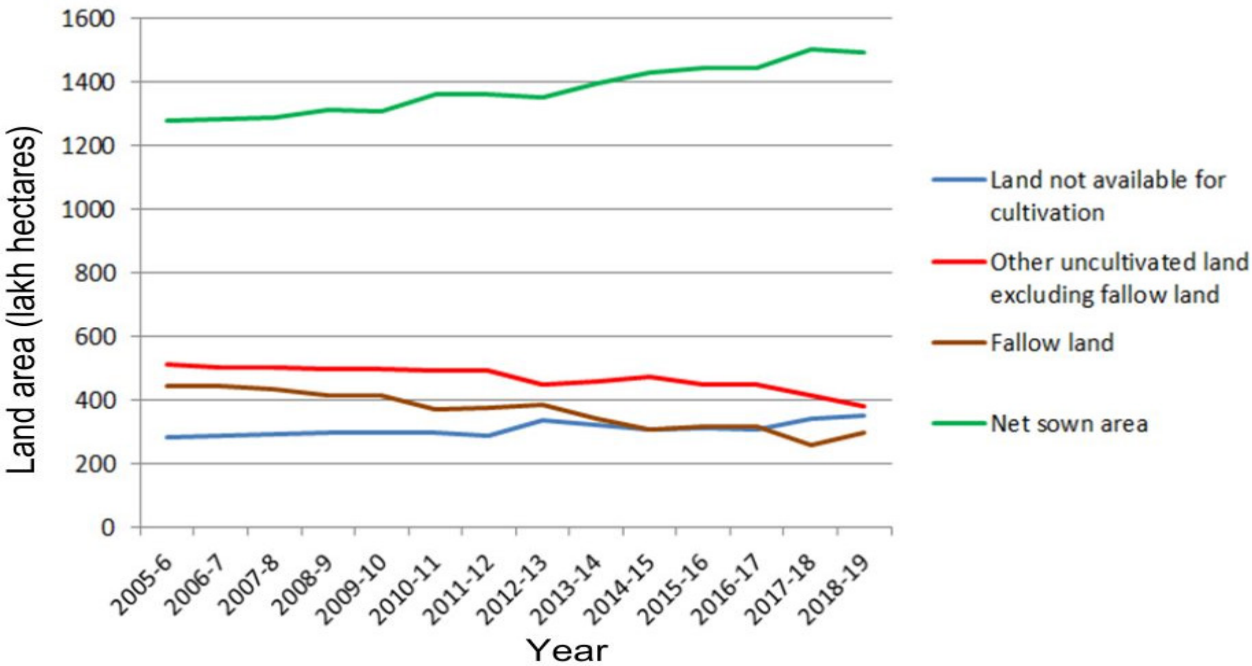


Figure 1.12. Long-term trends in land use/ land cover using satellite data

Desertification Status Mapping at 1:500,000 scale for 2018-2019, 2011-13 and 2003-05-time frames have been completed for the entire country. The analysis reveals that 83.69 million hectares (Ha) underwent desertification in 2018-19, whereas areas undergoing desertification were 82.64 million Ha in 2011-13 and 81.48 million Ha in 2003-05. The desertification and Land Degradation Atlas of India has been published in the form of a national atlas depicting desertification status, processes of degradation and severity level (Figure 1.13)

Wetlands play an important role as an ecosystem as well as play a role in carbon sequestration. The National Wetland Inventory project has been carried out to update wetland inventory and perform decadal change analysis (2017-18 vs 2006-07) using Indian Remote Sensing satellite data. At the country scale, 2,31,195 wetlands (> 2.25 Ha) were mapped in 2017-18 with an area of 15.98 million Ha. A decadal wetland change analysis for the earlier inventory of the 2006-07 timeframe revealed an increase of 0.64 million ha (4.18%) compared to the earlier inventory. The wetland conservation project 'Conserving and Sustainably Managing Gangetic Floodplains of Uttar Pradesh' was sanctioned in June 2020 towards the comprehensive conservation and management of 282 Gangetic floodplain wetlands within a buffer of 10 km of the river Ganga in 27 Ganga riverbank districts of Uttar Pradesh. Similarly, a project called "Conserving and sustainably managing Gangetic floodplain wetlands of Bihar" was sanctioned to the state of Bihar in December 2021 for wetland inventory, assessment and management planning within 10 km on either side of the main Ganga River channel in 12 districts in Bihar. The project will primarily focus on 387 natural wetlands > 2.25 Ha. in area.

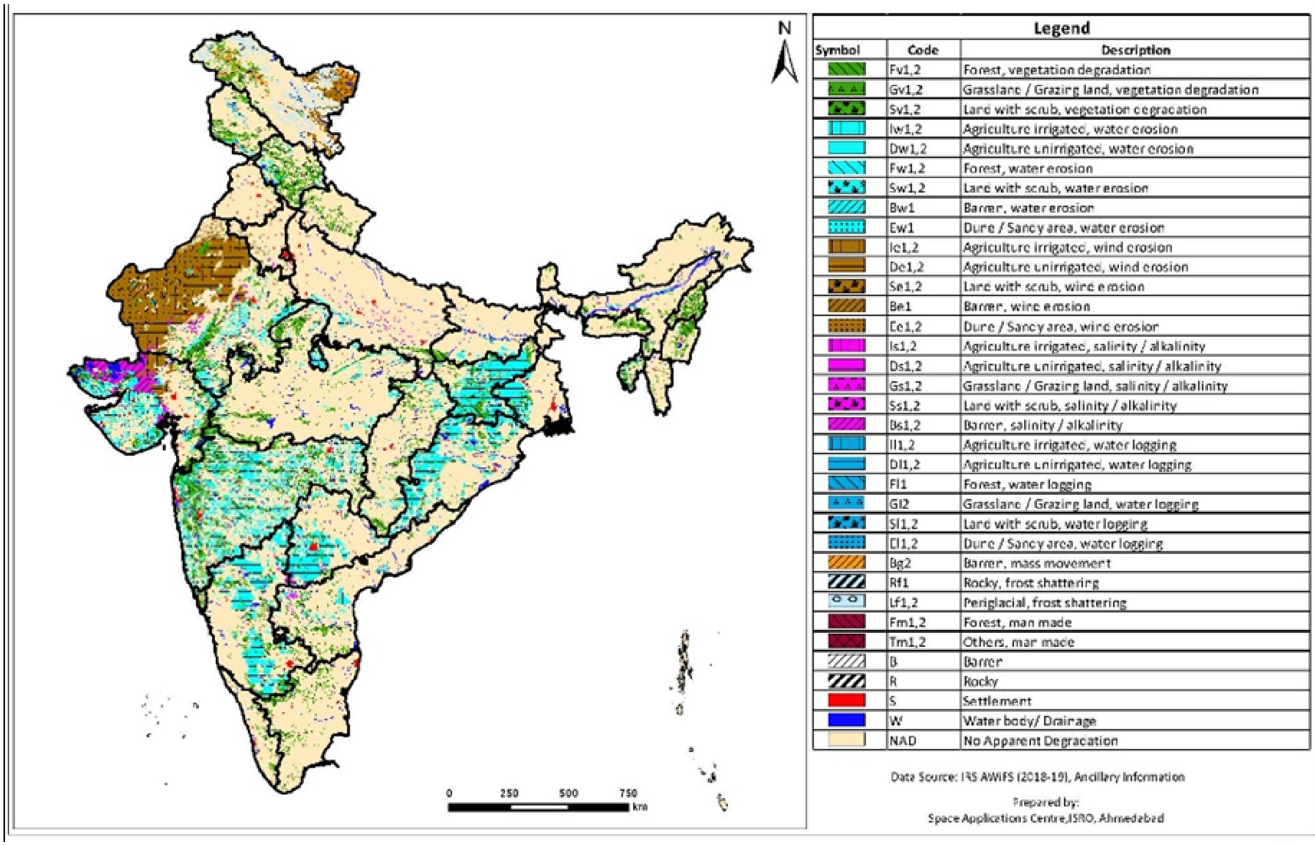


Figure 1.13: Desertification/land degradation status map of India (2018-19)
Source : Desertification and Land Degradation Atlas of India, 2021

1.6.4 Agriculture, climate variability, and climate change

Agriculture and allied activities play a central role in India's economy. This sector refers to the production of agricultural and horticultural crops, livestock, fishing, forestry and logging. The sector is also the largest provider of livelihood and employment. It contributes significantly to the Indian economy. According to the Census of India (2011), more than half the workforce of India continued to be engaged in agriculture and allied activities. In 2019-2020, as per Economics Survey 2020-21, the Gross Value Added (GVA) of agriculture and allied sector activities at constant prices (2011-12) was INR 19.48 lakh crores. The production of foodgrain stood at 296.65 million tonnes which is higher by 11.44 million tonnes than the production of food grain of 285.21 million tonnes achieved during 2018-19. This was produced over a net sown area of 139.35 million hectares. It must also be noted that production in allied activities of crops, livestock and fish production, have also been significant in recent times. This is summarised in the following figures on the growth of production and sub-sectoral share of sectors in Agricultural GVA in Table 1.1.

Growth (over the previous year) in the total GVA of the Economy and that in the GVA of agriculture and allied sectors at 2011-12 basic prices is given in Table 1.1.

Table 1.1 Growth in total GVA of economy and GVA of agriculture and allied sectors (at 2011-12 basic prices) (in percent)[5]

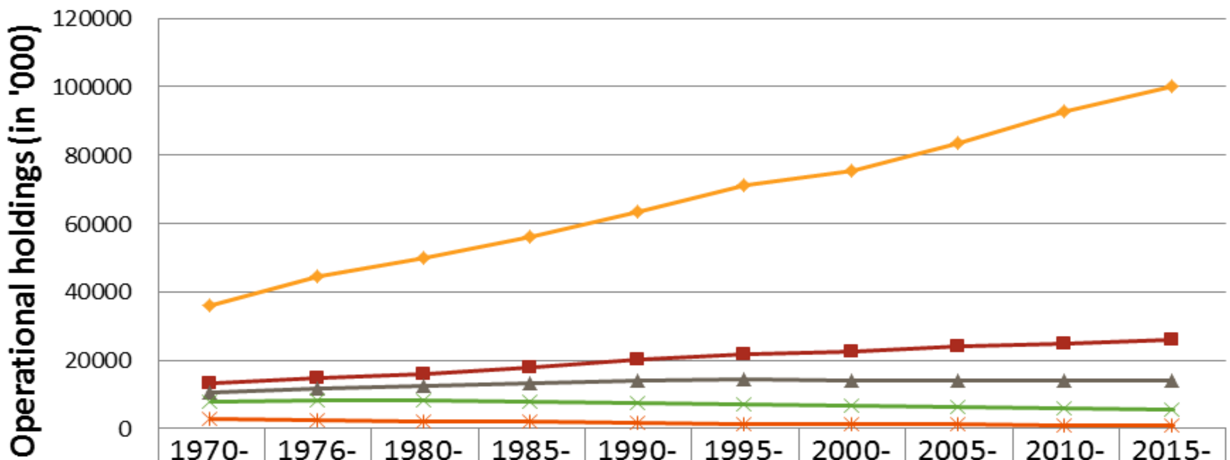
Year	Total Economy	Agriculture & Allied Sector	Crops	Livestock	Forestry & Logging	Fishing
2016-17	8.0	6.8	5.3	10.0	5.5	10.4
2017-18	6.2	6.6	5.4	7.9	5.4	15.2
2018-19	5.8	2.1	-2.4	8.7	7.6	8.5
2019-20	3.8	5.5	5.5	7.5	0.3	4.4
2020-21	-4.8	3.3	1.9	6.1	0.7	6.0

Source: National Statistical Office, Ministry of Statistics and Programme Implementation, Govt. of India

The development of agricultural production and productivity is key to rural development in India and is also crucial to addressing poverty reduction concerns. In this context, it is important to note that agriculture is critical to the incomes and livelihoods of small and marginal farmers in India (who form the bulk of the persons employed in agricultural cultivation). Some key figures describing the size distribution of holdings are described in Figure 1.14 and summarised in the text below:

- The average size of operational holdings in India has decreased over the past few decades; the average size of operational holdings had declined to 1.08 Ha in 2015-16 compared to 1.15 Ha in 2010-11.
- There has been a significant increase in marginal operational land holdings (less than 2 Ha). In 2015-16, the distribution of operational land holdings across size classes was as follows: 1,00,251 marginal land holdings (as compared to 92,826 in 2010-11), 25,809 small holdings (compared to 24,779 in 2010-11), 13,993 semi-medium holdings (2-10 Ha; compared to 13,896 in 2010-11).
- Large operational holdings (10 ha and above) in India declined to 838 in 2015-16 as compared to 973 in 2010-11.
- The states of Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal (14 in total) accounted for 91.01 per cent of the total number of operational holdings in the country.

5 Department of Agriculture & Farmers Welfare - Annual Report 2022-23. https://agricoop.gov.in/Documents/annual_report_english_2022_23.pdf



	1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
Marginal	36200	44523	50122	56147	63389	71179	75408	83694	92826	100251
Small	13432	14728	16072	17922	20092	21643	22695	23930	24779	25809
Semi-Medium	10681	11666	12455	13252	13923	14261	14021	14127	13896	13993
Medium	7932	8212	8068	7916	7580	7092	6577	6375	5875	5561
Large	2766	2440	2166	1918	1654	1404	1230	1096	973	838

Figure 1.14 . Number of Operational land holdings by size class of farmers and size of operational land holdings (in 1000 hectares) across different agricultural census records

Source: MoSPI, MoA&FW

Two broad observations must be made in the case of agriculture and climate change in India. The first is that the predominance of small and marginal farmers and the absence of large-scale or 'industrial agriculture' in India indicates that the burden of mitigating GHG emissions from other sectors cannot be passed on to this section of the population in India, as well as across the developing world. Climate change is now an additional burden due to anthropogenic emissions, to which their contribution has been minimal. The second observation to be made is that Indian agriculture and the millions of small and marginal farmers engaged within it are particularly vulnerable to climate variability, extreme events, and long-term climate change. Climate change adaptation policies must distinguish between current and future climate change to better understand the differentiated impact of climate variability across socioeconomic categories of producers, agroclimatic zones, and crop production. In Indian context, there is double challenge of the risks faced by the agricultural sector (and allied activities) and overall rural development. These risks refer to risks from extreme events, climate variability, low levels of productivity, as well as general conditions of socioeconomic well-being in rural regions of India.

A report on the vulnerability of Indian agriculture to climate parameters by the Indian Council for Agricultural Research (ICAR) indicated that several districts of India are highly vulnerable to such risks in terms of exposure as well based on their socioeconomic indicators (Ramanrao et al., 2016). The states with the greatest number of districts classified with very high and high vulnerability include – Rajasthan, Gujarat, Uttar Pradesh, Madhya Pradesh, Karnataka and Maharashtra. Similarly, of the 115 districts that are highly vulnerable to climate change and variability, 18 are in Uttar Pradesh, 16 in Madhya Pradesh, 15 in Bihar, 9 in Haryana, 7 in Chhattisgarh and 6 each in Jharkhand, Gujarat and Rajasthan. Further, the exposure of such districts to climate change and variability includes- drought incidence, changes in minimum temperature, and a decrease in rainfall during the early monsoon (June and July).

In terms of broad adaptation strategies, this indicates that a combination of technological interventions to improve adaptive capacity and resilience and welfare schemes to improve socioeconomic conditions is key.

Government of India (GoI) has implemented several programmes to improve capacity-building and scientific knowledge regarding the impacts of climate variability and climate change on Indian agriculture. The GoI is currently issuing location and crop-specific weather-based advisories for the benefit of the farming community of the eastern Uttar Pradesh region every Tuesday and Friday under Gramin Krishi Mausm Seva (GKMS) Scheme in collaboration with IMD, ISRO and the Ministry of Agriculture & Farmers Welfare, Government of India through different print/visual/Radio/ IT based media including short message service (SMS) and Interactive Voice Response Service (IVRS). Around 115 maps and yield trends and graphs of the status of agroecosystems, climatic trends, and vulnerability have also been developed. Regional disparity analysis of seasonal wetness across India was undertaken to understand the time dependency of precipitation anomalies for seasonal drought occurrence for seven homogeneous rainfall regions of India. The impact assessment on crops using various climate model scenarios and crop simulation models shows a decline in wheat, rice and pigeon pea yield.

In contrast, sugarcane shows a decline in sugar content in future due to the combined effect of rising temperature and elevated CO_2 levels with an erratic shift in rainfall patterns that is likely to show increased agricultural vulnerability to changing climate. An India-Centric Climate Model (ICCM) is a major initiative currently being undertaken for reliable future climate projections at the district level to assess the impacts of climate change on agriculture, health, water resources, and the energy sectors. Through rigorous validation and verification of hundreds of models, one of the best-performing models is customised.

Other schemes which are crucial for the implementation of long-term adaptation strategies include – the National Plan for Dairy Development (NPDD), National Livestock Mission (NLM), National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), National Mission on Agricultural Extension & Technology (NMAET), Prime Minister Fasal Bima Yojana (PMFBY), National Horticulture Mission (NHM), Pradhana Mantri Krishi Sinchayi Yojana (PMKSY), Integrated Management of Public Distribution System(IM-PDS), Pradhan Manthri Awas Yojana (Grameen), Rural Infrastructure Development Fund (NABARD), Mahatma Gandhi National Employment Guarantee Act, National Rural Livelihood Mission (NRLM), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), and Jal Shakti Abhiyan.

1.6.5 Water systems: Monitoring

The Government of India recognises that climate change manifests itself in important ways through significant changes in the water cycle. Climate change impacts have direct consequences for water security. Collection, compilation, storage, retrival of water related data in various constituents of hydrological cycle is very important for analyzing the impacts of climate change on them & taking up the adaptive measures at different scales. The initiatives in this regard are given below in detail:

1.6.5.1 Hydrological Observation and Data Collection

Central Water Commission (CWC) maintains hydrological & meteorological data collection network and water quality monitoring stations throughout the country. The data is used for assessment of water resources, flood forecasting, project planning, dispute resolution, water quality management in addition to various research and studies including related to climate change. Presently, CWC is maintaining 1,543 hydrological observation stations on the rivers throughout the country.

1.6.5.2 Reservoir Monitoring Sytem

CWC monitors water level of 146 reservoir in the country which contribute to 178.185 BCM of live storage (69.11% of total live storage). The detailed information bulletin is released on weekly basis.

1.6.5.3 Monitoring of Glacial Lakes and Water Bodies

Among others, climate change is likely to increase retreat of glaciers which may further lead to increase in the number of glacial lakes and also expand the size of existing ones. This combined with other disturbances such as avalanches and falling boulders is making the glacial lakes vulnerable to breaches, unleashing sudden, potentially disastrous floods in the downstream areas.

Monitoring of Glacial lakes/ Water bodies in the Indian Himalayan region using satellite remote sensing has been taken up by CWC to assess changes in their size over the passage of time. CWC undertook the monitoring of 477 Glacial lakes/ Water bodies of size more than 50 ha. in the Indian Himalayan region on monthly basis every year from June to October.

1.6.5.4 Coastal Management Information System (CMIS)

Large population lives within a distance of 50 km from the coast. Vast set of data on sediment transport, wave, tides, bathymetry, geological data, satellite imageries, etc., is required to analyze the problems related to coastal areas. Sea level rise is likely to aggravate the problem and affect a large nearby residing population in future. Hence, under CMIS, the coastal data in respect of various parameters is being collected at eight sites to tackle coastal erosion keeping in view the long-term perspective and challenges of climate change.

1.6.5.5 Ground Water Level Monitoring

Central Ground Water Board (CGWB) has a network of nearly 26,000 wells spread throughout the country for monitoing of ground water levels. Water level measurements are done 4 times in a year. In addition to this, State Governments also have their own monitoring networks. CGWB has established a climate change montoring network in the coastal areas of Tamil Nadu & Puducherry. The network comprises 60 purpose-built piezometers to measure water level as well as salinity using digital sensors with telemetry systems.

1.6.5.6 Ground Water Assessment

Assessment of availability and utilization of ground water is an important aspect in assessing climate change impacts and devising adaptations/mitigation plans. Government of India has put in place a cloud-based system for assessment of ground water resources. The assessments are done jointly by CGWB and the State Government agencies. So far, the assessments used to be carried out at 2-3 years interval. From 2022 onwards, the Government has initiated assessment of ground water resources on an annual basis.

1.6.5.7 National Project on Aquifer Management (NAQUIM)

India has initiated a NAQUIM program for delineation of aquifiers, characterization of aquifiers and preparation of management plans. Total 2.5 million sq km was identified to be covered under NAQUIM studies and the entire area has been covered. Detailed NAQUIM studies have been initiated in priority areas.

1.6.5.8 National Water Informatics Centre (NWIC)

The NWIC was set up by the Government of India to act as a central repository of updated water data and allied themes. Its mandate is to ensure timely and reliable water resources data acquisition, collation, management & its dissemination to provide tools for decision-making in the field of water resources management. The main objectives of NWIC are:

- Collection of available data from varied sources, generate new database, organize in standardized GIS format and provide scalable web-enabled information system.
- Maintaining, updating, collating and disseminating water data and information.
- Sharing of hydro-meteorological data amongst central and state government organisations and other stakeholders of water & general public.
- Provide tools to create value-added maps by way of multilayer stacking of GIS database so as to provide an integrated view of the water resources scenarios, and
- Collaborate with national/ international research institutes.

NWIC is maintaining two web-enabled water resources data platforms; India-WRIS & WIMS.

1.6.5.9 India-Water Resources Information System (India-WRIS)

India-WRIS is a standardized national Geographic Informationa System (GIS) framework that provides a “single-window” platform for dissemination of data on water resources and allied themes. It allows users to search, access, visualize, understand and analyse comprehensive and contextual water data for the assessment, monitoring, planning and development of water resources in the context of Integrated Water Resources Management (IWRM). The India-WRIS portal is hosting static, dynamic, and semi-dynamic water resources spatial and non-spatial data under 130 GIS layers for the entire country.

One of the most significant features of the India-WRIS Platform is its user-friendly interface. With comprehensive data and easy-to-use tools, users can take decisions about water usage and conservation. This platform aims to provide a central hub for all water-related information, including data on level, quality, and more. Providing stakeholders with information about water management enables them to make informed decisions and manage resources effectively.

The India-WRIS Platform also offers convenient access to hydro-meteorological data from different Central and State agencies. Users can easily access real-time data with just a click, ensuring seamless and efficient access to the latest information. It makes it easier to manage water resources effectively by providing users with relevant data.

1.6.5.10 Water Information Management System (WIMS): An integrated digital data Collection platform

WIMS is a water resource data collection and compilation platform. The data is compiled through web-based manual data entry and automated data entry through telemetric sensors. The portal can only be accessed by Central and State agencies through user credentials provided by NWIC.

The system has functionalities for managing data entry and processing, storage & management, data analysis and reporting. The platform offers various module-wise applications facilitating database addition, updation and sharing. Some of the major modules of WIMS are Station Management Module, Manual Data Entry Module, Data Validation, Sediment Module, Water Quality Module etc. Different data parameters in the system include groundwater quality, surface water quality, groundwater level, rainfall, reservoirs, river level and flow. This application also has a provision to send flood and disaster mitigation alerts through SMS & email to Central & State Disaster Management Authorities. It serves as an internal application used by the Central and State water departments to update data.

1.6.5.11 Drinking Water Quality Monitoring

Under Jal Jeevan Mission, all States/ UTs have opened water quality testing facilities for testing drinking water samples collected by public at nominal rates, as it will help in encouraging rural population to get their water samples tested and in building confidence in the quality of water being supplied to their homes. State Public Health Engineering Departments have network of 2,087 water quality testing laboratories (1,283 NABL accredited/ recognized). The mission has focused on acquiring National Accredition Board for Testing and Calibration Laboratories (NABL) accreditation for all labs, as it will increase confidence in data testing. An online portal 'Water Quality Management Information System (WQMIS)' has been developed for water quality sample collection, testing and uploading/ communicating results to users. On this portal an individual can register their sample and choose a lab nearby to get the water sample tested.[6]

1.6.5.12 Ground Water Quality Monitoring

Central Ground Water Board generates ground water quality data on a regional scale through a network of nearly 17,000 wells spread throughout the country. In addition to this, information on quality of ground water is also generated as part of other studies like aquifer mapping, ground water exploration, etc. This information is shared with the state government agencies.

6 This portal can be accessed at following weblink: https://ejalshakti.gov.in/WQMIS/

1.6.5.13 Surface Water Quality Monitoring

Central Water Commission (CWC) plays an important role in the monitoring water quality of rivers by observing water quality at 782 key locations (657 on Hydrological Observation network and 125 Water Quality Sampling Sites as of January 2023). In addition, CWC also monitors water quality of water bodies across India starting 1st March 2023. Till date, 82 water bodies have been identified for water quality monitoring.

1.6.6 Forests and Biodiversity

Forests and the biodiversity contained within them are important ecosystems within the territory of India. They are also an important source of raw materials, income, and employment for millions. The vulnerability of forests, the need for their conservation, and addressing the development concerns of populations within forest areas are three broad concerns that guide India's policy in this sector.

Over the past decade, India has significantly increased its forest area. Globally it ranks third in terms of the average annual net gain in the forest area. In the last decade (between 2010 to 2020), an average of 2,66,000 ha of additional forest area every year or adding approximately 0.38 per cent of the 2010 forest area every year between 2010 to 2020. This is described in Figure 1.15.

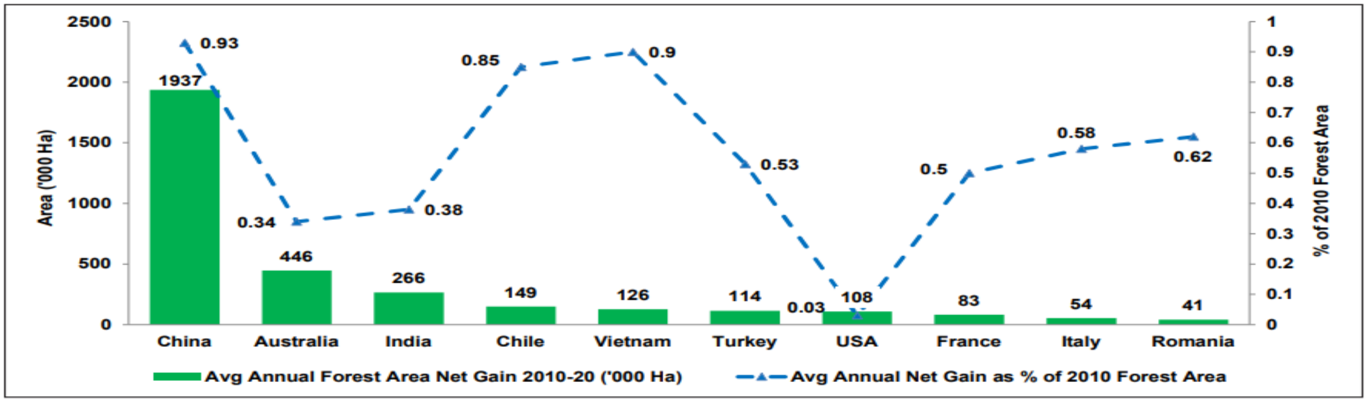


Figure 1.15. Top Ten Countries by Average Annual Net Gain in Forest Area (2010-20)

Source: Forest Survey of India (Ministry of Environment Forest and Climate Change), (2021).

India's forest cover has increased from 6,92,027 sq.km in the year 2011 to 7,13,789 sq.km in the year 2021. Also, the total tree cover has increased from 95,027 sq.km to 95,748 sq.km, leading to an increase in the total area under tree and forest cover from 23.81% of the country's geographic area in 2011 to 24.62% in 2021. There is a net increase in forest cover by 26,666 sq.km from 2011 to 2021 (FSI, 2021). This increase in total forest cover is mainly attributed to an increase in very dense forest (all lands with tree canopy density of 70 per cent and above), which rose by 19.54 per cent between 2011 and 2021. Open forest (all lands with tree canopy density between 10-40 per cent) also improved by 6.71 per cent, while moderately dense forest (all lands with tree canopy density between 40-70 per cent) declined by 4.32 per cent between 2011 and 2021. Arunachal Pradesh accounted for 21 per cent of India's very dense forest in 2021, followed by Maharashtra (9 per cent), Odisha (7 per cent), Chhattisgarh (7 per cent) and Madhya Pradesh (7 per cent). The top five states in terms of open forest in 2021. Madhya Pradesh accounted for 12 per cent of India's moderately dense forest in 2021, followed by Odisha (8 per cent), Maharashtra (7 per cent), Chhattisgarh (5 per cent) and Assam (5 per cent). It is also important to note that the composition of forest cover in seven major cities – Ahmedabad, Bengaluru, Chennai, Delhi, Hyderabad, Kolkata and Mumbai- in 2021 was 509.72 sq. km, which was 10.21 per cent of the total geographical area of these cities, and 0.07 per cent of India's forest area. These figures and their trends are described in Figure 1.16.

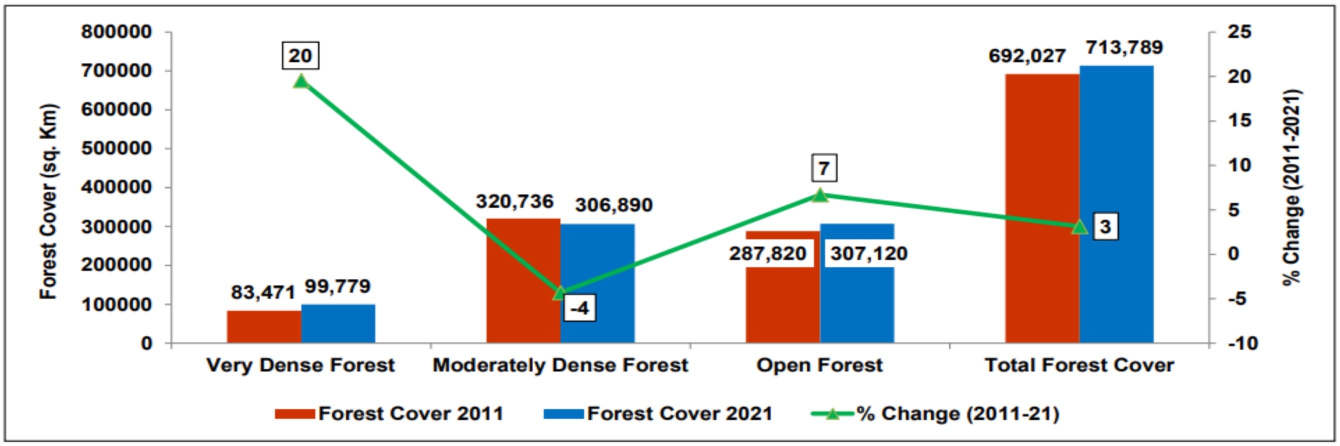


Figure 1.16. Forest Cover of India (2011 and 2021)

Source: Forest Survey of India (Ministry of Environment Forest and Climate Change), (2021).

Note: Categorisation based on tree canopy density of all lands; Very dense forest: density > 70%; Moderately dense forest: density between 40-70%; Open forests: density between 10-40%

Scientific forestry interventions with attention to concerns of local populations are an important aspect of India's different and varied afforestation programmes. Important site-specific forest plantation measures in India include afforestation plantation and the plantation of seedlings over the past three years. Between 2017 and 2020, 13000 hectares of afforestation took place. One billion seedlings have been planted yearly in the same period. Both these measures across some important State and Union Territories of India are provided below in Figures 1.17 and 1.18.

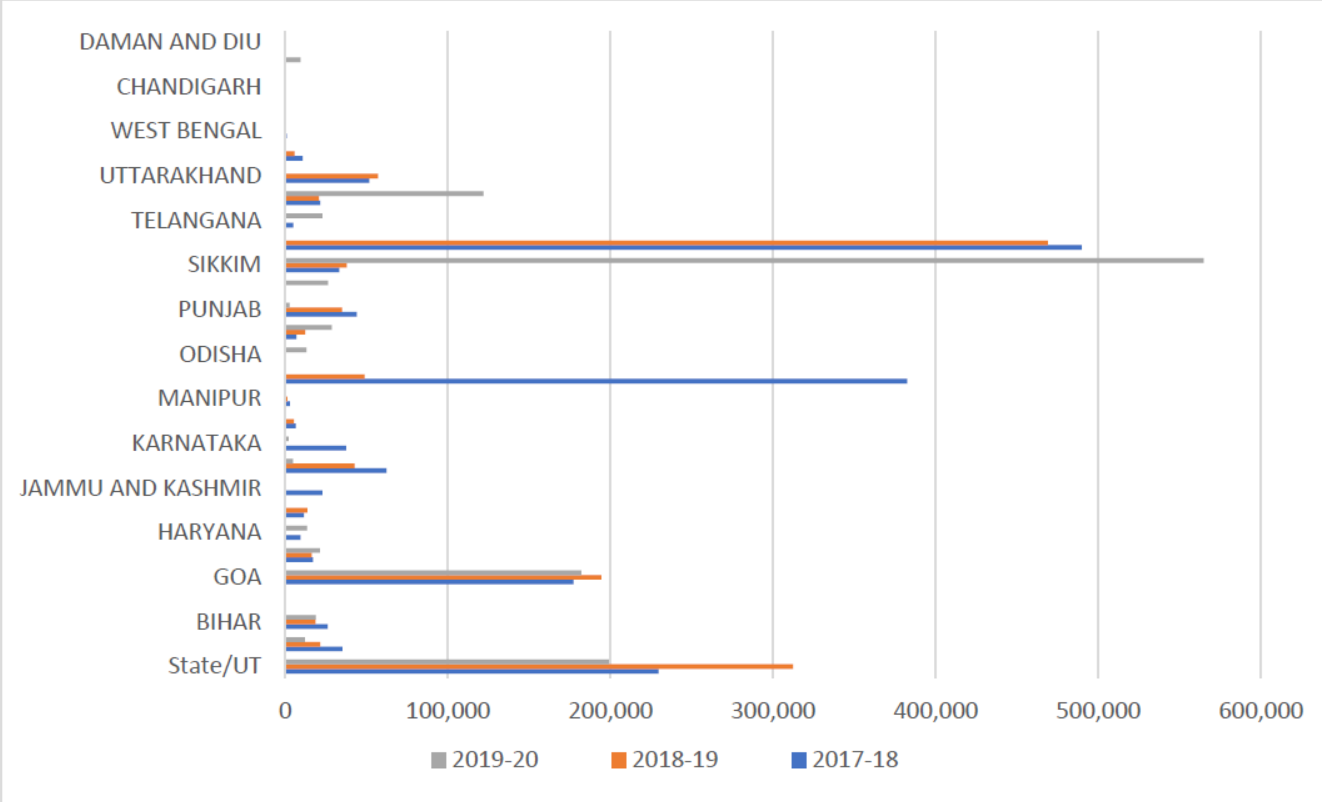


Figure 1.17. Major measures of afforestation achieved in various states 2017-20; Area Covered under Plantation (Public and Forest lands) in 100 Hectares

Source: State government and Union territories reports to MoSPI

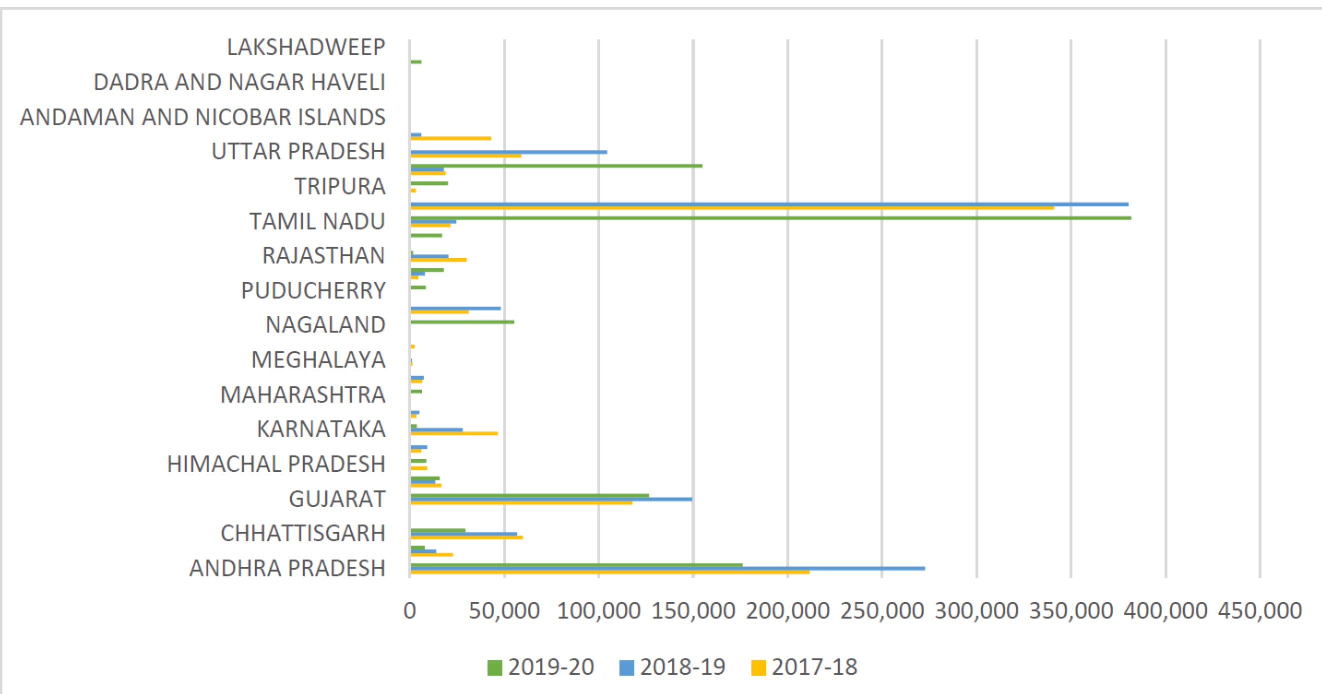


Figure 1.18. Major measures of afforestation achieved in various states 2017-20; Number of seedlings planted (Public and Forest lands) in 1000s

Source: State government and Union territories reports to MoSPI

As indicated earlier, forests in India are also inclusive of various species of biodiversity, including threatened and at-risk flora and fauna. This is particularly true of the unique ecosystems of forests and mountain ranges present in the Himalayan region of the country. In the case of the western Himalayas, 242 Red Data species and 456 threatened plant species in the region and an inventory of 490 tree species with 372 wild and 118 cultivated species have been recorded within the Western Himalayan region. Eight representative Long-Term Observation Sites (LTOS) in Alpines in Trans Himalaya (Bryans Valley) and Greater Himalaya (Chaudans Valley) are established in collaboration with Kailash Sacred Landscape Conservation Development Initiative (KSLCDI) to understand variations in trends of the Climate Change impacts on vegetation across the region.

Species distribution models have been developed underpinning the distributional patterns in the current time frame, which are in line with the ground-truthed data. Differential grid-based analysis was conducted along with remote sensing data and ground-based information on biotic, anthropogenic and physical factors. The majority (56%) of grids in the entire Indian Himalayan Region (IHR) showed moderately degraded habitats, whereas 27% showed near-natural status. Few (17%) grids are highly impacted by poor ecosystem health. Most of the degraded grids are at lower elevations, closer to human habitations. In the Western and Eastern Himalayas, high altitudes (>3000m asl) exhibit better habitat conditions for key faunal species. Aquatic and wetland habitats at higher altitudes are most threatened to owe to intensive land use practices, diversion of water and rapid infrastructure development. The indicator species like snow trout and musk deer in IHR have been projected to shift their distribution northwards and to higher elevations with a concurrent loss at their lagging edges in response to climate change as per the consensus modelling framework. Another related concern for biodiversity in India is the threat of biological invasion of alien species. In this regard, a comprehensive database has been created for 50 invasive alien species in India (Figure 1.19).

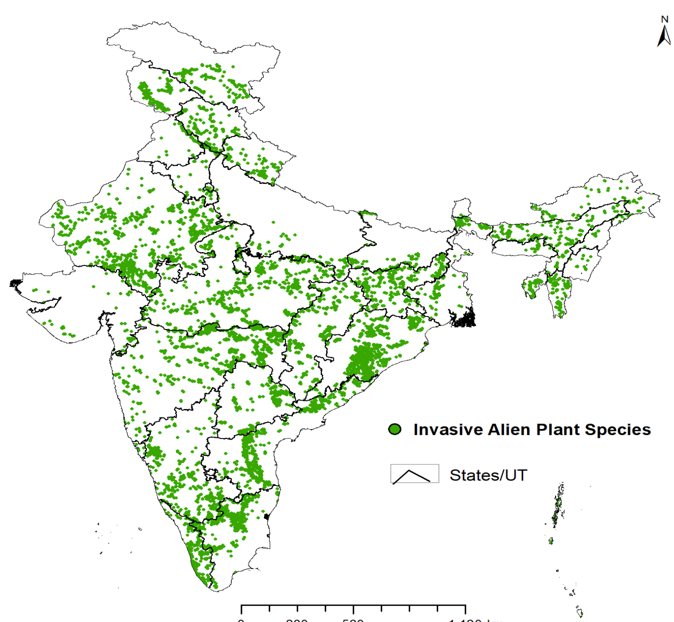


Figure 1.19. Map showing the distribution of invasive alien plant species in India

Ministry of Environment, Forest and Climate Change (MOEF&CC) has set guidelines for Green Belt

Development of 33% of total project area for any industrial plant and further increase of green belt cover by 40% of the total land area beyond the permissible requirement of 33%, wherever, feasible for new projects.

Stipulation of green belt outside the project premises such as avenue plantation, plantation in vacant areas, social forestry, etc.

1.7 Energy profile

This section provides a description of India's primary energy supply and primary energy demand. The information and statistics for these were obtained from the report on India's energy statistics prepared by the Ministry of Statistics and Programme Implementation in India for the year 2022 and 2023 (MoSPI, 2022; MoSPI, 2023). In recent times, the energy mix in India has seen a steady shift from conventional sources to renewable sources. This is line with the ambitions and commitments made by India in its NDC submitted to the UNFCCC. Energy Intensity in India (energy consumed per unit of GDP (2011-12 prices)) decreased to 0.2245 MJ/rupee in 2021-22(P) from 0.2801 MJ/rupee in 2012-13. India's per capita energy consumption in 2021-22(P) stood at 24,453 MJ/person. It must be stated that India's energy and electricity consumption is well below developed countries.

1.7.1 Primary energy supply

In 2021-22, primary energy supply added up to 739.386 million tonnes of oil equivalent (Mtoe) (MoSPI, 2023). As per present estimates, India has a renewable energy potential of about 15,10,491 MW for commercially exploitable sources viz. wind – 6,95,509 MW at 120 m mast height, small hydro – 21,134 MW; bio-energy – 42,312 MW, solar power – 7,48,980 MW and industrial waste – 2,556 MW (MoSPI, 2023; MNRE, 2023). The installed electricity generation capacity stood at 4,16,058.89 MW in 2022-23 (a 4.14% increase from 2021-22). The installed capacity of renewable sources (excluding large hydro) of electricity generation from utilities was over 13.90% from the previous year (2022-23 over 2021-22). In the same period, the installed capacity of thermal sources grew at a meager 0.491%. The total installed capacity of renewable sources including large hydro as on 31.03.2023 stood at 1,72,009.98 MW out of which, 27.24% was large hydro power, 38.82% was solar power, and 27.79% was wind power. Solar power installed capacity grew by 23.68% from 2021-22 to 2022-23. Tables 1.2 and 1.3 describe these figures for the primary energy supply and commercial energy production.

Table 1.2: Primary energy supply for 2021-22(P) (in ktoe)

No.	Fuel	Supply in ktoe
1	Coal	415032
3	Crude Oil	246987
4	Oil Product (net import)	23209
5	Natural Gas	59939
6	Nuclear Power	12278
7	Hydro Power	13070

No.	Fuel	Supply in ktoe
8	Solar, Wind, Others	15429
9	Electricity (net import)	141
	Total (1-9)	**739386**

Source: MoSPI, 2023

Table 1.3: Trends in commercial energy production

No.	Fuel	Units	2000-01	2010-11	2020-21	2021-22
1	Coal	Mt	313.70	532.69	716.08	778.190
2	Lignite	Mt	34.35	37.73	36.61	47.49
3	Crude Oil	Mt	32.43	37.68	30.49	29.69
4	Natural Gas	BCM	29.48	52.22	28.67	34.02
5	Hydro power	BkWh	74.36	114.57	150.65	151.627
6	Nuclear Power	BkWh	16.90	26.27	43.03	47.112
7	Renewable Energy	BkWh	-	-	297.547	322.54

Source: MoSPI, 2023

1.7.2 Primary energy demand

Compared to India's population, energy utilisation is low. In 2021-22 (P), India's per capita energy consumption was 24,453 MJ. This figure, however, also indicates a growth in India's per capita energy consumption has increased from 19,769 MJ (megajoule) in 2011-12 to 24,453 MJ in 2021-22 (23.6 per cent). To meet its energy needs, India is highly dependent on the import of crude oil. Net imports of crude oil have increased from 184.80 Mt during 2012-13 to 211.98 Mt during 2021-22 (P) (MoSPI, 2023).

Table 1.4. Per capita energy consumption in India (2011-2021)

No	Year	Per capita energy consumption (MJ)	Per capita electricity consumption (kWh)
1	2011-12	19769	884
2	2012-13	20874	914
3	2013-14	21003	957
4	2014-15	21951	1010
5	2015-16	22319	1075
6	2016-17	22745	1122
7	2017-18	23712	1149
8	2018-19	24699	1181
9	2019-20	24378	1208
10	2020-21	22369	1161
11	2021-22	24453	1255
12	2022-23	-	1331

Source: MoSPI, 2023

Despite the growth in the renewable energy sector in India, the country's industrial growth, as expected for developing countries, is still significantly dependent on fossil fuels, coal being the predominant energy source. The power sector and industry are the main consumers of primary energy from coal and natural gas. However, India's per capita coal consumption is still lower (0.73 tonne/person) than that of most developed countries and other emerging economies as well (USA: 1.91 tonne/person; Germany: 2.62 tonne/person; Australia: 4.52 tonne/person; China: 2.70 tonne/person) (IEA, 2019).

India's final energy consumption (end use) was 5,25,708 Ktoe. The industrial sector consumed 50.59% of the total final energy consumption. The industry sector's most energy-intensive industries were iron and steel, accounting for 15.29% of the industrial energy use, followed by chemicals and petrochemicals at 5.36% and construction at 2.09%. Agriculture, residential consumption, commercial sector, public sector, and not specified (others) sectors represented 38.53% of the total final consumption in the country. The transportation sector consumed 10.88%.

Between 2012-13 and 2021-22, the Compound Annual Growth Rate (CAGR) of coal production was 3.8 %, accompanied by a 4.21% increase in coal imports (CAGR 2012-13 to 2021-22 (P)). Therefore, there was a higher growth in demand than could be supplied by domestic production. There is a need for India to focus on enhancing the domestic production of coal to be able to reduce import dependence in this sector (MoSPI, 2023). However, dependency for coking coal of steel grade quality will remain, as India does not have natural reserves for such grade coal.

1.7.3 Energy security, post-COVID recovery, and future

India's energy security policies seek to address questions of better standards of living, improved economic growth, and contributing towards climate mitigation. Although India's energy generation capacities and energy consumption is increasing, it is well below the capacities and consumption of most developed countries. On the policy front, the primary objective for India's energy security is to ensure that energy is available and accessible at affordable prices to increase economic growth and improve levels of human development. At the same time, there has been a concerted effort to increase the share of renewable energy sources within India's energy mix. Most recently, based on the address of the Prime Minister and approval by the Union Cabinet, India has submitted an ambitious NDC target, as part of its updated NDCs, to reduce the emissions intensity of its GDP by 45% in 2030 as compared to 2005. Further, this plan also includes the increase in the capacity of non-fossil fuel-based power sources to meet 50% of the requirement by 2030.

While India's current stage of development cannot replace coal fully in the industrial sector, even in the power sector, an over-reliance on renewable energy without the capacity to manufacture them domestically would be an economic disadvantage for the country. RE is not available 24X7. Therefore, till storage becomes viable, fossil fuel-based generation use cannot be phased out. It would also lead to higher costs for consumers in the country because of higher upfront cost for renewable sources which are entirely borne from domestic resources in the absence of international finance fromdeveloped countries.

The situation created by COVID-19 will change the demand, supply, and import scenario in ways that have yet to be discovered or easily forecast. Coal is an essential and reliable energy source domestically available in abundance for India. India also has the indigenous capacity to use this resource while maximising economic benefits for its population. Currently, non-fossil fuel sources of energy have a significant dependence on imported technology and fuels.

1.8 Sustainable development and broader socio-economic transitions

India has made significant strides in eradicating poverty, improving access to electricity and clean drinking water, and generally improving its people's standards of living, along with achieving general economic growth. In the recent past, the Indian economy has withstood various shocks and stresses caused by global factors, including the global COVID-19 pandemic, that caused severe uncertainty and disruptions of product supply chains. Since the second pandemic wave (April 2021), the Indian economy has shown signs of recovery. This recovery includes a drastic increase in the vaccination coverage of India's population and an improvement in India's production supply chains. Actual economic output has recently surpassed the pre-COVID level of 2019-20. Various national and international estimates project that the Indian economy is estimated to grow between 8-9.5 per cent in 2022-23 (Ministry of Finance, GoI, 2021; 2022)

As seen in sections 1.3, 1.4, and 1.5 exposure to extreme events, the vulnerability of populations, and the negative consequences of such events remain an essential concern for the Indian population. The ability to improve climate adaptation strategies, vulnerability mapping and disaster management are also intrinsically tied to the overall improvement of socio-economic parameters in the living conditions of India's population.

The objective of achieving a sustainable transition to improve the living and working conditions of all citizens of India guides the policies of the Central Government of India. This section will highlight the broader trends and patterns of socio-economic transitions in eradicating poverty, sustainable urbanisation, and sustainable transportation.

1.8.1 Achievement of SDGs

1.8.1.1 International context

The Sustainable Development Report (SDR) reviews progress made each year on the Sustainable Development Goals (SDGs) since their adoption by the 193 UN Member States in 2015. Countries are ranked by their overall score, which measures the total progress towards achieving all 17 SDGs. The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved. India's rank has improved from 121 in 2022 to 112 in 2023. The overall score has improved from 60.3 to 63.45.

1.8.1.2 Achievement of SDGs, efficient resource use, and reduction of pollution in India

This sub-section highlights India's progress in achieving the Sustainable Development Goals (SDGs) and policy frameworks for achieving broader sustainability transitions. An essential aspect of India's policy to achieve SDGs is that state government initiatives lead it. In order to monitor this transition, the National Institute of Transforming India (NITI Aayog) monitors and publishes the SDG India Index and Dashboard [derived from the National Indicator Framework (NIF)], developed by the Ministry of Statistics and Programme Implementation (MoSPI) and the United Nations Resident Coordinator Office (UNRCO) in India. Figure 1.20 provides a state-wise performance map for different states in India in 2019 and 2020.

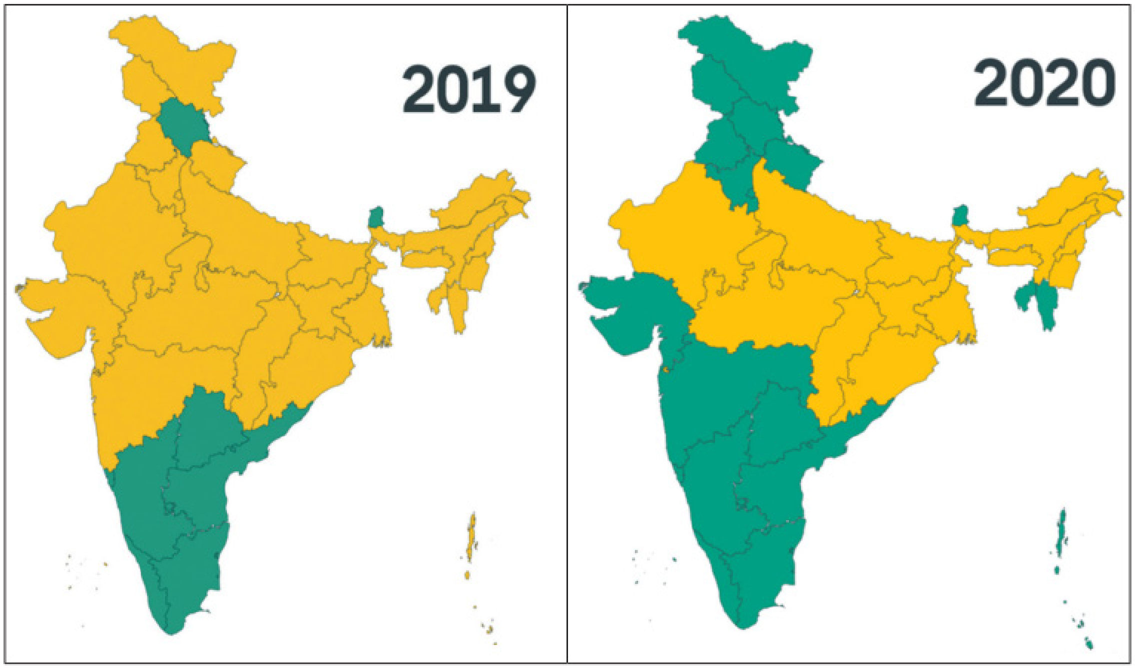


Figure 1.20: Performance of States/UTs on the NITI Aayog SDG India Index (2019 and 2020)

Source: NITI Aayog; Image source: Chapter 6; Economic census survey of India 2021-22

Note: Yellow indicates Performer (Score 50-64), Green indicates Front Runner (Score 65-99)

The NITI Aayog SDG Index and dashboard indicate that India's overall score improved to 66 in 2020-21 from 57 in 2018-19. The significant improvements in SDG indicators were related to SDG 3 (good health and well-being;), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy; achieved by 15 states and 5 union territories), SDG 10 (reduced inequalities), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 15 (life on land) and SDG 16 (peace, justice, and strong institutions). India has achieved universal energy access in all the states and Union Territories (SDG 7.1).

This improvement in SDG indicators has resulted from changes in national policy and their implementation. These changes include forest protection and rejuvenation improvements, waste management policies, compliance for gross water polluting industries, and strict adherence to global industrial and vehicular emission standards.

In particular, as highlighted in section 1.7, forest cover in India recorded a significant increase with dense forest cover increasing. Forest covers 24% of India's total area (2% of the global forest area) in 2020 (see the section on Forests). The efficient utilisation of groundwater resources (recharge, equitable distribution, and moderating rate of water utilisation) remains a cause of concern across many states in India. Monitoring groundwater resources in India is based on categorising groundwater units (designated groundwater areas across administrative blocks) based on their water utilisation rate. Between 2004 and 2020, the number of units categorised as "safe" declined significantly, while the share of semi-critical and critical units increased (Central Ground Water Board, Government of India, 2020).

Regarding river pollution, monitoring and compliance of polluting industries have improved water pollution standards in major rivers. The compliance of Grossly Polluting Industries (GPIs) located in the river Ganga (main stem and tributaries) has seen an increase from 81% of GPIs following compliance in 2020 as compared to 39% in 2017 [National Mission for Clean Ganga (NMCG)]. There has been a significant reduction in effluent discharge, from 349.13 MLD in 2017 to 280.20 MLD in 2020.

Reducing levels of air pollution in India, including particulate matter (PM) levels in its major cities, has been an important policy objective over recent years. The National Clean Air Programme (NCAP) was launched in 2019 with the explicit objective of reducing PM concentrations by 20-30% by 2024 (compared to 2017 levels) across most Indian cities. This programme includes the setting up of an extensive network of monitoring air pollution has been implemented across 132 cities. One hundred twenty-four cities have been identified as non-compliant with national ambient air quality standards. The Air Quality Early Warning System has been implemented in Delhi, Kanpur and Lucknow cities. To tackle air pollution significant steps have been achieved in improving vehicular emission standards and cleaner production standards across the industry. India has adopted BS-VI norms for fuel and vehicles since 2020. Improved accessibility and affordability of modern fuel sources have also been initiated across the country for fuels such as CNG, LPG and ethanol blending in petrol. In 2018, a ban on the use of imported pet coke was introduced for thermal power plants. Continuous emission monitoring devices that can be tracked in real-time have been incorporated across highly polluting industries. In 2020-21, 96 cities showed a decreasing trend of PM_{10} concentration (as compared to 2019-20). However, 36 cities continue to show an increasing trend in PM_{10} concentration (Ministry of Finance, 2021)

Recent policy changes such as the notification of the Plastic Waste Management Amendment Rules (2021), phasing out of single-use plastic (in 2022), the Extended Producer Responsibility notifications, and regulations to improve the circular economy are all set to improve India's standing in achieving cleaner production and consumption standards. Further, under the Paris Agreement of 2015, India has announced its Nationally Determined contribution (NDC). This includes the ambitious objective of LiFE-Lifestyle for Environment. The focus of this policy initiative is to improve efficiency and utilisation of resources while reducing waste generation and achieving improvement in consumption standards that are not environmentally destructive through a global mass movement.

1.8.2 Poverty reduction and sustainability

The eradication of poverty is an important goal for India's population. This section summarises the current status of poverty eradication in India, important policies that seek to do so, and its linkages to the SDG1 objective of "eradication of poverty in all its forms everywhere". A significant portion of the Indian population have been uplifted from conditions of destitute poverty at the time of Independence. This project continues in recent times with revisions in the national poverty line to reflect decent standards of living. Between 1973 and 2018, the headcount ratio of people living below the poverty line fell from 54.9% of its population to 20.8%. However, approximately 346 million people remain below the poverty line. As per NITI-Aayog's National Multidimensional Poverty Index (2023), 135 million people escaped multidimensional poverty between 2015-16 and 2019-21. In India, poverty levels are estimated for rural and urban populations separately based on the quinquennial survey rounds of consumer expenditure surveys conducted by the National Statistical Office (NSO) of the Ministry of Statistics and Programme Implementation (MoSPI). The current poverty line used by the NSO is based on the recommendations of the Tendulkar Committee Report. The major tool to tackle poverty in India is the implementation of various welfare measures, policies of social security, and programmes to improve the living conditions of vulnerable and marginalised communities. Some of the important schemes and their coverage are provided below.

According to the latest National Family Health Survey (2019-2020), the percentage of households with any usual member covered by a health scheme or health insurance increased to 40.99 % in 2019-20 compared to 28.7 % in 2015-16. The Anganwadi Services Scheme [earlier named The Integrated Child Development Scheme (ICDS)] is an important policy measure implemented in India. The Anganwadi Services Scheme provides pre-school education, food, and primary healthcare to children less than 6 years of age and their mothers. The number of beneficiaries under the ASS in 2019 stood at 95,018,684. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), enacted on August 25, 2005 provides 100 days of employment (in a year) to adult members of rural households willing to do public-related work. For 2021-22, approximately 99% of persons willing to do such work were covered under the MGNREGA scheme. Access to finance is an important indicator that leads to the overall improvement in both consumption and productive activity in a developing country. According to the National Bank for Agriculture and Rural Development (NABARD) (2019-20), the number of Self-Help Groups (SHGs) to which bank credit linkage was provided stood at 31.46 lakhs in 2019-20 as compared to 18.32 lakhs in 2015-16. The implementation of the policies mentioned above is also an important sub-goal of SDG1, including the implementation of "nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable".

1.8.3 Housing: Poverty and sustainability

A decent house positively impacts life through improving education, health, security and dignity. Recognising this fact, the Government of India launched the Pradhan Mantri Awas Yojana-Urban (PMAY-U) on 25th June 2015 to provide all-weather pucca houses (permanent houses) to all eligible families with all basic civic amenities in the urban areas of the country. The Mission addresses the 'housing poverty' dimension by enabling housing ownership to the beneficiaries, significantly impacting overall urban poverty and improving the security of the beneficiaries. During its 7 years of implementation, PMAY-U achieved a milestone of sanctioning more than 123 lakh houses and emerged as one of the largest affordable housing schemes in the world. More than 100 lakh houses have been grounded for construction. Of these houses, more than 60 lakh houses have been completed and delivered to the beneficiaries. PMAY-U has brought transformation in the life of a spectrum of beneficiaries, impacting their overall well-being. The basic premise of the scheme has been serving the Economically Weaker Section. The scheme has impacted the lives of women in a big way by promoting women's empowerment. The scheme mandates that house ownership should be in the name of the female head or joint ownership. An estimated about 94 lakh houses are either in the name of women or in joint ownership. The pucca house with kitchen and toilet/bathroom has fuelled dignity and esteem in the life of women. The Mission adopts an inclusive approach, providing equal opportunity to all, irrespective of gender, caste, creed or religion. Given the magnitude, this scheme has registered path-breaking success in comparison to earlier housing schemes of the government.

Recognising that not everyone migrating to cities requires a house on an ownership basis, Affordable Rental Housing Complexes (ARHCs) were launched as a sub-scheme of PMAY-U to provide dignified rental housing to the urban poor at an affordable cost near their work-places. Under the Scheme, Government funded vacant houses are being converted into ARHCs, and Public/Private land-owning agencies are constructing houses. Promoting new global innovative construction technologies has been another area of focus to transform the housing sector. Six Light House Projects (LHPs) consisting of approximately 1000 houses each are being constructed in Six States to demonstrate innovative construction technologies.

1.8.4 Urban waste management and circular economy

Rapid urbanisation in the last few decades has aggravated the challenge of sanitation and waste management in India. As per Census 2011, approximately 12% of the Urban population was still practising Open Defecation (OD). Moreover, a mere 18% of the municipal solid waste (MSW) generated in Urban India was scientifically treated. The Swachh Bharat Mission (Clean India Mission) (SBM), launched by Prime Minister Narendra Modi on October 2nd, 2014, was aimed at addressing these challenges while also taking forward the country's committed mandate of meeting the Sustainable Development Goals (SDGs).

The first phase of SBM-Urban was implemented from October 2, 2014 to September 30, 2021. The outlay of the Mission was INR 62,009 crores (~ 8 billion USD), including the Government of India's share of INR 14,623 crores (~ 2 billion USD). Since 2014, all 35 States & Union Territories (UTs) have become Open Defecation Free (ODF), i.e., 4,371 Statutory towns (among 4,372) are ODF. In order to sustain ODF outcomes and achieve comprehensive safe sanitation for all, the Mission, going beyond its ODF mandate, involves field assessments through an independent third party.

Scientific processing of waste has gone up four times since 2014, from a mere 18% to 73%. Moreover, 98% of urban wards in the country are covered by a door-to-door collection of MSW. 89% of wards have started segregation of waste at source. SBM-U has created a significant impact in the last seven years that has exceeded the targets set out at the start of the Mission. The tangible impact on the ground has been made possible through a multi-pronged approach comprising regulatory and policy level changes, sustainable infrastructure creation, and focus on attitudinal and behavioural change among people, which have been the hallmarks of SBM-U. In making urban India ODF, more than 70 lakh toilets have been built, delinked from socio-economic status or land rights, thus changing women's and children's lives and giving them greater dignity and safety.

The Mission has created a deep impact on people's health, livelihoods, quality of life and most importantly, in their thoughts and behaviour. The Mission has also opened up unprecedented entrepreneurial opportunities in waste processing, including for women SHGs, and other disadvantaged sections of society. The SBM-U has adopted the principles of a circular economy for solid and liquid waste management, resulting in the successful creation of an ecosystem encouraging entrepreneurship in the sanitation and waste management space and empowering women-led SHGs through convergence with other government programs as National Urban Livelihood Mission (NULM). The high involvement of SHGs has resulted in a sustainable source of income generation for its members, thereby reducing poverty. Moreover, the involvement of groups such as women, transgenders and other marginalised sections of society through SHGs has resulted in equitable growth.

In Solid Waste Management, the prime driver has been the concept of "waste to wealth" through maximum resource recovery, with the adoption of circular economy approaches, for addressing climate change challenges, and contributing to creating resilient cities. The implementation of solid waste management policies focuses on coverage of all households and municipal waste-generating entities, door-to-door collection, source segregation, scientific waste processing, and legacy waste remediation. There are many potential environmental benefits of adopting a Circular Economy in municipal solid and liquid waste. For example, compost and Bio-CNG from wet waste can reduce GHG emissions by about 10.36 million tonnes of CO_2 equivalent and by 41.09 MT from MSW in 2030. For liquid waste, the circular economy approach can help reduce CO_2 equivalent emissions by 36.67 MT from wastewater. In the long run, these interventions would be crucial to honouring India's pledge to reduce total projected carbon emissions by one billion tonnes by 2030 or becoming 'net-zero' by 2070.

1.8.5 Urban transport and infrastructure

Urban transport is an integral part of urban development and is a State subject. Hence, respective State Governments are responsible for initiating, developing and funding urban transport infrastructure including metro rail projects. The Central Government considers financial assistance for metro rail proposals in cities or urban agglomerates based on extant policy, the feasibility of the proposal and the availability of resources, as and when posed by concerned State Governments. Further, realising the rapidly growing challenges of Urban Transport, the Government of India formulated a National Urban Transport Policy in April 2006. The policy aims to ensure accessible, safe, affordable, quick, comfortable, reliable and sustainable mobility for all. Some significant components of this policy are highlighted below.

Metro rail, in recent years, has been addressing the mobility requirements in major cities of India. In order to create an ecosystem for enhancing the metro rail network in the country, MoHUA has also formulated the Metro Rail Policy 2017. The policy bridges the much-needed gap for ascertaining and enhancing the feasibility of metro rail projects from an economic, social and environmental perspective. At present, about 774 km of route length of metro rail is already operational in 20 cities. In addition to the above, about 1005 km (including 82 km of rapid regional rail transit (RRTS) system) of metro rail is under construction in 27 cities in the country. The operationalisation of metro rail in various cities has resulted in reducing the congestion and pollution on the road as well as a reduction in passenger travel time, hence increasing their efficiency. Due to the modal shift of transport and regenerative braking in metro rail in India, there is a significant reduction in carbon emissions. This Ministry has also issued standard specifications for a rail-based light metro system named 'Metrolite' and Rubber Tyred Electric Coaches Powered by Overhead Traction System named 'Metro Neo' with exclusive right of way. These systems will be ideal for tier-2 cities and peripheral areas of tier-1 cities. Metrolite and Metro Neo systems would provide the same experience and ease of travel in terms of comfort, convenience, affordability, safety, punctuality, reliability, and environment-friendliness as a conventional metro system. The proposals for implementing 17 Metro rail/ Metro Lite/ MetroNeo/ Regional Rapid Transit System (RRTS) of about 658 km have been received in the Ministry from various State/Union Territory Governments. They are under various stages of examination/approval.

In order to raise the share of public transport in an urban area, the Ministry of Housing & Urban Affairs (MoHUA) is in the process of launching a new scheme, 'Augmentation of City Bus Services including Associated Infrastructure and Green Urban Mobility Initiative Scheme', to support augmentation of public bus transport services including associated infrastructure, which will be implemented through the deployment of new buses on PPP model to enable private sector players to finance, acquire, operate and maintain the buses over 10 years.

The Urban Mobility India (UMI) Conference and Expo is an annual flagship event of the Ministry of Housing and Urban Affairs, organised as enunciated in the National Urban Transport Policy, 2006. The UMI conference has been organised since 2008 through the Institute of Urban Transport (India), a registered Society under the purview of the Ministry. The primary objective of this conference is to share, disseminate and update knowledge to the participants on best urban transport practices, nationally and globally. The event brings together national and international experts, technology and service providers, policymakers, practitioners and officials from the urban transport sector under one roof.

The Indian Metro Rail Organizations' Society (I-Metro) was registered under Societies Act. in July 2018. The I–Metro Society provides a common platform where Indian Metro Rail Companies, including RRTS, share their knowledge, experience, information, best practices, and innovations in all aspects of Urban Rail transport in a secure environment, which promotes cooperation among them. I–Metro is also assisting its members in creating a resource of information which could be relied upon as a tool for efficient decision-making in rail-based public transport systems in India.

1.8.6 Transport

The transportation sector consisting of transport infrastructure and its effective and sustainable management are key to building capacities for improved sustainable development and long-term adaptation strategies.

The Government of India recognises that with the growth in income levels and urbanisation, the demand for transportation in India is likely to increase. As a consequence, policies and programs have been implemented over the past decade and a half to address these concerns, as well as the concern about the environmental impact of transportation (particularly emissions). As far as climate change is concerned, transportation by road and air are the most significant segments of this sector. This section relies on information from annual reports and statistics prepared by the Ministry of Road Transport and Highways, as well as the Ministry of Civil Aviation.

1.8.6.1 Road-based transport

Road transport is India's dominant mode of goods and passenger transport, accounting for the largest traffic share and contribution to the national economy. The road network in India has expanded significantly over the years, improving connectivity within the country. While the total length of the highways in the country has more than doubled from 57,737 Km in 2001 to 1,44,955 Km in 2022, the rural road network has grown much faster, increasing from 19,72,016 Km in 2001 to 45,35,511 Km in 2019. With the growth in the road network and rise in per capita income, the Indian automobile demand has grown exponentially, and the total number of registered vehicles has increased by about six times within the last two decades. There are about 30 crore registered vehicles in India till March 2021. Further, India has become one of the largest auto markets, with the total industry estimated sales of more than 2.1 million automobiles in FY2020.

The Total Fuel Consumption (TFC) by the transport sector in India has more than doubled in ten years, more than tripled since 2000 and stood at 94 Mtoe or 17% of TFC in 2017. The transport sector currently accounts for 10 per cent of the total energy consumption in India, which is much lower than other countries. Between 2008 and 2018, the annual energy consumption from Indian transport increased by 22%. In India, passenger vehicles account for less than 30 per cent of the total energy consumed by the transportation sector. The highest contributor to energy consumption in this sector is freight transport. Road transport accounted for 90% of domestic transport energy demand, followed by rail and domestic aviation. Oil products supplied 95% of total energy in the sector, mostly diesel and petrol. Fuel consumption in the road sector amounts to 106.24 million tonnes and shows a nearly 77% increase during the last ten years, from 59.95 million tonnes to 106,241 million tonnes. The GoI has subscribed to BS-VI emissions standards for new vehicles to address this challenge and abate vehicular emissions.

The Government of India is taking several measures to reduce emissions from road transportation. Programs for Bus Rapid Transit System (BRTS) implemented under the Jawaharlal Nehru Urban Renewal Mission have aided the adoption of Compressed Natural Gas (CNG) based buses in cities. This improved urban air quality while reducing overall emissions from this sector. Recently, through the Bharatmala Pariyojana, there has been a sustained effort to optimise the efficiency of freight and passenger movement by developing economic corridors, coastal and port connectivity roads and green-field expressways. Enabling such efficient vehicular movement by reducing the overall travel distance, a substantial reduction in fuel consumption per year is being achieved. The National Electronic Toll Collection Program, by way of FASTag, has been a significant success with a 97% adoption rate, which has helped decongest the toll plazas.

A vehicle scrapping policy is being aggressively implemented to ensure the safe disposal of end of life vehicles, reducing emissions due to older polluting vehicles and supporting the transition to electric vehicles. Improving vehicular fuel efficiency has been a priority for the Government of India. In this regard, stringent BS-VI emission standards for vehicles have been enforced since April 2020. Similarly, there has been a sustained effort to transition to alternate fuels sources such as CNG, LNG, LPG, ethanol, methanol, Hydrogen, H-CNG etc. Technological studies and necessary support infrastructure development are in progress to adapt such fuels. Adoption of flex fuel, with increases in ethanol, while reducing gasoline, is also encouraged. There have also been efforts to achieve energy efficiency by improving the transportation system's efficiency through regulation Corporate Average Fuel Efficiency (CAFE) norms and the use of technology to improve traffic flow and load aggregation.

The Government of India is implementing the Ethanol Blended Petrol (EBP) Programme and Sustainable Alternative Towards Affordable Transformation (SATAT) to ensure environmental sustainability and reducing import dependence. The National Policy on Biofuels (2018) lays down indicative target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel by 2030. Further in 2022, the Government amended the National Policy on Biofuels – 2018 which has advanced the target of 20% blending of ethanol in petrol to ESY 2025-26 from 2030 (PIB, 2022).

1.8.6.2 Civil aviation

Aviation plays a key role in the economic prosperity of a nation, besides providing a worldwide rapid transportation network. It facilitates tourism by taking persons from one country to another and contributes significantly to world trade. However, it also poses challenges due to adverse impacts on the environment. The emissions from aircraft engines are similar to that of any ground vehicle. However, it is different from other emissions as most of them occur at high altitudes and their influence on the atmosphere can be highly localised. The civil aviation industry in India has ushered in a new era of expansion, driven by factors such as low-cost carriers, modern airports, Foreign Direct Investment (FDI) in domestic airlines, advanced information technology interventions and growing emphasis on regional connectivity. As per the International Air Transport Association, India will become the third-largest aviation market in the world in terms of passengers by 2026. With a large population, India's economy is still growing, and its per capita emissions and per capita air travel are relatively lower than other developed countries. As air travel plays an important role in driving the economic development of any nation, any action to cut down emissions from international aviation will adversely affect the growth of the industry and the country's growth. In order to formulate an effective policy to address the challenge of climate change, an important requirement is to determine the sources and level of aviation's CO_2 emissions, identify trends and make predictions about future growth. This is particularly important for fast-growing industries, such as the Indian aviation industry. India represents a growing aviation market with more than 80 operational airports and carried more than 201.9 million passengers in 2019-20.

Carbon emissions from the aviation sector is around 2% to 3% of global anthropogenic CO_2 emissions. Domestic aviation represents aircraft having domestic operations within the country. At the domestic level, without specific environmental policies, there are no targets to reduce emissions from the aviation sector. Further, at the UNFCCC level, non-Annex countries do not have any legally binding obligations to reduce their emissions, which is well captured in the principle of CBDR-RC. The voluntary initiatives carried out at various levels are described below.

The main source of aviation carbon emissions is the exhaust from the aircraft engines and the Auxiliary Power Unit (APU). Apart from engines and APU, the other direct sources contributing to carbon emissions are ground support equipment, vehicles operating inside the airports, etc. As indirect sources, heating/ cooling plants, energy consumption for airport terminal buildings, airport and runway lighting systems, firefighting equipment, etc., are also responsible for contributing towards carbon emissions. Therefore, any fuel and energy consumption savings will directly reduce aviation's carbon emissions. With this objective, the following measures are adopted:

- Upgradation of aircraft fleet through renewal and engine modernisation program for better fuel efficiency
- To further improve fuel efficiency, airlines have started looking towards new aircraft models with state-of-art technologies and more fuel-efficient engines that may result in a substantial reduction in emissions in future.
- Airlines have also adopted "Single Engine Taxi–in/out" policies and procedures specific to their operations.

Airports in India are committed to conducting their business in an environment-friendly and sustainable manner by minimising the impact of their activities on the environment through optimisation of natural resource utilisation and energy consumption, resulting in reduced emissions. Energy conservation and renewable energy development, along with emission reduction, is an integral part of their business strategy towards achieving credibility and sustainability in aviation. With this objective, the following measures are adopted:

- Adoption of Carbon Accounting & Management System for reducing airport GHG emissions
- Participation in Airport Carbon Accreditation Programs
- Use of advanced aerobridges fitted with Fixed Electrical Ground Power and Preconditioned Air in order to minimise aircraft and vehicular pollution
- Install solar power plants and solar water heaters at airports to promote renewable energy use.

Further, air navigation initiatives for enroute, terminal airspace, and improvement in ground efficiency have been adopted. In conclusion, India and its aviation industry have taken several important steps to address aviation's contribution to climate change.

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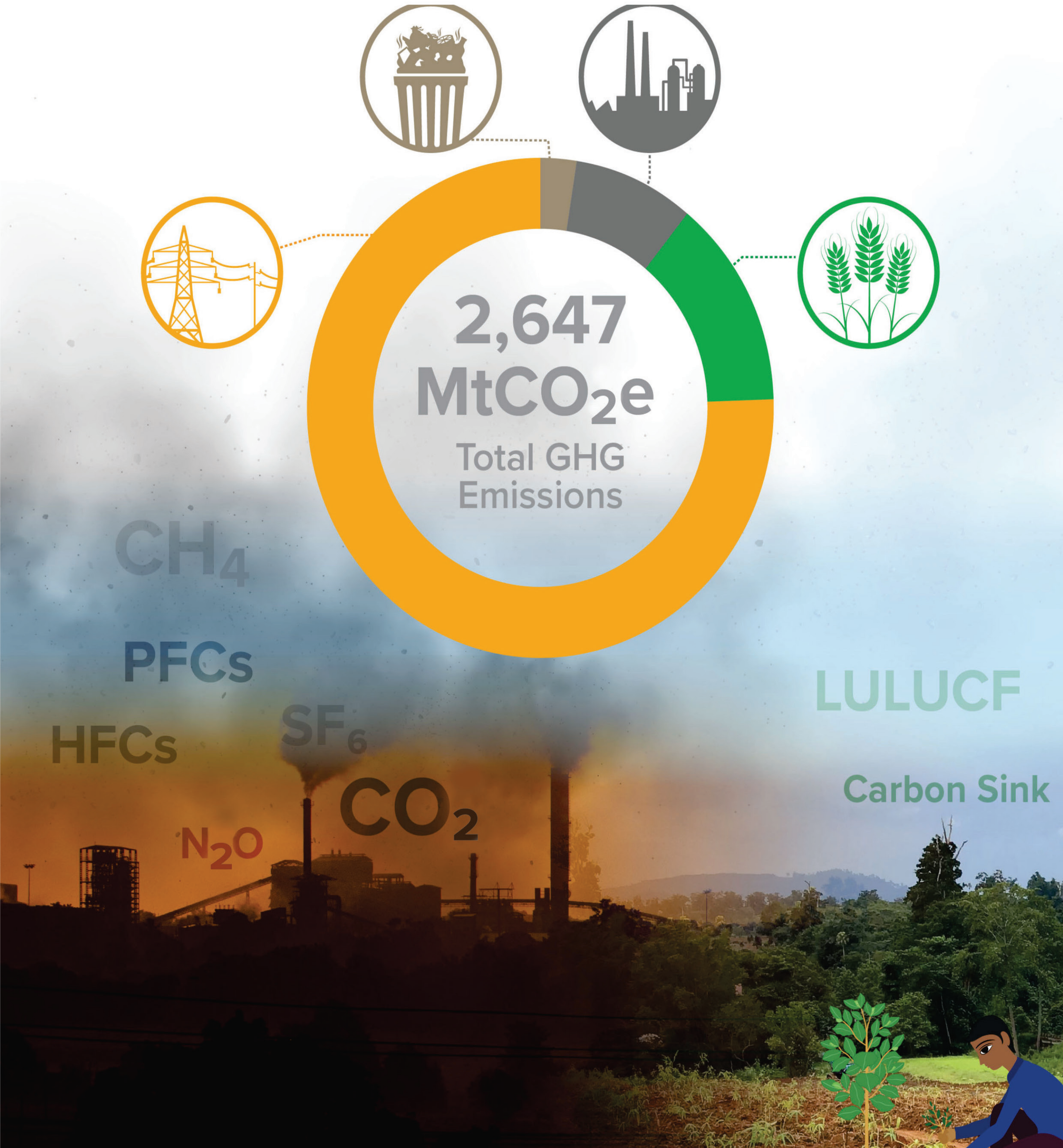
National Greenhouse Gas Inventory



NATIONAL GREENHOUSE GAS INVENTORY

Chapter 02

2.1 Introduction

Information on India's Greenhouse Gas (GHG) inventory for 2019 is provided in this chapter, along with descriptions of the methods, data sources, uncertainties, quality assurance (QA) / quality control (QC) activities completed and trend analysis. The chapter also includes data from the prior inventory submission, which helps to ensure the transparency, consistency, comparability, completeness, and accuracy of the inventory.

The national GHG inventory is created in accordance with the updated guidelines 17/CP.8 intended for reporting National Communications (NCs) from Non-Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC), as required by UNFCCC guidelines for NCs preparation. The update is in line with reporting capacities, deadlines, data accessibility, and reporting support levels.

This chapter provides a thorough explanation of the greenhouse gas inventory for the year 2019, which includes information on the sources and sinks of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) emissions. Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), and Waste are the sectors covered. India has used the 2006 IPCC guidelines for GHG inventories, the Revised 1996 IPCC guidelines for LULUCF, and the 2003 IPCC Good Practice Guidance for LULUCF. The 2006 IPCC guidelines have been followed to the extent possible, as per the extant capacities.

2.2 Institutional Arrangement for GHG Inventory

Along with other government agencies, scientific and research institutions from India participated in the creation of the national inventory. The preparation of the inventory is coordinated by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (GoI), including by bringing together various expert institutions that compile sectoral data and carry out research to obtain country-specific emission factors. The MoEFCC entrusted studies to expert institutions and established contact with other government agencies responsible for official statistics and activity data. The technical team in charge of the inventory conducts technical discussions with the partners, monitors the updating and availability of information, and carries out quality control.

In their respective fields of sectoral expertise, twelve Indian scientific and research institutions completed the inventory preparation exercise. Since India's Initial National Communication, many of these institutions and experts have contributed to the inventory preparation process. Various Ministries, Governmental agencies, Industrial Associations and public sector organisations contributed to the creation of the national inventory. The institutions involved in creating inventories across various sectors are listed in Figure 2.1.

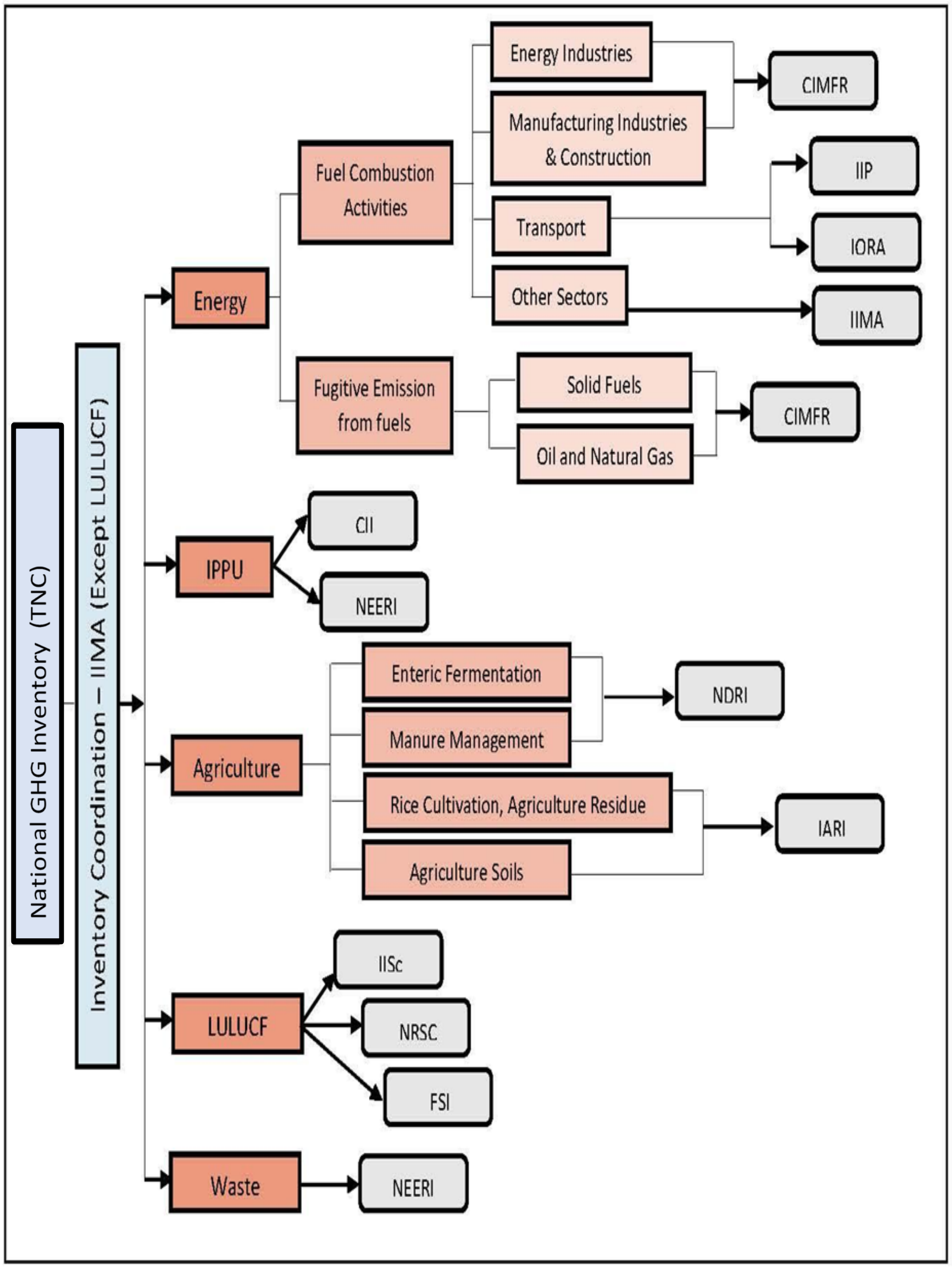


Figure 2.1: Institutions involved in GHG inventory preparation

Acronyms:

CII: Confederation of Indian Industry, New Delhi

CIMFR: Central Institute of Mining and Fuel Research, Dhanbad

FSI: Forest Survey of India, Dehradun

IARI: Indian Agricultural Research Institute, New Delhi

IIMA: Indian Institute of Management, Ahmedabad
IIP: Indian Institute of Petroleum, Dehradun
IISc: Indian Institute of Science, Bengaluru
IORA: IORA Ecological Solutions, New Delhi
NDRI: National Dairy Research Institute, Karnal
NEERI: National Environmental Engineering Research Institute, Nagpur
NRSC: National Remote Sensing Centre, Hyderabad

2.3 Methodology

The IPCC Guidelines (IPCC, 2006) provide a detailed estimation methodology for all the sectors and sub-sectors. The IPCC has created a system of methodological tiers to denote various degrees of methodological complexity. Tier 1 utilises an IPCC default value, Tier 2 uses country-specific emission factors based on measurements or IPCC Tier 2 emission factors, and Tier 3 is the most complex and data-intensive. Tier 3 may include models and inventory management systems tailored to address national circumstances, repeated over time, and determined by high-resolution activity data and disaggregated at the sub-national level. Both default and country-specific emission factors have been employed and presented in Table 2.1 for all categories and gases (IPCC, 1996).

Table 2.1: Summary of emission factors and methodologies in the Third National Communication

Type of emission factor and level of methodological tier employed for GHG estimation						
Gas	**CO_2**		**CH_4**		**N_2O**	
Sector/ Category	**Method used**	**Emission Factor**	**Method used**	**Emission Factor**	**Method used**	**Emission Factor**
1. Energy						
A. Fuel combustion activities						
1. Energy industries	T1, T2, T3	D, CS	T1	D	T1	D
2. Manufacturing industries & construction	T1, T2, T3	D, CS	T1, T2	D	T1	D
3. Transport	T1, T2	D, CS	T1, T2	D	T1, T2	D
4. Other sectors	T1, T2	D, CS	T1	D	T1	D
B. Fugitive emission from fuels						
1. Solid fuels	NO		T2, T3	CS	NO	
2. Oil and natural gas	NO		T1	D	NO	
2. Industrial Process and Product Use (IPPU)						
A. Mineral industry	T1, T2	D, CS	NO		NO	
B. Chemical industry	T1, T2	D, CS	T1	D	T1, T2	D, CS
C. Metal industry	T1, T2	D, CS	T1	D	NO	
D. Non-energy product use	NO		NO		NO	

Type of emission factor and level of methodological tier employed for GHG estimation						
Gas	**CO_2**		**CH_4**		**N_2O**	
Sector/ Category	**Method used**	**Emission Factor**	**Method used**	**Emission Factor**	**Method used**	**Emission Factor**
E. Production of halocarbons	NO		NO		NO	
3. Agriculture						
A. Enteric fermentation	NO		T1, T2	D, CS	NO	
B. Manure management	NO		T1	D	T1	D
C. Rice cultivation	NO		T2	CS		
D. Agricultural soils	NO		NO		T2	CS
F. Field burning of agricultural residues	NO		T1	D	T1	D
4. Land Use, Land Use Change and Forestry (LULUCF)						
A. Forest land	T2	CS	T2	D, CS	T2	D, CS
B. Cropland	T2	CS	NO		NO	
C. Grassland	T2	CS	NO		NO	
D. Settlements	T2	CS	NO		NO	
E. Wetlands	NE		NE		NE	
F. Other Land	NA		NA		NA	
5. Waste						
A. Solid waste disposal on land	NO		T2	D, CS	NO	
B. Waste-water handling	NO		T1, T2	D, CS	T1, T2	D, CS
Memo item (not accounted in total emissions)						
International bunkers	T1, T2	D	T1, T2	D	T1, T2	D
CO_2 from biomass	T1	D	NO		NO	
T1- Tier 1; T2- Tier 2; T3- Tier 3; CS- Country Specific; D- IPCC Default, NO-Not Occurring, NA-Not Applicable, NE-Not Estimated						

Global Warming Potential (GWP) is a quantified measure of the globally averaged relative radiative forcing of a particular GHG (see Table 2.2). It is defined as the accumulated radiative forcing within a specific time horizon caused by emitting 1 kilogram (kg) of the gas, relative to that of the reference gas CO_2. Direct radiative effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are GHGs, or when a gas influences other radiative important processes such as the atmospheric lifetimes of other gases. All calculations in the present report use the GWP of GHGs for 100 years, IPCC AR2 (IPCC, 1995).

Table 2.2: Global Warming Potentials Used

GHG	GWP (100 year)
CO_2	1
CH_4	21
N_2O	310
HFC-23	11700
HFC-134a	1300
CF_4	6500
C_2F_6	9200
C_4F_{10}	7000
C_6F_{14}	7400
SF_6	23900

Furthermore, for the national GHG inventory, as set forth in paragraph 12 of Decision 17/CP.8, to the extent possible, the key categories are analyzed, pursuant to IPCC Good Practice Guidance, to identify the subsectors that should be prioritized in terms of methodological refinement, taking into consideration the national circumstances, as well as the contribution of the identified subsectors to the total emissions (UNFCCC, 2002).

2.4 Quality Assurance (QA), Quality Control (QC)

Following the 2006 IPCC Guidelines, national inventories have to be transparent, well documented, consistent, complete, comparable, assessed for uncertainties, and should be subjected to verification and QA/QC exercise. A few of the processes covered by the quality system are employee training, inventory planning and preparation, QA/QC procedures, peer-reviewed publications, data storage, follow-up, and improvements. The QA/QC plan also includes a timetable that details the various phases of the inventory, from its conception to its final reporting. The quality system ensures that the inventory is systematically planned, prepared and followed up in accordance with specified quality requirements, so that the inventory is continuously developed and improved (IPCC, 2006a).

The MoEFCC and other government agencies involved in the reporting on climate change ensured that the methodologies used in the reporting and inventories of emissions and removals meet the standards necessary to uphold the highest level of accuracy. The government agencies have followed internal routines to plan, prepare, check and act/follow up the quality assurance and control work and consult one another with the aim of developing and maintaining a coordinated quality system. The IPCC GPG section's list of Tier 1 general inventory level QA and QC procedures is used (IPCC, 2006a). Every category's emission is also examined and contrasted with previous years. All time series for the data have undergone careful examination to look for outliers and confirm that the levels are appropriate.

Quality Control

Quality control is the check that is made during the inventory preparation on different types of data, emission factors and calculations that have been made. The quality control takes place according to general requirements (Tier 1) which applies to all types of data used as support material for the reporting, and the specific requirements for quality control (Tier 2) which are applied to certain types of data and/or emission sources (IPCC, 2006a). In this inventory preparation exercise, general Tier-1 QC measures, according to the 2006 IPCC Guidelines, have been carried out as follows:

- Checked whether assumptions and criteria for the selection of activity data, emission factors, and other estimation parameters were documented, compare with international agency estimates.
- Checked for transcription errors in data input and references.
- Checked that emissions and removals were calculated correctly.
- Checked that parameters and units were correctly recorded and that appropriate conversion factors were used.
- Checked the integrity of database files.
- Checked for consistency in data between source categories.
- Checked that the movement of inventory data among processing steps was correct.
- Checked that uncertainties in emissions and removals were estimated and calculated correctly.
- Checked time series consistency.
- Checked completeness.
- Compared the reference and sectoral approach.
- Conducted trend checks.
- Reviewed internal documentation and archiving.

Quality Assurance

According to IPCC Good Practice Guidance, good practice for QA procedures requires an objective review to assess the quality of the inventory and to identify areas where improvements should be made. Furthermore, it is good practice to use QA reviewers who have not been involved in preparing the inventory. In India, the MoEFCC is in charge of examining the inventory to determine its quality and potential for improvement. To prepare the national GHG inventory, the following duties and tasks have been completed.

- Determined information needs were complied with the methodological requirements stipulated by the 2006 IPCC Guidelines.
- Prepared and sent information queries to select data sources using official correspondence, telephone, and e-mail.
- Identified potential data sources, including organizations and independent experts.
- Collected data (activity data and emission factors) for all source/sink categories for Energy, IPPU, Agriculture, Waste and LULUCF Sectors.
- Analysed information to use for calculation of emissions and reductions.

- Checked reliability of input data through the comparison of the same or similar data from alternative data sources and time-series assessment in order to identify changes that cannot be explained.
- Processed and archived data.
- Assessed consistency of the methodologies applied, inventory improvement recalculations.
- Checked reliability of results, elimination of errors.
- Developed and implemented QC procedures under supervision of MoEFCC.
- Implemented Quality assurance conducted by MoEFCC staff and relevant experts.
- Key category analysis was done.
- Uncertainty assessment analysis was done.
- Final validation done by expert's group and the steering committee through MoEFCC.
- Prepared final version of the inventory report.
- Documented and archived all data used in preparation of the national inventory report.
- Submitted the inventory report by MoEFCC to UNFCCC Secretariat.

2.5 National Greenhouse Gas Emissions

In 2019, India's total GHG emissions excluding LULUCF amounted to 3,132 $MtCO_2e$ and including LULUCF amounted to 2,647 $MtCO_2e$. Total national emissions (including LULUCF) have increased by 4.56 per cent with respect to total national emission of 2016 and by 115.42 per cent since 1994 (Figure 2.2 and Table 2.3). The main contributors of the total GHG emission are CO_2 emissions generated due to burning of fossil fuels, methane emissions from livestock and increasing aluminium and cement production. The LULUCF sector was remain net sink during the inventory period 2019.

Table 2.3: Sector-wise National GHG emission in $MtCO_2e$ for 1994-2019

GHG Sources and Removals	1994	2000	2007	2010	2014	2016	2017	2018	2019
	Mt CO_2e								
Source	INC	SNC	SNC	BUR1	BUR2	BUR3	TNC	TNC	TNC
Energy	744	1027	1374	1510	1910	2129	2204	2344	2374
Industrial Processes and Product Use (IPPU)	103	89	142	172	202	226	244	263	264
Agriculture	344	356	373	390	417	408	411	417	421
Land Use, Land Use Change and Forests	14	-223	-177	-253	-301	-308	-312	-437	-485
Waste	23	53	58	65	78	75	70	72	73
Total (without LULUCF)	1214	1524	1947	2137	2607	2839	2929	3096	3132
Total (with LULUCF)	1229	1301	1772	1884	2306	2531	2617	2659	2647

Source: (MoEF, 2004); (MoEF, 2012); (MoEF, 2010); (MoEFCC, 2015); (MoEFCC, 2018); (MoEFCC, 2021).

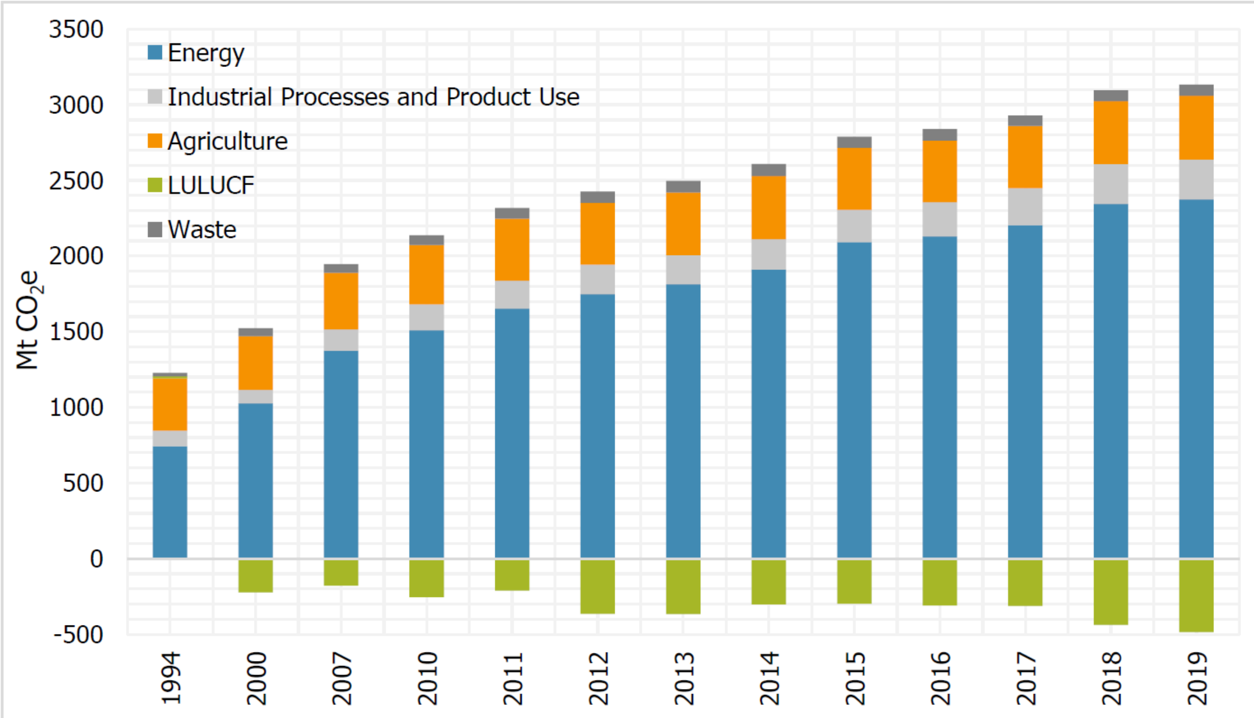


Figure 2.2: Sector-wise National GHG emission in Mt CO_2e for 1994-2019.
Source: (MoEF, 2004); (MoEF, 2012); (MoEF, 2010); (MoEFCC, 2016); (MoEFCC, 2018), (MoEFCC, 2021).

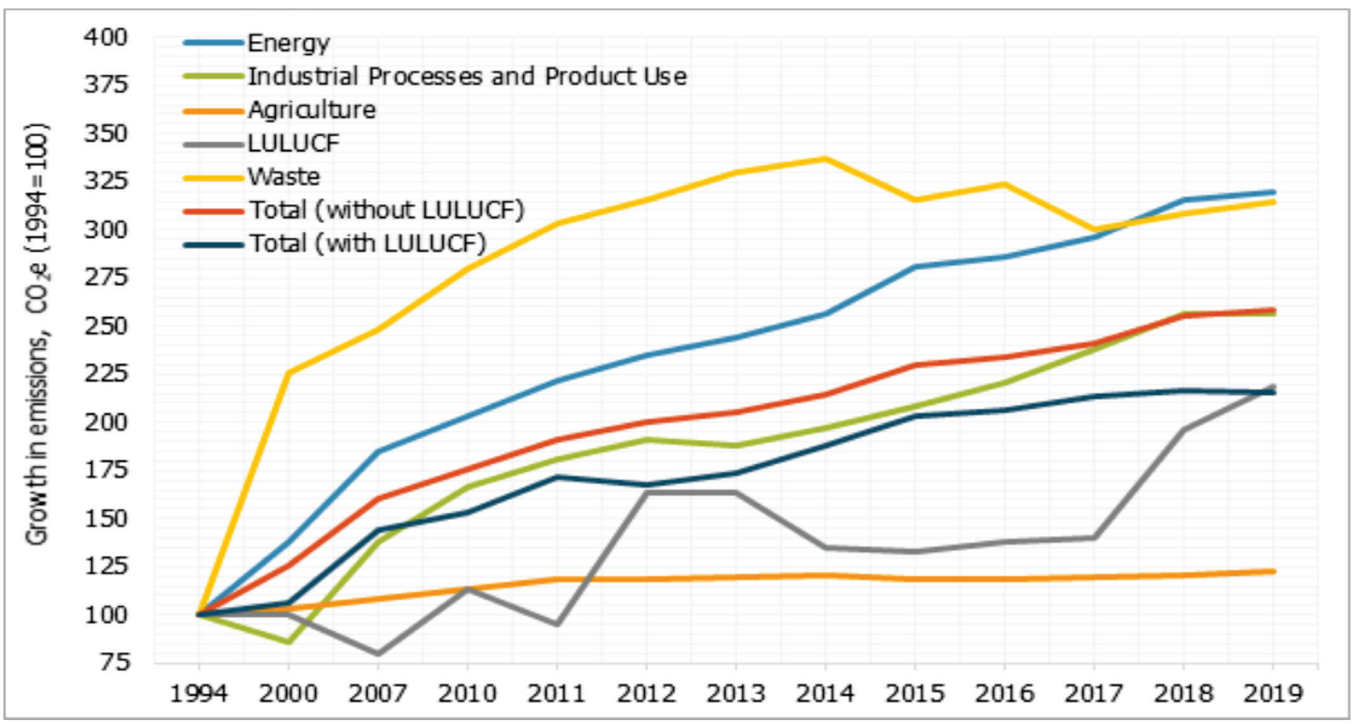


Figure 2.3: Growth in emissions of greenhouse gases, relative to 1994, illustrated by source categories, 1994-2019. Index 1994 = 100.
Source: (MoEF, 2004); (MoEF, 2012); (MoEF, 2010); (MoEFCC, 2016); (MoEFCC, 2018), (MoEFCC, 2021).

In the section on sector-specific emissions, activity data and country-specific emission factors that were used to prepare the inventory are listed in a tabular format. Where emission factors were not specified, India used the default emission factors from the IPCC 2006 guidelines. India has experienced substantial economic growth since 1994, generating a general growth in GHG emissions. Examining the overall trend from 1994 to 2019, total CO_2e emissions (without LULUCF) increased by 158 per cent. Energy sector has the highest growth of 219 per cent for the period of 1994 to 2019 due to continuous increase of fossil fuel combustion. The waste sector has the second highest growth of 215 per cent over the period of 1994 to 2019 due to the increase in population and industrial activities, but its contribution to overall emissions always remains around 3 per cent, as their absolute contribution is very low. For the same period, the IPPU sector has grown by 157 per cent while the agriculture sector has grown by 22 per cent (Figure 2.3). Between 2000 and 2019, the sector of LULUCF reported a growth in GHG removals of 118 per cent.

2.5.1 Summary GHG Emission in 2019

In 2019, India emitted 31,320,28 Gg of CO_2e GHGs from Energy, IPPU, Agriculture and Waste sectors. LULUCF sector remained a net sink in 2019, accounting for the removal of 4,85,472 GgCO_2e of emissions. Considering total emissions and removals, net national emissions in 2019 were 26,46,556 GgCO_2e. The energy sector contributed the most to the overall emissions with 75.81 per cent, followed by agriculture sector 13.44 per cent, IPPU sector by 8.41 per cent and Waste sector by 2.34 per cent (Figure 2.4). A summary of sector wise national emissions and removals is presented in the Table 2.4.

Table 2.4: Sector-wise National GHG emission in Gg for 2019

GHG sources and removals	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC 23	CF_4	C_2F_6	SF_6	CO_2 equivalent
Energy	2305998	NO	2034	83	NO	NO	NO	NO	2374330
IPPU	183044	NO	222	12	2	5	1	0.004	263540
Agriculture	NO	NO	14542	373	NO	NO	NO	NO	420968
LULUCF	9726	496656	48	1	NO	NO	NO	NO	-485472
Waste	NO	NO	2684	54	NO	NO	NO	NO	73189
Memo Items	801279	NO	0.12	0.17	NO	NO	NO	NO	801335
Total without LULUCF	**2489042**	**--**	**19482**	**522**	**2**	**5**	**1**	**0.004**	**3132028**
Total with LULUCF	**2498768**	**496656**	**19531**	**523**	**2**	**5**	**1**	**0.004**	**2646556**

Abbreviation: NO – Not Occurring.

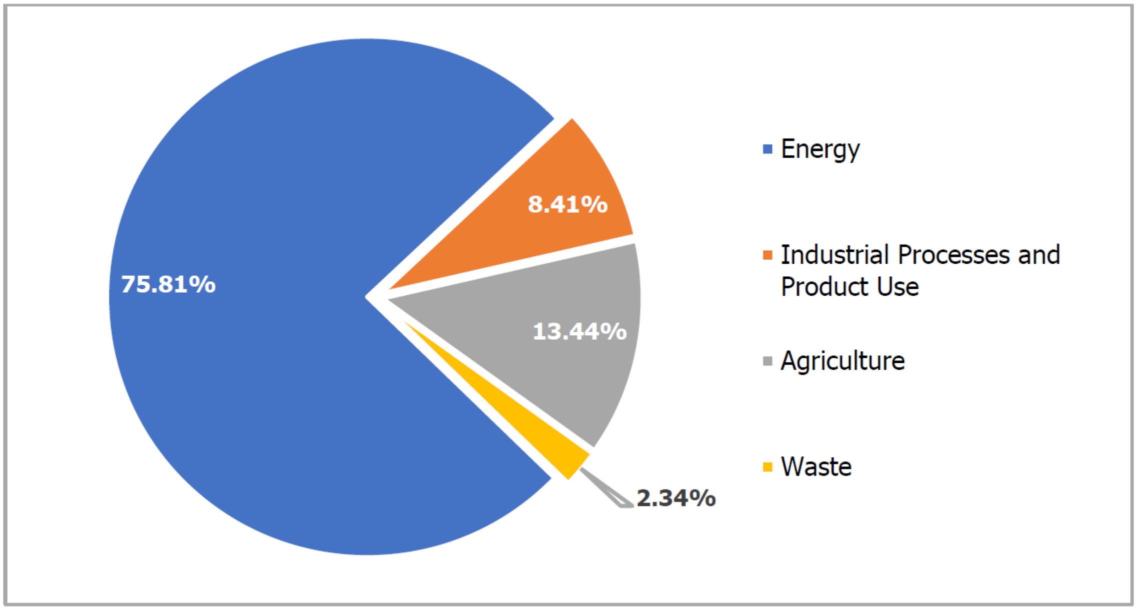


Figure 2.4: Distribution of GHG emissions ($GgCO_2e$) by sector, 2019

Energy sector emissions comprises of emissions from electricity production (1A1a-CO_2), contributing 39 per cent of the total emissions; road transport (1A3b-CO_2), 9 per cent of the total emissions; 7 per cent of the total emissions from enteric fermentation (3A1-CH_4); 5 per cent of the total emissions from each non-specific industries (1A2m-CO_2), residential (1A4b-CO_2) and iron and steel (1A2a-CO_2), 4 per cent of the total emissions from cement production (2A1-CO_2), commercial/institutional (1A4a-CO_2), also refineries (1A1b-CO_2) and agricultural soils (3C4-N_2O) each contribute 3 per cent of the total emissions, respectively. Emissions from rice cultivation (3C7-CH_4), cement (1A2f-CO_2), aluminium production (2C3-CF), lime production (2A2-CO_2) and Production of halocarbons and sulphur hexafluoride (2E-SFC) contribute 2, 2, 1, 1 and 1 per cent of total emissions respectively (Figure 2.5). Figure 2.5 shows percentage share of the top 15 key emission categories for India for 2019 in terms of CO_2e.

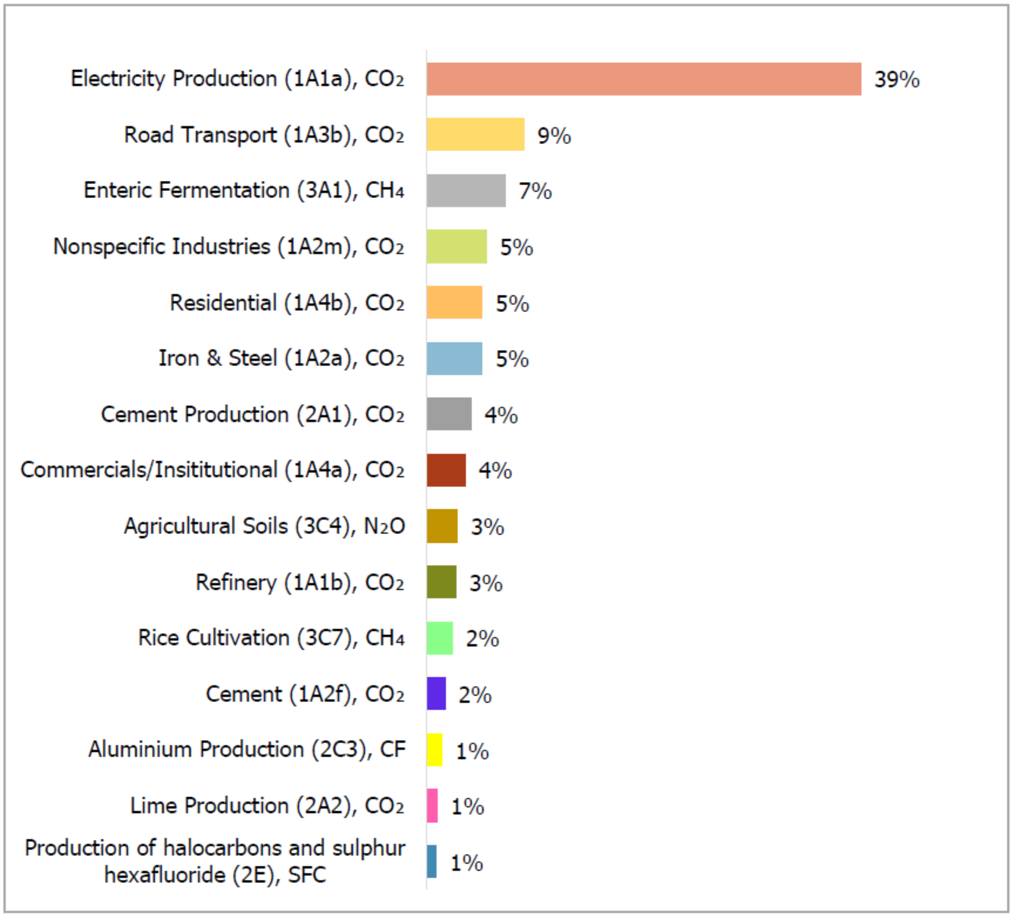


Figure 2.5: Percentage share of greenhouse gas emissions by category, 2019

2.6 Emission trends by gas

In 2019, GHG emissions excluding LULUCF at the national level by type of GHG were as follows: emissions of CO_2 accounted for 24,89,042 Gg (79.47 per cent); CH_4 emissions accounted for 4,09,127 GgCO_2e (13.06 per cent) and N_2O emissions accounted for 1,61,841 GgCO_2e (5.17 per cent). In the case of fluorinated gases, emissions of HFC were 27,949 GgCO_2e (0.89 per cent), CF_4 emissions 31,749 GgCO_2e (1 per cent), C_2F_6 emissions 12,219 GgCO_2e (0.39 per cent) and SF_6 emissions 100 GgCO_2e (Figure 2.6).

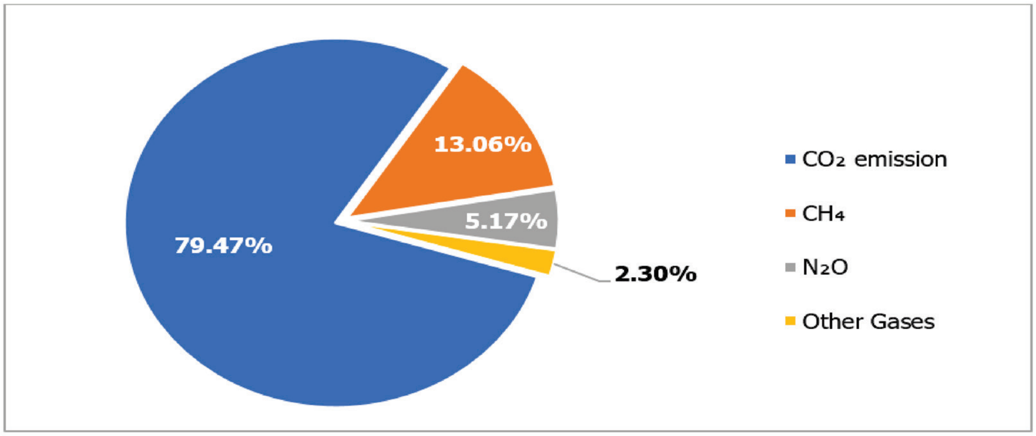


Figure 2.6: Gas-wise emission for the year 2019

2.7 Emission trends by sources

2.7.1 Energy sector

The Energy sector, which includes the consumption of fossil fuels in the country and their associated fugitive emissions, is the main GHG emitting sector in the country, contributing to 76 per cent of the total GHG emissions in 2019 (excluding LULUCF). The total emissions from the energy sector were 23,74,330 Gg CO_2e in 2019, increasing by 11.5 per cent since 2016, mainly due to the steady increase in the country's energy consumption, including the consumption of coal and natural gas for power generation and the consumption of liquid fuels for transportation. Figure 2.7 shows the relative distribution of GHG emissions across the energy sector.

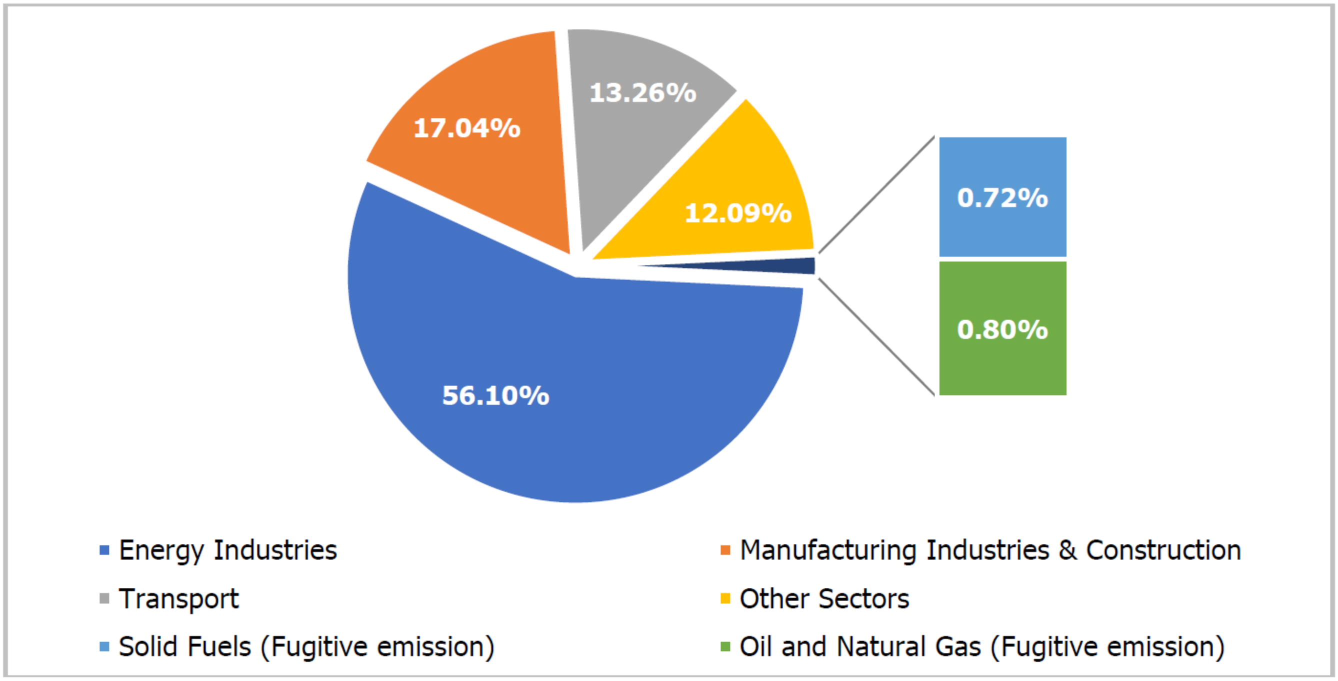


Figure 2.7: Distribution of CO_2e emissions across the Energy Sector Categories in 2019

Energy sector emitted 93 per cent of the total national CO_2 emissions in 2019. This was primarily caused by fossil fuel combustion activities, which included the energy industries as well as manufacturing, transportation, and other industries. Energy-related fuel combustion activities account for 98.49 per cent of all emissions. 1.51 per cent of the total GHG emissions from the energy sector were caused by fugitive emissions.

Fuel combustion activities (1.A)

The fuel combustion category includes emissions from fossil fuel burning, inside or outside of a device designed to heat, or provide heat to a process through heat or mechanical work. The total emissions from this category increased by 2,46,183 (12 percent) from 2016 levels to 23,38,432 GgCO_2e emissions in 2019. Within the category, energy industries are the largest contributor with a 57 per cent (13,31,901 GgCO_2e) of total emissions, followed by 17 per cent (4,04,676 GgCO_2e) from manufacturing industries and construction, 13 per cent (3,14,817 GgCO_2e) from transport and 12 per cent (2,87,039 GgCO_2e) from other sectors in 2019 (Figure 2.8).

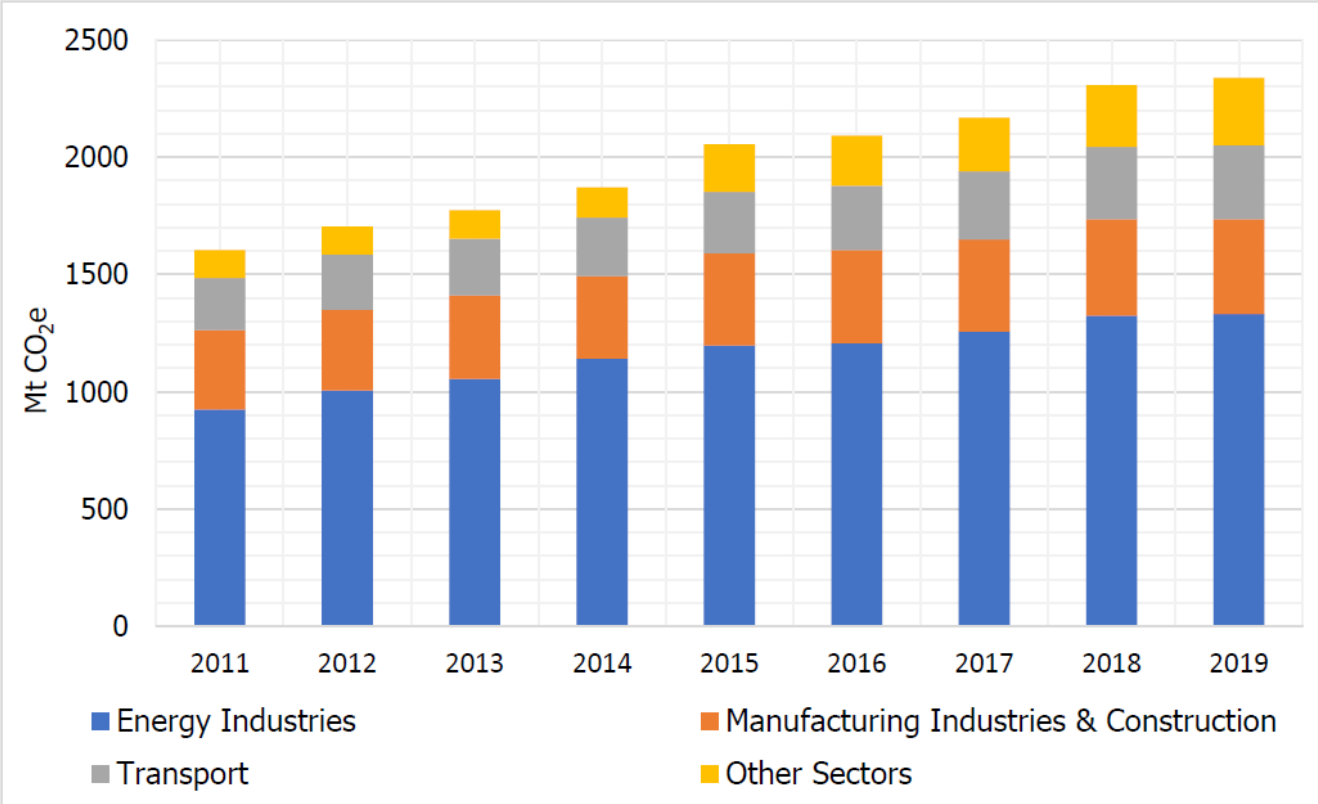


Figure 2.8: Fuel combustion activities: GHG emissions ($MtCO_2e$) per subcategory, 2011-2019

Energy industries (1.A.1)

This subcategory considers GHG emissions due to fossil fuels combustion for energy production industries and fuel extraction. Electricity production is accounted for approximately 40 per cent of the total national emissions without LULUCF in 2019, which is the highest emitting category in India. In 2019, these emissions accounted for 12,39,807 $GgCO_2e$, increasing 10 per cent (1,12,075 $GgCO_2e$) since 2016. Within this subcategory, electricity and heat production account for 93 per cent of the total, with petroleum refining accounting for 6 per cent and the manufacture of solid fuels and other energy industries accounting for 1 per cent. The consumption patterns of the fuels in energy industries have been shown in Table 2.5 and Figure 2.9. The overall country-specific emission factors used in energy industry emission estimation are shown in Table 2.6. It should be noted that sector-specific conversion factors and carbon emission factors have been estimated for specific categories, namely power generation, iron and steel industries, cement, and a few other industries (Table 2.8).

Table 2.5: Category wise fuel consumption in the energy industries (1A1) in 2017 to 2019.

Fuel consumption (TJ)	Year	Liquid Fuels	Gaseous Fuels	Solid Fuels
Electricity and Heat Production (1A1a)	2017	104131	556095	12042123
	2018	113869	564840	12716478
	2019	111090	521435	12777830

Fuel consumption (TJ)	Year	Liquid Fuels	Gaseous Fuels	Solid Fuels
Petroleum Refining (1A1b)	2017	-	1304753	-
	2018	-	1356150	-
	2019	-	1453757	-
Manufacture of Solid Fuels and Other Energy Industries (1A1c)	2017	-	-	597591
	2018	-	-	623029
	2019	-	-	637818

Sources: (CEA, 2017, 2018, 2019, 2020); (MoC, 2017, 2018, 2019, 2020); (CMIE, 2021); (MoC, 2017a, 2018a, 2019a, 2020a); (MoPNG, 2016, 2017, 2018, 2019); (MoSPI, 2017, 2018, 2019) (MoPNG, 2019a, 2020a, 2021a); (CEA, 2017a, 2018a, 2019a, 2020a).

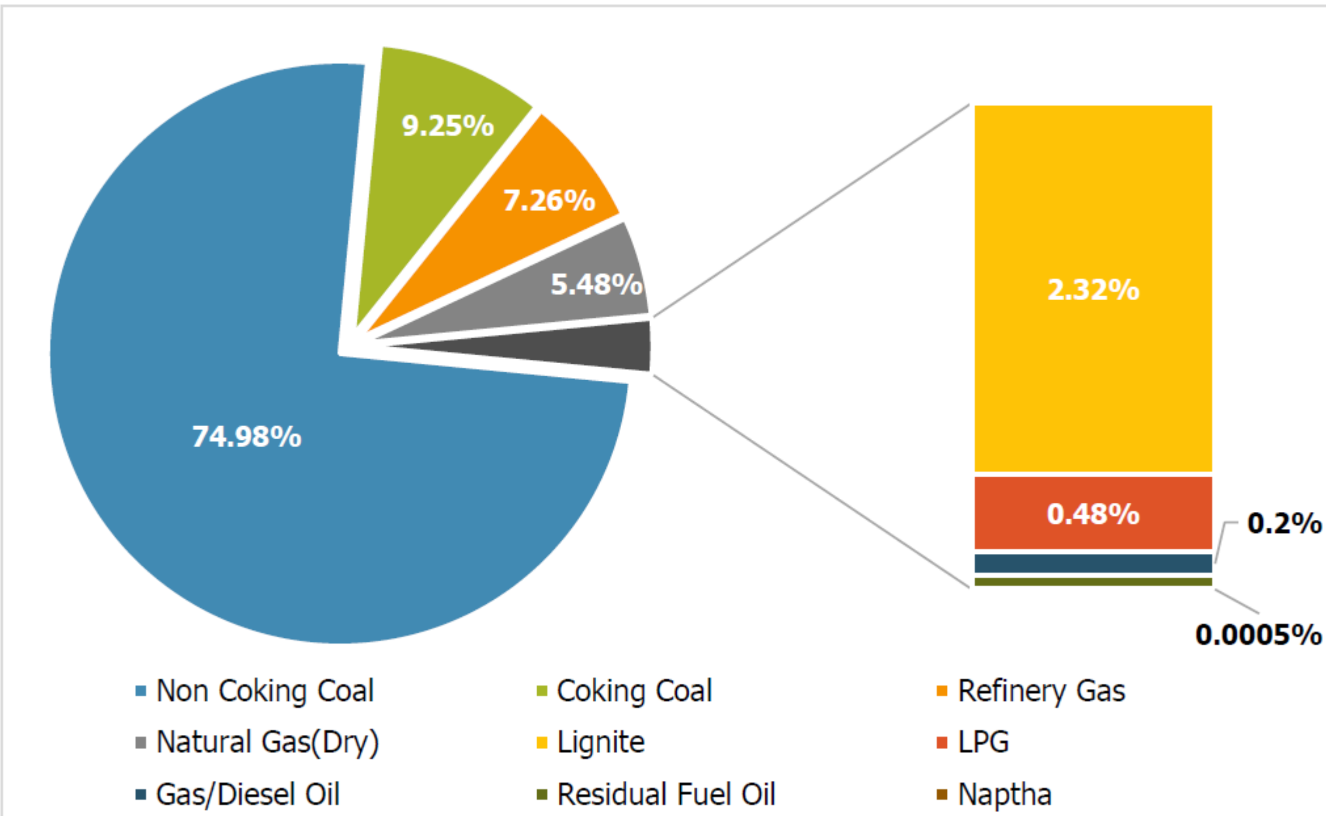


Figure 2.9: Share of fuel consumption for energy industries for the year 2019

Table 2.6: Country Specific emission factors used in the energy industries (1A)

Fuel-wise emission factors	Electricity and heat production (1A1a)		Manufacture of solid fuels and other energy industries (1A1c)	
	Net calorific value (TJ/Kt)	Carbon emission factor (tC/TJ)	Net Calorific value (TJ/Kt)	Carbon emission factor (tC/TJ)
Coking coal	23.66	25.55	23.66	25.55
Non-coking coal	17.09	26.39	18.26	26.28
Lignite	9.8	28.9	9.8	28.9

Manufacturing industries & construction (1.A.2)

This subcategory includes GHG emissions generated by fossil fuels burning in industry, including burning for power and heat generation for in-house use. In 2019, GHG emissions accounted for 4,04,676 GgCO_2e, which was 16.92 per cent of total CO_2e emissions from the energy sector, category emission was increasing by 1.74 per cent (6,937 GgCO_2e) since 2016. Although overall emissions in the sector have increased, emissions in the Cement, Nonferrous metal, Textile/Leather, Fertiliser, and Non-specific industries have decreased. Iron & steel, Mining and quarrying, and Engineering sector all played important roles in increasing emissions from 2016 to 2019. Within the subcategory, Non-specific Industries contribute the most with 42.24 per cent, followed by 39.22 per cent by Iron and Steel industry, 13.03 per cent by Cement industry, 1.27 per cent by Mining and Quarrying, 1.21 per cent by Fertilizer industry and less than 1 per cent by Chemical, Non-ferrous metals, Pulp and Paper, Textile/ Leather and Bricks and Engineering sectors individually (Figure 2.10 and Table 2.7).

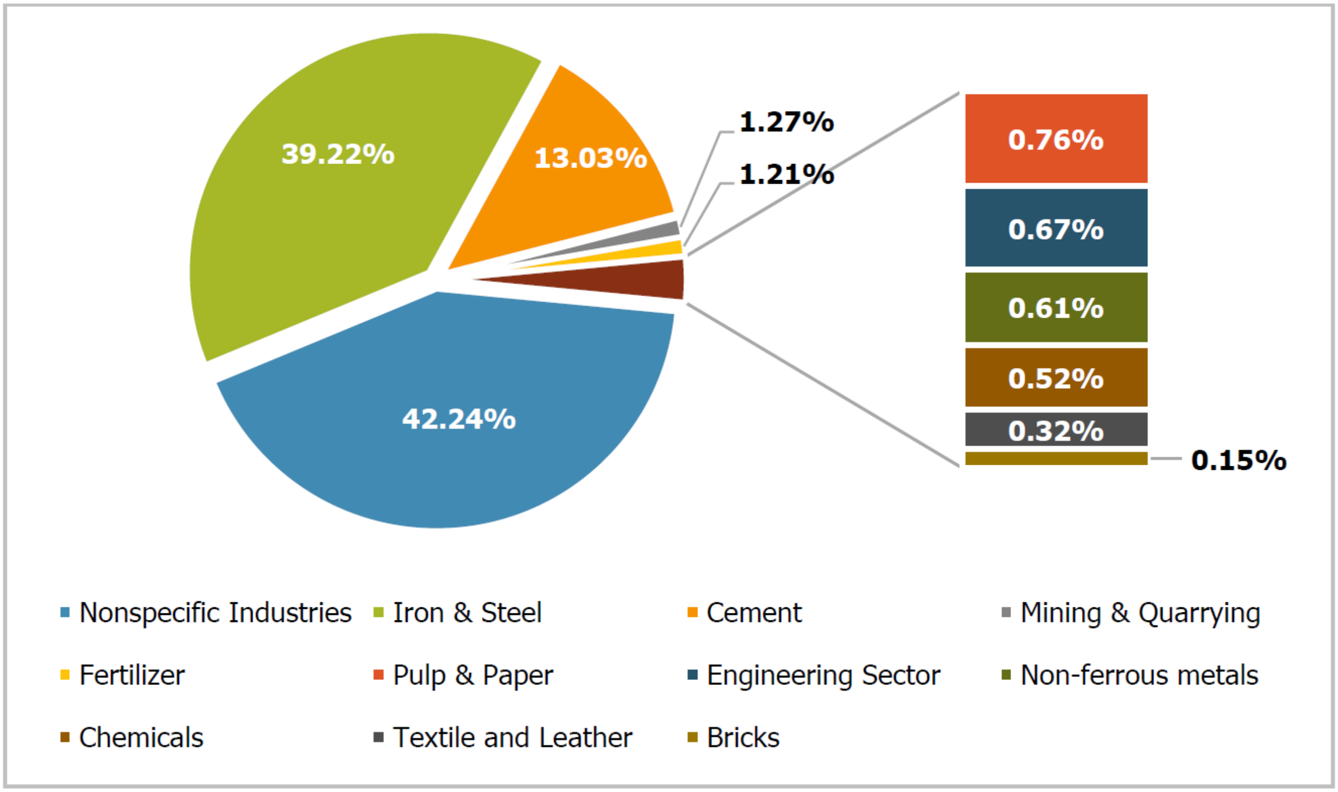


Figure 2.10: Distribution of CO_2e emissions across the manufacturing industries & construction categories in 2019

Table 2.7: Category wise fuel consumption in the manufacturing industries & construction (1A2) in 2017 to 2019.

Fuel consumption (TJ)	Year	Liquid Fuels	Gaseous Fuels	Solid Fuels
Iron & Steel (1A2a)	2017	54648	50965	1473010
	2018	54712	50220	1660554
	2019	50886	30510	1637955

Fuel consumption (TJ)	Year	Liquid Fuels	Gaseous Fuels	Solid Fuels
Cement (1A2f)	2017	360077	-	193552
	2018	358179	-	193103
	2019	359691	-	184454
Non-ferrous metals (1A2b)	2017	11687	-	33864
	2018	16065	-	18365
	2019	15233	-	13119
Pulp & Paper (1A2d)	2017	-	-	33059
	2018	-	-	35738
	2019	-	-	31247
Chemicals (1A2c)	2017	15911	-	7949
	2018	18658	-	8210
	2019	17775	-	7472
Mining & Quarrying (1A2i)	2017	56644	-	-
	2018	63861	-	-
	2019	69277	-	-
Textile and Leather (1A2l)	2017	3725	-	26105
	2018	3371	-	29568
	2019	2956	-	10181
Bricks (1A2k)	2017	-	-	6074
	2018	-	-	7600
	2019	-	-	5819
Fertilizer (1A2e)	2017	21695	-	41667
	2018	20214	-	38682
	2019	17101	-	38423
Engineering Sector (1A2h)	2017	28333	-	-
	2018	32831	-	-
	2019	36345	-	-
Nonspecific Industries (1A2m)	2017	209841	146956	1517321
	2018	187379	144774	1548310
	2019	196208	173016	1523755

Sources: (MoPNG, 2017a, 2018a, 2019a, 2020a, 2021a); (CMIE, 2021); (MoC, 2017, 2018, 2019, 2020)

The analysis of a large number of coal samples from various categories found in India yielded India-specific emission factors for coal. Table 2.8 provides a summary of sector-specific and country-specific values.

Table 2.8: Country specific emission factors used in the manufacturing industries & construction (1A2) and electricity power generation (1A1ai)

Fuel wise Emission Factors	Electricity Power Generation (1A1ai), Iron & Steel (1A2a)		Chemicals (1A2c), Textile and Leather (1A2l), Bricks (1A2k), Fertilizer (1A2e), Nonspecific Industries (1A2m)		Pulp & Paper (1A2d)		Non-ferrous metals (1A2b)		Cement (1A2f)	
	Net Calorific Value (TJ/Kt)	Carbon Emission Factor (tC/TJ)	Net Calorific Value (TJ/Kt)	Carbon Emission Factor (tC/TJ)	NetCalorific Value (TJ/Kt)	Carbon Emission Factor (tC/TJ)	Net Calorific Value (TJ/Kt)	Carbon Emission Factor (tC/TJ)	Net Calorific Value (TJ/Kt)	Carbon Emission Factor (tC/TJ)
Coking coal	23.66	25.55	23.66	25.55					23.66	25.55
Non-coking coal	17.09	26.39	20.4	26.06	18.35	26.26	18.17	26.28	20.15	26.08
Lignite	9.8	28.9	9.8	28.9					9.8	28.9

Transport (1.A.3)

This subcategory includes GHG emissions generated by fossil fuels burning in all activities of national transportation, excluding military operations (maritime and aerial). Emissions from the transport sector total 3,14,817 GgCO_2e, accounting for about 13 per cent of total GHG emissions from the energy sector in the country for 2019. It is also the key emission category for India (without LULUCF). It has increased by 15 per cent (40,383 GgCO_2e) from 2016 levels, mainly due to higher fuel consumption and improvement of the road infrastructure in the country.

The road transport sector accounted for 91 per cent of the total GHG emissions from the transport sector, followed by civil aviation (6 per cent), railways (2 per cent) and water-borne navigation (1 per cent). Fuel consumption data for road, aviation and navigation sectors have been sourced from the statistics provided by Ministry of Petroleum and Natural Gas (MoPNG). For railways, data has been sourced from the statistics published by the Ministry of Railways (MoR).

Table 2.9: Category wise fuel consumption in the road transport (1A3b) in 2017 to 2019.

Fuel Consumption (TJ)		2017	2018	2019
Road Transport	Petrol	1091067	1165319	1260128
	Diesel	2060532	2144637	2169776
	Light Distillate Oil	76	172	114
	Fuel Oil	968	3552	4668
	Compressed Natural Gases	123362	142385	153812
	Liquefied Petroleum Gases	8530	8478	8335
Off Road (Tractors)	Diesel	252326	263473	267581

Sources: (MoPNG, 2019a, 2020a, 2021a), (PPAC, 2021).

The Railways sector consumes electricity, diesel, petrol, furnace oil and nominal amounts of coal. To avoid double counting, GHG emissions due to consumption of electricity in railways is not included but is covered under 1A1a in electricity generation category (1A1), Table 2.10.

Table 2.10: Category wise fuel consumption in the railways (1A3c) in 2017 to 2019

Fuel Consumption (TJ)	2017	2018	2019
Coal	25.61	21.10	6.23
Wood	0.10	-	0.004
HSD	1,01,189	97,878	87,944
LDO	0.73	-	0.18
Petrol	2.26	-	0.31
Kerosene	84.07	22.26	31.64

Source: MoR, 2017; 2018; 2019; 2020.

For the aviation sector, comprising of domestic and international aviation, segregated Aviation Turbine Fuel (ATF) consumption data for both the sectors was collected. The emission estimates made for the combustion of ATF in international aviation is reported separately as the memo item under international bunkers. In 2017, 2018, and 2019, India consumed 2,49,725 TJ, 2,69,936 TJ, and 2,71,886 TJ of aviation turbine fuel, respectively.

The Navigation sector emission estimates are based on fuel consumption (HSDO, LDO and FO) segregated across national and international maritime fleet. Emission estimates made for international fleet is reported as the memo item under marine bunkers separately.

Table 2.11: Category wise fuel consumption in the navigation (1A3d) in 2017 to 2019

Fuel Consumption (TJ)	2017	2018	2019
Fuel Oil	11801	14403	15913
High Speed Diesel Oil	26220	27359	28040
Light Diesel Oil	223	220	125

Source: MoPNG, 2017a, 2018a, 2019a, 2020a.

Other sectors (1.A.4)

This subcategory includes GHG emissions from fossil fuels burnt in commercial and institutional buildings, in homes and in activities related to agriculture, forestry, fisheries and the fishing industry. Cooking, lighting, space heating and cooling, refrigeration, and pumping characterize the residential, commercial, and agriculture sectors included in this category. In 2019, the other sectors together emitted 2,87,039 Gg of CO_2e, of which approximately 55 per cent was contributed by the residential sector, about 38 per cent by the commercial sector and rest 6 per cent by the biomass burnt for energy (non-CO_2 GHGs) and agriculture/fisheries sectors put together.

Table 2.12: Category wise fuel consumption in the other sectors (1A4) in 2017, 2018 and 2019

Fuel consumption (TJ)	Year	Coking Coal	Non-Coking Coal	Natural Gas	Liquefied Petroleum Gases	Other Kerosene	Gas/ Diesel Oil	Residual Fuel Oil
Commercial/ institutional (1A4a)	2017	-	877200	76260	98658	4249	-	-
	2018	-	999600	82173	111836	4262	-	-
	2019	-	1040400	97296	123661	3789	-	-
Residential (1A4b)	2017	118300	146064	408084	962640	159152	-	-
	2018	94640	412080	344383	1027734	141527	-	-
	2019	94641	604860	322993	1091495	95208	-	-
Agriculture/ Forestry/ Fishing (1A4c)	2017	-	-	8104	358	-	26778	2065
	2018	-	-	8262	869	-	27854	3133
	2019	-	-	8554	1172	-	27306	3215

Source: (MoPNG, 2019a, 2020a, 2021a); (PPAC, 2021); (IEA, 2021); (MoC, 2017a, 2018a, 2019a, 2020a)

Comparison with reference and sectoral approach

A comparison of CO_2 emissions results obtained with the reference approach and the sectoral approach allows verifying the validity of the overall calculations performed. The reference approach uses the total values of national energy statistics, while the sectoral approach uses values related to each category that as a whole add up to the national energy sector.

The reference approach was also used to estimate CO_2e emissions from fuel combustion for the year 2019. The difference in estimates of CO_2 emissions from fuel combustion using the sectoral and reference approaches was around 8 per cent in 2017 to 2019. It is proposed to work on refining the GHG estimates in future communications and reduce the gap. The reference approach emissions were around 71 per cent from solid fuel combustion, around 26 per cent from liquid fuel and the remaining 3 per cent was from gaseous fuel combustion in 2019.

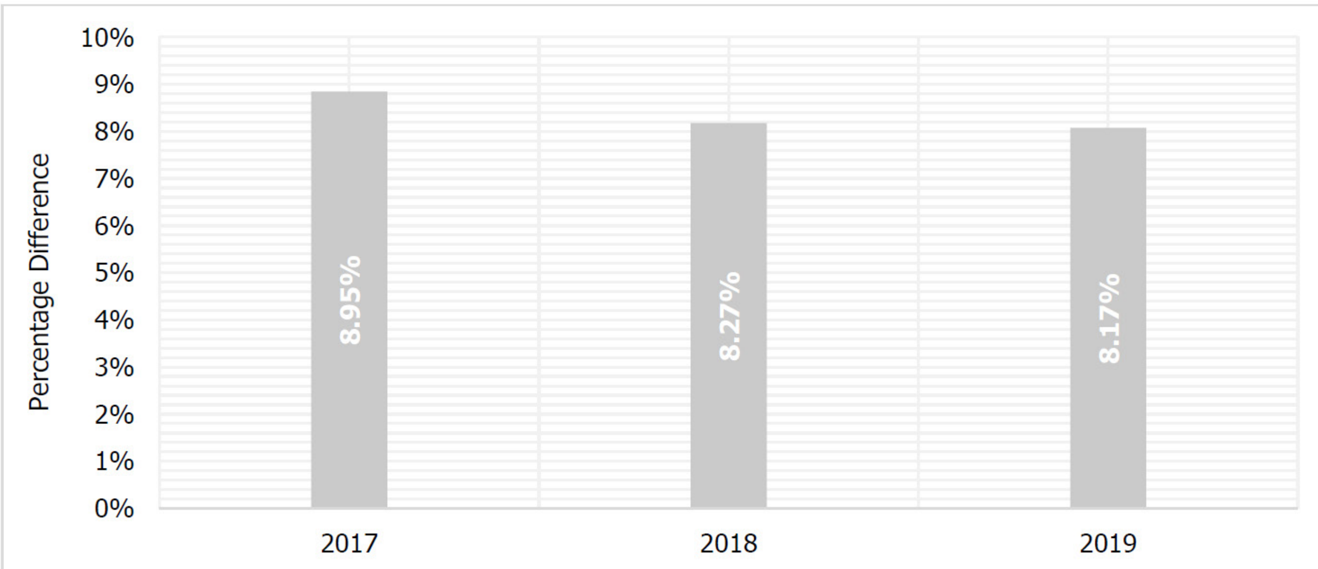


Figure 2.11: Percentage difference between CO_2 emission with the Sectoral approach and the Reference approach, 2017-2019

Fugitive emissions from fuels (1.B)

All intentional or unintentional GHG emissions released during the extraction, processing, storage and distribution of fossil fuels are considered as fugitive emissions. The total fugitive emissions in the year 2019 were 35,898 $GgCO_2e$, of which 47 per cent were from coal mining and post mining operations and 53 per cent were from oil and natural gas production and handling systems. Between 2016 and 2019, fugitive emissions to the atmosphere decreased by 3 per cent, owing primarily to lower levels of oil and gas production and gas processing.

Solid fuels (1.B.1)

Methane is the most significant GHG released during coal mining and handling. Data on coal production from surface and underground mines was collected to estimate methane emissions. Emissions from surface mining increased by 17 per cent and underground mining decreased by 39 per cent over the period 2016-2019. Underground coal production data from underground mines is available under different categories (like Degree I, II and III). Due to a very few numbers of abandoned coal mines in India, abandonment done many years back, and very low production when the mines were active, the contribution of methane from these is considered insignificant and not estimated.

The amount of methane produced per tonne of coal produced is an emission factor for fugitive methane emissions (both underground and above ground mining). Several measurements were taken in order to calculate the fugitive methane emission factors for coal mining and handling activities. Table 2.13 presents a list of country-specific emission factors for fugitive methane emissions from coal mining and handling activities. It may not be out of place to mention here that these emission factors (EFs) from coal mining and handling activities have been incorporated in the IPCC Emission Factor Database after due vetting of the Editorial Board with designated EF IDs 122973-122975 for underground mining and 124920-124921 for surface mining (IPCC, 2020).

Table 2.13: Country-specific emission factors for coal mining activities

Operation (Mining / Post mining)	Methane emission factor (m^3/tonne)			
	Surface mining	Underground mining		
		Degree - I	Degree - II	Degree - III
Mining	1.18	2.91	13.08	23.64
Post Mining (Handling)	0.15	0.98	2.15	3.12

Table 2.14: Coal production in coal mining activities in 2017, 2018 and 2019

Operation (Mining / Post mining)	Coal production (million tonne)			
	Surface mining	Underground mining		
		Degree - I	Degree - II	Degree - III
Mining and handling (2017)	674.85	35.92	6.29	0.26
Mining and handling (2018)	717.93	35.81	6.27	0.25
Mining and handling (2019)	731.99	34.67	6.07	0.25

Sources: (MoC, 2017a, 2018a, 2019a, 2020a); (DGMS, 2017, 2018, 2019).

Efforts have also been made to provide an outlook towards future directions in inventory preparation in coal mining. It has been postulated that CO_2 emissions from coal mining might be significant and need investigation in line with 2019 IPCC Refinements (Singh, 2019).

Oil and natural gas (1.B.2)

The sources of fugitive emissions from oil and gas systems include, but are not limited to, equipment leaks, evaporation and flashing losses, venting, flaring, incineration and accidental releases (e.g., pipeline dig-ins, well blow-outs and spills). While some of these emission sources are engineered or intentional (e.g., tank, seal and process vents and flare systems), and therefore relatively well characterized, the quantity and composition of the other emissions are generally subject to significant uncertainty. Emission due to leakage/venting and flaring decreased by 1.67 per cent, while total emission from oil and gas systems decreased by 5.87 per cent over the period of 2016-2019. The data on flaring activities from the oil and gas sector to estimate CO_2 emissions needs further refinement in future reporting. As per the assessment, the associated fugitive CO_2 emissions are much less and considered as insignificant.

For fugitive emissions from oil and natural gas handling activities such as production, processing, distribution and venting/flaring, the IPCC default values of methane emission factor have been used and estimated methane emission from oil and natural gas system in India is presented in Table 2.15.

Table 2.15: Methane emissions from oil & gas systems in India (Gigagram) (2017-2019)

Year	Wells	Oil Production	Refinery Throughput	Gas Production	Gas Processing	Gas distribution	Leakage	Flaring	Total Emission
2017	6	11	17	116	336	274	167	0.6	928
2018	7	11	17	116	341	277	169	0.5	939
2019	7	10	17	114	328	263	160	0.5	899

2.7.2 Industrial Processes and Product Use Sector

The IPPU sector, which includes GHG emissions produced by a variety of industrial activities that transform raw materials by chemical or physical means, represented 8.35 per cent of GHG emissions (without LULUCF) in 2019. The same year, their emissions reached 2,63,540 GgCO_2e, increasing by 16 per cent since 2016 mainly due to the increase in the production of cement, aluminium, and lime (Figure 2.12). List of country-specific emission factors used in the IPPU sector are listed in the Table 2.20.

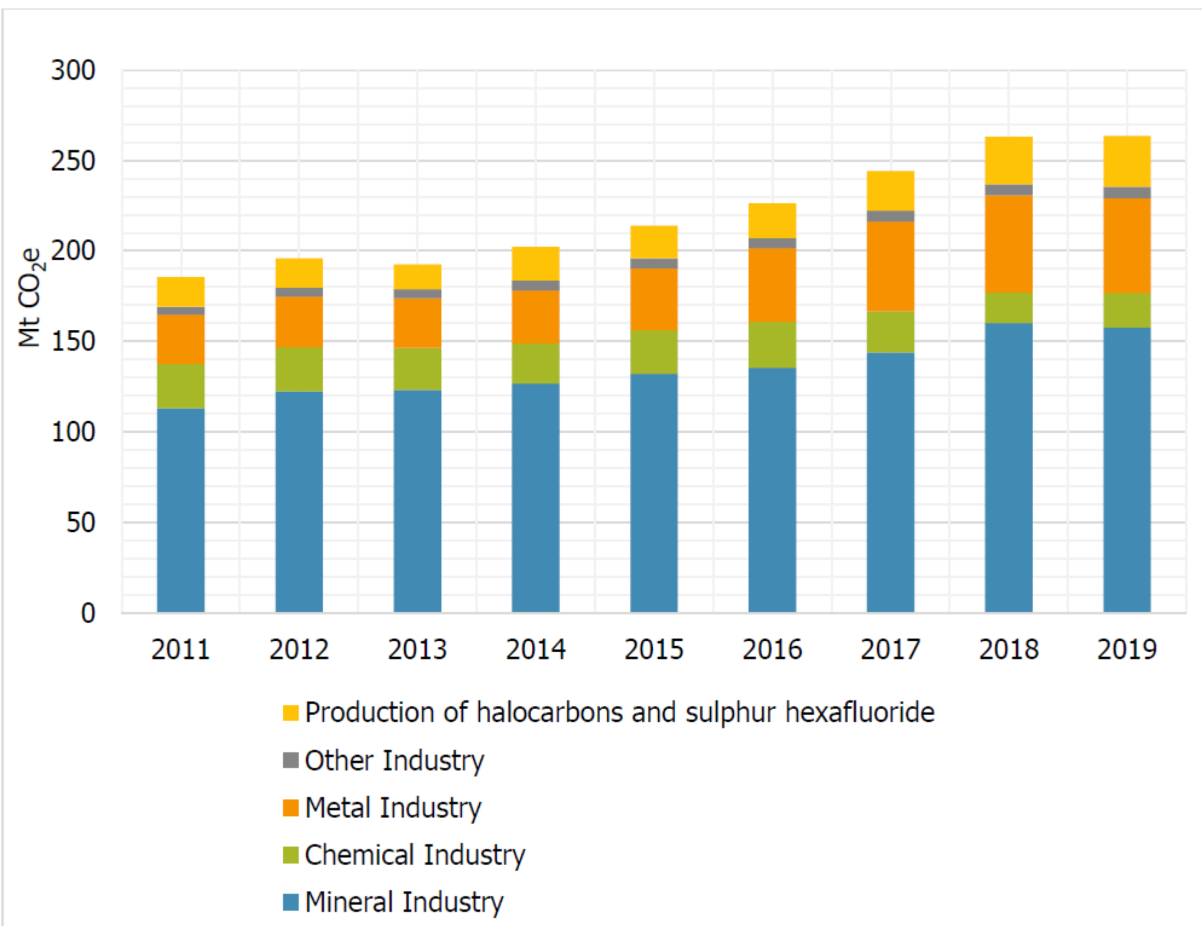


Figure 2.12: Industrial Processes and Product Use: GHG emissions (MtCO_2e) per subcategory, 2011-2019

The category includes the emission estimates of CO_2, CH_4, N_2O, HFC-23, CF_4, C_2F_6, and SF_6. In 2019, the main GHG emitted by the sector was CO_2, representing 69.46 per cent of the total GHG emissions in the sector, followed by CF_4 with 12.05 per cent, HFC with 10.61 per cent, C_2F_6 with 4.64 per cent and N_2O with 1.45 per cent. CH_4 amounts to 1.77 per cent of the emissions and SF_6 to 0.04 per cent (Figure 2.13).

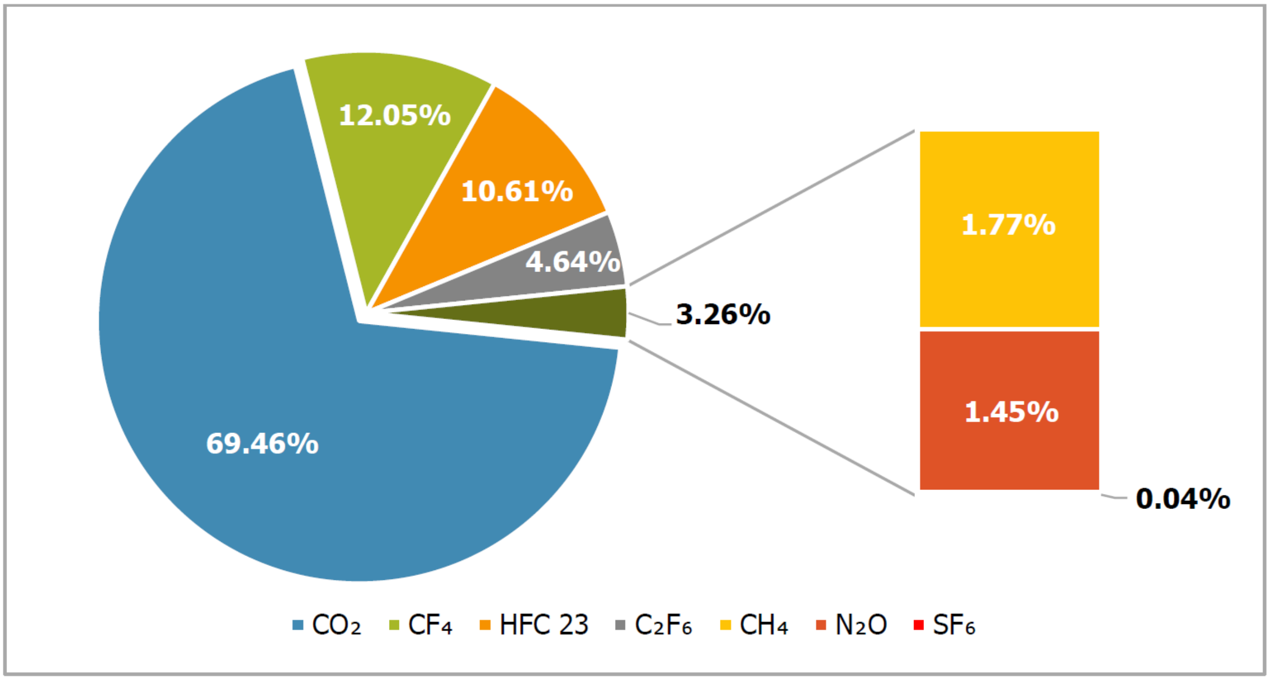


Figure 2.13: Gas wise distribution of emissions from IPPU sector in 2019

Mineral industries (2.A)

CO_2 emissions from processes resulting from the use of carbonated raw materials in the production and use of a variety of industrial mineral products are included in this category. There are two major pathways for CO_2 release from carbonates: calcination and acid-induced CO_2 release. The process-related CO_2 equivalent emissions for the year 2019 from Cement, Lime, Glass and Ceramics are 1,26,620 Gg (80.31 per cent), 30,643 Gg (19.44 per cent), 379 Gg (0.24 per cent) and 23 Gg (0.01 per cent) respectively.

In India, about 97 per cent of the total production of limestone during 2018-19 was of cement grade and 3 per cent of other grades (IMYB, 2020). To avoid double counting, GHG emissions associated with the use of limestone in the cement manufacturing sector have been allocated accordingly.

Table 2.16: Types of production in the mineral industries (2A) during 2017, 2018 and 2019

Production/consumption (million tonne)	2017	2018	2019
Clinker production	209.40	233.78	239.27
Quick lime production	190.05	211.21	208.28
Dolomitic lime production	2.20	2.65	2.23

Production/consumption (million tonne)	2017	2018	2019
Glass (Float, Sheet, Bottles) production	2.544	2.567	2.480
Mass of calcium carbonate consumed	0.0230	0.0241	0.0253
Mass of dolomite consumed	0.0247	0.0258	0.0270

Sources: (CMA, 2017, 2018, 2019, 2020); (MoM, 2017, 2018, 2019); (AIGMF, 2017, 2018, 2019); (MoM, 2017, 2018, 2019).

Chemical industries (2.B)

This category includes GHG emissions from the production of several inorganic and organic chemicals, for which several countries' experience has confirmed that the sector contributes significantly to global or national GHG emissions.

In 2019, GHG emissions from this sector accounted for 19,277 GgCO_2e, a decrease of 23.98 per cent since 2016. This is due to a decrease in ammonia, titanium dioxide, ethylene, and carbon black production. During the same time period, nitric acid, soda ash, and methanol emissions increased. Within the category, ammonia production was the highest, with total CO_2 emissions of 6,656 Gg in 2019, followed by emissions from ethylene production 6,034 GgCO_2e, emissions from nitric acid production is 3,573 GgCO_2e, emissions from soda ash production 1,076 GgCO_2e, emissions from carbon black production 818 GgCO_2e, emissions from EDM & VCM production 319 GgCO_2e, emissions from caprolactam production 240 GgCO_2e, emissions from ethylene oxide production 256 GgCO_2e, emissions from methanol production 144 GgCO_2e, emissions from carbide production 90 GgCO_2e and titanium dioxide production 71 GgCO_2e (Figure 2.14).

Table 2.17: Types of production in the chemical industries (2B) during 2017, 2018 and 2019

Production (million tonne)	2017	2018	2019
Ammonia production	14.94	14.72	14.40
Nitric acid production	1.714	1.739	1.874
Caprolactam production	0.0862	0.0909	0.0862
Calcium carbide production	0.0867	0.0842	0.0818
Titanium dioxide production	0.0580	0.0573	0.0514
Soda ash production	3.026	3.163	3.331
Carbon black production	0.532	0.542	0.512
Methanol production	0.240	0.269	0.200
Ethylene production	4.172	3.930	5.808
Ethylene dichloride production	0.282	0.325	0.344
Vinyl chloride monomer production	0.781	0.792	0.857
Ethylene oxide production	0.272	0.247	0.284

Sources: (MoC&F, 2017, 2018, 2019); (FAI, 2021); (CMIE Prowess, 2021); (MoC&F, 2017a, 2018a, 2019a); (AMAI, 2017, 2018, 2019)

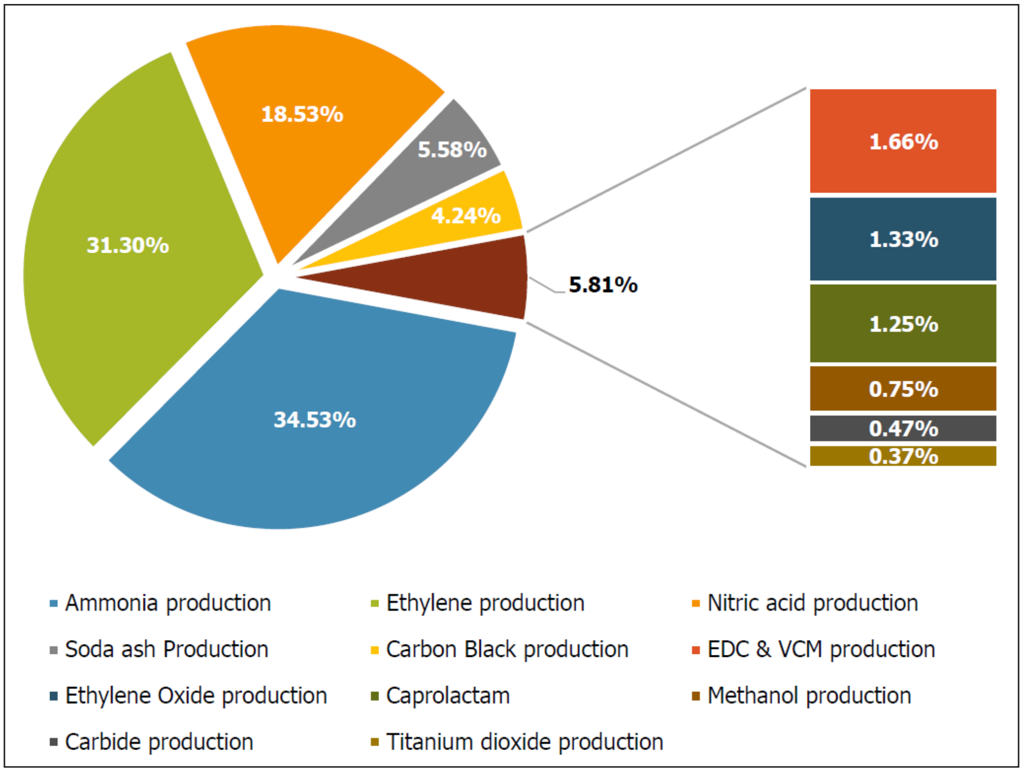


Figure 2.14: Distribution of CO_2e emissions across the Chemical Industries Categories in 2019

Metal industries (2.C)

GHG emissions from the production of metals such as ferroalloys, lead, zinc, aluminium, and magnesium are included in this category. The energy sector has reported metallurgical coke-related process emissions in iron and steel production. The total CO_2 equivalent emissions from metal industries for 2019 are 52,279 Gg, which was 28.09 per cent higher than 2016 levels. This may be attributed to the increased production of aluminium. Aluminium industry emissions cover 95 per cent of the emissions of the metal industries in India and also a key emission category in India. Magnesium production is the single estimated source of SF_6 for 2019 emitting 100.95 $GgCO_2$eq.

Table 2.18: Types of production in the metal industries (2C) during 2017, 2018 and 2019.

Production (million tonne)	2017	2018	2019
Ferro chromium	0.944	0.944	0.927
Ferro manganese	0.518	0.518	0.165
Ferro silicon	0.090	0.090	0.090
Silico manganese	0.309	0.335	0.326
Aluminium	3.401	3.696	3.629
Lead	0.162	0.190	0.185
Zinc	0.791	0.696	0.688
Magnesium	0.0002	0.0002	0.0002

Source: (MoM, 2017, 2018, 2019); (Brown, et al., 2019); (MoC&F, 2017a, 2018a, 2019a).

Non-energy product use (2.D)

This category estimates emissions from first use of fossil fuels as a product for primary purposes other than, i) combustion for energy purposes, and ii) use as feedstock or reducing agent. The products covered here comprise lubricants and paraffin waxes.

In India, the lubricant market is dominated by the transportation sector. The total CO_2 emissions resulting from lubricant use in 2019 were 2,236 GgCO_2e, an increase by 8.50 per cent since 2016.

Emissions from the use of waxes occur primarily when waxes or paraffin derivatives are burned during use (for example, candles), incinerated with or without heat recovery, or in wastewater treatment (for surfactants). Total GHG emission from paraffin wax for non-energy purposes was 165 GgCO_2e in 2019, increase by 56 per cent since 2016.

Table 2.19: Types of production in the non-energy product use (2D) during 2017, 2018 and 2019.

Production (million tonne)	2017	2018	2019
Lubricant production	3.781	3.722	3.793
Paraffin wax consumption	0.215	0.264	0.280

Source: MoPNG, 2017a, 2018a, 2019a.

Production of halocarbons (2.E)

This category estimates emission from production of halocarbons which generated 27,949 GgCO_2e (HFC23) in 2019, increasing by 45 per cent since 2016. Production of Hydrochlorofluorocarbon was 0.0645, 0.0772 and 0.0827 million tonne in 2017, 2018 and 2019, respectively.

Other industry (2.H)

This category estimates emission from Pulp & Paper industries, which generated 3,969 GgCO_2e in 2019, showing an increase of 18.81 per cent compared to 2016 emissions. Production of paper was 18.40, 19.25 and 20.29 million tonne in 2017, 2018 and 2019, respectively.

Table 2.20: Country specific emission factor used in the IPPU sector

Category	Type of gas	Emission factor	Source
2.A.1 Cement	CO_2 (Tier II)	0.5292 tonne CO_2/tonne clinker produced (With CKD correction factor)	Country specific emission factor developed during INC
2.B.2 Nitric Acid	N_2O (Tier II)	4 – 11 kg N_2O/tonne HNO_3	Company specific and based on CDM database
2.B.7 Soda Ash	CO_2 (Tier II)	250 kg CO_2/tonne natural soda ash produced 70 kg CO_2/tonne of Soda Ash produced and 3 kg CO_2/tonne of soda ash produced	Technical EIA Guidance for soda ash industry - MoEF. Prepared by IL&FS, 2010.

Category	Type of gas	Emission factor	Source
2.B.9.a	HFC-22 (Tier I)	0.0289 tonne HFC-23/tonne HCFC-22 produced	Country specific emission factor considered from Monitoring Report of Gujarat Fluoro-chemical Ltd. (Major producers of HCFC-22), Ratio of HFC23 generation to HCFC22 production as 2.89 per cent.
2.C.3 Aluminium	C2F6 (Tier I)	Prebaked: 0.44 kg C2F6 produced/ tonne of Aluminium produced Soderberg: 0.07 kg C2F6/tonne of Aluminium produced	Data taken from the International Aluminium Institute report on the aluminium industry's global perfluorocarbon gas emissions reduction programme results of the 2004 anode effect survey.

2.7.3 Agriculture sector

The main GHG emissions from the agriculture sector are methane from livestock's enteric fermentation and rice cultivation and nitrous oxide from manure management and agriculture soil. The agriculture sector represented 13 per cent of the total GHG emissions (4,20,968 GgCO_2e) in 2019, a decrease of 1 per cent compared to 2016 (Figure 2.4). Agriculture's contribution to total emissions is shrinking over the past years. In absolute terms, the agriculture sector increased by 3.22 percent over 2016 (Figure 2.15).

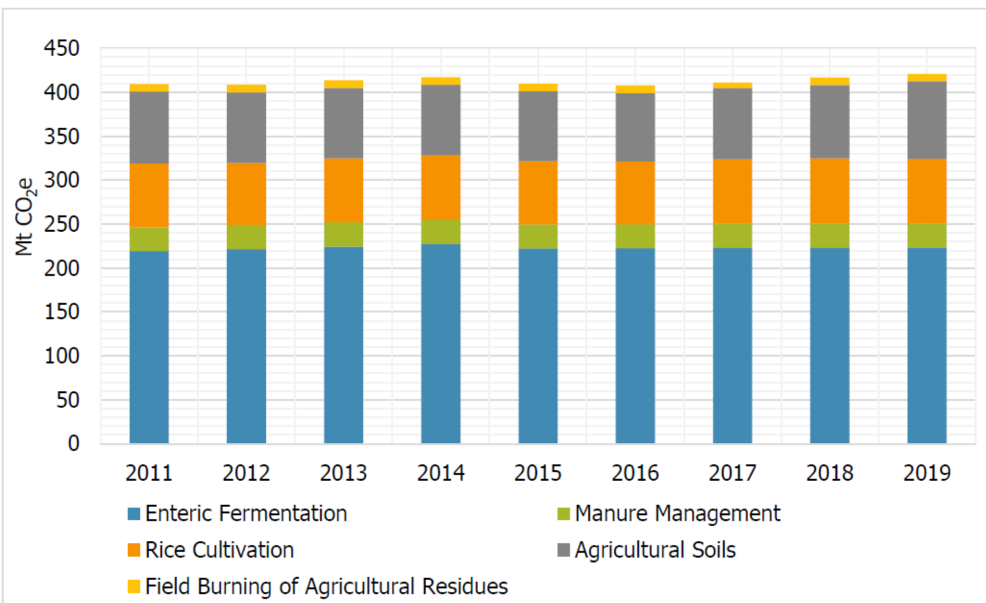


Figure 2.15: Trend in GHG emissions (MtCO_2e) from different subcategory of Agriculture sector, 2011-2019

Agricultural activities contribute to emissions of GHGs (CH_4 and N_2O) through a variety of processes. The main sources of CH_4 and N_2O emission in India are animal husbandry and crop production. Animal husbandry in India is dominated by cattle, buffalo, sheep, goat and pig. With regard to categories, 53.03 per cent of GHG emissions corresponds to enteric fermentation, followed by 21 per cent from agricultural soils (16.77 per cent from direct N_2O and 4.23 per cent from indirect N_2O), 17.44 per cent from rice cultivation, 6.54 per cent from manure management and 1.99 per cent corresponding to field burning of agricultural residues in 2019 (Figure 2.16).

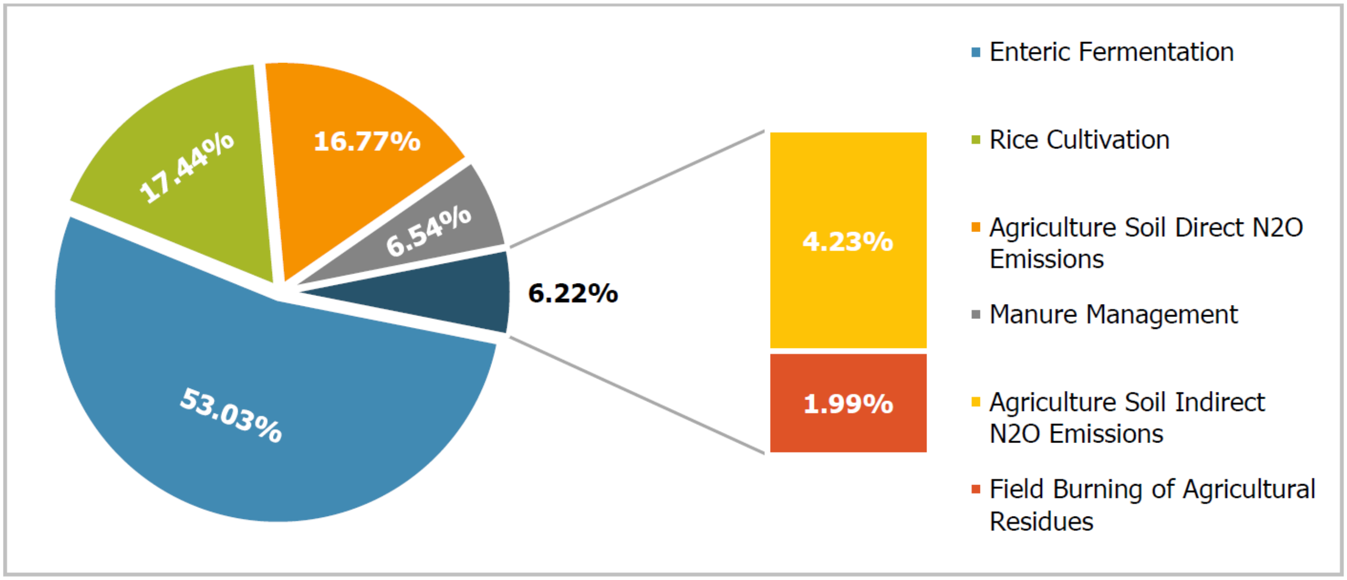


Figure 2.16: Distribution of CO_2e emissions (Gg) across the agriculture sector Categories in 2019

Enteric fermentation (3.A)

This category includes CH_4 emissions from herbivores as a by-product of the enteric fermentation. Ruminant livestock (e.g., cattle, buffalo, goat and sheep) are important sources while non-ruminants produce moderate amounts as well.

In 2019, emissions from this category accounted for 2,23,251 GgCO_2e, a minor increase of 0.27 per cent since 2016, due to increase in animal population, consisting of a 10 per cent increase in crossbred cattle, 4.11 per cent increase in goat, 3.81 per cent increase in indigenous sheep and 3.33 per cent increase in crossbred sheep (DoAHD&F, 2014), (DoAH&D, 2019). There was a 14.07 per cent decrease in crossbred pig, 3.90 per cent in indigenous pig, and around 2.66 per cent in indigenous cattle (Figure 2.17 and Figure 2.18).

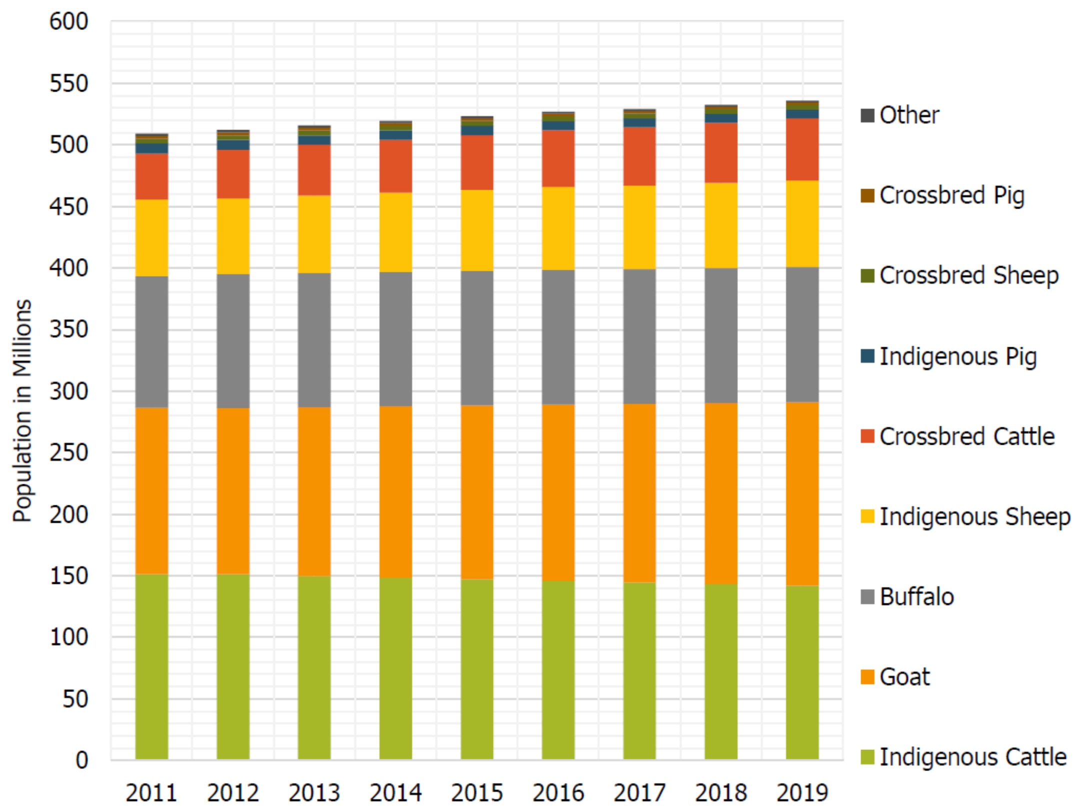


Figure 2.17: Population in millions by livestock category, 2011-2019

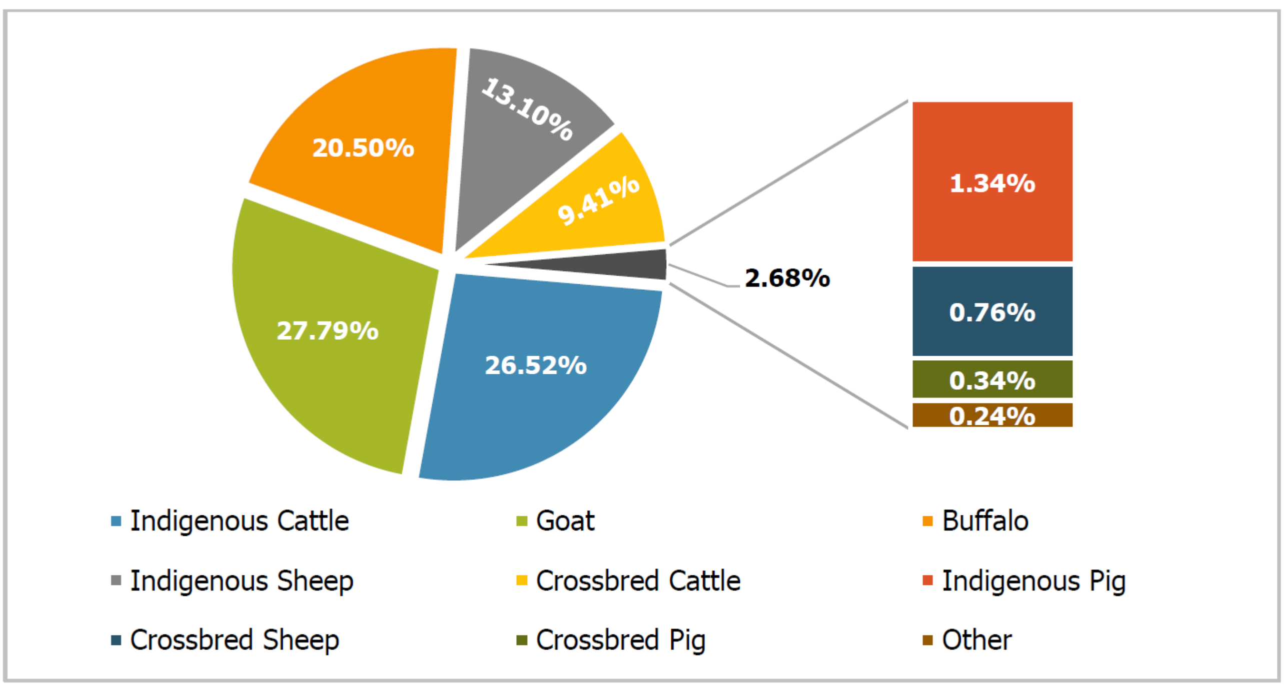


Figure 2.18: Population in percentage by livestock category, 2019

Manure management (3.B)

This category includes CH_4 and N_2O emissions of manure decomposition under conditions of low oxygen or anaerobic conditions. In 2019, the GHG emissions from this category accounted for 27,511 $GgCO_2e$, an increase by 1.04 per cent over the period of three years (2016-2019). Within the category, for methane emissions, buffalo account for most of the emissions, representing 44.70 per cent of the subcategory, followed by indigenous cattle with 31.95 per cent, Crossbred cattle with 18.70 per cent, while the rest cover around 4.65 per cent of emissions (Figure 2.19).

Table 2.21: Dung generation and country-specific emission factors across various livestock category in 2017, 2018 and 2019

Dung generation (kilo tonne)	2017	2018	2019
Crossbred cattle	42603	44030	45457
Indigenous cattle	99833	98339	96844
Buffalo	121249	121197	121145
Goat	11398	11495	11593
Crossbred sheep	547	549	551
Indigenous sheep	8315	8462	8609
Crossbred pig	118	113	107
Indigenous pig	588	579	571
Others	1863	1761	1659
Methane Emission Factors (Gram/ kg DMI)	**2017 – 2018 - 2019**		
Crossbred cattle	17 - 20*		
Indigenous cattle	16 - 18*		
Buffalo	10 - 17*		
Goat	10*		
Sheep	10*		

**Emission factor varies according to type of feed and age of animal*

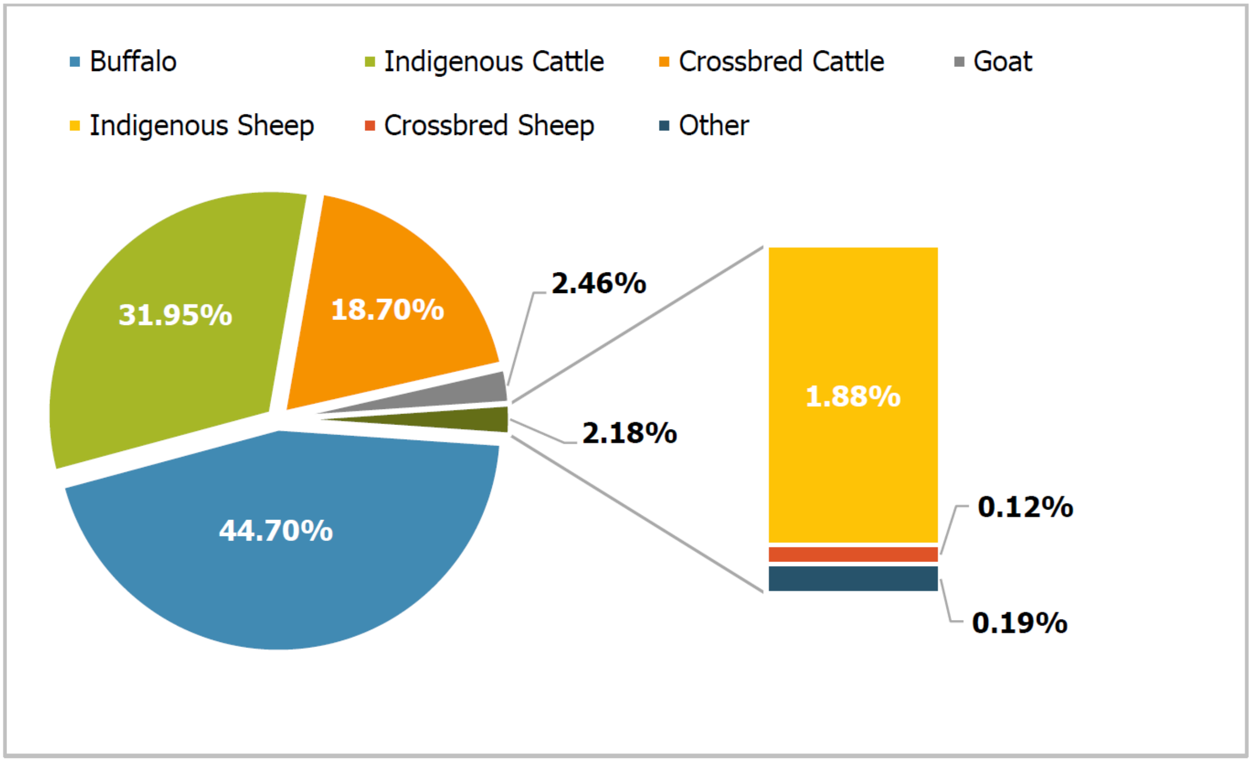


Figure 2.19: Methane emissions from manure management by livestock category, 2019

Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NOx during storage as solid. Within the category, for nitrous oxide emissions, buffalo account for most of the emissions, representing 42 per cent of the subcategory, followed by indigenous cattle with 34 per cent, crossbred cattle with 16 per cent and remaining with 8 per cent of the emissions during the year 2019 (Figure 2.20). However, during 2017 to 2019 there was not much change within this category of emission.

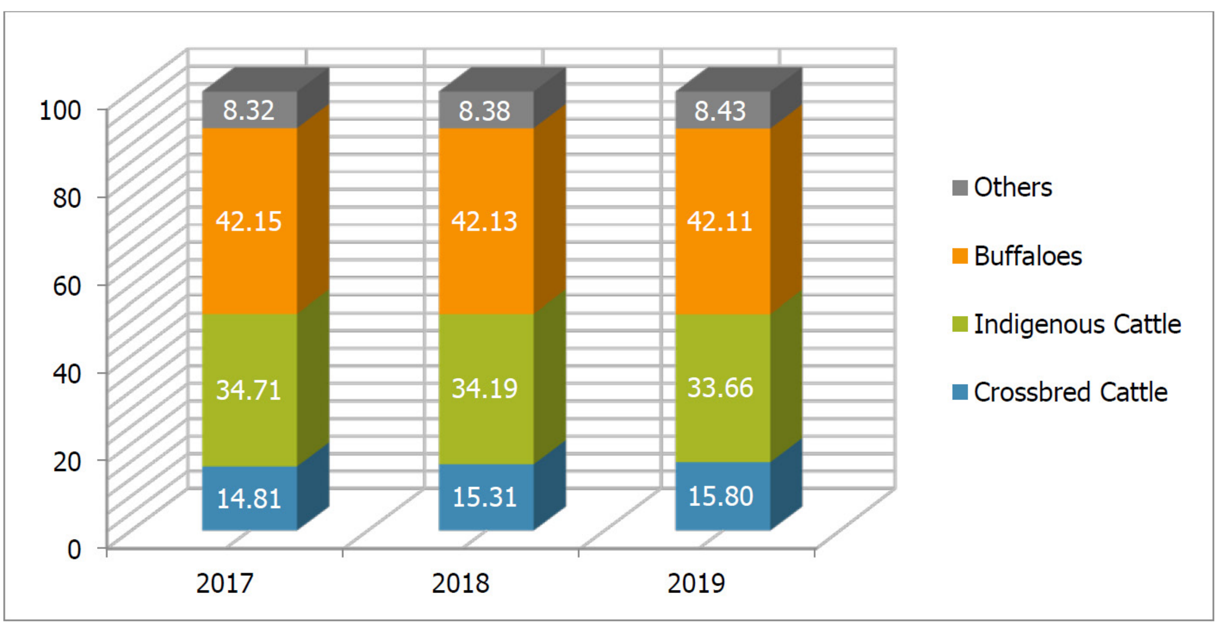


Figure 2.20: Nitrous Oxide emissions from manure management by livestock category, 2017-2019

Rice cultivation (3.C)

This category includes emissions of methane by the anaerobic decomposition of soil organic material in flooded rice paddies. In 2019, GHG emission from this category accounted for 73,437 GgCO_2e, an increase of 2.97 per cent from 2016. This change in trend of rice cultivation is directly related to increase in area under rice.

In 2019, the total area under rice cultivation in the country was 43.66 million ha, and 3,497 Gg of methane was emitted. Figure 2.21 depicts the estimated emissions from different ecosystem types under different water regimes. Of the total land under rice cultivation, 21.99 per cent is under multiple aeration, 20.66 per cent under single aeration, 17.48 per cent is continuous flooding, 12.72 per cent is upland, 12.52 per cent is drought-prone, 11.56 per cent is flood prone and 3.06 per cent is deep water rice system.

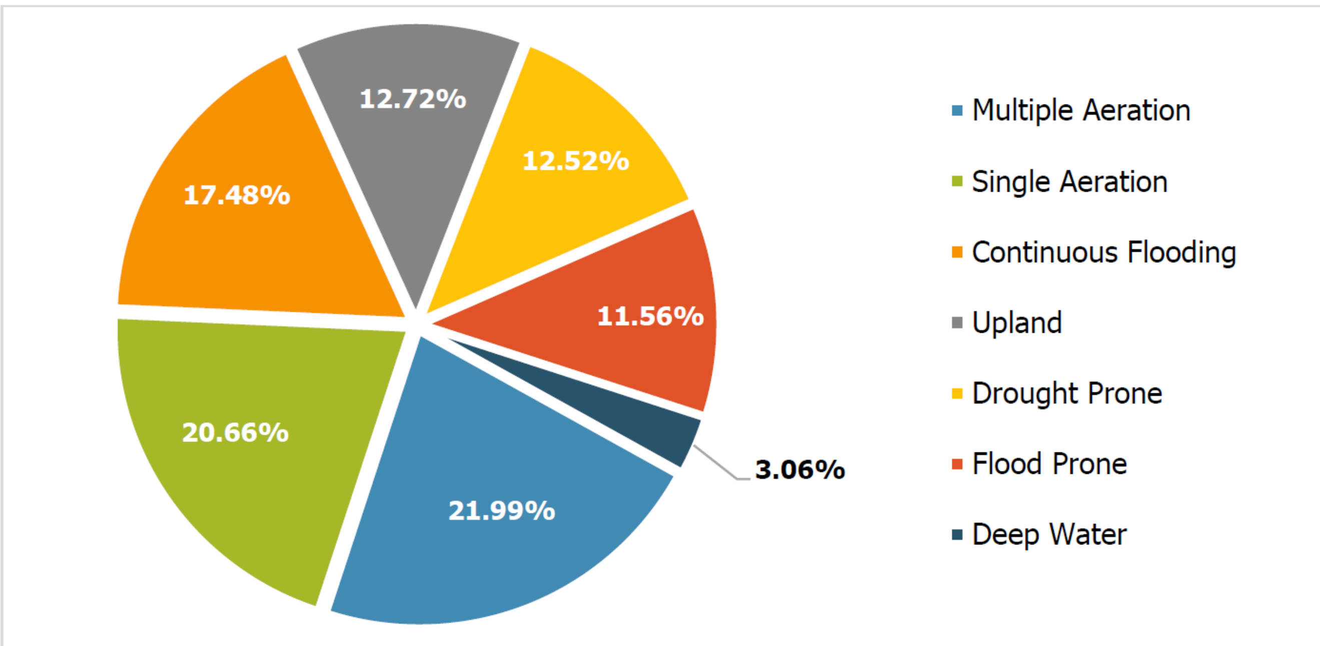


Figure 2.21: Rice area (in percent) under different types of water regimes, 2019

Agriculture soils (3.D)

In the national GHG inventory, the agriculture soils sub-sector is the largest single source of N_2O emissions. Soil N_2O emissions can be categorised into two types: direct and indirect. Net N additions to soils (synthetic or organic fertilisers, deposited manure, crop residues) and mineralization of N in soil due to cultivation/land-use change on mineral soils were used to estimate direct N_2O emissions. Indirect N_2O emission was estimated from the volatilization of NH_3 and NO_x from managed soils and the subsequent re-deposition of these gases and their products (NH_4 and NO_3) in soils, after leaching and runoff of N, mainly as NO_3 from managed soils. Total emissions of N_2O from managed soils have been estimated by adding direct and indirect N_2O emissions.

In 2019, GHG emissions from this category accounted for 88,412 GgCO_2e, a 13.67 per cent increase from 2016. Similar to emissions from enteric fermentation, there has been an increase in emissions in this sub-sector also due to the synthetic fertilizer-based nitrogen consumption. Within the category, direct emissions of N_2O from agricultural soils represent 79.86 per cent of the emissions, while indirect emissions of N_2O from agricultural soils represent 20.14 per cent of total emissions.

Table 2.22: Activity data used in agriculture soil (3D) during 2017, 2018 and 2019

Million tonne	2017	2018	2019
Nitrogen consumption*	16,959	17,629	19,101
Nitrogen from compost	1.1260	1.1260	1.1260
Nitrogen from crop residue	2.581	2.624	2.623
Manure nitrogen other than poultry	1.049	1.057	1.051
Nitrogen input from below ground biomass	2.341	2.384	2.376

**Source: (FAI, 2021).*

Table 2.23: Country specific emission factor used in agriculture soil (3D)

Parameter	Country specific coefficients
EF1 (N_2O emission from applied fertilizer)	0.55 %
EF4 (N_2O emission from volatilized N from fertilizer and manure)	0.50 %
EF5 (N_2O emission from leached and run-off N from fertilizer and manure)	0.50 %
$Frac_{GASF}$ (Gas loss through volatilization from inorganic fertilizer)	20 %
$Frac_{GASF-AM}$ (Gas loss through volatilization from manure)	20 %
$Frac_{leach}$ (Leaching loss of N from applied fertilizer and manure)	10 %

Source: (Pathak et al., 2002); (Bhatia et al., 2004; 2005; 2013); (Cowan et al., 2021); (Jain et al., 2016).

Field burning of agriculture residues (3.F)

The category includes CH_4 and N_2O emissions generated due to in-situ burning of agricultural waste at cropland. Residues from eight crops (rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed, and mustard) are generally burned in the field.

Emissions from field burning of agricultural residues were 287.83 Gg of CH_4 and 7.46 Gg of N_2O. In CO_2 equivalent terms, 8,358 Gg of emission occurred in 2019, showing a 5.42 per cent decrease from 2016 levels. Mostly due to proactive steps taken by Government to improve air quality.

Table 2.24: Country specific emission factor used in field burning of agriculture residues (3F)

Crop	Residue to crop ratio	Dry matter fraction	Fraction burnt
Rice	1.5	0.86	0.05 - 0.343
Wheat	1.7	0.88	0.1 - 0.25
Maize	1.5	0.88	0.1
Jute	2.15	0.80	0.1
Cotton	3	0.80	0.1
Sugarcane	0.4	0.88	0.25
Rapeseed & mustard	3	0.80	0.1
Millets	1.5	0.88	0.1

Source: (Andreae, M. O. & Merlet, P., 2001); (Gadde, B. et al., 2009); (Jain et al., 2014, 2018 and 2021), (IARI, 2015-2020); (Bandyopadhyay et al., 2001).

2.7.4 Land Use and Land-Use Change and Forestry Sector (LULUCF)

The LULUCF sector, which includes GHG emissions and removals associated with forestry and land-use change, is the only sector in the country that consistently absorbs CO_2, making it one of the most important sectors from the mitigation perspective. This sector removed 20 per cent of the country's carbon dioxide emissions in 2019. In the same year, its emissions reached -4,85,472 GgCO_2e, increasing its status as a sink by 58 per cent since 2016 (Figure 2.22). While Forestland, Cropland, and settlements are found to be a net sink, grasslands are found to be the only source land use category. With respect to total CO_2 removals in 2019, 70.69 per cent corresponds to cropland, followed by 29.87 per cent of forest land and 1.44 per cent of settlements (Table 2.25).

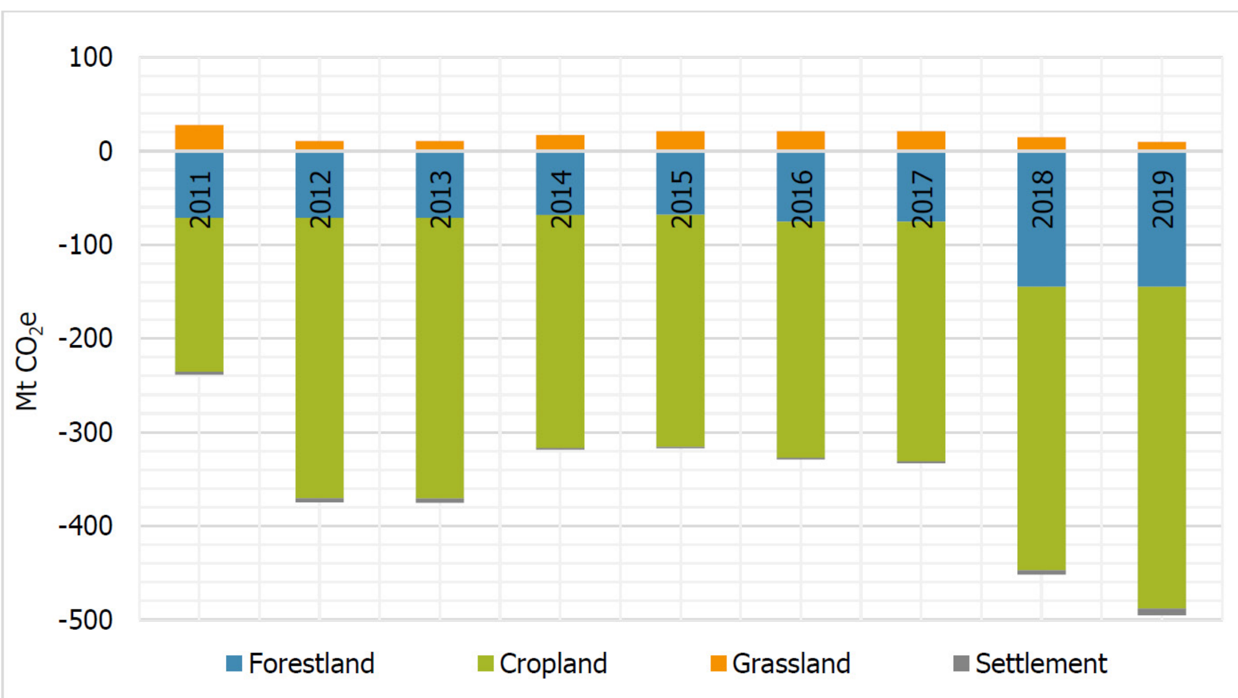


Figure 2.22: LULUCF: GHG emissions/removals (MtCO_2e) per subcategory, 2011-2019

Table 2.25: Total GHG balance for the 2019 in GgCO_2e

Land Category	Net CO_2	CH_4	N_2O	Total
Forest Land	-1,46,483	1,017	442	-1,45,025
Cropland	-3,43,174	-	-	-3,43,174
Grassland	9,726	-	-	9,726
Settlements	-6,998	-	-	-6,998
Total	**-4,86,930**	**1,017**	**442**	**-4,85,472**

Based on remote sensing data supplemented with ground-based observations, land use change from 2005 to 2016 was assessed across five classes: forest land, cropland, grassland, settlements, and other land. Table 2.26 shows the estimates for land use and land-use change from 2005 to 2016. The area under forest cover has increased marginally, as has the area under cropland, grassland, and settlements.

Table 2.26: Land use change for India for the period 2005-2019 (in a million ha)

Year	Forest Land	Cropland	Grassland	Settlements	Other land	Total area
2005	69.16	160.65	20.35	8.61	69.96	328.73
2006	69.24	160.94	20.42	8.72	69.41	328.73
2007	69.25	161.23	20.48	8.84	68.91	328.73
2008	69.27	161.53	20.55	8.96	68.42	328.73
2009	69.44	161.82	20.62	9.08	67.76	328.73
2010	69.50	162.12	20.69	9.20	67.23	328.73
2011	69.79	162.41	20.75	9.31	66.46	328.73
2012	69.98	162.71	20.82	9.43	65.79	328.73
2013	70.15	163.00	20.89	9.55	65.14	328.73
2014	70.49	163.29	20.89	9.55	64.51	328.73
2015	70.83	163.85	21.65	9.56	62.84	328.73
2016	71.03	164.40	22.42	9.57	61.31	328.73
2017	71.22	164.81	22.66	9.61	60.43	328.73
2018	71.30	165.22	22.91	9.64	59.66	328.73
2019	71.38	166.05	23.40	9.71	58.20	328.73

Source: FSI, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019.

Forest land (4.A)

This category includes GHG emissions and removals generated as a result of changes in living biomass, dead organic matter and soil organic carbon in Forest land that remains as such and in Land converted to forest land. In 2019, the GHG emissions recorded -1,45,025 GgCO_2e, increasing its status as a sink by 92 per cent since 2016.

Forest cover assessment and national forest inventory provide activity data and emission factors for carbon stock estimation. For the activity data, a biennial forest cover assessment (Approach 3) was used, which is a wall-to-wall mapping exercise based on satellite data. Furthermore, forest type data has been used to stratify forest cover into different forest types and canopy densities. The data collected during the national forest inventory were used to estimate emission factors (Tier 2). IPCC GPG 2003 methods were used to estimate carbon stock in different pools, namely above ground biomass, litter, deadwood, and soil organic carbon (SOC), with the exception of below ground biomass, which was calculated using IPCC default values (IPCC, 2003).

The area under forest land remaining forest land for the year 2019 is 70.31 million ha, and the land area converted to forest land during the year 2019 is estimated to be 1.07 million ha. Forest sector in India is a net sink. Wildfires have an important effect on the GHG emissions and removals from the forestlands. In the year 2019, more than 2.27 million ha (mild, moderate and heavy fire) area has been affected by fires with an impact on the net balance of GHG emissions, contributing 1,459 GgCO_2e. However, the total area affected by forest fire has decreased by 30 per cent compared to 2016.

Table 2.27: Activity data and emission factors used in forest land category (4A) during 2017, 2018 and 2019

Area (million ha), Carbon Stock (million tonne)	2017	2018	2019
Total area under forest	71.22	71.30	71.38
Area of forest land remaining forest land	69.59	70.24	70.31
Area of land converted to forest land	1.63	1.06	1.07
Carbon stock change in forest land remaining forest land	20.70	74.26	39
Carbon stock change in land converted to forest land	0.30	-34.26	1
Area subjected to mild fires	0.875	0.875	0.697
Biomass burnt (t/ha) in mild fire area	1.33	1.33	1.37
Area subjected to moderate fires	1.292	1.292	1.011
Biomass burnt (t/ha) in moderate fire area	4.01	4.01	4.43
Area subjected to heavy fires	0.772	0.772	0.565
Biomass burnt (t/ha) in heavy fire area	11.11	11.11	13.29

Source: (IPCC, 2003); (IPCC, 2006); (FSI, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021).

Cropland (4.B)

This category includes CO_2 emissions and removals from arable and plowable land, rice fields, and agroforestry systems where the vegetation structure is significantly different, with a lower threshold than forest land that is not expected to be exceeded in the future. In 2019, croplands recorded sequestration of -3,43,174 $GgCO_2e$, a 36 per cent increase from 2016, thereby making it the biggest contributor in this category.

The area under cropland, which is the net sown area, was estimated to be 166.05 million ha during 2019. The net sown area has increased from 160.65 to 166.05 million ha between years 2005 and 2019. The net sown area is sensitive to a number of factors such as rainfall, and market prices. In India, the area under cropland includes both net sown and fallow land area.

The approach adopted for estimating carbon stock changes in cropland is as follows:

i. Change in biomass carbon stock in cropland

ii. Soil organic carbon stock

iii. Biomass and soil carbon rates of change and stocks in cropland

The large sink potential of cropland is due to the following:

i. The mean annual increment in SOC in cropland is 0.367 tC/ha/year over 166.05 million ha, contributing to higher carbon sink from cropland.

ii. Larger area under this land category compared to other land categories including Forest Land e.g., Cropland accounts for about 51 per cent (166.05 million ha) of the total geographic area (328.73 million ha) as compared to about 22 per cent by forest land (71.38 million ha).

iii. The soil carbon in forest land is quite stable and does not change much over the years. However, cropland carbon is dynamic and as a result of management practices such as manure and fertilizer application, change in soil carbon in cropland is substantially higher.

Table 2.28: Activity data and emission factors used in cropland category (4B) during 2017, 2018 and 2019

Area (million ha), carbon stock (million tonne)	2017	2018	2019
Total area under cropland	164.81	165.22	166.04
Change in biomass carbon stock	9.23	21.85	32.65
Change in soil organic carbon stock	60.49	60.64	60.94
Rate of change in SOC (tonne carbon/ha/year)	0.367	0.367	0.367

Grassland (4.C)

This category includes GHG emissions and removals from land that is not arable or forest land, as well as all grassland and wild land for recreational areas, agricultural systems, and silvopastoral lands according to national definitions. The majority of the land is used for livestock grazing. The area under grassland is estimated to be 23.4 million ha for the year 2019 compared to 20.35 million ha in 2005. In 2019, the GHG emissions balance accounted for 9,726 GgCO_2e, a massive decrease of 54.32 per cent since 2016. This can be attributed to higher rates of conversion of land to grasslands. Within the category, emissions/removals are not available for land converted to grassland category due to non-availability of data. More studies are needed to refine the data, especially of soil carbon fluxes in grassland.

Table 2.29: Activity data and emission factors used in grassland category (4C) during 2017, 2018 and 2019

Area (million ha), Carbon Stock (million tonne)	2017	2018	2019
Total area under grassland	22.66	22.91	23.40
Change in biomass carbon stock	1.26	3.03	4.60
Change in soil organic carbon stock	-7.03	-7.10	-7.25
Rate of change in SOC (tonne carbon/ha/year)	-0.31	-0.31	-0.31

Settlements (4.E)

Unless already included in other categories, this category includes GHG emissions and removals generated on land with human settlements, urban areas, and infrastructure. Between 2005 and 2019, the area under settlement increased from 8.6 to 9.71 million ha. In this category, only CO_2 emissions and removals from biomass carbon is considered from settlements remaining settlements. Most of the expansion occurs in and around cities and villages which are dominated by marginal cropland and grassland. Further, area under forests in India is increasing which indicates there is no net conversion of forestland to settlements. The settlements land category was a net sink of CO_2 during the period 2005-2019. In 2019, the balance of GHG emissions accounted for -6,998 GgCO_2e increasing by 291 per cent since 2016.

Table 2.30: Activity data and emission factors used in settlement category (4E) during 2017, 2018 and 2019

Area (million ha), carbon stock (million tonne)	2017	2018	2019
Total area under settlements	9.61	9.64	9.71
Change in biomass carbon stock	0.54	1.27	1.91
Rate of change in SOC (tonne carbon/ha/year)	0.056	0.132	0.197

2.7.5 Waste

In 2019, the waste sector, which includes GHG emissions from microbiological processes occurring in organic waste under anaerobic degradation and the anaerobic treatment of domestic and industrial wastewater, accounted for only 2.34 per cent of GHG emissions. In the same year, its emissions were 73,189 GgCO_2e, decreasing by 2.72 per cent since 2016 (Figure 2.23). More than three-fourth (77.31 per cent) of the emissions from the waste sector come from wastewater treatment and discharge, followed by 22.69 per cent of the solid waste disposal.

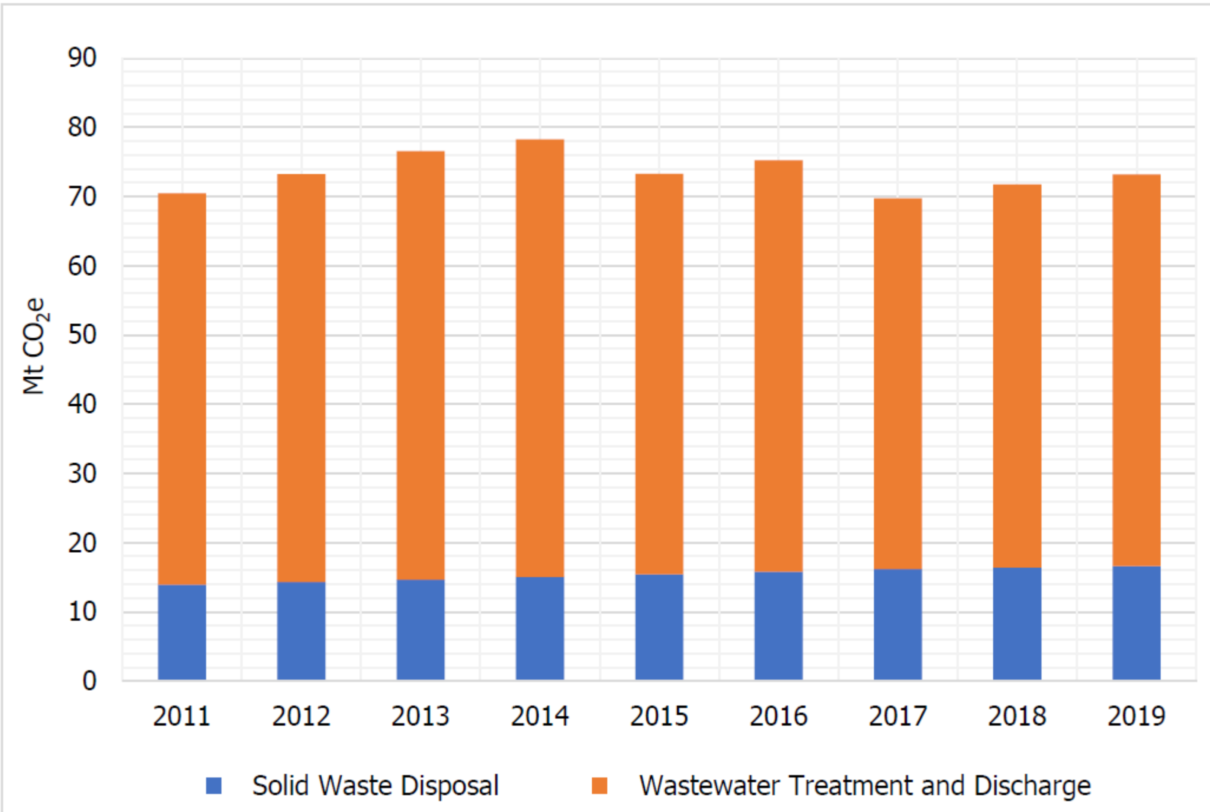


Figure 2.23: Waste: GHG emissions (MtCO_2e) per subcategory, 2011-2019

Solid waste disposal (5.A)

The category includes CH_4 emissions from the treatment and disposal of municipal, industrial, and other solid wastes at solid waste disposal facilities (SWDS). Solid waste disposal includes managed, unmanaged, and uncategorized waste disposed of in landfills. In 2019, GHG emissions accounted for 16,608 GgCO_2e, increasing by 4.90 per cent since 2016, as a result of an increase in population. In 2019, 59,245 Gg of MSW reached landfills in India, resulting in 791 Gg of Methane.

The first order decay (FOD) method is used by the IPCC to estimate CH_4 emissions from MSW landfill sites. MSW is relatively dispersed, and shallow disposal depths do not induce anaerobic conditions. A portion of the methane is released and used for gas recovery. Because most disposal sites do not practise methane recovery, the default value of R is zero in estimation.

Wastewater treatment and discharge (5.D)

GHG emissions from the treatment or disposal of wastewater by anaerobic means, such as domestic wastewater, commercial and industrial wastewater, and which can be treated on site (not collected), transferred through the sewerage service to a central facility (collected), or eliminated without treatment in the vicinity or via drains, are included in this category. In 2019, GHG emissions from this category accounted for 56,581 GgCO_2e, decreasing by 4.75 per cent since 2016 due to effective measures taken regarding domestic wastewater treatment. Within the category, domestic wastewater treatment and discharge contributes 68.22 per cent, while industrial wastewater treatment and discharge amounts to 31.78 per cent. Emission from domestic wastewater treatment and discharge decreased by 0.62 per cent and industrial wastewater treatment and discharge emission decreased by 12.54 per cent since 2016.

Alcohol, coffee, dairy products, fruits and juices, poultry, organic chemicals, petroleum, plastic and resins, pulp and paper, sea food processing, soap and detergents, starch production, sugar refining, tannery, vegetable oils, and vegetables are examples of industrial wastewater. Production in all 16 sectors generates wastewater with significant organic load, which has the potential to emit methane depending on the type of wastewater treatment. According to the analysis, the vegetable and fruits processing followed by pulp & paper and alcohol have the highest GHG emissions per tonne of product or unit volume of treated wastewater.

The value of Biochemical Oxygen Demand (BOD) is taken to be 41 g per capita per day from ENVIS (Environmental Information System) Centre on Hygiene, Sanitation, Sewage Treatment Systems and Technology, whereas the range is 27-41 in IPCC guidelines. Organic waste removed as sludge is considered to be zero. In general, methane is generated in anaerobic processes in wastewater treatment facilities and inefficiently managed aerobic processes. CH_4 generated at anaerobic facilities can be recovered or combusted but in India recovery is considered to be zero due to the unavailability of appropriate technology.

Table 2.31: Activity data and country-specific emission factors used in the wastewater treatment and discharge category (5D) in 2017, 2018 and 2019

<table>
<tr><th colspan="2"></th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td colspan="2">Country population (billion)</td><td>1.358</td><td>1.381</td><td>1.403</td></tr>
<tr><td colspan="2">Average protein consumption (kg/ per capita/ year)</td><td>21.95</td><td>21.95</td><td>21.95</td></tr>
<tr><td colspan="2">Maximum CH_4 producing capacity, Bo, kg CH_4/ kg BOD</td><td>0.25</td><td>0.25</td><td>0.25</td></tr>
<tr><td colspan="5">Methane Emission Factor Value</td></tr>
<tr><td rowspan="4">Type of latrine</td><td>Septic tank</td><td colspan="3">0.3</td></tr>
<tr><td>Latrine</td><td colspan="3">0.21</td></tr>
<tr><td>Sewer</td><td colspan="3">0.12</td></tr>
<tr><td>Other</td><td colspan="3">0.12</td></tr>
</table>

Industry production (million tonne)	2017	2018	2019	Wastewater generation (M^3 / Tonne)	COD Kg/ M^3	Methane correction factor
Alcohol	3.11	3.36	3.36	24	77	0.8
Coffee	0.35	0.32	0.32	15	10	0.8
Dairy products	5.58	5.60	5.66	6	4	0.5
Fruits and juices	0.48	0.50	0.52	20	5	0.8
Poultry	3.46	3.59	3.81	0.02	4	0.8
Organic chemicals	1.64	1.80	1.88	31	3	0.3
Petroleum	36.01	35.68	34.20	0.44	0.5	0.3
Plastic and resins	0.01	0.01	0.01	0.6	3.7	0.3
Pulp and paper	16.41	17.66	18.82	143	7	0.1
Sea food processing	11.99	12.51	13.03	13	2.5	0.3
Soap and detergents	3.08	3.16	3.15	3	0.85	0.3
Starch production	0.49	0.48	0.50	5.5	10	0.8
Sugar refining	34.11	33.07	31.60	1	6.2	0.8
Tannery	0.06	0.06	0.07	53	3.3	0.8
Vegetable oils	1.78	1.81	1.86	2	0.85	0.2
Vegetable	3.56	3.69	3.66	20	5	0.6

Source: (MoEF, 2010); (CSE, 2014); (FAO, 2016); (NEERI, 2010); (MoEFCC, 2018); (Census, 2011); (MoSPI, 2014); (CPCB, 2015).

2.8 Key categories

According to the IPCC Guidelines from 2006, identifying key categories is a good practise because it helps prioritise efforts and improves the overall quality of the national inventory. A "key category" is a source or sink category that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHGs in terms of absolute emissions, trend or uncertainty in emissions and removals (IPCC, 2006).

Table 2.32 presents the result of the level assessment using Approach 1 that identified 21 categories without LULUCF and 23 categories with LULUCF as key categories. As per IPCC Guidelines, 95 per cent cumulative contribution threshold has been used in this analysis to define an upper boundary for the key category identification.

In approach 1, key categories are identified using a pre-determined cumulative emissions threshold. Key categories are those that, when summed together in descending order of magnitude, add up to 95 per cent of the total level (IPCC 2006 GL volume 1, page 4.12).

Table 2.32: Key category level assessment with and without LULUCF for 2019

	2019 Without LULUCF			2019 With LULUCF		
Sr. No.	IPCC Code, Category, Gas	Gg CO_2e	Level %	IPCC Code, Category, Gas	Gg CO_2e	Level %
1	1A1a Electricity production, CO_2	1233554	39.39%	1A1a Electricity production, CO_2	1233554	33.89%
2	1A3b Road transport, CO_2	277460	8.86%	3B2 Cropland, CO_2 Removal	343174	9.43%
3	3A1 Enteric Fermentation, CH_4	223251	7.13%	1A3b Road transport, CO_2	277460	7.62%
4	1A2m Nonspecific Industries, CO_2	170142	5.43%	3A1 Enteric Fermentation, CH_4	223251	6.13%
5	1A4b Residential, CO_2	158462	5.06%	1A2m Nonspecific Industries, CO_2	170142	4.67%
6	1A2a Iron & steel, CO_2	157920	5.04%	1A4b Residential, CO_2	158462	4.35%
7	2A1 Cement production,-CO_2	126620	4.04%	1A2a Iron & steel, CO_2	157920	4.34%
8	1A4a Commercials/Institutional, CO_2	109961	3.51%	3B1 Forestland, CO_2 Removal	146483	4.02%
9	3C4 Agricultural soils, N_2O	88412	2.82%	2A1 Cement production, CO_2	126620	3.48%
10	1A1b Refinery, CO_2	83206	2.66%	1A4a Commercials/Institutional, CO_2	109961	3.02%
11	3C7 Rice Cultivation, CH_4	73437	2.34%	3C4 Agricultural soils, N_2O	88412	2.43%
12	1A2f Cement, CO_2	52546	1.68%	1A1b Refinery, CO_2	83206	2.29%
13	2C3 Aluminium production, CF	43968	1.40%	3C7 Rice Cultivation, CH_4	73437	2.02%
14	2A2 Lime production, CO_2	30643	0.98%	1A2f Cement, CO_2	52546	1.44%
15	2E Production of halocarbons and sulphur hexafluoride, HFC	27949	0.89%	2C3 Aluminium production, CF	43968	1.21%
16	3A2 Manure Management, N_2O	24865	0.79%	2A2 Lime production, CO_2	30643	0.84%
17	4D1 Domestic and Commercial Wastewater, CH_4	21785	0.70%	2E Production of halocarbons and sulphur hexafluoride, HFC	27949	0.77%
18	1A3a Civil Aviation, CO_2	19440	0.62%	3A2 Manure Management, N_2O	24865	0.68%
19	4D2 Industrial Wastewater, CH_4	17981	0.57%	4D1 Domestic and Commercial Wastewater, CH_4	21785	0.60%

	2019 Without LULUCF			2019 With LULUCF		
Sr. No.	IPCC Code, Category, Gas	Gg CO_2e	Level %	IPCC Code, Category, Gas	Gg CO_2e	Level %
20	4D1 Domestic and Commercial Wastewater, N_2O	16815	0.54%	1A3a Civil Aviation, CO_2	19440	0.53%
21	4A Managed Waste Disposal on Land, CH_4	16608	0.53%	4D2 Industrial Wastewater, CH_4	17981	0.49%
22				4D1 Domestic and Commercial Wastewater, N_2O	16815	0.46%
23				4A Managed Waste Disposal on Land, CH_4	16608	0.46%
Total		**2975022**		**Total**	**3464680**	

The trend of emission contributions from each category is examined to determine where the greatest absolute changes (either increases or decreases) have occurred over a given time period. Table 2.33 shows India's National GHG inventory from 2011 to 2019, with and without LULUCF, using the trend assessment Tier 1 methodological approach.

Table 2.33: Key category trend assessment with and without LULUCF for 2011-2019

	2011-2019 without LULUCF			2011-2019 with LULUCF		
Sr. No.	IPCC Code, Category, Gas	Trend Assessment (Txt)	% Contribution to Trend	IPCC Code, Category, Gas	Trend Assessment (Txt)	% Contribution to Trend
1	1A4a Commercials/Institutional, CO_2	0.1202298	39.74%	1A4a Commercials/Institutional, CO_2	0.10176805	30.22%
2	1A4b Residential, CO_2	0.0314046	10.38%	3B2 Cropland, CO_2 Removal	0.06460309	19.19%
3	1A1a Electricity production, CO_2	0.0278747	9.21%	1A4b Residential, CO_2	0.02459166	7.30%
4	3A1 Enteric Fermentation, CH_4	0.0237588	7.85%	3B1 Forestland, CO_2 Removal	0.02447657	7.27%
5	2C3 Aluminium production, CF	0.0119647	3.95%	3A1 Enteric Fermentation, CH_4	0.02386923	7.09%
6	1A1b Refinery, CO_2	0.0095320	3.15%	1A2m Nonspecific Industries, CO_2	0.01045894	3.11%
7	1A2m Nonspecific Industries, CO_2	0.0091210	3.01%	2C3 Aluminium production, CF	0.00962075	2.86%
8	3C7 Rice Cultivation, CH_4	0.0079963	2.64%	3C7 Rice Cultivation, CH_4	0.00800737	2.38%
9	3C4 Agricultural Soils, N_2O	0.0076062	2.51%	3C4 Agricultural Soils, N_2O	0.00790147	2.35%

	2011-2019 without LULUCF			2011-2019 with LULUCF		
Sr. No.	**IPCC Code, Category, Gas**	**Trend Assessment (Txt)**	**% Contribution to Trend**	**IPCC Code, Category, Gas**	**Trend Assessment (Txt)**	**% Contribution to Trend**
10	1A3b Road transport, CO_2	0.0070309	2.32%	1A1b Refinery, CO_2	0.00692541	2.06%
11	1B2b Natural gas, CH_4	0.0034499	1.14%	1A1a Electricity production, CO_2	0.00505915	1.50%
12	2E Production of halocarbons and sulphur hexafluoride, HFC	0.0031543	1.04%	1A2a Iron & Steel, CO_2	0.00389321	1.16%
13	2A1 Cement production, CO_2	0.0029974	0.99%	1B2b Natural Gas, CH_4	0.00319559	0.95%
14	4D2 Industrial Wastewater, CH_4	0.0029760	0.98%	4D2 Industrial Wastewater, CH_4	0.00283670	0.84%
15	3A2 Manure Management, N_2O	0.0027057	0.89%	3B3 Grassland, CO_2	0.00282407	0.84%
16	1A3b Road transport, N_2O	0.0025474	0.84%	1A2f Cement, CO_2	0.00272659	0.81%
17	1A2f Cement, CO_2	0.0022318	0.74%	3A2 Manure Management, N_2O	0.00270969	0.80%
18	1A1c Manufacturing of Solid Fuel, CO_2	0.0020364	0.67%	2E Production of halocarbons and sulphur hexafluoride, HFC	0.00228542	0.68%
19	4D1 Domestic and Commercial Wastewater, CH_4	0.0018677	0.62%	1A3b Road transport, N_2O	0.00208943	0.62%
20	2B1 Ammonia production, CO_2	0.0017462	0.58%	4D1 Domestic and Commercial Wastewater, CH_4	0.00194133	0.58%
21	1A2a Iron & Steel, CO_2	0.0017086	0.56%	1A3b Road transport, CO_2	0.00179286	0.53%
22	2C3 Aluminium production, CO_2	0.0016015	0.53%	1A1c Manufacturing of Solid Fuel, CO_2	0.00162260	0.48%
23	1A2m Fertilizer, CO_2	0.0013547	0.45%	2B1 Ammonia production, CO_2	0.00160470	0.48%
24	4D1 Domestic and Commercial Wastewater, N_2O	0.0011628	0.38%	3B5 Settlement, CO_2 Removal	0.00145810	0.43%
25				2C3 Aluminium production, CO_2	0.00128782	0.38%
26				4D1 Domestic and Commercial Wastewater, N_2O	0.00125857	0.37%
Total		**0.28806**		**Total**	**0.32081**	

2.9 Uncertainty assessment

Uncertainty estimates, according to the IPCC Guidelines (2006), are an essential component of a comprehensive inventory of GHG emissions and removals. The uncertainty analysis should be used to prioritise national efforts aimed at improving the accuracy and precision of future inventories, as well as to guide decisions on the methodology to be used. The Tier 1 methodological approach was used to estimate the overall inventory uncertainty. The overall inventory uncertainty was estimated using the Tier 1 methodological approach. An estimate of the overall quantitative uncertainty (±6.74 per cent level uncertainty and ±8.85 per cent trend uncertainty) in various categories is shown in Table 2.34. The uncertainty of estimates has been depicted by a range within which the estimated emissions lie. Uncertainties associated with the activity data were sourced from the data sources, or from the researchers who have done the collection of such data based on expert judgement of inventory estimation teams, and/or from IPCC 2006 Guidelines.

Table 2.34: Overall Inventory Uncertainty in India for 2019

Sr. No.	IPCC Category	Category Number, Name	Gas	2011 emissions or removals (Gg CO_2 equivalent)	2019 emissions or removals (Gg CO_2 equivalent)	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year T	Type A sensitivity	Type B sensitivity	Uncertainty in Trend in National Emissions introduced by Emission Factor / Estimation parameter uncertainty (%)	Uncertainty in Trend in National Emissions introduced by Activity Data Uncertainty (%)	Uncertainty introduced into the Trend in Total National Emissions (%)
1	Energy	1A1a Electricity production	CO_2	867254	1233554	10.00%	5.00%	11.18%	0.001939	0.026389	53.23%	0.18660%	7.52824%	0.56709%
2	Energy	1A3b Road transport	CO_2	193898	277460	5.00%	3.00%	5.83%	0.000027	0.006635	11.97%	0.02815%	0.84665%	0.00718%
3	AFOLU	3A1 Enteric Fermentation	CH_4	219244	223251	5.00%	50.00%	50.25%	0.001283	0.031506	9.63%	2.22781%	0.68124%	0.05427%
4	Energy	1A2m Nonspecific Industries	CO_2	143739	170142	20.00%	5.00%	20.62%	0.000125	0.010408	7.34%	0.07360%	2.07671%	0.04318%
5	IPPU	1A4b Residential	CO_2	80343	158462	5.00%	5.00%	7.07%	0.000013	0.021514	6.84%	0.15212%	0.48354%	0.00257%
6	Energy	1A2a Iron & steel	CO_2	119844	157920	20.00%	5.00%	20.62%	0.000108	0.001752	6.81%	0.01239%	1.92753%	0.03716%
7	Energy	2A1 Cement production	CO_2	88810	126620	5.00%	5.00%	7.07%	0.000008	0.002840	5.46%	0.02008%	0.38637%	0.00150%
8	IPPU	1A4a Commercials/Institutional	CO_2	23023	109961	10.00%	5.00%	11.18%	0.000015	0.034020	4.75%	0.24056%	0.67108%	0.00508%
9	Energy	3C4 Agricultural Soils	N_2O	81701	88412	20.00%	5.00%	20.62%	0.000034	0.009497	3.82%	0.06715%	1.07913%	0.01169%
10	Energy	1A1b Refinery	CO_2	48648	83206	25.00%	100.00%	103.08%	0.000750	0.007531	3.59%	1.06502%	1.26950%	0.02746%
11	AFOLU	3C7 Rice Cultivation	CH_4	72670	73437	15.00%	15.00%	21.21%	0.000025	0.010691	3.17%	0.22680%	0.67226%	0.00503%
12	AFOLU	1A2f Cement	CO_2	43121	52546	15.00%	20.00%	25.00%	0.000018	0.002475	2.27%	0.07000%	0.48102%	0.00236%

Sr. No.	IPCC Category	Category Number, Name	Gas	2011 emissions or removals (Gg CO_2 equivalent)	2019 emissions or removals (Gg CO_2 equivalent)	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year T	Type A sensitivity	Type B sensitivity	Uncertainty in Trend in National Emissions introduced by Emission Factor / Estimation parameter uncertainty (%)	Uncertainty in Trend in National Emissions introduced by Activity Data Uncertainty (%)	Uncertainty introduced into the Trend in Total National Emissions (%)
13	Energy	2C3 Aluminium production	CF	19950	43968	5.00%	5.00%	7.07%	0.000001	0.007337	1.90%	0.05188%	0.13416%	0.00021%
14	IPPU	2A2 Lime production	CO_2	24011	30643	5.00%	75.00%	75.17%	0.000054	0.000781	1.32%	0.08284%	0.09350%	0.00016%
15	Waste	2E Production of halocarbons and sulphur hexafluoride	HFC	16392	27949	15.00%	50.00%	52.20%	0.000022	0.002500	1.21%	0.17679%	0.25585%	0.00097%
16	Waste	3A2 Manure Management	N_2O	24600	24865	15.00%	50.00%	52.20%	0.000017	0.003618	1.07%	0.25580%	0.22762%	0.00117%
17	IPPU	4D1 Domestic and Commercial Wastewater	CH_4	20114	21785	10.00%	20.00%	22.36%	0.000002	0.002330	0.94%	0.06592%	0.13295%	0.00022%
18	Energy	1A3a Civil Aviation	CO_2	13504	19440	5.00%	3.00%	5.83%	0.000000	0.000513	0.84%	0.00218%	0.05932%	0.00004%
19	AFOLU	4D2 Industrial Wastewater	CH_4	21580	17981	10.00%	75.00%	75.66%	0.000019	0.004827	0.78%	0.51199%	0.10974%	0.00274%
20	Waste	4D1 Domestic and Commercial Wastewater	N_2O	14815	16815	15.00%	75.00%	76.49%	0.000017	0.001385	0.73%	0.14686%	0.15393%	0.00045%
21	Waste	4A Managed Waste Disposal on Land	CH_4	13932	16608	15.00%	50.00%	52.20%	0.000008	0.000959	0.72%	0.06782%	0.15203%	0.00028%
Total				**2317287**	**3132028**				**0.004543**					**0.007841**
Total Uncertainties						**Uncertainty in Total Inventory**			**6.74%**		**Trend Uncertainty**			**8.85%**

2.10 Time series information

Consistent time series information of the GHG inventory starting from the last (second) national communication (inventory year 2000) to 2019 has been presented in the bar chart (see Figure 2.24). A summary table (Table 2.35) has been provided for national GHG inventory information contained in previous submissions. Inventory of 1994 was communicated in INC (MoEF, 2004). SNC contained a national inventory of 2000 (MoEF, 2012). Inventory of 2007 was given in SNC as a proactive approach (MoEF, 2010). Inventory of 2010 was provided in BUR-1 (MoEFCC, 2016). In 2018, India had furnished its BUR-2 containing the national inventory of 2014 (MoEFCC, 2018) in 2018 and its last submission India submitted its BUR-3 which contains the national inventory of 2016 (MoEFCC, 2021).

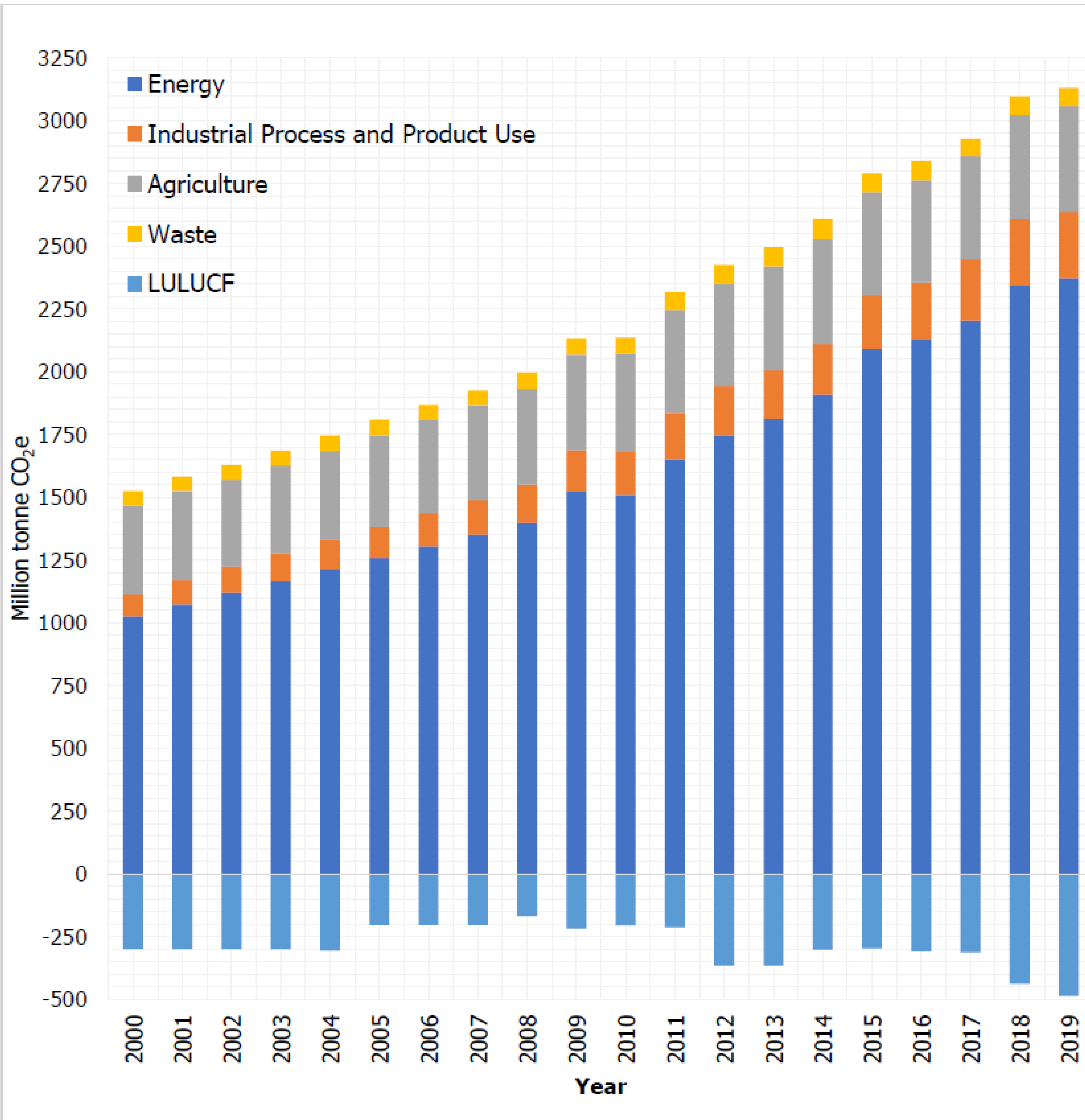


Figure 2.24: Time series information of GHG emissions

Table 2.35: India's total emissions, 2011-2019

GHG Sources and Removals	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Gg CO_2 Equivalent								
1. Energy	1651928	1747686	1813559	1909766	2092102	2129428	2204263	2344325	2374330
A. Fuel Combustion Activities	1604503	1704639	1774788	1871709	2055017	2092250	2168704	2307753	2338432
1. Energy Industries	924258	1005813	1053981	1140983	1197123	1206587	1255716	1324177	1331901
2. Manufacturing Industries & Construction	338816	343603	356771	351910	394092	397739	393312	412086	404676
3. Transport	221202	236020	241253	250173	261517	274434	290732	307328	314817
4. Other sectors	120228	119202	122783	128643	202286	213490	228944	264162	287039
B. Fugitive Emission from fuels	47426	43047	38771	38057	37084	37179	35559	36572	35898
1. Solid fuels	16388	16086	15568	16547	16614	17121	16065	16862	17017
2. Oil and Natural gas	31037	26961	23203	21511	20470	20058	19494	19710	18880
C. CO_2 Transport and Storage	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Industrial Processes and Product Use	185543	196023	192616	202278	214020	226407	244143	262999	263540
A. Mineral Industry	113193	122469	123369	126856	132075	135468	144048	160222	157665
B. Chemical Industry	24387	24419	23190	22175	24269	25358	22696	16814	19277
C. Metal Industry	27289	28033	27356	29242	34068	40814	49631	53735	52279
D. Other	4283	4812	4955	5428	5581	5507	5955	6109	6370
E. Production of halocarbons and sulphur hexafluoride	16392	16290	13745	18576	18027	19259	21812	26117	27949
3. Agriculture	409374	408435	413683	417218	409703	407821	411091	416769	420968
A. Enteric Fermentation	219244	221666	224280	227157	222396	222655	222784	223017	223251
B. Manure Management	27221	27484	27766	28101	27220	27227	27503	27507	27511
C. Rice Cultivation	72670	70600	72884	72843	71834	71322	73625	74268	73437
D. Agricultural Soils	81701	80112	80047	80529	79715	77781	81064	83511	88412
E. Prescribed Burning of Savannas	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Field Burning of Agricultural Residues	8539	8573	8706	8589	8538	8836	6115	8465	8358
4. LULUCF	-210913	-364221	-364569	-301193	-296092	-307820	-311778	-437000	-485472
A. Forestland	-71438	-71438	-71222	-68215	-68033	-75343	-75320	-144803	-145025
B. Cropland	-163990	-298869	-299410	-248610	-247521	-251975	-255627	-302455	-343174
C. Grassland	27746	10614	10649	17216	21039	21289	21131	14932	9726
D. Wetlands	NE	NE	NE	NE	NE	NE	NE	NE	NE
E. Settlement	-3231	-4529	-4586	-1583	-1578	-1790	-1963	-4674	-6998
F. Other Land	NA	NA	NA	NA	NA	NA	NA	NA	NA

GHG Sources and Removals	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Gg CO_2 Equivalent								
G. Harvested Wood Products	NO	NO	NO	NO	NO	NO	NO	NO	NO
H. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA
5. Waste	70442	73208	76539	78227	73247	75232	69716	71733	73189
A. Solid waste disposal on land	13932	14307	14685	15065	15448	15832	16203	16392	16608
B. Waste-water handling	56509	58900	61854	63162	57799	59401	53513	55341	56581
Memo Items	768201	783702	797485	812068	755291	789359	793057	797502	801335
International Bunkers	6399	6207	5083	4981	5281	6095	6157	6950	7114
Aviation	3623	3791	3742	3714	3830	4396	4775	5442	5832
Marine	2776	2416	1341	1267	1451	1699	1382	1508	1282
CO_2 from Biomass	761802	777494	792401	807087	750010	783265	786900	790552	794221
Total (without LU-LUCF)	2317287	2425352	2496397	2607488	2789072	2838889	2929214	3095826	3132028
Total (with LULUCF)	2106374	2061131	2131828	2306295	2492980	2531069	2617436	2658825	2646556
Abbreviations: IE – Included Elsewhere; NE – Not Estimated; NO – Not Occurring, NA – Not Applicable.									

In accordance with Decision 2/CP.17, non-annex I parties should submit updates of their national GHG inventories in their BUR as contained in paragraphs 8-24 in the Annex to decision 17/CP.8, India's national GHG inventory for 2016 is presented in Tables 2.36 (Table a and Table b).

Table 2.36: India's National GHG Inventory for 2019 (Gg)

Table (a). National greenhouse gas inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol and greenhouse gas precursors								
Greenhouse Gas Source and Sink Categories (Gigagram)	**CO_2 emissions**	**CO_2 removals**	**CH_4**	**N_2O**	**CO**	**NO_x**	**NMVOCs**	**SO_x**
Total national emissions and removals	2498768	496656	19531	523				
1. Energy	2305998	NA	2034	83				
A. Fuel combustion (sectoral approach)	2305998		324	83				
1. Energy industries	1325215		18	20				
2. Manufacturing industries and construction	402799		6	6				
3. Transport	306738		57	22				
4. Other sectors	271248		243	34				
5. Other (please specify)	NO		NO	NO				

Table (a). National greenhouse gas inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol and greenhouse gas precursors								
Greenhouse Gas Source and Sink Categories (Gigagram)	**CO_2 emissions**	**CO_2 removals**	**CH_4**	**N_2O**	**CO**	**NO_x**	**NMVOCs**	**SO_x**
B. Fugitive emissions from fuels	NO		1709					
1. Solid fuels			810					
2. Oil and natural gas			899					
2. Industrial processes	183044	NO	222	12				
A. Mineral products	157665							
B. Chemical industry	14777		33	12				
C. Metal production	8200		0.49	NO				
D. Other production	NO							
E. Production of halocarbons and sulphur hexafluoride								
F. Consumption of halocarbons and sulphur hexafluoride								
G. Other (Pulp and paper)	2401		189	NO				
1. Lubricant	2236		NO	NO				
2. Paraffin wax	165		NO	NO				
3. Pulp & paper	NO		189	NO				
3. Solvent and other product use	NO			NO				
4. Agriculture	NO		14542	373				
A. Enteric fermentation			10631					
B. Manure management			126	80				
C. Rice cultivation			3497					
D. Agricultural soils			NO	285				
E. Prescribed burning of savannahs			NO	NO				
F. Field burning of agricultural residues			288	7				
G. Other (please specify)	NO		NO	NO				
5. Land-use change and forestry	9726	-496656	48	1				
A. Changes in forest and other woody biomass stocks	NE	NE						

Table (a). National greenhouse gas inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol and greenhouse gas precursors

Greenhouse Gas Source and Sink Categories (Gigagram)	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO	NO_x	NMVOCs	SO_x
B. Forest and grassland conversion	NO	-146483	NO	NO				
C. Abandonment of managed lands		NE						
D. CO_2 emissions and removals from soil	9726	-343174						
E. Other (please specify)	NO	-6998	48	1				
6. Waste			2684	54				
A. Solid waste disposal on land			791					
B. Waste-water handling			1894	54				
C. Waste incineration								
D. Other (please specify)			NO	NO				
7. Other (please specify)	NO	NA	NO	NO				
Memo items								
International bunkers	7058		0.12	0.17				
Aviation	5781		0.04	0.16				
Marine	1277		0.08	0.01				
CO_2 emissions from biomass	794221							

Abbreviations: IE – Included Elsewhere; NE – Not Estimated; NO – Not Occurring, NA – Not Applicable.

Table (b). National greenhouse gas inventory of anthropogenic emissions of HFCs, PFCs and SF_6

Greenhouse Gas Source and Sink Categories (Gigagram)	HFCs a, b			PFCs a, b			SF_6 a
	HFC-23	HFC-134	Other (to be added)	CF_4	C_2F_6	Other (to be added)	
Total national emissions and removals	2.389	NO	NA	4.884	1.328	NA	0.004
1. Energy							
A. Fuel combustion (sectoral approach)							
1. Energy industries							

Table (b). National greenhouse gas inventory of anthropogenic emissions of HFCs, PFCs and SF_6							
Greenhouse Gas Source and Sink Categories (Gigagram)	**HFCs a, b**			**PFCs a, b**			**SF_6 a**
	HFC-23	**HFC-134**	**Other (to be added)**	**CF_4**	**C_2F_6**	**Other (to be added)**	
2. Manufacturing industries and construction							
3. Transport							
4. Other sectors							
5. Other (please specify)							
B. Fugitive emissions from fuels							
1. Solid fuels							
2. Oil and natural gas							
2. Industrial processes	2.389	NO	NA	4.884	1.328	NA	0.004
A. Mineral products							
B. Chemical industry							
C. Metal production	NA	NO	NA	4.884	1.328	NA	0.004
D. Other production							
E. Production of halocarbons and sulphur hexafluoride	2.389	NA	NA	NA	NA	NA	NA
F. Consumption of halocarbons and sulphur hexafluoride	NA	NA	NA	NA	NA	NA	NA
G. Other (please specify)							
3. Solvent and other product use							
4. Agriculture							
A. Enteric fermentation							
B. Manure management							
C. Rice cultivation							
D. Agricultural soils							
E. Prescribed burning of savannahs							
F. Field burning of agricultural residues							
G. Other (please specify)							
5. Land-use change and forestry							

Table (b). National greenhouse gas inventory of anthropogenic emissions of HFCs, PFCs and SF_6							
Greenhouse Gas Source and Sink Categories (Gigagram)	**HFCs a, b**			**PFCs a, b**			**SF_6 a**
	HFC-23	**HFC-134**	**Other (to be added)**	**CF_4**	**C_2F_6**	**Other (to be added)**	
A. Changes in forest and other woody biomass stocks							
B. Forest and grassland conversion							
C. Abandonment of managed lands							
D. CO_2 emissions and removals from soil							
E. Other (please specify)							
6. Waste							
A. Solid waste disposal on land							
B. Waste-water handling							
C. Waste incineration							
D. Other (please specify)							
7. Other (please specify)	NA	NA	NA	NA	NA	NA	NA
Memo items							
International bunkers							
Aviation							
Marine							
CO_2 emissions from biomass							

Abbreviations: IE – Included Elsewhere; NE – Not Estimated; NO – Not Occurring, NA – Not Applicable.

Appendix

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	**CO_2 removal**	**CH_4**	**N_2O**	**HFC 23**	**CF_4**	**C_2F_6**	**SF_6**	**CO_2 equivalent**
Total Emission	**2489042.42**		**19482.24**	**522.07**	**2.39**	**4.88**	**1.33**	**0.00**	**3132027.55**
Net Emission	**2498768.07**	**496655.88**	**19530.67**	**523.49**	**2.39**	**4.88**	**1.33**	**0.00**	**2646555.88**
1. Energy	**2305998.37**		**2033.74**	**82.66**					**2374330.36**
A. Fuel Combustion Activities	2305998.37		324.32	82.66					**2338432.47**
1. Energy Industries	1325214.59		17.97	20.35					**1331900.68**
a. Electricity production	1233553.76		13.63	19.25					**1239807.01**
b. Refinery	83206.30		3.70	0.15					**83329.16**
c. Manufacturing of Solid Fuel	8454.53		0.64	0.96					**8764.51**
2. Manufacturing Industries & Construction	402798.54		5.95	5.65					**404676.13**
a. Cement	52545.97		1.26	0.49					**52725.17**
b. Iron & steel	157919.66		1.82	2.49					**158729.46**
c. Nonferrous metals	2439.11		0.06	0.03					**2449.28**
d. Chemicals	2086.01		0.06	0.02					**2093.91**
e Pulp & paper	3061.78		0.03	0.05					**3076.96**
f. Food & beverages	NE								
g. Non-metallic minerals	NE								
h. Mining & quarrying	5141.33		0.21	0.04					**5158.58**
i. Textile/leather	1275.61		0.02	0.02					**1281.27**
j. Bricks	607.50		0.01	0.01					**610.33**
k. Fertilizer	4889.46		0.09	0.07					**4912.39**
l. Engineering Sector	2690.03		0.11	0.02					**2698.90**

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC 23	CF_4	C_2F_6	SF_6	CO_2 equivalent
m. Nonspecific Industries	170142.08		2.29	2.42					**170939.87**
n. Glass Ceramic	NE								
3. Transport	306737.65		57.15	22.19					**314816.52**
a. Road transport	277459.57		56.36	21.57					**285328.58**
b. Civil Aviation	19439.88		0.14	0.54					**19611.30**
c. Railways	6519.55		0.44	0.05					**6545.15**
d. Navigation	3318.66		0.22	0.03					**3331.48**
4. Other sectors	271247.59		243.24	34.46					**287039.15**
a. Commercials/ Institutional	109960.74		1.52	1.58					**110484.00**
b. Residential	158461.90		4.58	1.25					**158944.96**
c. Agricultural/ fisheries	2824.95		0.10	0.02					**2833.11**
d. Biomass burnt for energy			237.03	31.61					**14777.08**
B. Fugitive Emission from fuels			**1709.42**						**35897.88**
1. Solid fuels			810.36						**17017.49**
a. Above ground mining			653.39						**13721.15**
b. Underground mining			156.97						**3296.34**
2. Oil and Natural gas			899.07						**18880.40**
a. Oil			34.09						**715.82**
b. Natural gas			704.58						**14796.26**
c. Venting and Flaring			160.40						**3368.32**
2. Industrial Processes and Product Use	**183044.05**		**222.21**	**12.30**	**2.389**	**4.884**	**1.328**	**0.004**	**263540.38**

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC 23	CF_4	C_2F_6	SF_6	CO_2 equivalent
A. Minerals	**157665.26**								**157665.26**
1. Cement production	126619.97								**126619.97**
2. Lime production	30642.75								**30642.75**
3. Limestone and Dolomite Use	NE								
5. Glass	379.08								**379.08**
6. Ceramics	23.46								**23.46**
B. Chemicals	**14777.20**		**32.72**	**12.30**					**19277.37**
1 Ammonia production	6656.34								**6656.34**
2 Nitric acid production				11.52					**3572.57**
3. Carbide production	89.98								**89.98**
4. Titanium dioxide production	71.16								**71.16**
5. Soda ash Production	1075.99								**1075.99**
6. Methanol production	134.01		0.46						**143.67**
7. Ethylene production	5668.56		17.42						**6034.48**
8. EDC & VCM production	319.27								**319.27**
9. Ethylene Oxide production	245.07		0.51						**255.74**
10. Acrylonitrile production	0.00		0.00						**0.00**
11.Carbon Black production	516.83		14.33						**817.71**
12. Caprolactam				0.78					**240.46**

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC 23	CF_4	C_2F_6	SF_6	CO_2 equivalent
C. Metal Production	**8200.44**		**0.49**			**4.884**	**1.328**	**0.004**	**52278.80**
1. Iron & Steel production	IE								
2. Ferroalloys production	2216.38		0.49						**2226.68**
3. Aluminium production	5878.71					4.884	1.328		**49846.39**
4. Lead production	72.23								**72.23**
5. Zinc production	32.56								**32.56**
6. Magnesium Production	0.57							0.004	**100.95**
D. Non-energy product use	**2401.15**								**2401.15**
1. Lubricant	2236.06								2236.06
2. Paraffin wax	165.09								165.09
E. Production of halocarbons and sulphur hexafluoride					**2.389**				**27948.81**
F. Consumption of halocarbons and sulphur hexafluoride									
H. Other			**189.00**						**6370.15**
1. Pulp & paper			189.00						**3969.00**
3. Agriculture	**0.00**		**14541.80**	**372.87**					**420967.78**
A. Enteric Fermentation			10630.99						**223250.70**
B. Manure Management			126.00	80.21					**27511.07**
C. Rice Cultivation			3496.99						**73436.73**

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	**CO_2 removal**	**CH_4**	**N_2O**	**HFC 23**	**CF_4**	**C_2F_6**	**SF_6**	**CO_2 equivalent**
D. Agricultural Soils				285.20					**88411.61**
Direct N_2O Emissions				*227.75*					*70602.58*
Indirect N_2O Emissions				*57.45*					*17809.03*
F. Field Burning of Agricultural Residues			287.83	7.46					**8357.67**
4. LULUCF	9725.65	496655.88	48.43	1.42					**-485471.67**
A. Forestland		146483.33	48.43	1.42					**-145024.78**
B. Cropland		343174.21							**-343174.21**
C. Grassland	9725.65								**9725.65**
D. Settlement		6998.34							**-6998.34**
F. Other land		NA							
5. Waste			2684.48	54.24					**73189.03**
A. Solid waste disposal on land			790.85						**16607.95**
1. Managed Waste Disposal on Land			790.85						**16607.95**

Detailed Greenhouse Gas Emissions from India, in 2019, by Sources and Removals by Sinks (Emissions are in Gigagrams).									
	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC 23	CF_4	C_2F_6	SF_6	CO_2 equivalent
B. Waste-water handling			**1893.63**	**54.24**					**56581.07**
1. Industrial Wastewater			856.24						**17981.09**
2. Domestic and Commercial wastewater			1037.38	54.24					**38599.99**
Memo Item (not accounted in total Emis-sions)	801279.20		0.12	0.17					**801335.00**
International Bunkers	**7057.75**		**0.12**	**0.17**					**7113.56**
Aviation	5780.67		0.04	0.16					**5831.64**
Marine	1277.08		0.08	0.01					**1281.91**
CO_2 from Bio-mass	**794221.45**								**794221.45**

Abbreviations: IE – Included Elsewhere; NE – Not Estimated; NO – Not Occurring, NA – Not Applicable.

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Mitigation

CLIMATE CHANGE MITIGATION

Chapter 03

3.1 INTRODUCTION

Global Greenhouse Gas emissions must be reduced to limit anthropogenic global warming. India is committed to an effective and fair contribution to global climate action to achieve this goal. India's contribution to historical emissions, and therefore, to the current levels of global warming, is very low. Nevertheless, India has pledged to undertake ambitious climate change mitigation efforts, based on its access to a fair and equitable share of the global carbon budget as well as keeping in view its significant developmental needs and aspirations.

The nature and scale of contributions by individual countries to climate change mitigation will vary based on equity, the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR&RC), national circumstances, and historical responsibility. India's contribution to climate change mitigation is considerably larger compared to its past and current responsibility for climate change. The mitigation efforts are undertaken despite the developmental challenges the country faces, which are exacerbated by the aftermath of the COVID-19 pandemic and the global energy crisis.

In this context, this chapter, as part of India's Third National Communication (TNC) to the UNFCCC, will highlight the following: i) scale and scope of the extensive steps that India has taken to enhance its contribution to climate change mitigation, by pursuing sustainable and low carbon development; ii) challenges before India in meeting its twin goals of development and environmental sustainability; and iii) scale of India's mitigation efforts in the context of its responsibility, capability, and fair share.

3.1.1 The Global context

As noted in the chapter on National Circumstances, global warming is a global collective action problem. Hence, the question of mitigation in one country cannot be isolated from the global context and the mitigation action of other countries. This is exacerbated by the high level of disparity in emissions level between countries. Hence, this chapter on mitigation will begin with an introduction to the global context.

The world has already warmed by about 1.09 deg. C (0.95–1.20 deg. C) as compared to the pre-industrial period (IPCC, 2023). Carbon dioxide (CO_2) emissions are the largest contributor to this warming. According to the IPCC (2021), about 2,390 (±240) gigatonnes of CO_2 ($GtCO_2$) have been emitted cumulatively by the world between 1850 and 2019. More than four-fifths of the global carbon budget available to the world for limiting global warming to 1.5 deg. C (>50% probability), and two thirds of the global carbon budget available to the world for limiting global warming to 2 deg. C (>67% probability), is already exhausted (IPCC, 2022).

Annex-I countries, with about 19% of the global population, are responsible for about 68% of global historical GHG emissions between 1850 and 2019 (Gütschow et al, 2021). On the other hand, India alone is home to about 17.8% of the global population but is responsible for only 4% of the global cumulative emissions between 1850 and 2019 (ibid). Table 3.1 shows the fair share vs. actual emissions for some developed and developing countries for the period 1850 to 2019. The fair share is estimated as a per capita share of the total carbon budget.

Table 3.1 Per Capita Fair Share of the Global Carbon Budget and Actual Emissions for Select Countries/Regions (1850-2019)

Historical Cumulative CO_2 Emissions (1850-2019) including non-LULUCF emissions	Remaining Global Carbon Budget (2020 - Global Net-Zero) - 50% Probability of limiting warming to 1.5 deg. C	Remaining Global Carbon Budget (2020 - Global Net-Zero) - 67% Probability of limiting warming to 2 deg. C	Country / Region	Per Capita Fair Share of the Global Carbon Budget (1850-Net-Zero) for a 50% probability of 1.5 deg. C	Per Capita Fair Share of the Global Carbon Budget (1850-Net-Zero) for a 67% probability of 2 deg. C	Actual Cumulative non-LULUCF CO_2 Emissions (1850-2019)*
[$GtCO_2eq$]	[$GtCO_2eq$]	[$GtCO_2eq$]		[$GtCO_2eq$]	[$GtCO_2eq$]	[$GtCO_2eq$]
2390	500	1150	Australia	10	12	19
			USA	123	151	433
			EU (27) + UK	218	267	301
			China	529	649	233
			India	514	630	55
				2890	3540	1699

Data Source: Values calculated as a per capita share of the total carbon budget. The global carbon budget is a combination of past emissions and the remaining carbon budget from IPCC (2021). Actual non-LULUCF CO_2 emissions are from Gütschow et al (2021). *The PRIMAP database from which the values of actual emissions are taken does not include LULUCF emissions.

All countries need to contribute to the efforts to mitigate global warming. However, the scale and extent of contribution must be determined based on the principles of equity and CBDR-RC as enshrined in the UNFCCC. It is also to be noted, as per Article 4, para 7, of the UNFCCC, that poverty eradication and sustainable development are the overriding priorities of developing countries. But the exhaustion of the global carbon budget, leaving a minor part of the carbon budget for the major part of the population of the world, imposes a double burden on the developing countries, particularly large developing economies like India.

In order to provide a big boost to promote just and equitable energy solutions at a global platform, India was instrumental in bringing together the International Solar Alliance (ISA). ISA was launched jointly by the Prime Minister of India and the then President of France at COP-21 in Paris, France. It provides a common platform where the global community, including bilateral and multilateral organizations, corporate, industry, and other stakeholders, can make a positive contribution to the common goals of increasing utilisation of solar energy in meeting energy needs of ISA member countries in a safe, convenient, affordable, equitable and sustainable manner. As of July 2023, 116 countries are signatories of ISA, out of which 94 countries have ratified the ISA Framework Agreement.

India's energy consumption in 2021-22 (P) was 33,508 Petajoule (PJ) (MoSPI, 2023a). This translates to a per capita energy consumption of about 24.45 Gigajoules (GJ) (MoSPI, 2023a). This is significantly less than the world average of 75.6 GJ per person for the same year. Even if we exclude the Organisation for Economic Co-operation and Development (OECD) countries, the average per capita energy consumption of non-OECD countries is about 56.2 GJ, more than double that of India.

In this larger global context, the key principle that informs India's climate policy, therefore, is to pursue its development goals according to national circumstances while keeping within its fair share of the global carbon budget. India has laid out the four key considerations underlying its long-term low-carbon development strategy (MoEFCC, 2022a). These are: i) India has contributed little to global warming; ii) India has significant energy needs for its development; iii) India is committed to low-carbon development strategies for its development and is committed to pursuing them, as per national circumstances; and iv) India needs to build climate resilience. Further, the broad sectoral strategies for achieving India's long-term goals is described across six major sectors in India's low-carbon development strategy document.

This chapter will discuss in detail the various initiatives for climate change mitigation, undertaken at the economy-wide scale and across sectors in India. Section 2 will provide an overview of the trends in emissions, economy-wide emissions intensity, and the roles of improved energy efficiency in reducing the overall emissions intensity of GDP in the last decade. It will also discuss the progress India has made toward meeting its quantitative pledges submitted through its Nationally Determined Contribution (NDC) to the UNFCCC. The subsequent sections will discuss in detail specific sector-wise initiatives in the power sector, industrial sector, buildings and domestic energy use sector, transport sector, agricultural sector, and forestry sector.

3.2 Overview of emissions trends and mitigation action

In its first NDC submitted to the UNFCCC, India had pledged to achieve a reduction in its emissions intensity of GDP by 33-35% by 2030 compared to 2005 levels. As per latest GHG inventory data reported in chapter 2 of this report, India has already achieved a 33% reduction in 2019 compared to 2005 levels.

A reduction in energy intensity of GDP implies an increase in energy efficiency. Similarly, reduced emissions intensity of energy implies a shift to low emitting sources of energy i.e., renewable energy integration. An overall reduction in the emissions intensity can also result from a structural shift towards the services sector in the economy.

3.2.1 Economy-wide emissions intensity

One of the important features of growth and development of the country is the continuous reduction in the emission intensity of the economy which is the total amount of greenhouse gas emissions emitted for every unit increase of GDP. India has successfully continued to decouple its economic growth from Greenhouse Gas emissions, resulting in the reduction of the emission intensity of its Gross Domestic Product (GDP) as the following table indicates.

Table 3.2 Reduction in Emission Intensity (2005-2019)

Period	Reference year for calculation of GHG Emissions	Reduction in Emission Intensity
2005-2010	2010	12%
2005-2014	2014	21%
2005-2016	2016	24%
2005-2019	2019	33%

Thus, as per current National GHG Inventory, the emission intensity has further reduced to 33% between 2005 and 2019 indicating decoupling of India's GDP from GHG emissions. The TNC brings out the efforts undertaken by different sectors of the economy in reducing the emission intensity and in decoupling the economic growth from GHG emissions through the use of modern technologies and innovative techniques and by pursuing policies that promote efficiency, equity and resilience which form the core values of 'Atmanirbhar Bharat'. Shift towards cleaner fuels and behavioral changes to move towards sustainable production and consumption are also helping in reducing emission intensity.

3.2.2 Current Pledges

India has a strong and consistent record of implementing action to meet its pledges and has achieved its pre-2020 voluntary commitments. Its policies and actions are acknowledged to be compatible with the 2^{0}C warming target of the Paris Agreement (MoEFCC, 2022a).

India submitted its Intended NDC to UNFCCC on October 2, 2015 as per decision 1CP/20 of the 20th session of Conference of Parties (COP 20) held in Lima in December 2014 (MoEFCC, 2016). India has communicated its NDC, for the period 2021-2030, which inter alia, include tangible contributions such as reduction of emission intensity of its GDP by 33 to 35 percent by 2030 from 2005 level; achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF); create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2e through additional forest and tree cover by 2030.

India's emissions intensity of gross domestic product (GDP) has reduced by 33 per cent between 2005 and 2019. India's share of non-fossil sources based installed capacity of electricity generation, as on March 2023, was about 41%. India achieved its NDC target of having 40% of its installed electricity capacity from non-fossil fuel resources in 2021, nine years in advance. During 2005 to 2019, additional carbon sink of 1.97 billion tonnes of CO_2 equivalent has been created.

Given its successful implementation of low carbon growth policies, and the growing need to also signal to the world, especially to developed countries, that they must be more ambitious in their targets and implement policies and actions domestically to meet the same, India has updated its NDC in August 2022 (MoEFCC, 2022b). The elements of India's updated NDCs are[1] :

- Meet 50% of India's cumulative electric power installed capacity from non-fossil sources by 2030.
- Reduce the emissions intensity of GDP by 45% below 2005 levels by 2030.
- Put forward and further propagate a healthy and sustainable way of living based on the traditions and values of conservation and moderation, including through a mass movement for LiFE – Lifestyle for Environment as a key to combating climate change.

India also announced its Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS), in accordance with Article 4.19 of the Paris Agreement under the UNFCCC. India's LT-LEDS discusses the following key aspects of its long-term strategy.

1. Low carbon development of electricity systems consistent with development
2. Developing an integrated, efficient, inclusive low-carbon transport system.
3. Promoting adaptation in urban design, energy and material-efficiency in buildings, and sustainable urbanisation
4. Promoting economy-wide decoupling of growth from emissions and development of an efficient, innovative low-emission industrial system
5. Exploring and developing CO_2 removal and related engineering solutions
6. Enhancing Forest and vegetation cover consistent with socio-economic and ecological considerations

Numerous targeted policies, programmes, and activities have already been implemented to transition towards low-carbon development pathways. The following sections provide an overview of the specific sector-wise policies and initiatives employed in the power sector, industrial sector, buildings and domestic energy use sector, transport sector, agricultural sector, and forestry sector.

3.3 Mitigation efforts in the power sector

India's per capita electricity consumption is very low, at only 1331 kWh/person (including captive generation) in 2022-2023 and demand for electricity is expected to increase as the Indian economy continues to grow. For India, the need for low carbon development in this sector must thus be reconciled with meeting the growing electricity requirements of its people. Mitigation efforts in the power sector must include considerations of cost-effective pathways, integration of efficient technologies, and energy security.

Despite its low historical contribution to emissions and low per capita electricity consumption, India has made ambitious pledges and contributed significantly to climate change mitigation. In its updated

1 The full submission of India's updated NDC is available at https://unfccc.int/NDCREG

Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), India announced that 50% of the cumulative installed capacity of electricity would be achieved from non-fossil fuel energy resources by 2030, with the help of transfers of technologies and low-cost international finance including from the Green Climate Fund (MoEFCC, 2022b). In keeping with this pledge, India has set ambitious domestic goals and made significant strides towards increasing the share of non-fossil fuel sources in the power sector. Figure 3.1 shows the installed capacity in FY 2023, and Figure 3.2 shows the trend in source-wise capacity between 2015 and 2023.

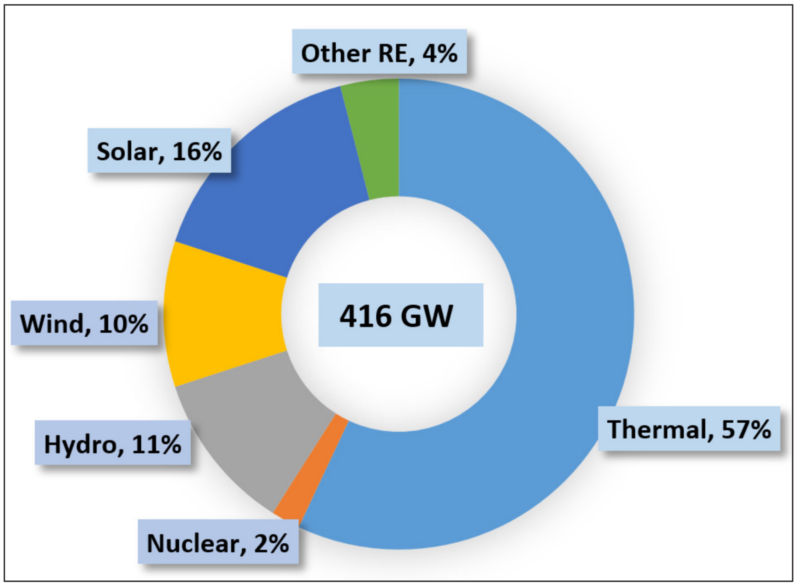

Figure 3.1 Source-wise Installed Capacity as on 31st March 2023
Source: CEA, 2023b

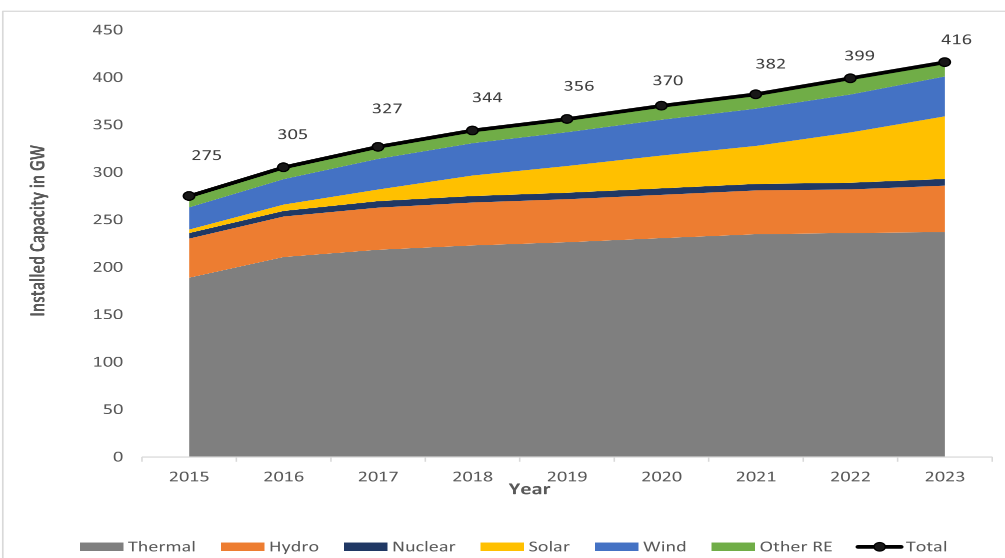

Figure 3.2 Source-wise capacity between 2015 and 2023[2]
Source: CEA, 2023a

2 The capacity figures provided for each year are till the end of each financial year rather than the calendar year.

As seen in Figures 3.1 and 3.2, the share of non-fossil fuels, especially that of solar and wind-based power generation has grown rapidly in the last few years, especially since 2015, the year in which the Paris Agreement was signed.

3.3.1 Current and projected power demand

India has recently achieved universal household electrification and current efforts are focused on further improving the quality and reliability of supply, especially in rural areas (MoEFCC, 2022a). Excluding the pandemic period, when the sector saw a dip in electricity demand – decline of 8% between 2019 and 2020 (CEA, 2020b) - the sector's long-term drivers of demand remain unaffected. Power demand has recovered in the post-pandemic period and in 2022-2023, peak power demand was 215 GW[3]. In May 2022, the maximum electricity supplied was 4,574 MU (POSOCO, 2022a).

The total electricity consumed including utilities and non-utilities during the year 2021-22 was 1316764.73 GWh as compared to 1230207.98 GWh during the year 2020-21 registering growth of 7.04% over the previous year (CEA, 2023a).

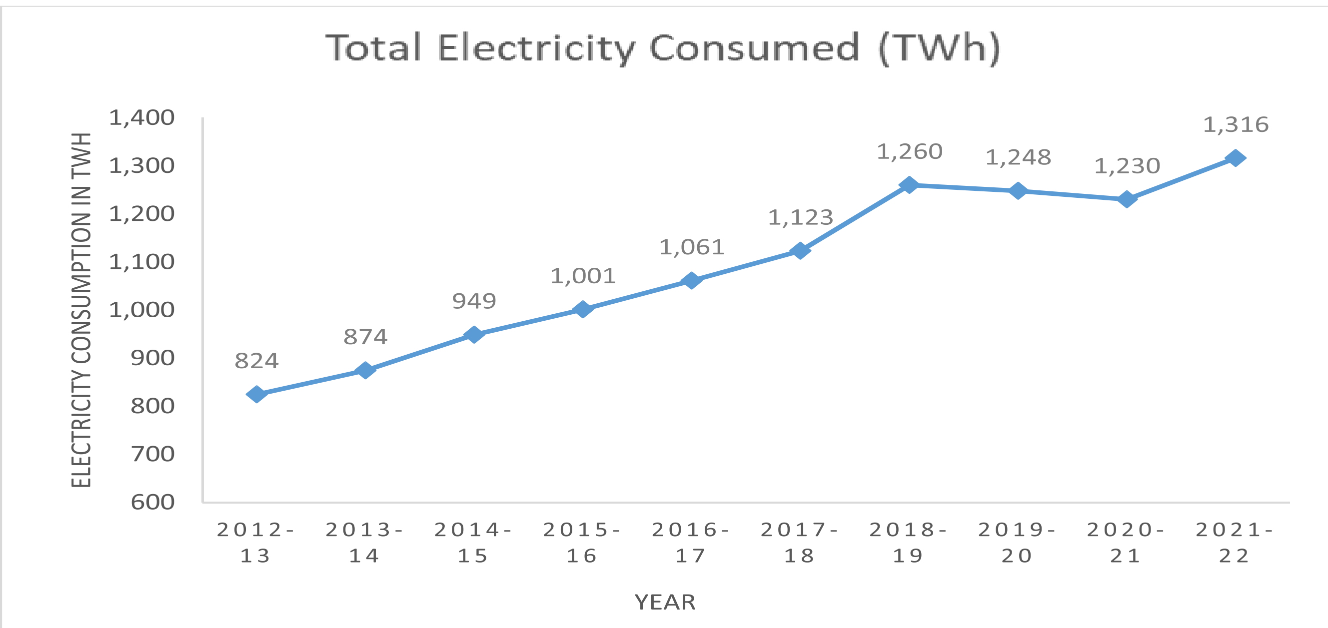

Figure 3.3 Electricity consumption between 2012-2013 to 2021-22(P)
Source: MoSPI, 2023a

3 As per information received from Ministry of New and Renewable Energy

Studies have also projected the electricity demand for India for different economic growth and technology diffusion scenarios. Some of these scenarios are summarised in Table 3.3.

Table 3.3 – Different projections for India's future electricity requirements

Agency/Report	Target Year	Electricity Generation Required at Busbar (TWh)	Peak Demand (GW)
India Energy Outlook – Stated Policies Scenario and India Vision Case (IEA, 2021a)	2030	2461 – 2599	NA
	2040	3887 – 4225	NA
Central Electricity Authority – 20th Electric Power Survey (Utilities only)	2029-30	2279	334
	2036-2037	3095	465
	2041-2042	3776	574
Report on Long Term Demand Forecasting - Baseline and Optimistic scenarios (Utilities only) (CEA, 2019)	2030	2172 - 2220	293 – 302
	2037	2976 - 3175	398 – 427
Optimal Electricity Mix 2029-30 Version 2.0 (CEA, 2023)	2030	2279.64	334.8
India Energy Security Scenarios, 2047 – NITI Aayog (NITI Aayog, n.d.)	2037	3594.72	NA
	2042	4815.04	NA
	2047	6401.5	NA

NA: Not Available

Based on CEA's Long-Term electricity demand forecasting report of 2019, the energy demand in 2037 is expected to increase to 2976 TWh in the baseline scenario, and to 3175 TWh in the optimistic scenario (CEA, 2019). Similarly, the peak demand in 2037 is expected to range from 398 to 427 GW (baseline to optimistic). On the other hand, IEA projects much higher values for 2040, with generation levels ranging from 3887 to 4225 TWh (IEA, 2021b). This study includes generation from captive power plants.

3.3.2 Demand side management initiatives in the power sector

Given the growing electricity demand and the need to ensure a reliable and affordable supply of electricity, it is imperative that India's efforts towards low carbon sustainable development emphasize demand side management (DSM). In keeping with this understanding, the Government of India is pursuing DSM initiatives aggressively. The goal is to reduce energy costs for utilities, and in the long term, limit the requirement for further generation capacity augmentation and strengthening of the transmission and distribution system (MoP, 2021a). The Bureau of Energy Efficiency, a nodal organisation under the Ministry of Power, has made major efforts to increase energy efficiency as part of the National Mission for Enhanced Energy Efficiency. Numerous sectors are being covered by ambitious energy efficiency programmes being implemented as part of the Roadmap of Sustainable and Holistic Approach to National Energy Efficiency (ROSHANEE) strategy. The specific policies and schemes introduced by the government for Demand Side Management are outlined in this section.

3.3.2.1 Strengthening Grid Infrastructure

Deen Dayal Upadhyaya Gram Jyoti Yojana

Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) is an integrated scheme covering all aspects of rural power distribution. The primary objectives of the scheme are:

- Separation of agriculture and non-agriculture feeders facilitating judicious rostering of supply to agricultural and non-agricultural consumers in rural areas.
- Strengthening and augmentation of sub-transmission and distribution infrastructure in rural areas, including metering at distribution transformers, feeders and consumers' end.
- Connecting every village and every hamlet to electricity.

Additionally, it also covers electricity access to all rural households and aims to reduce Aggregate Technical & Commercial (AT&C) losses. This will help in ensuring 24x7 power supply for non-agricultural consumers and adequate power supply for agricultural consumers. The cumulative progress made under DDUGY as on December 31, 2021 are listed below (MoP, 2021a):

- 7,179 sub-stations commissioned (includes augmentation of 4,414 sub-stations)
- 16.28 Lakh distribution transformers commissioned
- 9.79 Lakh Crore Km of LT Lines erected
- 1.22 Lakh Crore Km of 11 kV Feeders segregated
- 5.39 Lakh Crore Km 11kV Lines erected
- 0.15 Lakh Crore Km 33 and 66 kV HT Lines erected
- Energy Meters in 153.80 Lakh consumer premises
- 0.13 Lakh 11 kV Feeders installed

Integrated Power Development Scheme

To ensure reliable and good quality power supply in urban areas, the government approved the "Integrated Power Development Scheme" (IPDS) in 2014. The main components of the scheme are:

- Strengthening of sub-transmission and distribution networks
- Metering of distribution transformers, feeders, and consumers
- IPDS also takes forward approved outlays from the Restructured Accelerated Power Development and Reforms Program (R-APDRP) and includes the remaining urban towns not covered in R-APDRP. The scheme will ensure IT enablement of the distribution sector and strengthening of distribution networks in these towns.
- Smart metering solutions and solar panels with net-metering for government buildings

- Real Time-Data Acquisition System projects for accurate measurement of power interruption parameters like SAIDI/SAIFI at 11kV feeder level

The following progress has been achieved under IPDS as on 31st December, 2021 (MoP, 2021a):

- 985 new 33/11kV substations have been commissioned including indoor substations
- Augmentation of as many as 1599 existing 33/11 kV substations have been completed by providing additional power transformers or capacity enhancement
- More than 86,000 distribution transformers have been installed or augmented
- Aerial bunched cables of more than 62,000 Crore Km and underground cables of more than 20,000 Crore km have been laid
- More than 23,000 Crore Km of HT lines and 10,000 Crore Km of LT lines are completed
- Solar rooftops of more than 45,000 KWp have been installed
- Over 1000 smaller towns under IT phase-II have been IT enabled for better consumer services and digital payments
- Saubhagya Scheme - Achieved universal electricity access by connecting 2.9 cr household to electricity.

Smart Meter National Program

The government is taking several measures to ensure reduction of distribution losses and improve access to electricity. For improved efficiencies in the electricity distribution system, utilities need to enhance their metering infrastructure. In this regard, the Smart Meter National Program (SMNP) was announced with a target of deploying 2500 Lakh smart meters.

Energy Efficiency Services Limited (EESL), under the administration of the Ministry of Power, is working towards mainstreaming energy efficiency and is implementing the world's largest energy efficiency portfolio in the country. So far, more than 20 Lakh smart meters have been installed and are operational as summarised in Table 3.4.

Table 3.4 Progress under the Smart Meter National Program

	Total Smart Meters Installed (till 31st March 2022)
Installations for SMNP	24.62 lakhs

Source: EESL, 2021a.

3.3.2.2 Improvements in Energy Efficiency

Perform Achieve and Trade (PAT) for distribution utilities

For energy efficiency improvement, distribution utilities (DISCOMs) have been part of the Perform Achieve and Trade (PAT) Cycle II launched in 2016. Demand side management interventions have not only helped utilities to reduce peak electricity demands, but have also deferred high investments in generation, transmission and distribution networks (MoP, 2021a). Table 3.5 summarizes the savings and emissions reductions achieved by distribution companies (DISCOMs) under PAT-II.

Table 3.5 Achievement in DISCOMs under PAT II

	Period	Energy Savings Target (Mtoe)	Energy saving Achieved (Mtoe)	CO_2 Emissions Reduction ($MtCO_2$) for year 2018-19
DISCOMs - PAT Cycle II	2016-2019	4.675	2.423	25.44

Source: BEE, 2023

By the end of 2022, implementation of PAT scheme has resulted in energy savings of about 24.34 Mtoe translating into avoiding of about 105.02 million tonnes of CO_2 emissions.

Through the adoption of various energy efficiency schemes/programmes overall energy savings of 44.43 Mtoe, i.e., 6.0% of the total primary energy supply of the country for the year 2021-22 has been reported. The equivalent reduction in CO_2 emissions is around 280.77 million tonnes annually.

Municipal Demand Side Management

Municipalities consume a significant amount of energy for street lighting, water supply, and sanitation services. Recognizing the potential for energy saving in this sector, the Bureau of Energy Efficiency (BEE) initiated the Municipal Demand Side Management (MuDSM) project in 2007. The programme has improved the overall energy efficiency of the urban local bodies and has resulted in reducing the cost of energy supply (MoP, 2021b). It has led to substantial savings in electricity consumption resulting in emission reductions of 5.87$MtCO_2$ in 2021-22 (BEE, 2023).

Street Lighting National Programme

The Street Lighting National Programme (SNLP) is being implemented by the Energy Efficiency Services Limited (EESL) across India, to replace conventional streetlights with energy efficient streetlights with no upfront cost to urban local bodies. During the financial year 2021 – 22, EESL installed 8 lakh LED Street Lights where cumulative achievement as on 31st March 2022 is 1.26 Crore.LED streetlight installations have been completed in 1060 urban local bodies out of the 1600 bodies that have enrolled in the programme.

LED streetlights installed in this programme are equipped with a Central Control and Monitoring System. This allows remote monitoring and operation ensuring that the streetlights are automatically switched on or off based on location specific solar timings around the year. Table 3.6 provides an overview of the energy savings and emissions reduction achieved under the scheme.

Table 3.6 Activities and initiatives under the MuDSM programme

Year	Number of LED street-lights installed	Energy savings (billion units)	Emissions Reduction ($MtCO_2$)
2018-19	3,013,210	6.74	5.87
2019-20	2,278,792		
2020-21	832,873		
2021-22	802,426		

Source: BEE, 2023.

SLNP programme has led to energy savings of 6.74 billion units and reduction of 5.87 million tonnes of CO_2 emissions during FY 2021-22 on account of the implementations carried out during the FY 2017-21.

Municipal Energy Efficiency Programme

The Municipal Energy Efficiency Programme is being implemented with Atal Mission for Rejuvenation and Urban Transformation (AMRUT) to unlock India's immense potential for savings in energy and the cost of water supply. This is being done by retrofitting energy-efficient pump sets across 500 AMRUT cities.

To facilitate market transformation and replicate Municipal Energy Efficiency Program (MEEP) on a large scale in India, EESL had signed MoU with the Ministry of Housing and Urban Affairs (erstwhile MoUD) on 28th September 2016.

As on 31st March 2020, agreements with 390 urban local bodies in 22 states and 3 union territories have been completed. EESL will carry out the upgradation of the pumping system including installing efficient pumps matched with system requirements, essential valves in the pipelines, and improved electrical systems for operation of the pump sets.

Energy audits are being conducted across different urban local bodies. As of 31st March 2021, energy audits for 335 cities have been conducted successfully. EESL has signed implementation agreements with 39 Urban Local Bodies (ULBs) in the state of West Bengal and 18 pumps have been replaced with an achievement of 25-30% savings.

3.3.2.3 Capacity building of DISCOMs

The capacity building programme for DISCOMs launched by Bureau of Energy Efficiency (BEE), aims to promote demand side management. The primary objectives are to undertake load management programmes, develop DSM action plans, and implement DSM activities in the relevant divisions of the DISCOMs. The activities initiated under this programme from 2017 onwards are (BEE, 2023):

- Included 62 distribution companies (DISCOMs) at pan India level.
- Dedicated DSM cells have been established at these DISCOMs.

- DSM action plans have been prepared based on load survey carried out for all beneficiary DISCOMs and submitted to DISCOMs for their implementation.
- DSM regulations have been notified for 24 States and 8 UTs. Remaining states are pursuing to notify their DSM regulations for their respective states.
- On DSM & energy efficiency, 1,450 master trainers from senior and middle management officials of DISCOMs have been trained and capacity building of 7650 circle level officials have been trained under this program.
- 69 DSM proposals have been prepared for 53 DISCOMs and submitted to respective DISCOMs for implementation is estimated that there is a saving potential of 22919 MW and an annual saving of about 62696 MU lies with these 28 DISCOMs and the investment requirement is about Rs. 44, 994 Crore.

3.3.3 Supply-side initiatives in the power sector

3.3.3.1 Thermal Power

There are currently a limited number of energy sources and technologies that countries can use to power their growth and development. Geographical, technological, economic, and political constraints, or a combination of some or all of them impede the development and penetration of energy technologies uniformly across the world. However, expanding and modernising industrial production, improving agricultural productivity, increasing the provision of infrastructure for housing, transport, healthcare, and education among other things, all require an increase in energy supply. In the last decade, India has increased the capacity of variable renewable energy (VRE) sources in its power system exponentially. For example, the capacity of VRE sources, that include solar, wind, small hydro, and biomass-based energy sources, was 18 megawatts (MW) in 1990. By March 2023, the capacity of these sources of power has increased to 125.15 GW. This means that the country has added about 3,792 MW of RE capacity (not counting large hydropower) every year since 1990. Installed capacity of solar energy in India has increased by more than 25 times from 2.63 GW in March 2014 to 66.78 GW in March 2023 (CEA, 2014; CEA, 2023b).

This RE expansion in India has been facilitated by fiscal incentives, subsidies, and policy support which will be discussed in the next section. However, VRE sources, especially wind and solar energy, can vary significantly over a span of 24 hours, across days, and across seasons. In India, the availability of wind energy is higher during monsoon when annual energy demand is relatively low due to a lower agricultural load. On the other hand, solar energy supply varies daily, going from zero to maximum capacity in a span of less than 12 hours, even as the total availability changes seasonally as well. Daily energy demand patterns do not follow the availability-based generation pattern of VRE sources; In most regions in India, power demand peaks in the evening, when there is no solar energy. Therefore, as the amount of VRE-based power generation expands, it is imperative that the capacity of the system to buffer its variability is also strengthened.

Intermittency introduced in the grid by smaller amounts of VRE can be absorbed by the grid and grid balancing can be achieved by ramping down (and up) other sources of energy. However, the potential for ramping is constrained technologically. Natural gas and hydro plants have higher ramping speeds and are therefore well suited for grid balancing. Unfortunately, India's natural gas reserves are low and hydro resources, in addition to being geographically constrained, are also used in India for multiple critical purposes such as for drinking water supply and irrigation. In addition to the challenge of managing this daily variability, a long period of low generation from VRE sources, because of environmental conditions, can also lead to concerns of energy security (Kanitkar et al., 2021).

Battery Energy Storage systems (BESS) are expensive. Ministry of power procures 1000 MWh of battery storage at Rs 10 Per unit. Hydrogen as a storage technology has promise and can be plausible in the medium to long-term. The National Hydrogen Mission launched in 2023 by the Government of India is an important step in this direction. For the near term to possibly midterm, with increasing energy demand, and currently available technology, India's energy mix is therefore critically dependent on coal, for supplying the increasing energy demand and also for backing-up and balancing the increasing amount of VRE sources in the grid.

Thermal power capacity based on coal and lignite form 52% of the total installed capacity in the country as of 31 March 2022 and provide 72% of the total electricity supply for the FY 2021-22 (NPP, 2022; CEA, 2022c). This capacity forms the baseload of the electricity supply and also aids in balancing the grid. Over the last decade, roughly 80% of the generation has been supplied by thermal power stations. Figure 3.4 shows the annual generation from thermal power plants with respect to total generation between 2010-11 and 2021-22(P).

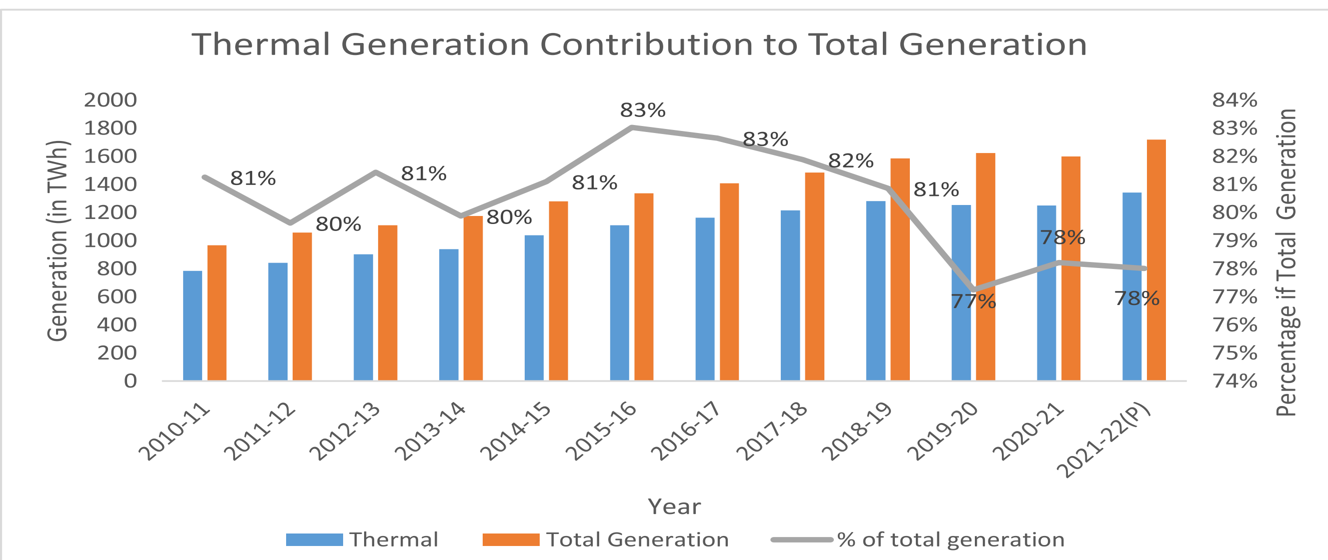

Figure 3.4 Annual Electricity Supply from Thermal Power Plants between 2010-11 and 2021-2022 (P)
Source: MoSPI, 2023a.

Acknowledging both, the critical role of thermal power plants (especially those based on coal), in India's power sector and India's responsibility to contribute to climate change mitigation, the Government of India has initiated multiple programs to improve the efficiency and reduce emissions from thermal power stations.

Transition to Super-critical, Ultra-super-critical, and Advanced ultra-super-critical plants

Programs to replace existing sub-critical plants (<500MW) with super-critical, ultra-super-critical, and advanced ultra-super-critical plants have been initiated by the Government of India.

About 241 Units with capacity of 17.3 GW have been retired from the 10th Plan period onwards till September 2021 (MoEFCC, 2022a). About 31.6 GW of new thermal capacity is under construction (CEA, 2021b) and is expected to be commissioned by 2030. The transition to super critical plants allows for increased operational, economic, and environmental benefits. Overall, due to higher efficiency of supercritical and advanced supercritical plants, it is expected that fuel consumption, auxiliary consumption, and water consumption will reduce (Krishnan et al, 2019). Super-critical units have an emissions factor of 0.816 kg CO_2/kWh based on designed heat rate, as compared to 500 MW sub-critical plants where the emissions factor is 0.853 kg CO_2/kWh (CEA, 2020a).

The clean coal technologies such as Supercritical, Coal Gasification, Ultra Supercritical and Advanced Ultra Supercritical Technologies are being adopted to support the transition of coal and lignite-based power supply: By 2030, about 30.6 GW of super-critical and ultra-super-critical capacity is expected to be commissioned. India also aims to achieve about 100 million tonnes of coal gasification by 2030 through investments exceeding INR 4 Trillion (PIB, 2020a).

Use of Clean Coal Technology like Coal Gasification would mitigate the adverse Environmental Impact of conventional Coal Usage and the following steps have been undertaken to promote sustainability and development of Coal Gasification Technology in the country:

a. A new Sub-sector ‘Production of Syn-Gas leading to coal gasification’ has been created under the Non-Regulated Sector linkage auctions in order to encourage coal gasification technology so that new consumers requiring coal for coal gasification are incentivized.

b. Government has approved in 2022 that Coal India Limited / SCCL may provide long term allotment of coal to their own gasification plants. This move will encourage the coal gasification technology in the country and will help in early establishment of this new use of coal.

To encourage such use of clean fuel sources, the government is providing a 50% rebate on revenue share to the successful bidders of coal mines, for quantity of coal consumed or sold or both for coal gasification or liquification. (PIB, 2022a). Bharat Heavy Electric Limited (BHEL), National Thermal Power Corporation (NTPC), and Indira Gandhi Centre for Atomic Research (IG-CAR) formed a consortium in 2010 to promote research and development of advanced ultra-super-critical technology in India. Two Ultra Supercritical technology units of 660 MW capacity each have already been commissioned in August 2019. Plants based on ultra-super critical technology emit about 7.6 per cent less CO_2 as compared to conventional sub-critical units (MoEFCC, 2021a).

Perform Achieve and Trade (PAT)

Thermal power plants have participated in the second and third cycle of the Perform Achieve and Trade (PAT) scheme. Under this scheme they were able to achieve significant emissions reduction as shown in Table 3.7. In PAT cycle II, thermal power plants were able to overachieve their target by 21%, showing that steps taken for energy efficiency have resulted in emissions reduction (BEE, 2023).

Table 3.7 Achievements under PAT Cycles II and III for thermal power plants

PAT Cycle	Period	Energy Savings Target (Mtoe)	Energy Savings Achieved (Mtoe)	Reduction in CO_2 Emissions ($MtCO_2$)/year*
II	2016-2019	3.134	3.435	11.57
III	2017-2020	0.406	0.724	2.94

Source: BEE, 2023.
***The emission reduction numbers are for the last year of the respective PAT Cycle.**

3.3.3.2 Hydro Power

As of 31st March, 2023, the installed capacity of hydro power in India is about 52 GW, of which about 46.8 GW is classified as 'large hydro power' (i.e. power plants of greater than 25 MW capacity) and about 4.9 GW is of small hydro power (CEA, 2023b). Of the large hydro capacity, about 4.9 GW is also operational as pumped hydro storage (CEA, 2023b). Figure 3.5 shows the expansion of hydroelectric power over the past decade.

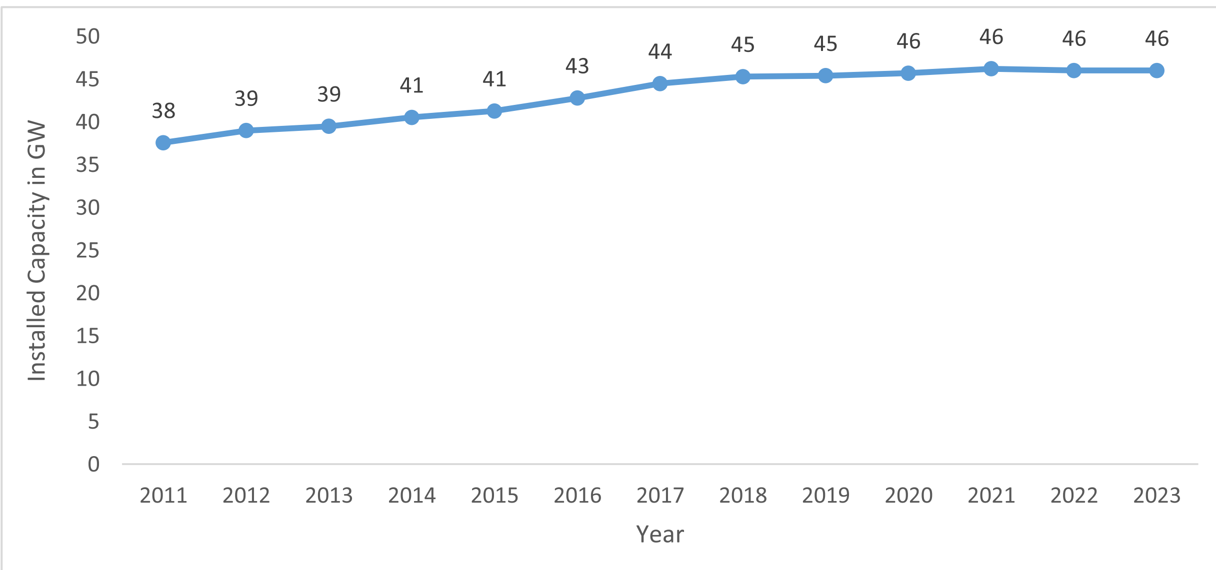

Figure 3.5 Installed capacity of hydroelectric power above 25 MW (CEA, 2023a)

Table 3.8 shows the as yet unutilised potential for hydroelectric stations and pumped storage plants in India.

Table 3.8 – Estimates of unexplored potentials of hydro power and pumped storage plants

	Identified Hydro Capacity in GW
Conventional Hydroelectric Plants	145.3
Pumped Storage Plants	96.5

Source: MoP, 2019.

On an average, around 10% of total generation over the past decade has come from hydroelectricity. Figure 3.6 shows the contribution of hydroelectric power in total electricity generation between 2010-11 and 2021-22(P).

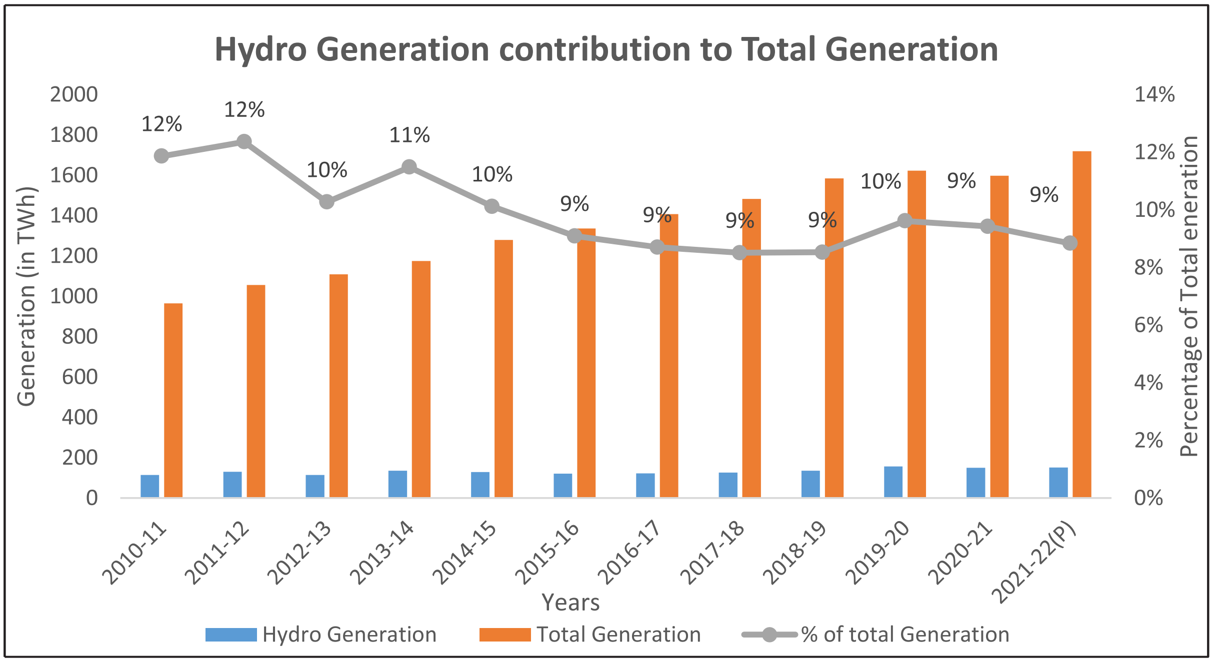

Figure 3.6. Generation and contribution of hydroelectric power between 2010-11 and 2021-22(P)

Source: MoSPI, 2023a

About 31.4 GW of large hydroelectric installed capacity is expected to be commissioned by 2030. This includes 76 projects across the country, and around 6580 MW of Pumped Storage Capacity (MoP, 2021b).

Generation from hydroelectric plants and pumped storage plants has a crucial role to play for future RE capacity expansion. Hydro power plants have fast ramp rates, they provide stability for RE generation and help in meeting peak demand. Additionally, excess RE generation can be stored in pumped storage plants. As hydro-power technology has reached market maturity, and these plants can be constructed with the nation's domestic resources, they have the potential to provide a source of stable power supply without reliance on imports. This supports India's vision of energy secure expansion of sustainable energy supply. The Ministry of Power issued a notification (vide No. 23/03/2016-R&R) on 29 January 2021 which included the Hydropower Purchase Obligation (HPO) to be met by Distribution Companies (DISCOM) as a part of their Renewable Purchase Obligation (RPO) on a yearly basis (MoP, 2021b). The HPO trajectory from FY 2022-23 to FY 2029-30 is shown in the table below.

Table 3.9 – HPO trajectory till 2030

Year	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
HPO	0.35%	0.66%	1.08%	1.48%	1.80%	2.15%	2.51%	2.82%

Source: MoP, 2022d.

3.3.3.3 Nuclear Power

Nuclear power capacity has been growing slowly in India over the last decade. There are currently 22 commercial nuclear reactors totalling 6.78 GW in India as of now (31st March 2023). The growth in nuclear power capacity between 2010 and 2022 is shown in Figure 3.7.

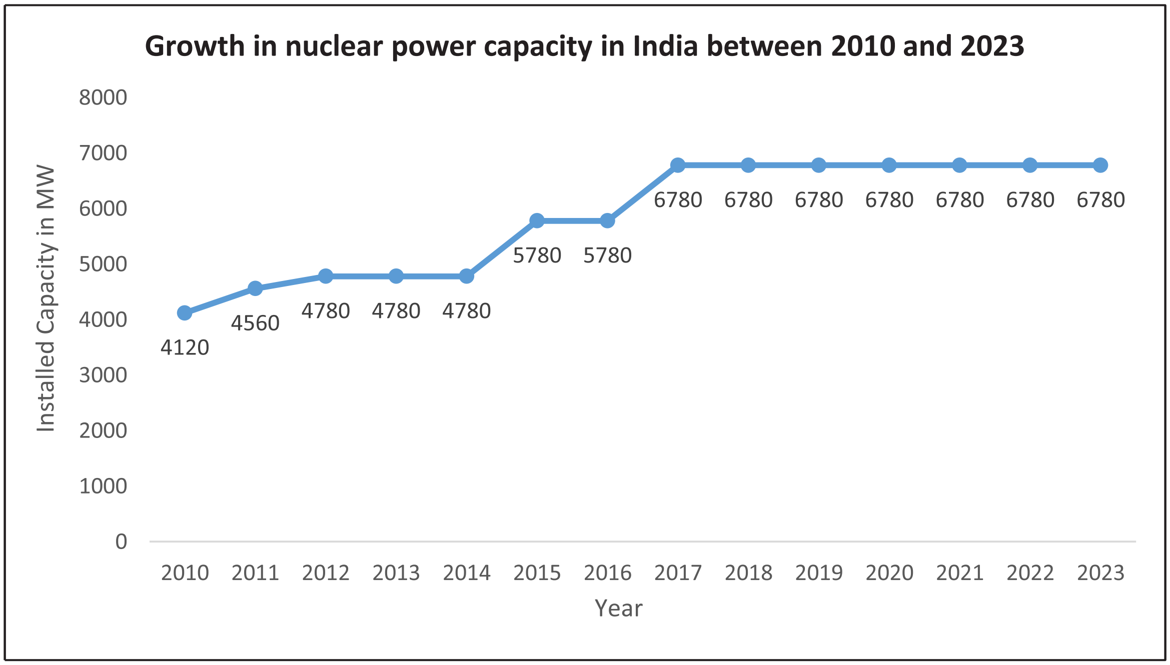

Figure 3.7 Growth in nuclear power capacity in India between 2010 and 2023

Source: CEA, 2023a

On an average, nuclear energy has contributed about 3% to the total generation in the country over the past decade. Figure 3.8 shows the trend in electricity generation from nuclear power plants and their contribution to the total electricity generation between 2010-11 and 2021-2022(P).

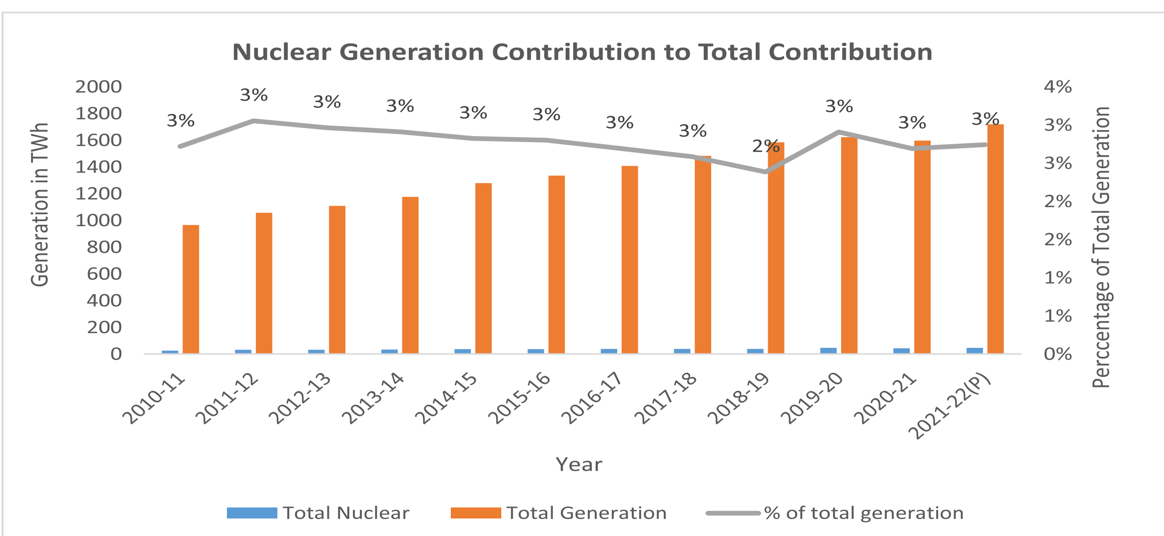

Figure 3.8 Electricity from nuclear power plants and contribution to total electricity generation

Source: MoSPI, 2023a

By 2027, an additional capacity of 5,800 MW is expected to be commissioned. By 2030 therefore, the capacity of nuclear power generation is expected to increase to 15,480 MW (Department of Atomic Energy, 2020).

3.3.3.4 Solar Power

The Government of India is providing sustained policy support as well as improved cost competitiveness for development of clean sources of energy. It has taken massive efforts to increase generation from solar power which can be seen from the growth in solar capacity over the last decade.

Figure 3.9 shows the growth of solar capacity in India between 2015 and 2023. Solar energy contributes to more than 50% share in the total RE segment making it the largest contributor among all RE sources.

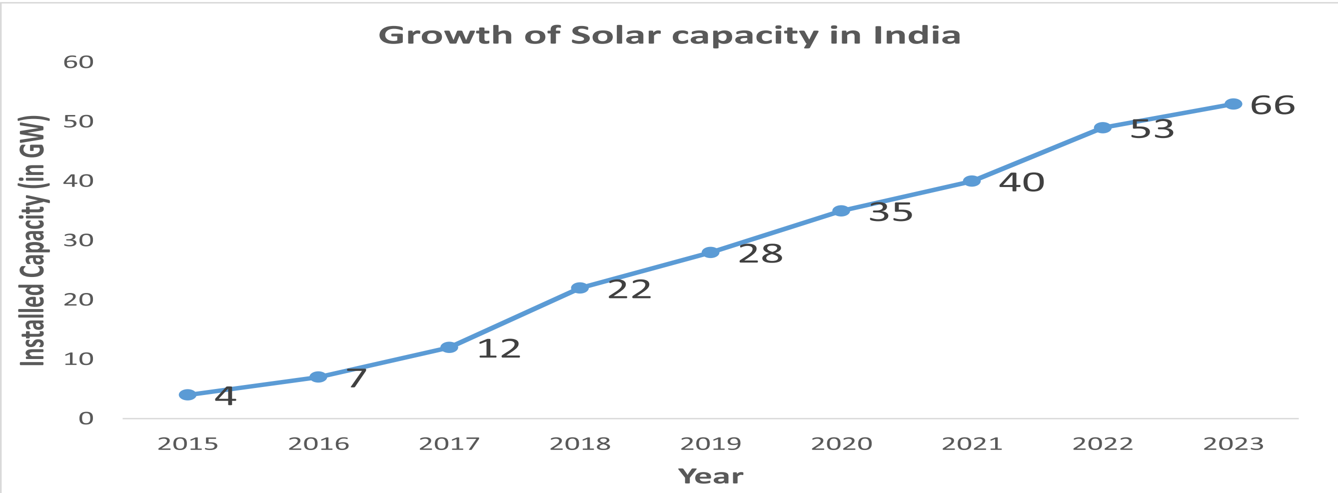

Figure 3.9 Growth of Solar capacity in India between 2015 and 2023
Source: CEA, 2023

The policies and fiscal incentives in place to promote solar energy and other renewable energy sources are discussed in detail in subsequent sections.

3.3.3.5 Wind Power

India has made early investments in wind power. Along with solar, wind capacity has also increased over the last decade. The growth of wind capacity in India between 2015 and 2023 is shown in Figure 3.10.

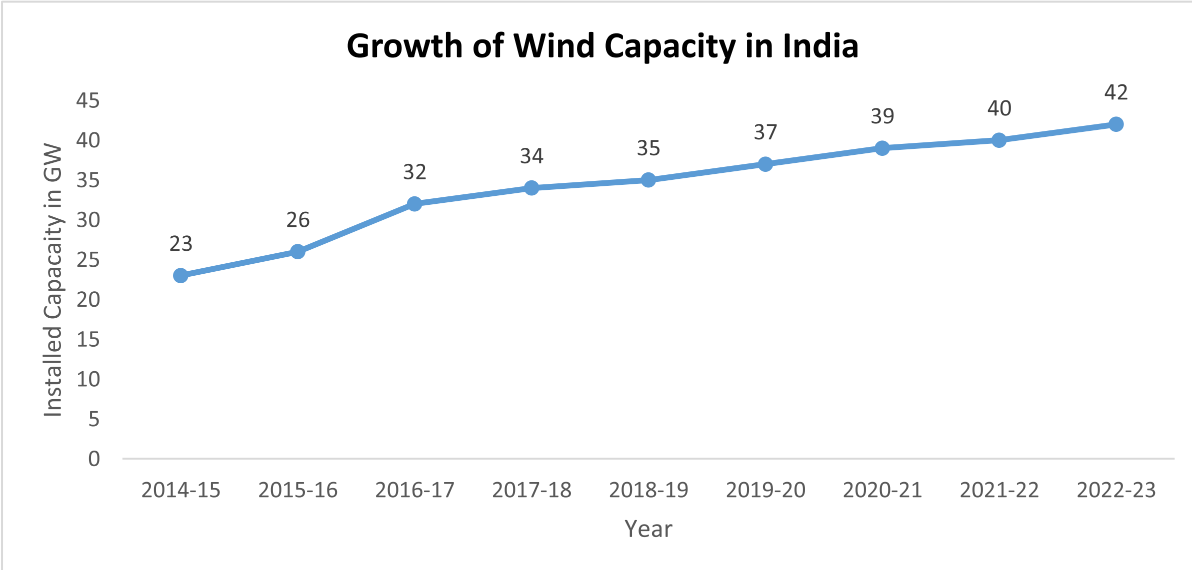

Figure 3.10 Growth of Wind Capacity in India
Source: NIWE, 2021; CEA, 2023c

The National Institute of Wind Energy (NIWE) has estimated the wind potential in India to be 695.5 GW at 120 m hub height (MoSPI, 2023a).

3.3.4 Policy Initiatives for increasing RE penetration

3.3.4.1 Policies and guidelines for increasing RE and non-fossil fuel deployment

The share of variable RE in the total installed generation capacity has increased from 14% at the end of FY 2014-15 to 30% at the end of FY 2022-23. Between 2015-2023, while the total generation capacity has increased at a CAGR of 5%, variable RE generation increased at a CAGR of 14% (CEA, 2023a). Renewable Generation Obligation as per Revised Tariff Policy, 2016 notified by the Ministry of Power in February 2023, mandating coal/lignite-based thermal generating station to establish renewable energy generating capacity of a minimum of forty percent (40%) of the capacity (in MW) or procure and supply renewable energy equivalent to such capacity. The country also has a lot of untapped renewable energy potential. Therefore, The Union Government and respective State administrations have offered policy and regulatory support to access the potential of renewable energy (Soonee et. al., 2012).

Electricity Act 2003

The Electricity Act, 2003 laid the foundation for the development of renewable energy in India. Sections 61 (tariff regulation) and 86 (functions of state commission) of the Act specifically outline the promotion of cogeneration and generation of electricity from renewable sources by providing suitable measures for connectivity with the grid and sale of electricity. The Act further specifies the purchase of electricity from renewable sources and a percentage of the total electricity consumption in the area of a distribution licensee. Also, the Act advises the SERCs to promote electricity generation from renewable sources.

National Electricity Policy 2005

The National Electricity Policy 2005 stated an urgent need to promote the generation of electricity from renewable sources. Initiatives were encouraged to reduce the capital cost of renewable projects to reduce the cost of energy by promoting competition within such projects.

Tariff Policy 2006

The Tariff Policy of 2006 included provisions regarding renewable energy and co-generation. It mandated respective state electricity commissions to fix a minimum share (percentage) for energy purchase from renewable sources considering resource availability and tariff impact.

National Action Plan on Climate Change 2008

The National Action Plan on Climate Change (NAPCC) was launched in 2008. It consists of nine missions which are aimed at achieving the country's mitigation and sustainable development goals in various sectors. The Jawaharlal Nehru National Solar Mission (JNNSM) is one of these nine missions which promotes increasing share of solar energy in the total energy supply mix and thereby address the energy security challenge (MNRE, 2021a). It aimed to deploy 100 GW of solar power by the year 2022 with 40 GW of grid-connected rooftop projects and 60 GW of large and medium land-based solar-power projects This mission also promotes 2 GW of off-grid solar applications, including 20 million solar lights by 2022. Major initiative is to enable a policy framework to create a favourable environment for developing solar manufacturing capacity which includes supporting Research and Development and capacity building activities. A solar RPO of 0.25% was set up in FY 2010 and an increase of 0.25% every year till it reaches 3% in FY 2021. Presently, this aim has been overachieved as the current solar RPO for the FY 2021-22 is 10.5%, indicating a significant growth of solar power.

Tariff Policy 2016

The Tariff Policy 2016 promotes the Renewable Energy Certificate (REC) mechanism for compliance with Renewable Purchase Obligations (RPO). RPOs are mandatory requirements for distribution utilities to purchase a certain percentage of their total electricity requirements from renewable energy sources. While RPOs were introduced earlier, the Tariff Policy of 2016 provided a long-term trajectory for RPOs as indicated by the Ministry of Power (MoP) in consultation with the MNRE. RPO and REC mechanism are covered in detail in the later part of the chapter.

3.3.4.2 Impact of Electricity Act 2003 and Tariff Policy 2006 on Renewable energy expansion

The passing of the Electricity Act, 2003, the Tariff Policy, 2006, state-level policies, quantity-based instruments, and greater private sector participation has played a crucial role in promoting the development of installed renewable capacity. Electricity Act, 2003 explicitly mandated the State Electricity Regulatory Commissions (SERCs) to develop RE. Following this, many states introduced Feed-in-Tariff policies. Feed-In Tariff (FIT) is a policy mechanism which provides long term contracts at higher prices to renewable energy producers compared to conventional sources. This helps RE generation to become more competitive. FITs and RPOs (Renewable Purchase Obligations for DISCOMs) constitute the backbone of the policy of a majority of states in India to promote power generation from renewable energy sources.

The Electricity Act, 2003 created a conducive environment at the national level for States to promote RE by recognizing this new source of electricity as a priority and the Tariff Policy of 2006 provided more precision on the timetable for the implementation of support measures. Schmid (2012) studied the empirical effect of the Electricity Act, 2003 and the Tariff Policy, 2006 on developing renewable energy in nine Indian states in India viz., Andhra Pradesh, Gujrat, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh, and found that these public policies had a significant impact on the development of new technologies in the renewable energy sector.

3.3.4.3 Incentives extended to VRE sources in the operational phase

Must run status for Renewable Energy Plants

According to the Indian Electric Grid Code (IEGC) 2010, renewable energy sources along with nuclear power plants are accorded 'must run' status. The 'must run status' policy implies that the distribution utilities (DISCOMs) must purchase all the power produced by the renewable generators irrespective of exceeding the utilities' regulatory mandate for obligatory purchases (CERC, 2010). This effectively implies that renewable energy plants do not have to follow the load dispatch protocol as other conventional plants and RE must be dispatched when it is available. Curtailment is not allowed unless other than for technical reasons and grid security issues.

However, this has resulted in an overall rise in power procurement costs for the DISCOMs and finally for consumers. Kanitkar et al. (2021) estimates that states in Southern India, which is the region with the highest installed capacity of RE, pay an additional cost of $200 to $350 million/year as a result of this policy. These costs do not include the additional taxes paid on coal or the cost of grid integration. This is simply the avoided cost of carbon incurred by the states when they back down cheaper power to accommodate RE generation when it is available.

Renewable Purchase Obligations

Renewable Purchase Obligations (RPOs) are quantity instruments that target the quantity of renewable energy produced. The Electricity Act, 2003 mandated uniform RPO in which State Electricity Regulation Committees (SERCs) determine the obligated entities under the RPO policy measure, comprising distribution companies, captive consumers, and open access users to provide a fillip to the ambitious renewable energy targets. The SERCs then set a percentage of total electricity consumption that must be satisfied by renewable energy. SERCs determine the RPOs based on each state's varying renewable energy potentials and their impact on power pricing in a given state.

The Electricity Act, 2003 further mandates that any entity, whether obligated or not, can choose to buy and consume RE based on their requirements either through own generation from renewable energy sources or by procuring RE through open access from any developer with whom an agreement is made, or by requisition (order) from a distribution licensee. Also, the obligated entities can meet their RPO requirement by purchasing Renewable Energy Certificates (RECs) under the applicable regulations. The REC mechanism was introduced to enable more states and consumers to meet their renewable purchase obligations cost-effectively (Chatterjee, 2017). The RPO policy is instrumental in driving renewable energy installations in India. The NAPCC envisaged a dynamic minimum Renewable Purchase Standard of 5% during FY 2009-10, which increased by 1% per annum over the next ten years.

Total RPO increased to 24.61% for the year 2022-23. As per the mandated long-term trajectory for RPO, 10.50% of the electricity procured by any State must be from solar energy sources by 2021-22 (MoP, 2021b). Table 3.10 shows the long-term RPO trajectory specified by the Ministry of Power beyond FY2022.

Table 3.10 RPO trajectory specified by the Ministry of Power, Government of India

Year	Wind RPO	HPO	Other RPO	Total RPO
2022-23	0.81%	0.35%	23.44%	24.61%
2023-24	1.60%	0.66%	24.81%	27.08%
2024-25	2.46%	1.08%	26.37%	29.91%
2025-26	3.36%	1.48%	28.17%	33.01%
2026-27	4.29%	1.80%	29.86%	35.95%
2027-28	5.23%	2.15%	31.43%	38.81%
2028-29	6.16%	2.51%	32.69%	41.36%
2029-30	6.94%	2.82%	33.57%	43.33%

(HPO- Hydropower Purchase Obligation)*
Source: Ministry of Power order No. 09/13/2021-RCM (MoP, 2022d).

Waiver of Inter-State Transmission Charges for Solar and Wind Energy

The National Tariff Policy (NTP) of 2016 provides that 'In order to further encourage renewable sources of energy, no inter-state transmission charges and losses may be levied till such period as may be notified by the Central Government on transmission of the electricity generated from solar and wind sources of energy through the inter-state transmission system for sale'. The waiver is available for a period of 25 years from the date of commissioning of such projects and is limited only for those projects entering into Power Purchase Agreements (PPAs) for sale of electricity to the Distribution Companies for compliance of their renewable purchase obligation. Subsequently, this deadline was further extended to 30th June 2025 (MNRE, 2023b). This waiver is also applicable to solar-wind hybrid power plants, as well as solar photovoltaic projects commissioned under the second phase of the MNRE's Central Public-Sector Undertaking (CPSU) scheme and those commissioned under Solar Energy Corporation of India Limited's (SECI) tender under the manufacturing-linked capacity scheme. This reduces the delivered cost of electricity from VRE sources for the DISCOM by up to 0.65 rupees/kWh. The second phase of CPSU scheme was issued on 30 September 2019, for setting up 12 GW of Grid Connected Solar PV power projects (MNRE, 2019).

Renewable Energy Certificate (REC) mechanism

REC is a market-based instrument to promote renewable energy and facilitate renewable purchase obligations (RPO). Recognising that renewable resources are also not evenly distributed across the country, it encourages setting up of larger generation capacities at resource rich locations and, through a process of certification create a market-based instrument which can be traded, on Central Electricity Regulatory Commission (CERC) approved power exchanges, to obligated entities or voluntary buyers to fulfil their Renewable Purchase Obligation/Social Responsibility. High cost of generation from RE sources inhibits local distribution licensees from buying renewable power. However, through a combination of mandatory purchase obligations and renewable energy certificates, this problem is sought to be addressed (Soonee et. al., 2017).

In November 2010, the Ministry of Power (MoP) launched the Renewable Energy Certificate mechanism implemented by the Central Electricity Regulatory Commission (CERC) under the Jawaharlal Nehru National Solar Mission. The REC policy is aimed at addressing the mismatch between the availability of RE sources and the requirement of the obligated entities to meet their respective RPOs (Gupta & Purohit, 2013). The introduction of the REC framework creates a national market for RE generators to recover their costs. Following this, many generators stepped forward to register themselves under the REC mechanism.

The trading of RECs began in March 2011 on the Indian Energy Exchange (IEX) platform and Power Exchange of India (PXI). The trading takes place on the last Wednesday of every month on IEX and PXIL.

RECs have a finite lifespan of one thousand and ninety-five days (currently), within which they must be utilized. If unused, they will be revoked, resulting in an inventory loss for the holder. Going forward new renewable energy and storage technologies such as hydrogen, pumped hydropower, and off-shore wind are expected to come into the market. The inclusion of such technologies as separate shares in RECs will create a means to balance the high initial costs involved in their setup.

The yearly trend of RECs issued, RECs traded through power exchanges, and RECs self-retained are given in Figure 3.11 for the duration of 2011 to 2022. From the graph, it can be inferred that the redemption of RECs increased since the launch of the mechanism, and issuance of RECs reduced considerably after FY 2015-16 owing to a change in eligibility conditions pertaining to captive power plants.

Figure 3.11 RECs issued, redeemed, and self-retained annually between 2011-12 and 2021-22

Source: (POSOCO, 2022a); (POSOCO, 2022b)

Relaxation from charges payable due to deviation by the way of over/under injection

The Central Electricity Regulatory Commission (CERC) has given relaxation to Deviation Charges for generating stations based on wind or solar or hybrid of wind-solar resources in Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2022 (vide notification No. L-1/260/2021/CERC) (CEA, 2021c). The developers of renewable energy projects will be able to reduce the financial risks associated with the variable nature of RE resource supply due to this increase of the permitted deviation band.

Green Term Ahead Market (GTAM)

The GTAM, launched in 2020, facilitates additional avenues to RE generators for sale of renewable energy. It also enables obligated entities to procure renewable power at competitive prices to meet their RPO and provides a platform to environmentally conscious open access consumers and utilities to buy green power.

Green Day Ahead Market (GDAM)

The GDAM, launched in October 2021, facilitates a marketplace for trading of RE Power on a day-ahead basis for accomplishment of green targets. It supports the integration of green energy in the grid in an efficient, competitive and transparent manner.

Development of the Renewable Energy Management Center (REMC)

To address the large-scale integration of renewable energy in India's energy system, the Government of India has set up the Renewable Energy Management Centres (REMCs) at National, State and Regional level for real time monitoring of RE generation. The REMC provides support for forecasting and scheduling of RE generation through these control centers. REMCs are established/being established, at 13 locations so far and are helping in effectively controlling and managing RE generation. Through improved forecasting and scheduling RE resources are better utilized in the system, and at the same time grid security and reliability are also maintained.

Flexibility in Generation and Scheduling of Thermal and Hydro Power Stations through bundling with Renewable Energy

The Ministry of Power vide notification (No. 09/11/2021-RCM dated 12th April, 2022) notified a revised scheme for "Flexibility in Generation and Scheduling of Thermal/Hydro Power Stations through bundling with Renewable Energy and Storage Power" (MoP, 2022a). This scheme enables thermal/hydro power generators to establish or procure energy from a RE power plant which is either co-located within the premises or at other locations. The transmission charges for bundling RE power with thermal/hydro power when RE plant is co-located within the premises of a generating station are exempted. This will provide power generators an opportunity to optimally utilize RE sources and also help in reducing emissions.

The Central power sector regulator CERC through Grid code implemented 55 % minimum power technical level and all inter-state generating stations are presently operating in this flexible mode where during the day the generation is brought down to lower level and during evening peak, it is increased to full load. This operating scenario is now remaining to be perpetual as more and more Renewable power would be integrated into the grid.

Further, in view of the increasing RE integration in the Grid, CEA came up with regulation on 'Flexible Operations of Coal Based Thermal Generating Units', dated 25thJanuary, 2023 in which the coal based thermal power generating units shall have flexible operation capability with minimum power level of 40%.

Revised Policy for Biomass Utilisation through Co-firing in Coal based Power Plants

In order to promote use of biomass pellets in coal based thermal power plants and reduce use of coal, the Ministry of Power has issued the "Revised Policy for Biomass Utilisation for Power Generation through Co-firing in Coal based Power Plants" on 8th October, 2021 (MoP, 2021d). Under this policy, all thermal power plants are mandated to use coal along with a 5% blend of biomass pellets, made primarily of agro residue. With effect two years after the date of issuance of this order, and afterwards, the obligation shall grow to 7% (with the exception of those having Ball & Tube mills, the usage of biomass shall remain 5 percent).

3.3.4.4 Fiscal Incentives extended to VRE sources

The rapid growth in solar power installations has been aided by several policy measures implemented by the Central Government to ramp up VRE capacity additions in India.

- In 1987, the Government of India (GoI) set up a dedicated financial institution, Indian Renewable

Energy Development Agency (IREDA) to provide finance on concessional terms to the RE sector. Between FY 2015-16 to FY 2019-20 alone, IREDA has financed the wind sector to the tune of INR 26,137 Crores and has also provided INR 25,493 crores of finance to the solar energy sector (IREDA, 2020).

- On December 12, 2014, the Government of India rolled out the scheme for 'Development of Solar Parks and Ultra Mega Solar Power Projects' with an aggregate capacity of 20 GW that was enhanced to 40 GW on March 21, 2017. The timeline of the scheme is extended till 2025-26. Under the scheme, 50 parks of a total capacity of 37.45 GW have been sanctioned against target of 40 GW and these solar parks are at different stages of development. So far, in the sanctioned parks, solar projects of capacity of 10.24 GW have been commissioned. The total Central Grant approved under the Scheme is INR 8100 crores. In the approved parks, the required land of around 200,000 acres has been identified out of which land of over 163,000 acres has already been acquired for development of these parks.
- Government of India (through the Solar Energy Corporation of India Ltd. or SECI) provides Central Financial Assistance (CFA) of up to INR 25 lakhs per solar park for preparation of Detailed Project Report (DPR). Besides this, CFA of up to INR 20 lakhs per MW or 30% of the project cost, including grid-connectivity cost, whichever is lower, is also provided on achieving the milestones prescribed in the scheme.
- The cost of developing solar parks is met from the four main sources of funds (i) central grant up to the current limit of INR 20 lakhs per MW; (ii) loans from domestic/multilateral/bilateral funding agencies; (iii) State Government grants; and (iv) charges from solar developers in the form or upfront and periodic payments.
- The procurement of land for solar parks and handover of possession of the developed land to solar developers on a plug & play model (without any upfront investment) is one of the major enablers which is made available by the Central and State Governments
- Nine Central Public-Sector Undertakings (CPSUs) participated in the CPU Phase-I scheme which aimed at setting up of 1000 MW Grid Connected Solar PV power projects. Seven CPSUs are involved in Phase-II (12,000 MW) of this Scheme. As per the Ministry of New and Renewable Energy (MNRE), under the CPSU Phase-II Scheme, 8.2 GW capacity has been allocated and 1.5 GW has been commissioned.
- Since land is a constraint to reach the target of 100 GW solar energy capacity by 2022, rooftop solar scheme (RTS) was projected to achieve a target of 40 GW (out of the 100 GW solar by 2022). Under Rooftop Solar Scheme, against the target of 40 GW, total 9.3 GW capacity has been installed, including 2.2 GW in the residential sector. Further, Government has also launched a National Portal wherein the beneficiaries can directly apply for getting the rooftop solar systems installed. This scheme will be implemented with financial support to the tune of INR 11,814 crores through the DISCOMs (MNRE, 2021d). In addition, residential RTS installations are eligible for a 20% to 40% upfront investment capital subsidy.

- In 2015, GoI initiated the Green Energy Corridor (GEC) Project for evacuation of large-scale renewable energy from RE-rich states to other states in the country. Under GEC Phase-I Scheme, 8,940 circuit kilometres have been completed. Further, Phase-II with a target of 10,753 circuit kilometres of transmission has been launched by the Government. The estimated project cost is INR 10,141 crores with 40% of the total funds coming from an MNRE grant (INR 4,056 crore), 40% loan from KFW, Germany (EUR 500 million) and the balance 20% as equity from the states.
- Solar capacity addition presently depends largely upon imported solar PV cells and modules as the domestic manufacturing industry has limited operational annual capacities of around 2,500 MW for solar PV cells and 9,000-10,000 MW for solar PV modules. On April 28, 2021, GoI announced a production-linked-incentive (PLI) scheme for manufacturing 'High Efficiency Solar PV Modules', with an outlay of INR 4,500 crores over a five-year period (MNRE, 2021c). The key objective of this scheme is to promote manufacturing of high efficiency solar PV modules in India and reduce import dependence in solar power equipment. To further boost indigenous manufacturing, manufacturing linked tenders (3 GW solar cell & 3 GW solar module) have been issued. One of the major initiatives in Renwable Energy manufacturing sector is launch of Production Linked Incentive (PLI) scheme with 8737 MW capacity (fully integrated) awarded under tranche-1 and 39,600 MW capacity (fully/ partially integrated) awarded under tranche-2.
- GoI has also extended fiscal incentives such as accelerated depreciation, Goods and Services Tax (GST) at lower rates, concessional custom duty, eligibility for priority sector lending, etc., besides permitting Foreign Direct Investment (FDI) up to 100 percent for RE development.
- To overcome constraints in funding for RE projects due to various sectoral issues, the Reserve Bank of India (RBI) has also doubled the loan limits for renewable energy under priority-sector lending.
- In all, the Central Government has incurred a cumulative expenditure of INR 11,287 Crores from FY 2017-18 to FY 2020-21 (up to 16th March 2021) only to promote grid interactive VRE projects. In 2019, GoI also announced an aid package of Rs. 34,035 crores for small-scale solar energy projects in agriculture under the PM-KUSUM (MNRE, 2022) scheme.

3.3.5 Development of energy storage infrastructure

Energy storage has a significant role in grid integration of variable and intermittent RE generation sources. The Government of India has taken various steps and formed committees for development of storage capacity in India that will help large scale RE Integration into the system.

The Department of Heavy Industry (DHI) has brought out a Production Linked Incentive (PLI) Scheme viz: 'National Programme on Advanced Chemistry Cell (ACC) Battery Storage' for achieving manufacturing capacity of fifty (50) GigaWatt Hour (GWh) of ACC and 5 GWh of "Niche" ACC with an outlay of INR 18,100 crores.

Steps have been taken to enable procurement and utilisation of Battery Energy Storage System (BESS). In 2022, the Ministry of Power issued guidelines under section 63 of the Electricity Act (MoP, 2022a). The main objectives of these guidelines are to promote procurement of BESS in various formats (individual RE projects or separate) and for varied applications (power supply firming, ancillary services, grid support etc). Additionally, the guidelines also promote transparency and standardization for BESS projects. The guidelines specify that the BESS may be charged through a combination of RE and non-RE power. Particular business cases have been identified in these guidelines which are listed below:

- RE supply with BESS: BESS is included as part of the RE Project, and ownership of the RE and BESS assets lies with the generator. This can be utilised to meet peak power and firm dispatchable RE requirements of procurers.
- BESS with transmission infrastructure: This model aims to increase duration of use of transmission systems and strengthen grid stability.
- Storage as an asset for balancing services and flexible operations: In this case BESS is utilised by system operators for frequency control and balancing services.
- Storage for Distribution: This is for strengthening DISCOM operations. BESS can be connected at the load centres, and it may be suitably utilized by the DISCOM to manage its peak load, grid resilience, portfolio management and flexible operations.

Any business case other than the ones mentioned above may also be considered and will be subjected to the same guidelines. In March 2022, Solar Energy Corporation of India Limited issued a tender for a 500 MW/1000MWh Standalone BESS that will provide DISCOMs with storage facilities for on-demand use. The government has also promoted Pumped Storage Plants (PSP) and BESS by waiving off Inter-state transmission system charges for all projects commissioned up to 30th June 2025. The order was issued by the Ministry of Power on 21st June, 2021 (MoP, 2021a). Additionally, as per the Central Electricity Authority's (CEA) Optimal Energy Mix study, Pumped Storage Plants and BESS have been identified to be essential in meeting storage requirements in 2030 (CEA, 2020c). The projected capacity of Pumped Storage Plants required as per this study is estimated to be around 10 GW by 2030. Currently the installed capacity of PSP in India stands at 4.7 GW. Around 1.58 GW capacity is expected to come by 2026 and around 18 GW capacity is under survey and investigation (CEA, 2022b). Like the mandates set for RPOs, targets for purchase obligations from storage have also been set as demonstrated in Table 3.11.

Table 3.11 Long-term EPO targets from 2023

Financial Year	Storage (on energy basis)
2023-24	1%
2024-25	1.5%
2025-26	2%
2026-27	2.5%

Financial Year	Storage (on energy basis)
2027-28	3%
2028-29	3.5%
2029-30	4%

Source: Ministry of Power Order No. 09/13/2021-RCM (MoP, 2022d)

3.3.6 Promotion of Green Hydrogen technology

National Green Hydrogen Mission (NGHM) was launched in January 2023 with an outlay of Rs. 19,744 crores.

- The Guidelines for implementation of Strategic Interventions for Green Hydrogen Transition (SIGHT) Programme - incentive schemes for Electrolyser Manufacturing and Green Hydrogen Production, have been notified on 28th June 2023.
- Further, Request for Selection (RfS) for setting up Manufacturing Capacities for Electrolysers and for setting up production facilities for Green Hydrogen in India under said scheme have been issued in July 2023.
- NGHM portal has been developed for public awareness and scheme monitoring. 40 projects for Green Hydrogen/ Green Ammonia production and 19 projects for electrolyser manufacturing have been announced by various CPSUs/ Private Companies.

3.4 Mitigation in the industrial sector

The industrial sector has a critical role to play in the era of global warming. In India, the rapid development of the industrial sector is essential for poverty alleviation, the provision of employment and livelihoods, for increasing consumption and achieving India's developmental priorities as a developing nation. On the other hand, the transition to non-fossil fuel sources of energy and potential for abatement is extremely challenging in this sector, due to the costs involved as well as the availability and access to the requisite technology. Abatement technologies in many industrial sub-sectors are still in nascent stages of development, with little clarity on the feasibility of their implementation. A switch to low-carbon manufacturing will require adequate and reliable supply of cleaner sources of energy, as well as changes in the types of inputs and raw materials required in industries, both of which will impose high costs as current infrastructure installations might rapidly start becoming obsolete. Investment in technologies that enable recycling and reuse of the materials used could help in securing future supplies, as well as reduce the need for raw material extraction (Mitra, 2021).

The government is implementing various schemes for promoting domestic manufacturing, such as the 'Make in India' program to provide a boost to manufacturing in the country for creating 100 million additional manufacturing jobs in the Indian economy, as well as enhancing the contribution of the industrial sector to GDP to 25% by the end of 2022. In terms of current capacity, the sector's Gross Value Added (GVA) at current prices was estimated at US$ 348.53 billion as per the second advance estimates of FY21, while the GVA due to manufacturing is estimated to account for 19% of the country's real gross value added in the FY21 (MoEFCC, 2022a). The following sections provide a detailed discussion on current production capacities, energy and fuel consumption, interventions for efficiency improvement and emissions reduction or displacement achievements in key industrial sectors. The focus is on sectors that contribute the most to GHG emissions in India, even as other sectors have also been included. The following industries are discussed in further detail in this section – Cement, Iron and Steel, Aluminum, Fertilizers, Chemicals & Petrochemicals, Textiles, Paper & Pulp, and MSMEs.

3.4.1 Cement

Across all basic industrial processes in the world, cement production has been historically crucial in the growth of nations. India is the second largest manufacturer and consumer of cement globally. Like many developing nations, this increased production capacity has been and will continue to be instrumental in meeting the developmental needs of the nation. The industry has also been cognizant of its GHG emissions and has taken proactive measures to increase production efficiencies, while also reducing emissions per tonne of cement produced. This section describes the existing state of the industry, its energy and fuel use, and provide a list of actions taken for climate change mitigation.

3.4.1.1 Current state of cement manufacturing

The current total installed capacity of cement production in India is 556 million tonnes per annum (MTPA), which accounts for about 8% of the total global capacity (CMA, 2022). This production capacity is primarily supplied by a few large private companies. The industry has been the 5th largest contributor to the Indian exchequer and employs 20,000 people for every million tonnes of cement produced (ibid).

In FY2020 around 334 million tonnes of cement was produced. The present capacity operates at high levels of efficiency and this trend will improve for all future capacity addition. Figure 3.12 shows the installed capacity and production trends for cement for the period of 2015-2020 (CMA, 2022).

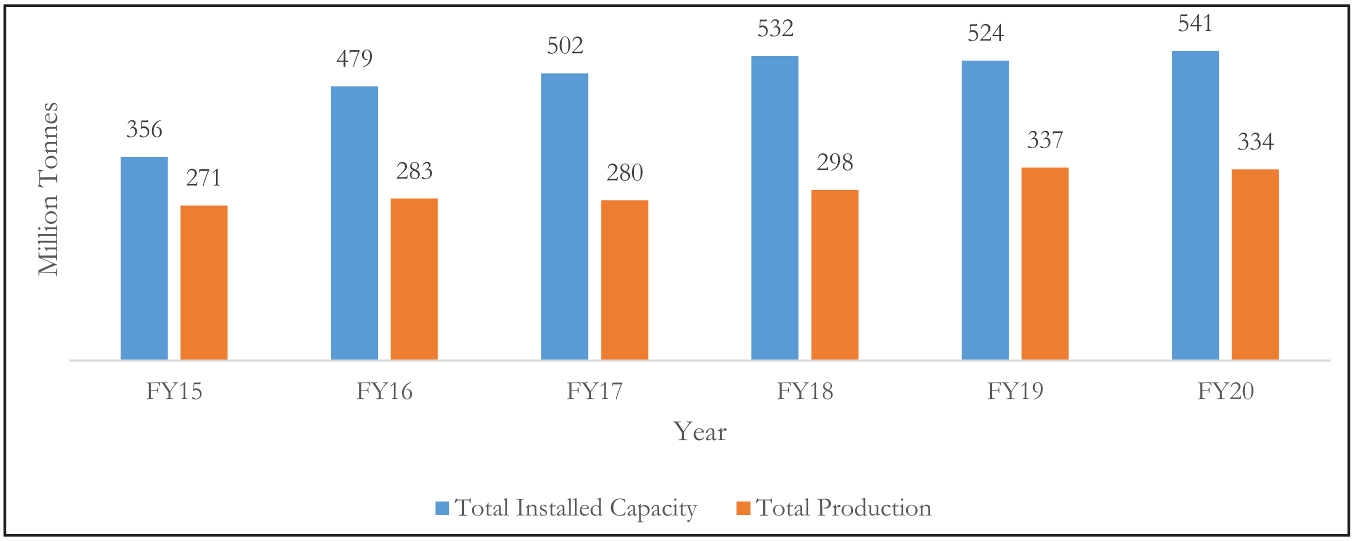

Figure 3.12 Annual Installed Capacity and Production in the cement industry

Source: Cement Manufacturers Association, 2022

The Indian cement industry's product profile has changed significantly over the years to include more blended cement in the mix. This essentially implies that the industry has consciously shifted to high quality and low carbon footprint production, enhanced by material use that promotes circular economy. Figure 3.13 shows the expanding trend of Portland Pozzolana Cement (PPC) over Ordinary Portland Cement (OPC) – a sign of increased utilisation of fly ash in cement production. In fact, about 26% of total fly ash was utilised in cement and concrete in FY2020. The cement industry also consumes 100% of slag residue from steel plants.

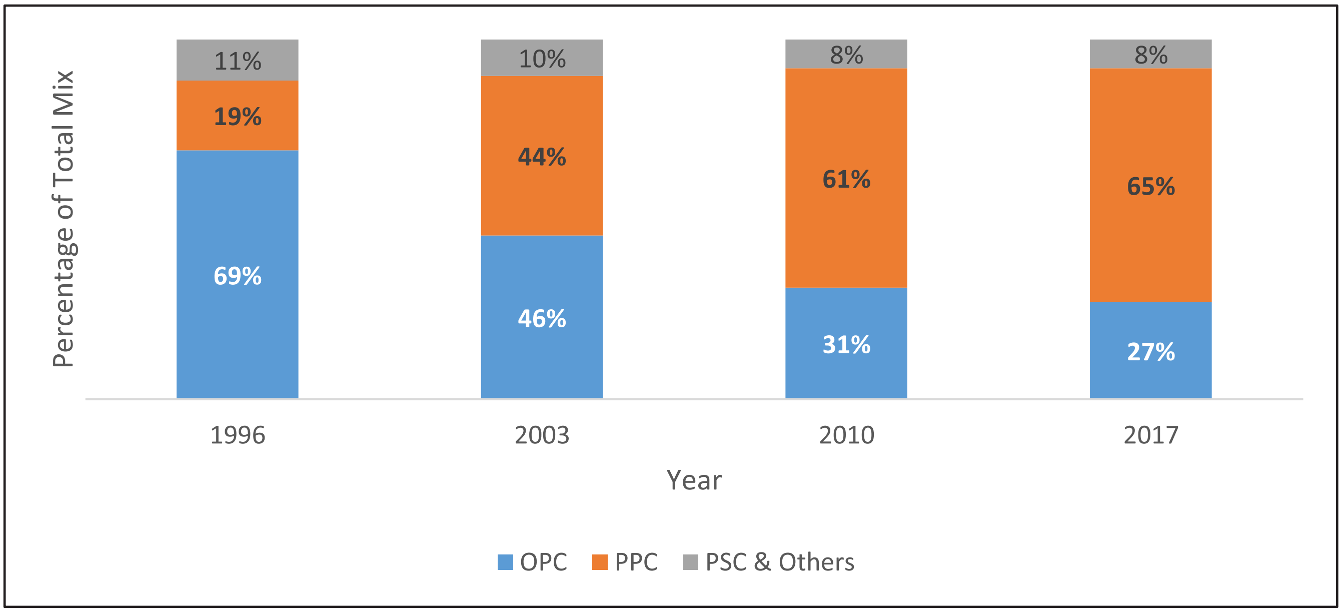

Figure 3.13 Cement product profile of the Indian Cement Industry
Source: Cement Manufacturers Association, 2022

Additionally, the cement sector has both energy use emissions, and industrial processes and product use emissions (IPPU). Steps to decarbonise the sector include utilisation of waste heat, alternative fuels, and carbon capture technology – thus targeting both type of emissions.

3.4.1.2 Energy Use & Fuel Consumption

The Indian cement industry is known for its efficient use of energy, with one of the lowest specific energy consumptions across the globe. Over the period of 1995-2015, there has been a 32% reduction in specific electricity consumption, from 110 kWh/ton of cement to 76 kWh/ton of cement (CII, 2019). Over the same time period, the specific thermal energy consumption reduced by 11% from 807 kcal/kg of clinker to 718 kcal/kg of clinker (ibid).

Coal and Lignite are the primary sources of energy used in the Cement manufacturing process with about 97% of the total fuel consumption coming from coal and lignite, 1% from oil and 2% from electricity (BEE, 2021). Figure 3.14 shows the trend of annual coal and lignite consumption over the years.

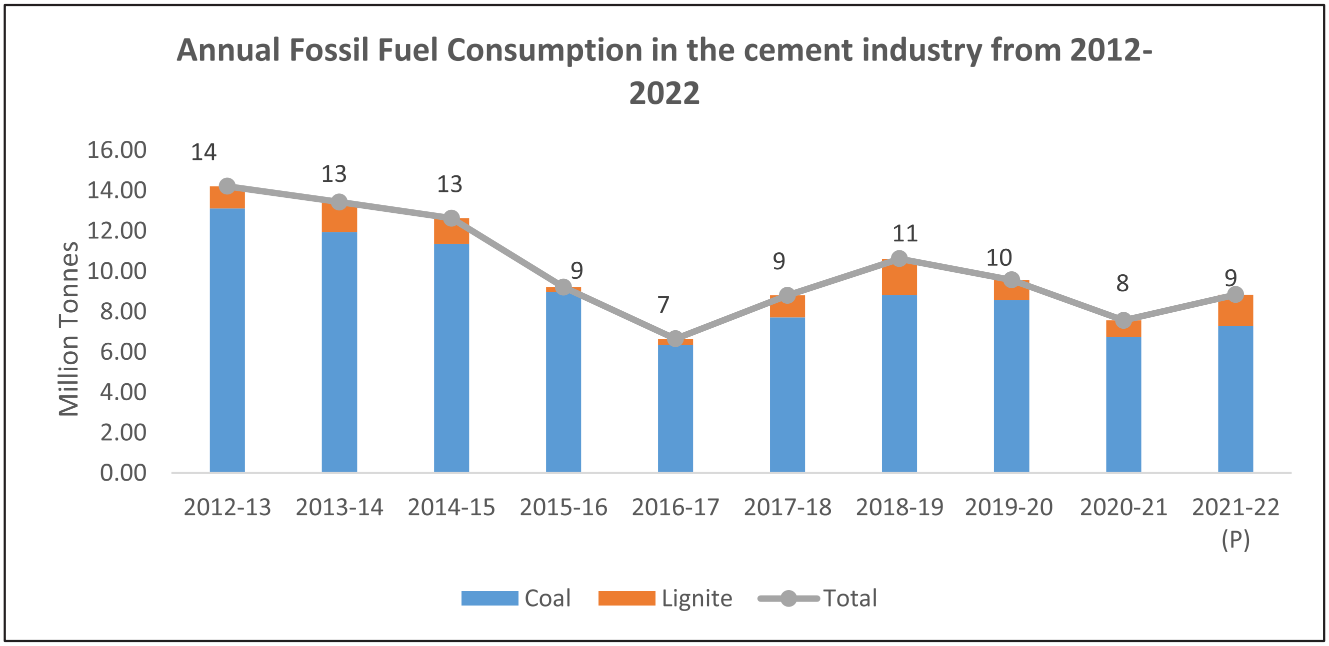

Figure 3.14 Annual Fossil Fuel Consumption in the cement industry from 2012-13 to 2021-2022(P)

Source: MoSPI, 2023a

3.4.1.3 Schemes & Interventions undertaken for Climate Mitigation

Reductions achieved through the Perform Achieve and Trade (PAT) Scheme

The Cement industry has been part of PAT cycles since its inception in 2012. New Designated Consumers (DCs) from the industry have participated in every rolling cycle. At present, the best performing plant in the industry consumes 19% less energy than the global average. Also, about 40% of the total installed capacity is less than 10 years old with the latest technology and equipment. Additionally, the Waste Heat Recovery Systems (WHRS) in the industry can meet up to 25-30% of the electrical power requirement, thus leading to a reduction of 1.2 kg of CO_2 per kWh (CMA, 2022).

Major steps implemented by the industry for emissions reduction are summarised below (MoEFCC, 2021g):

- Increased utilisation of alternative fuels and raw materials
- Installation of Waste Heat Recovery Systems (WHRS) from pre-heater outlets
- Installation of Kiln shell radiation recovery systems
- Calcium looping technology for carbon capture
- Blending of fly ash/ slag residue

Overall, in every cycle the industry has been able to overachieve its reduction targets and is expected to continue the same. In PAT cycle I, it was able to overachieve the target by 82% and in PAT cycles II and III, it was able to overachieve by 49% and 73% respectively. Table 3.12 summarizes these achievements in terms of energy savings and emissions reductions.

Table 3.12 Achievements of PAT in terms of energy savings and emissions reductions (Cement Industry)

PAT Cycle	Years	Energy Savings Achieved (in Mtoe)	CO_2 Emissions Reduction ($MtCO_2$)/ year*	Achievement over target (%)
I	2012-2015	1.48	4.34	+81.6%
II	2016-2019	1.559	5.45	+48.6%
III	2017-2020	0.156	0.339	+73.4%

Source: BEE, 2021.

***The emission reduction numbers are for the last year of the respective PAT Cycle.**

For PAT cycle I, there was a reported investment of about INR 26 billion spent on efficiency measures and technology upgrades (WBCSD and CII, 2019). If we consider the reduction in CO_2 emissions achieved in this cycle, then it has cost the industry about INR 5.9 billion per million tonne of CO_2 reduction. With continued efforts, the industry is expected to achieve CO_2 emissions of 0.35 tCO_2/t of cement production by 2050, which would be 45% lower than 2010 levels of 0.62 tCO_2/t (WBCSD and CII, 2019).

Utilisation of alternative fuels and raw materials (AFR)

The industry has also been able to expand its utilisation of alternative fuels and raw materials (AFR). Over time it has substituted 4% of its thermal energy use with non-recyclable plastics and municipal waste (CMA, 2022). In 2019-20 alone, roughly 0.3 million tonnes of plastic waste was utilised in cement co-processing or to produce refuse derived fuel (to be utilised in kilns) (CPCB, 2021). A variety of strategies have been put in place for AFR by companies that have reaped benefits through them. Some of these are listed below (IBEF, 2021a):

- Madras Cement's Alathiyur plant: Uses alternative fuels such as coffee husk and cashew nut shells which saves up to USD 1.7 million annually.
- UltraTech Cement: Uses tyre chips and rubber dust as alternative fuels. This results in a reduction of 30,000 tonnes of carbon emissions annually.
- Lafarge's Arasmeta plant: Substitutes 10% of coal with rice husks in kilns thus lowering its carbon emissions.

3.4.1.4 Future Targets, Potential Technologies for Substitution & Future Challenges

The Indian cement industry has considerably expanded the proportion of blended cement in the total mix. However, there is potential to increase further. Currently, some 17% of fly ash remains unutilised and the cement industry is considering ways to tap into this resource. There is also a regional pattern to fly ash utilisation with some states using fly ash below the national fly ash utilisation rate. Hence, there is potential to improve utilisation rates in these states (CMA, 2022). Also, composite cement in India mainly utilises slag and fly ash – a trend different from other developed nations who use other industrial waste as well. Introduction of new quality standards may aid in usage of other industrial waste and lead to further emissions reduction.

Additionally, companies such as UltraTech Cement and Dalmia Cement (market share: 39%) have already declared their intention to achieve carbon neutrality. UltraTech Cement aims to produce carbon neutral concrete by 2050, as per its commitment to 'The Global Cement and Concrete Association'. Dalmia cement aims to produce 100% low-carbon cement by 2031 for which it has a US$ 405 million carbon capture and utilisation investment plan. Additionally, it aims to be carbon negative by 2040 (IBEF, 2021a).

Steps to decarbonise also include efforts such as that of JK Cement Ltd., which in its MoU with the Punjab Renewable Energy Systems Private Limited, aims to increase the usage of biomass-based fuels and other alternative fuels to cut down its consumption of fossil fuels (IBEF, 2021a).

India has taken massive efforts for mitigation in spite of its financial, resource and technological constraints. While taking stock of its efforts and what is required for its future goals, the cement industry had identified key technologies that must be transferred, facilitated, or made available through technology transfers for increased contribution to emissions reductions. For the cement industry, the following additional technologies have been identified which would require additional investments (MoEFCC, 2021g):

- Technology for waste heat recovery from preheater exhaust and cooler vent for co-generation of power
- Wider adoption of grate cooler technology
- Wider adoption of low-NOx multi-channel burners for combustion

Overall, the cement industry has consistently improved production practices and overachieved its mitigation targets. While it has been able to achieve savings through the expansion of the mechanism of the circular economy, it has also invested massively to achieve its PAT targets. Future challenges on expansion of AFR, WHRS and carbon capture technologies lie primarily contingent on the access to climate finance and transfers of technology that India might receive.

3.4.2 Iron and Steel

3.4.2.1 Current state of Production and Consumption

India is the second largest producer of steel in the world, with an annual production of 109.14 million metric tons of crude steel and 102.62 million tonnes of finished steel in the FY 2019-2020. (MoS, 2022) In the global context, India's steel production, while the second largest, stands only at 10% that of the largest steel producer, the People's Republic of China. (IEA, 2020). India is also the world's largest producer of sponge iron, with a production of 33.1 million metric tonnes in 2020. India plans to achieve an annual production of 300 million tons by 2030-31 to meet growing demand. (MoS, 2017)

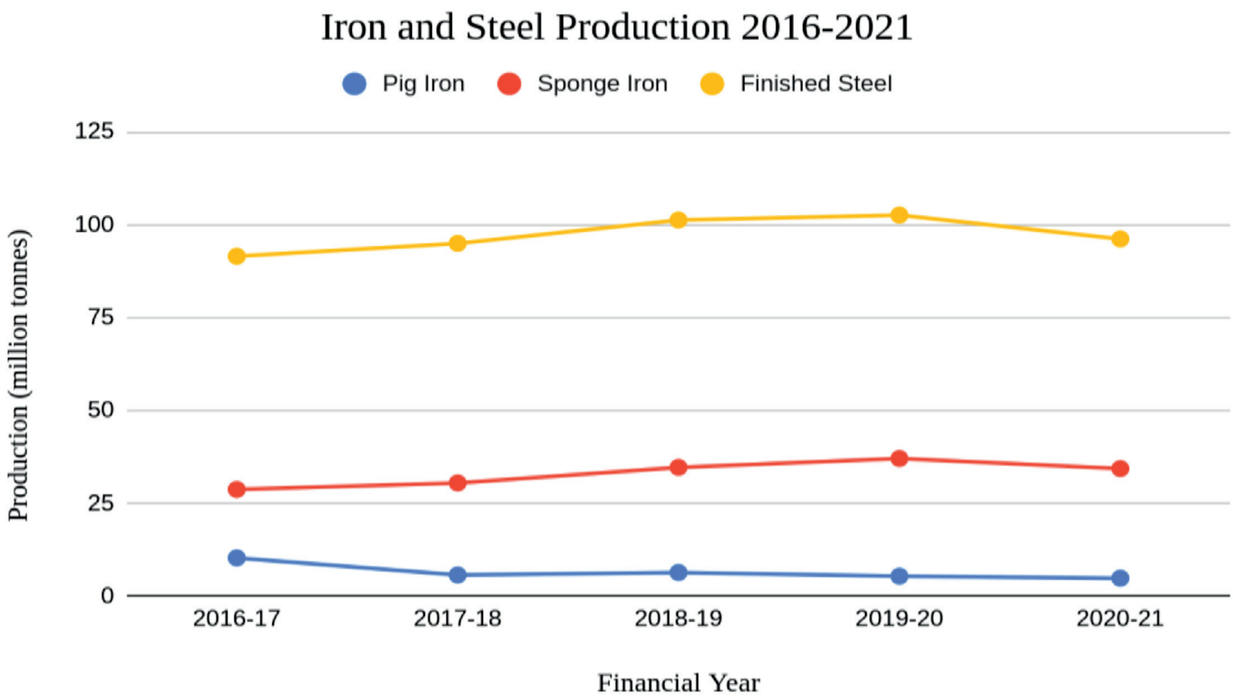

Figure 3.15 The production trends in sponge iron, pig iron and finished steel during 2016-2021
Source: LS Question, 2021

However, India's per capita consumption of steel stands only at 74.7 kg as of 2019-2020 (PIB, 2021e). While the per capita steel consumption has shown an increasing trend, rising from 57.6 kg in 2014-15, it is well below the global average of 224.5 kg per capita, and that of other large developing countries. Per capita steel consumption is projected to increase to 130 kg/capita by 2030-31. In rural India, the consumption is even lower at 19.6 kg/capita and is projected to increase to 38 kg/capita by 2030-31 (National Steel Policy, 2017).

A growing and competitive steel industry is central to meet the developmental objectives and industrial demands of India. Being a developing economy with a large population, India needs to meet increasing demands of affordable housing, public infrastructure, an expanding public transportation network, a growing automobile sector and the ship-building industry. India aims to domestically meet the entirety of the demand for steel for different industrial end uses by 2030-31, including high grade automotive steel, electrical steel, special steels and alloys for strategic applications.

The Iron and Steel sector in India employs a large number of people and has an employment multiplier factor of 6.8. It employs about 5 lakh people directly and about 20 lakh people indirectly. The Indian iron and steel sector is characteristically different from that of other large global producers due to the presence of a secondary steel sector which comprises a large number of small and medium enterprises engaged in production along the EAF/IF (Electric Arc Furnace/Induction Furnace) route utilising sponge iron, non-coking coal and scrap. As of 2016, there were 308 sponge iron producers, 47 electric arc furnaces and 1128 induction furnaces that produced semi-finished steel, and 1392 re-rolling plants that roll semi-finished steel into finished steel products. (National Steel Policy, 2017). By 2030, the secondary steel sector is anticipated to produce upto 90 million tonnes per annum, contributing 30% of the total targeted steel production of 300 million tonnes. These medium and small enterprises are part of the unorganised sector and provide livelihood opportunities for people in key iron ore bearing regions of India such as Jharkhand, Orissa and Chattisgarh. These small and medium steel enterprises are particularly vulnerable to external price shocks and the economic impacts of Covid-19.

3.4.4.2 Energy Use in the Iron and Steel Sector

Iron and Steel is a highly energy-intensive sector with a high consumption of fossil fuels for heating purposes, as well as coking coal for smelting in the BF/BOF (Blast Furnace-Blast Oxygen Furnace) production route. The consumption of coal, which is the major component of energy use in the steel industry and the sponge iron industry is given in the table 3.13 below.

Table 3.13 Consumption of coal in the steel and sponge iron.

Year	Coal consumption (in million tonnes)	
	Steel & Washery + Import Coking	Sponge Iron
2010-11	38.11	22.79
2011-12	47.86	21.69
2012-13	51.70	20.90
2013-14	53.05	18.49
2014-15	56.24	17.77
2015-16	57.08	7.76
2016-17	51.98	5.56
2017-18	58.45	8.53
2018-19	64.65	12.09
2019-20	63.74	10.53
2020-21	60.17	9.57
2021-2022 (P)	65.38	8.67

Source: (MoSPI, 2023a)

Within the industrial sector, Iron and Steel accounts for 7.2% of the energy used for the year 2021-22 (P) (MoSPI, 2023a). Apart from coal, the steel industry also uses other fuels such as diesel, fuel oil, lignite, Coalbed Methane (CBM) and natural gas in much smaller quantities. Since high-grade coking coal required for smelting is not available in India, it is imported. Coking coal import for the year 2019-20 stood at 51.83 million tonnes amounting to INR 61267 crores in value. (MoS, 2021).

3.4.2.2 Schemes & Interventions undertaken for Climate Mitigation

As communicated in India's first Nationally Determined Contribution (NDC), India is committed to minimizing the impact of the Iron and Steel Sector on global warming. The average emissions intensity of the steel industry was projected to reduce from 3.1 T/tcs (ton of CO_2/tonne of crude steel) in 2005 to 2.64 T/tcs in 2020 and subsequently to 2.4 T/tcs by 2030. The steel sector has achieved its 2020 targets, showing a decreasing trend in emissions intensity from 3.1 T/tcs in 2005 to 2.65 T/tcs in 2015 to 2.64 T/tcs in 2020. The steel industry is therefore well on track to achieve its 2030 targets.

Technologies adopted by industries

The reduction in emissions intensity in the iron and steel sector has been achieved by adopting a range of Best Available Technologies that improve the energy efficiency of production while mitigating greenhouse gas emissions. These technologies include power generation from waste heat recovered from sinter plants, hot stoves in blast furnaces and from coke dry quenching. Technological innovations adopted in the Blast Furnace include Bell Less Top Equipment (BLTE), Top Pressure Recovery Turbine (TPRT), Pulverised Coal Injection (PCI) and Dry type Gas Cleaning Plant (GCP). Interventions in steel rolling include the adoption of regenerative burners in reheating furnaces in rolling mills and hot charging of continuously cast products at higher temperature directly to rolling mills that eliminates the need for reheating furnaces. Measures have also been taken to establish cast house/stock house dedusting systems, convertor gas recovery in Blast Oxygen Furnace, energy monitoring and management systems, secondary fume extraction systems in steel melting, flexible thin slab casting and rolling for hot strip mills, near net shape casting, and adoption of Variable Voltage Variable Frequency (VVVF) drives for high-capacity electric motors.

Perform-Achieve-Trade (PAT) Scheme

Under the PAT flagship program of the Government of India, a total of 4.226 Mtoe of energy savings were achieved in the Iron and Steel sector during the period 2012-2020, amounting to total GHG emission reductions of 20.247 Mt CO_2eq.

Table 3.14 Emission reductions achieved through PAT cycles in the Iron and Steel sector

PAT cycle	Period	Number of designated consumers	Energy Saving Target (MToE)	Energy Saving (Mtoe)	Emission reduction ($MtCO_2$)/ year*
I	2012-15	67	1.486	2.1	6.51
II	2016-19	71	2.283	2.845	11.85
III	2017-20	29	0.457	0.572	1.691

Source: BEE, 2023.
**The emission reduction numbers are for the last year of the respective PAT Cycle.*

Projects undertaken in the small-scale steel sector

NEDO Model Projects in Energy Efficiency

In collaboration with the New Energy and Industrial Technology Development Organisation (NEDO) of the Government of Japan, the Government of India has facilitated the installation of model technologies in energy efficiency at large integrated steel plants in India: The Blast Furnace Stove heat recovery and coke dry quenching at Tata Steel Plant, Jamshedpur, and the sinter cooler waste heat recovery at the RINL (Rashtriya Ispat Nigam Limited) Steel Plant, Visakhapatnam. Further, Project Optimal Control technology on Energy Center for steel plants has been completed at the SAIL integrated steel plant in Burnpur.

Steel Scrap Recycling Policy

As per the World Steel Association, the integrated steelmaking route based on the BF-BOF, uses about 1,400 kg of iron ore, 800 kg of coal, 300 kg of limestone, and 120 kg of recycled steel to produce 1,000 kg of crude steel. Electric Arc Furnace (EAF) route, on average, uses 880 kg of recycled steel combined with varying amounts of other sources (DRI/HBI, hot metal), 16 kg of coal and 6439 kg of limestone, to produce 1,000 kg of crude steel. On an average, production of 1 ton of steel from scrap conserves an estimated 1,030 kg of iron ore, 580 kg of coal, and 50 kg of limestone. The utilisation of scrap steel in the EAF route saves energy and reduces carbon emissions (NITI Aayog, 2018). The Government of India has framed the Steel Scrap Recycling Policy, 2019 to facilitate and promote metal scraping centres and ensure the recycling of ferrous scrap and provides guidelines for collection and dismantling of scrap material (Steel Scrap Recycling Policy, 2019).

3.4.2.3 Potential for Substitution & Future Challenges

The Unlocking National Energy Efficiency Potential (UNNATEE) strategy plan for energy efficiency has identified the following technological interventions as best practices for possible adoption in the iron and steel sector in the future 2017-2031 (BEE, 2019):

1. Use of 100% pellets as iron burden reduce coal consumption, improves better metallization of pellets, reduces fines generation and iron ore loss and improves work environment.

2. High top pressure blast furnace also provides an ideal opportunity for recovering energy from the large volumes of pressurized top gas. Top Pressure Recovery Turbine (TRT) can be used to generate electricity from this high-top pressure.

3. Waste heat recovery from Direct Reduced Iron (DRI) process reduces massively the need for external fuel like coal for generating the same amount of electricity.

4. Direct rolling of hot continuous cast billet to produce Thermo Mechnically Treated (TMT) bars and therefore, completely avoided uses of furnace oil in reheating furnace.

5. Insulation of hot surface in after burning chamber and dust settling chamber in 500 tonnes per day (TPD) kiln. Surface to be covered with Rockwool and Galvanised Iron (GI) sheet cladding to reduce hot surface temperature from 150oC to 60oC.

There are a range of technologies, many already commercially available and some in the process of development, that can be deployed in the iron and steel sector with the provision of adequate investment and technological support, demonstrated in the table below.

Table 3.15 Potential technologies for enhancing energy efficiency and reducing emissions in the iron and steel sector

A.	**Commercially available technologies**
1.	Coke Dry Quenching (CDQ)
2.	Waste Heat recovery generation from low TPD Sponge Iron Plants
3.	Regenerative/ recuperative Burner for Reheating Furnace
4.	Sinter Plant Heat Recovery (Steam Recovery from Sinter Cooler Waste Heat)
5.	Sinter Plant Heat Recovery (Power generation from sinter cooler waste heat)
6.	Coal Moisture Control (CMC) system (Top Charged)
7.	Top Pressure Recovery Turbine (TRT)
8.	Pulverized Coal Injection (PCI) system
9.	Hot stove waste heat recovery
10.	Waste heat recovery from electric arc furnace
11.	Regenerative Burner Total System for Reheating Furnace
12.	Energy monitoring and management system
13.	Cogeneration with Gas Turbine Combined Cycle (GTCC)
14.	Low Grade Heat Recovery Using Organic Rankine Cycle
15.	Hot Blast Superheating with Plasma technology
16.	Advanced automation L-3 model online simulation of Blast Furnace
17.	Gas Oxygen refining technology
18.	Converter Gas Sensible Heat Recovery
B.	**Technologies under development**
19.	Hydrogen-based iron and steel making technologies
20.	CCS/CCUS technologies
21.	HISARNA technology under development in the Ultra-Low-Carbon Steel (ULCOS) Programme

Source: (MoS, n.d.a.), (MoS, n.d.b), (MoS, n.d.c), (MoS, n.d.d).

3.4.3 Aluminium Industry

3.4.3.1 Current state of Production and Consumption

India's primary aluminium production stood at 3.6 million tonnes and bauxite production at 21.8 million tonnes for the year 2019-2020. India was the third largest producer of primary aluminium and the fifth largest producer of Bauxite in the world, contributing 5.8% and 6.3% respectively of their total global production. However, Bauxite production at 20 million tonnes during 2020-21 has registered a decrease of 6.67% as compared to the previous year. (Ministry of Mines, 2022a).

Despite being a large producer of aluminium, India's per capita aluminium consumption stands at 2.5 kg per person, which is much below the global average of 8 kg per person, and ten times lower than consumption levels of 22-25 kg per person in developed countries. Aluminium consumption mostly occurs in the electrical industry, transport and automobile industry, followed by construction, machinery and consumer durables and packaging. The level of per capita aluminium consumption is reflective of the population's access to the associated industrial goods from these sectors. Projected increases in aluminium consumption are most likely to come from the automobile sector. Passenger and commercial vehicles use 160 kg and 240 kg of aluminium per unit globally. However, the average quantity of aluminium used in India is only 29 kg per unit currently.

3.4.3.2 Energy Use & Fuel Consumption

The process of extracting liquid aluminium from alumina (refined alumina oxide ore) involves electrolysis, which is highly energy intensive. Most aluminium plants utilize captive coal-based thermal power plants to meet the electricity demands. The technology deployed in the thermal power plant therefore is an important determinant of the energy intensity of aluminium production. A subcritical thermal power plant has low efficiency of 30% whereas advanced supercritical plants currently being deployed in India have efficiency exceeding 40% at their lower range. Electrical energy requirement for aluminium production amounts to 148.4 GJ per ton, which is 85% of the total energy requirement of 174 GJ per ton. The rest of the energy is utilized for processes such as alumina plant digestion, alumina plant calcination, and alumina plant power, aluminium casting, anode plant oil and anode plant electricity. Among the available technologies for aluminium smelting, the pre-bake smelting technology is more energy efficient and has lower emissions than the Soderberg smelter. In India, newer plants utilize the pre-baking route whereas plants with existing Soderberg smelters are being retrofitted to increase their energy efficiency. The transition from Soderberg to pre-baking method of production, along with furnace performance improvement is an important measure being deployed to increase energy efficiency and reduce emissions.

Recycling of aluminium is an effective way to reduce energy consumption. Aluminium is a highly recyclable material since it is very ductile and light weighted. The recycled metal requires 95% less energy to produce than the primary metal. Recycling of aluminium therefore reduces the emissions from allied sectors with high aluminium consumption such as the transport and automobile industry and the electrical industry.

3.4.3.3 Mitigation measures in Aluminium industry and policy measures

Energy Efficiency improvements through PAT

The PAT scheme has covered upto 12 aluminium plants as Designated Consumers (DCs) during the cycles I, II and III so far. The estimated energy savings and the CO_2 emissions mitigated through the PAT cycles are summarized in the table below.

Table 3.16 Achievement under PAT Cycles in the Aluminium industry

PAT Cycle	Year	Energy Savings (Mtoe)	CO_2 emissions reductions ($MtCO_2$)/year*	Number of Designated Consumers (DCs)
I	2012-2015	0.73	3.1	10
II	2016-2019	1.226	4.20	12
III	2017-2020	0.089	0.345	1
IV	2018-2021	Ongoing	Ongoing	Ongoing

Source: BEE, 2023.

**The emission reduction numbers are for the last year of the respective PAT Cycle.*

Measures taken by National Aluminium Company (NALCO)

The National Aluminium Company, a government enterprise under the Ministry of Mines, has set up a wind power project of 50.4 MW capacity at Gandikota in Andhra Pradesh and a second wind power plant of 47.6 MW has been commissioned at Jaisalmer, Rajasthan. Further, all the units of NALCO have adopted zero discharge policy with respect to waste water management. The wastewater is treated in effluent treatment plants and then is reused in the production process or for horticulture purposes on the plant site. NALCO has also set up a carbon sequestration unit at the captive thermal power plant in its unit in Orissa. It runs a pilot-cum-demonstration project that achieves sequestration in the captive plant by utilizing the cultivation of special strands of microalgae. NALCO has also introduced low-carbon technologies in the production process that contribute to reducing emissions (Ministry of Mines, 2022b):

1. Graphitization of cathode blocks used in smelters has led to reduction of specific electrical energy consumption at 55kWh/Mt. This leads to energy savings of 23.65 million units per year. This has achieved an estimated emissions reduction of 0.023 million tonnes of CO_2 per year.

2. Installation of ALPSYS pot regulation system in potlines minimizes the anode effect and the emissions of PFCs, i.e. tetrafluoromethane (CF4) and hexafluoroethane (C2F6).

3. Installation of anode slot cutting machine has led to the reduction of specific DC energy consumption at 140 kWh/Mt of hot metal. This is estimated to reduce CO_2 emissions by 0.031 million tonnes per year.

4. In its captive power plant, NALCO has introduced chemical cleaning of condensers and revamping of preheaters in boilers, leading to a decrease in specific coal consumption.

Replacement of IE1 class motors with IE2 and IE3 class motors has led to a decrease in energy consumption by 5% and 6.5% respectively. As of March 2021, 720 replacements of IE1 motors have been carried out.

Measures taken by Hindalco Ltd.

Hindalco industries (Hindustan Aluminium Corporation Limited), which is a subsidiary of the Aditya Birla Group, has reported that it has achieved a 15% reduction in energy consumption and a 17% reduction in GHG emissions in 2020 with reference to a 2015 baseline. They have deployed the low-carbon AP60 technology in two new plants and have developed an innovation for retrofitting an existing plant, i.e., the utilization of copper inserted collector bar in a low amperage smelter. It has also set up the first Smelter in India with a 30 MW Solar Plant Synchronized at 220 KV with a thermal captive power plant set up over a fly ash-filled waste land. Further, 60% of Hindalco's products come from recycled aluminium. (TERI, n.d.).

National Mineral Policy, 2019

The National Mineral Policy, 2019 states that natural resources are "a shared inheritance where the state is the trustee on behalf of the people to ensure that future generations receive the benefit of inheritance." In this context, a mechanism has been setup for an inter-ministerial body under the Ministry of Mines, comprising members from the Ministry of Coal, Ministry of Environment, Forest and Climate Change, Ministry of Tribal Affairs, Ministry of Rural Development, and others, which will function as a unified authority to inter alia ensure sustainable mining in line with the principles of sustainable development and intergenerational equity (Ministry of Mines, 2019).

3.4.4 Fertilizer Industry

Modern chemical fertilizers form critical inputs to agriculture and assume pivotal importance for India on its path to improve agricultural productivity and attain food security. The significant role played by chemical fertilizers is well recognized in meeting the domestic requirement of food grains and also generating exportable surpluses. Fertilizers contain one or more of the three elements that are important in plant nutrition viz. nitrogen, potassium, and phosphorus. The Indian government has laid emphasis on achieving self-sufficiency and self- reliance in food grain production and concerted efforts in this direction have resulted in increases in agricultural productivity. This is evident from the fact that from a very modest level of 52 Mt in 1951-52, food grain production increased to 308.65 Mt in 2020-21. This section provides an overview of the existing state of the industry, its energy use and fuel consumption and a comprehensive list of actions undertaken which contribute towards mitigation efforts of the industry.

3.4.4.1 Current state of Production

Owing to the increasing need for food production, the demand for fertilizers has consequently witnessed a significant yearly increase over the past several years, leading to the expansion of the domestic industry and increases in the imports of products and inputs that are not domestically accessible. India has achieved 75% self-sufficiency in the production capacity of urea and is able to manage its substantial requirement of nitrogenous fertilizers through indigenous industries besides imports (Department of Fertilizers, 2022). Similarly, 50% indigenous capacity has been developed with respect to phosphatic fertilizers to meet domestic requirements; however, the raw-materials and intermediates for the same are largely imported, increasing the dependence on imports to 90%; while requirement for Potash is met entirely through imports (ibid). Currently there are 32 urea manufacturing units in the country with a total re-assessed capacity of 232.94 Lakh Metric Tonnes per Annum (LMTPA). It is expected that with the commissioning of all the under-construction brownfield urea projects in the public sector, India would achieve near self-sufficiency in meeting the demand of urea for its own consumption.

The actual production of all fertilizers during the year 2020-21 and 2019-20 was 433.66 LMT and 425.92 LMT demonstrating a minor increase of 2% in comparison to the previous year. The estimated production of all major fertilizers in 2021-22 was 330.8 LMT. Figure 3.16 below provides an overview of the annual production of different kinds of fertilizers between 2016-2022.

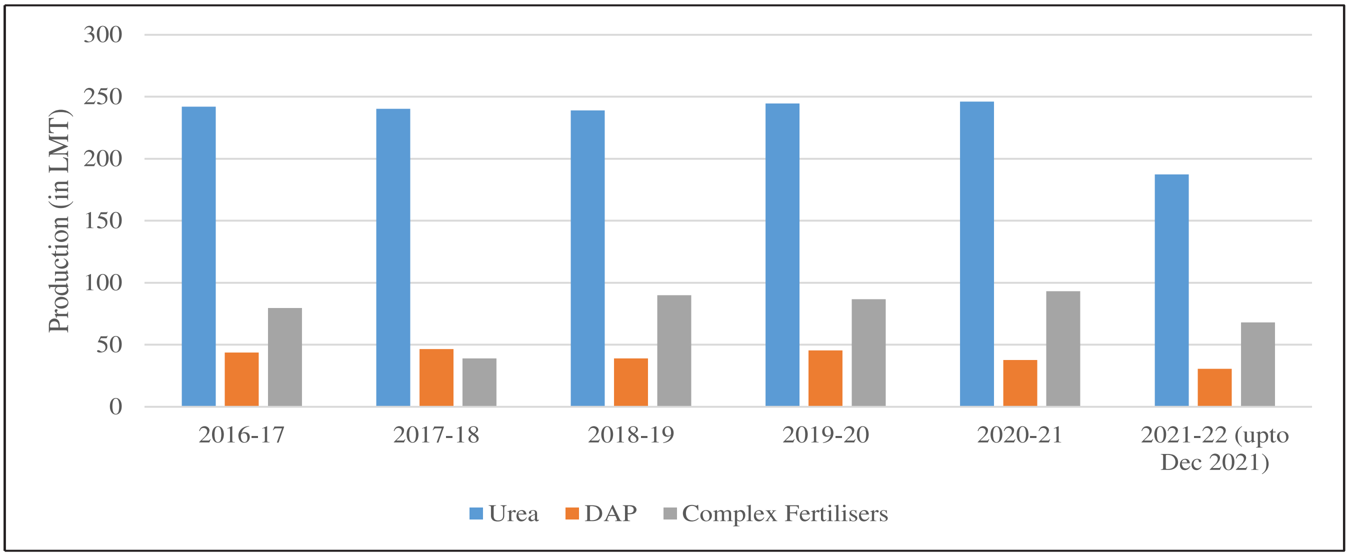

Figure 3.16 Yearly Production of Urea, DAP and Complex Fertilizers (in lakh metric tonnes)
Source: Annual Report 2021-22, Department of Fertilizers

3.4.4.2 Energy Use & Fuel Consumption

The demand for natural gas in India has increased significantly due to its higher availability, development of transmission and distribution infrastructure, savings from the usage of natural gas in place of alternate fuels, the environment friendly characteristics of natural gas as a fuel and the overall favourable economics of supplying gas at reasonable prices to end consumers (Petroleum & Natural Gas Regulatory Board, 2013). The power and fertilizer sector remain the two biggest contributors to natural gas demand in India and continue to account for more than 55% of gas consumption. Natural gas is used as feedstock and fuel in the urea sector, forming approximately 70–80% of the cost of production of urea, depending on feedstock prices and the energy efficiency of the plant (Department of Fertilizers, 2022). Out of 33 urea manufacturing units, 32 urea units utilise natural gas as feedstock, while one-unit utilises naphtha as feedstock (Department of Fertilizers, 2022). Figure 3.17 and 3.18 provide an overview of the status of fossil fuel consumption in the fertilizer industry for the period of 2012-13 to 2020-2021. They demonstrate the decreasing patterns of consumption of coal in the fertilizers and chemical industry.

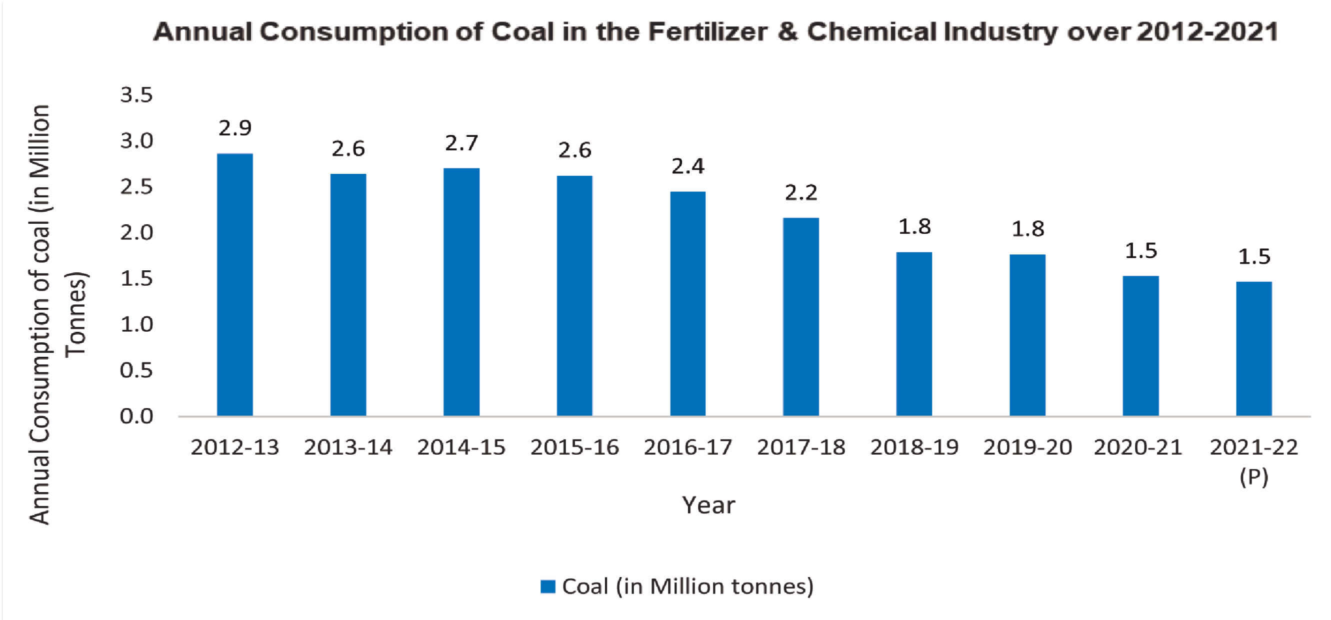

Figure 3.17 Annual Consumption of Coal in the Fertilizer & Chemical Industry over 2012-2022 (in million tonnes)

Source: MoSPI, 2023a

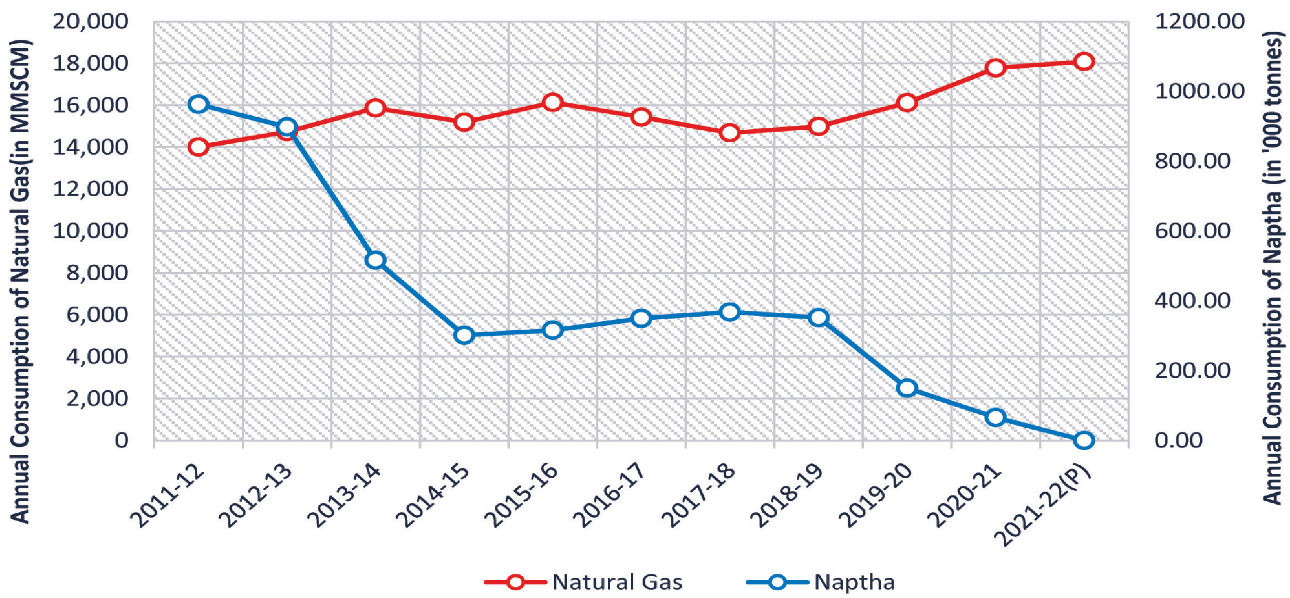

Figure 3.18 Annual Consumption of natural gas (in MMSCM) and naphtha (in '000 tonnes) in the Fertilizer industry over 2011-12 to 2021-22 (P)

Source: MoSPI, 2023a

Currently, India is the second-largest fertilizer-consuming country, the third-largest producer, and the world's largest importer of fertilizer materials. Contrarily, the per hectare application of mineral fertilizer in India remains much lower than in most of the developed and emerging economies. There exists a vast scope to increase the consumption of nitrogenous fertilizers further in India, as the current per hectare consumption at 89.7 kg is still very low compared to many developed and even neighbouring developing countries. Based on current pricing policy and growth trends, it is estimated that the demand

and supply of nitrogen fertilizers in India by 2030 would be 23.45Mt and 18.76 Mt, respectively (Tewatia & Chanda, 2017).

A report by the BEE, IGEN and CII (2018) undertook an assessment of the PAT cycle I to assess its efficacy and project future energy savings possible up to 2030 based on current levels of fuel and energy consumption. The report mentions that the total energy consumption for the fertilizer sector in the year 2030 without the impact of PAT is estimated to be 10.77 Mtoe, which may reduce to 9.99 Mtoe considering the impact of PAT.

Another projection of future consumption and production of fertilizers is undertaken by Hall et. al, (2020) which estimates that fertilizer consumption is expected to increase from around 45 kg per capita today to 75 kg per capita by 2050 (Hall et. al, 2020). According to the report, in keeping with the growing demand, the production of fertilizers is also expected to double, from the current capacity of 40 Mt today to 90 Mt by 2050 based on the assumption that domestic production would increase from approximately 75% of demand in 2020 to 90% by 2050 (ibid).

3.4.4.2 Schemes & Interventions undertaken for Climate Mitigation

Demand-side Management

Globally, Indian fertilizer Industry is amongst the best in implementing upgraded technologies and achieving optimum energy efficiency levels (BEE, 2021). In terms of CO_2 emissions, the net emissions of CO_2 in Indian plants were estimated to be 0.7 Mt CO_2/Mt of urea produced, which compared favourably with an average of 0.9 Mt CO_2/Mt of urea produced in the European Union (EU-27), 0.96 Mt CO_2/ Mt of urea produced in Africa, 1 Mt CO_2/ Mt of urea produced in the United States, 1.1 Mt CO_2/ Mt of urea produced in Russia, 1.2 Mt CO_2/ Mt of urea produced in Chinese gas-based plants and 2.3 Mt CO_2/ Mt of urea produced in Chinese coal-based plants in 2014 (DTE, 2019).

As a consequence of numerous measures for energy conservation, the average energy consumption of ammonia and urea plants has improved by more than 34% in the last three decades. The energy consumption of urea plants has improved from 8.9 Gcal per million tonnes of urea in 1987-88 to 5.8 Gcal per million tonnes urea in 2020-21 with the most efficient plants operating at an energy consumption level of 5.0 Gcal per million tonnes of urea (Chander, 2021). The following measures in the recent past have contributed towards demand-side management and improvement of energy efficiencies.

Introduction of Target Energy Norms (TEN) (Nov 2015)

With the objective of promoting energy efficiency in urea production, enhancing urea production, and rationalizing subsidy burden, the New Urea Policy (NUP) was notified in 2015 wherein urea units were categorized into three groups (with a few outliers) with the introduction of group energy norms to make the plants more energy efficient. The target energy norms have been all urea units leading to a reduction in energy consumption for 18 units out of 25 units in 2019-20 in comparison to the pre NUP period (2014-15) (Department of Fertilizers, 2022). This increase in energy efficiency is estimated to have saved subsidy outgo of the Government exchequer of INR 2,820.69 crore per annum in comparison to the pre-NUP 2015 regime (ibid).

Reductions achieved through the implementation of Perform Achieve and Trade (PAT)

The fertilizer industry has been included in the PAT cycles I and II since its inception in 2012. The table below summarizes these achievements in terms of energy savings and emissions reductions.

Table 3.17 Achievement under PAT Cycles in the Fertilizer industry

PAT Cycle	Years	Number of Designated Consumers (DCs)	Energy Savings Achieved (in Mtoe)	CO_2 Emissions Reduction ($MtCO_2$)/ year*
I	2012-2015	29	0.78	0.93
II	2016-2019	36	0.383	1.18

Source: BEE, 2023

**The emission reduction numbers are for the last year of the respective PAT Cycle.*

Some of the best practices and technology upgrades that have been commercially available in India and have implemented fertilizer manufacturing units under the ambit of the PAT scheme include:

- Installation of vapour absorption chiller (VAM) for chilling of gas at suction of ammonia synthesis gas compressors, process air compressors, CO_2 compressors & air compressors for gas turbines.
- Gas-based turbogenerator and associated heat recovery steam generators
- CO_2 as feed for urea production
- Changeover of feedstock from furnace oil, naphtha, and coal to natural gas
- Installation of CO_2 recovery units

Energy efficiency and conservation measures in complex fertilizer production

Energy contributes a small part in complex fertilizer production, still plants are making efforts to reduce the energy consumption to improve efficiency and reduce cost (Chander, 2021). Efforts for reducing energy consumption in phosphoric acid plants are focused to reduce power consumption in rock grinding section, pumps, fans, blowers, etc. including the adoption of following technologies (ibid):

- Modernization of phosphoric acid plant to a new process, aiding in eliminating the requirement of rock grinding section.
- Change of technology to pipe reactors has helped plants to reduce moisture content in slurry and recycle ratio. This in turn has helped in saving fossil energy for recycling, drying and granulation of products.
- Complex fertilizer plants integrated with sulphuric acid plants utilize waste heat from the sulphuric acid plant in drying. Waste heat available is also utilized to preheat cold ammonia before it goes to the pre-neutralizer.

3.4.4.3 Potential Technologies for Substitution & Future Challenges

This section highlights potential technologies that are tested and implemented.

Coal gasification-based urea production

Coal gasification is a part of the clean coal technology initiative of the government aimed at boosting the production of synthetic natural gas, energy fuel, urea for fertilizers and production of other chemicals. Considering strategic concerns of energy security and urea self-sufficiency owing to the country's vast coal reserves, it was decided to go ahead with the Talcher Fertilizer Limited plant based on coal gasification technology (PIB, 2021a). The gasification process adopted at the Talcher unit is a clean coal technology that replaces gasified coal instead of natural gas as feedstock thereby emitting only negligible SOx, NOx and particulate emissions (ibid). The project will improve the availability of fertilizer to farmers thereby boosting development of eastern region and will save transport subsidies for supply of urea in eastern part of the country. It would assist in reducing urea imports by producing syngas which shall be converted into 1.27 million metric tonnes of neem coated urea per annum leading to savings in foreign exchange GHG emissions. The Talcher plant shall also reduce dependence on important natural gas for production of urea leading to a reduction in the LNG import bill.

Green Hydrogen Mission

The Indian government announced the National Hydrogen Mission with the objective of meeting our mitigation targets as well as making India an export hub for Green Hydrogen and Green Ammonia (PIB, 2022b). The policy is aimed at meeting a target production of 5 million tonnes per annum of green hydrogen by 2030 and the related development of renewable energy capacity required for it (ibid). In India, green hydrogen can serve a dual purpose of enhancing our energy security as well as leading to a decarbonisation of the economy. The implementation of this policy would aid in the reduction of dependence on fossil fuel and crude oil imports for meeting our industrial demand for natural gas by allowing for the utilisation of clean and green hydrogen for the production of green ammonia/green methanol using renewable sources of energy. Green hydrogen has the potential to substitute fossil fuel utilisation in all major industries including fertilisers, chemicals, petrochemicals, refineries and steel units.

India's lack of domestic natural gas supply and high cost of imports have the potential to make green hydrogen competitive, provided conducive policies are oriented to incentivize domestic manufacturing of electrolysers, in line with the Government of India's Make in India's programme (Hall et. al, 2020). The government plans on the introduction of various incentives to promote and scale the production of green hydrogen including the following:

- Introduction of a Production-Linked Incentive (PLI) scheme for the manufacture of electrolyzers, mandating a 'green hydrogen purchase obligation' for the industry.
- Green Hydrogen / Ammonia manufacturers may purchase renewable power from the power exchange or set up renewable energy capacity themselves or through any other developer, anywhere.

- Waiver of inter-state transmission charges will be allowed to the manufacturers of Green Hydrogen and Green Ammonia for the projects commissioned before December 2030.
- The manufacturers of Green Hydrogen / Ammonia and the renewable energy plant shall be given connectivity to the grid on priority basis to avoid any procedural delays.

The fertilizer sector is also faced by certain challenges and policy implications in the future which will have to be addressed in order to optimize production and implement mitigation measures in the sector. One of the foremost challenges it faces is the uncertain availability of natural gas. With domestic production of natural gas not witnessing material growth and priority of the allocation of the same being shifted to the City Gas Distribution (CGD) sector, the share of R-LNG in the overall consumption mix has witnessed an increase over the last couple of years for the fertilizer industry.

Additionally, most of the fertilizer plants in India have already greatly improved their efficiencies and have reaped benefits of high potential energy saving schemes by making huge investments in the last few decades (ibid). Most urea plants have energy consumption within a range of 5.25 to 6.0 Gcal/tonne urea and any further incremental energy savings would necessitate replacement of capital equipment with huge investment leading to modest energy savings. The fertilizer industry has been optimizing resources to improve both efficiency and reliability, and further potential for mitigation and substitution of fossil-fuels and feedstocks would be contingent on the availability of technology transfers and finance available for the possibility of scaling up these technologies to make them cost-effective.

3.4.5 Chemical & Petrochemical Industry

The chemical and petrochemical industries form the fundamental pillars of industrial and agricultural progress in the country and provide primary inputs for several downstream industries, such as textiles, papers, paints, soaps, detergents, pharmaceuticals, varnish etc. The current per capita consumption of chemical products in India is about 1/10th the world average, indicating that the potential for meeting demand adequately is yet to be realized (Department of Chemicals and Petrochemicals, 2021). The industry is important as it has several linkages with other sectors of an economy. Also, the industry offers alternatives, which serve as substitutes for natural products and hence, has the capacity to meet the constantly growing demand that would otherwise strain the natural resources. Petrochemicals comprise of plastics and a host of other chemicals including derived hydrocarbons from crude oil and natural gas. They form important inputs to the textile and clothing, agriculture, packaging, infrastructure, healthcare, furniture, automobiles, information technology, electronics and communication and a host of other important industries.

3.4.5.1 Current state of Production

According to the National Accounts Statistics 2023, the chemical and chemical products sector accounted for 1.5% of the Gross Value Added for all economic activity in 2020-21 at current prices. The Index of Industrial Production (IIP) for the chemicals and petrochemicals for the period of 2016-2022 has ranged between 116 to 121 (ibid). Figure 3.19 provides an overview of the production of chemicals and petrochemicals for the period between 2016-17 and 2021-22.

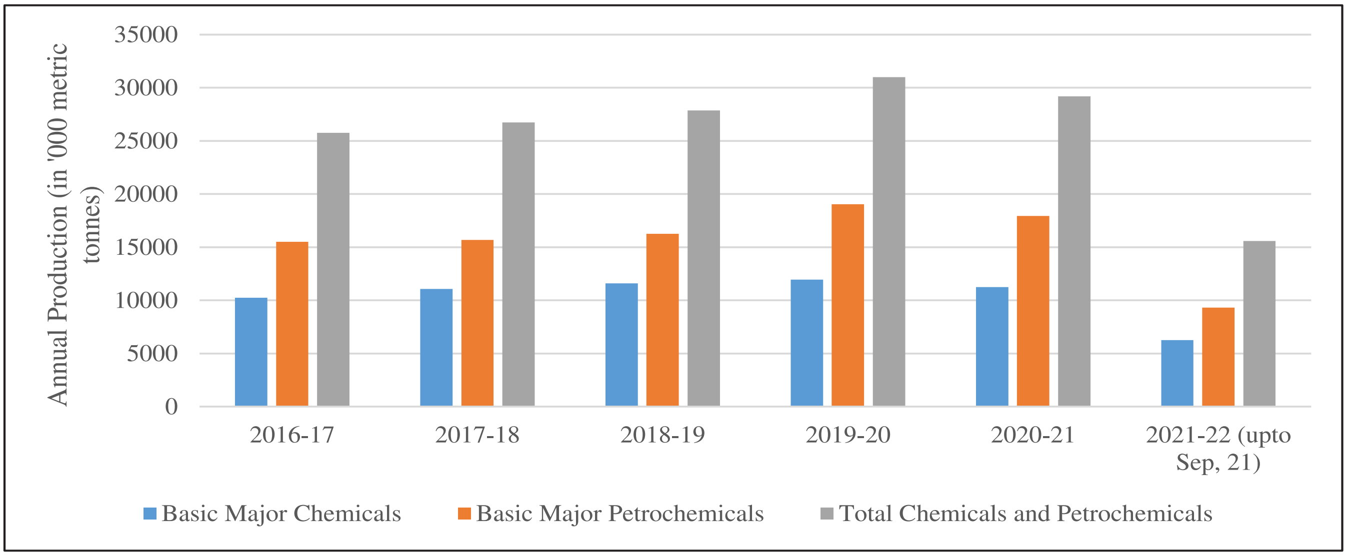

Figure 3.19 Total Production of Chemicals and Petrochemicals (in 000' metric tonnes)

Source: Department of Chemicals and Petrochemicals, Annual Report, 2021-22

Figures 3.20 and 3.21 provide an overview of the production of major chemical and petrochemical products within the industry.

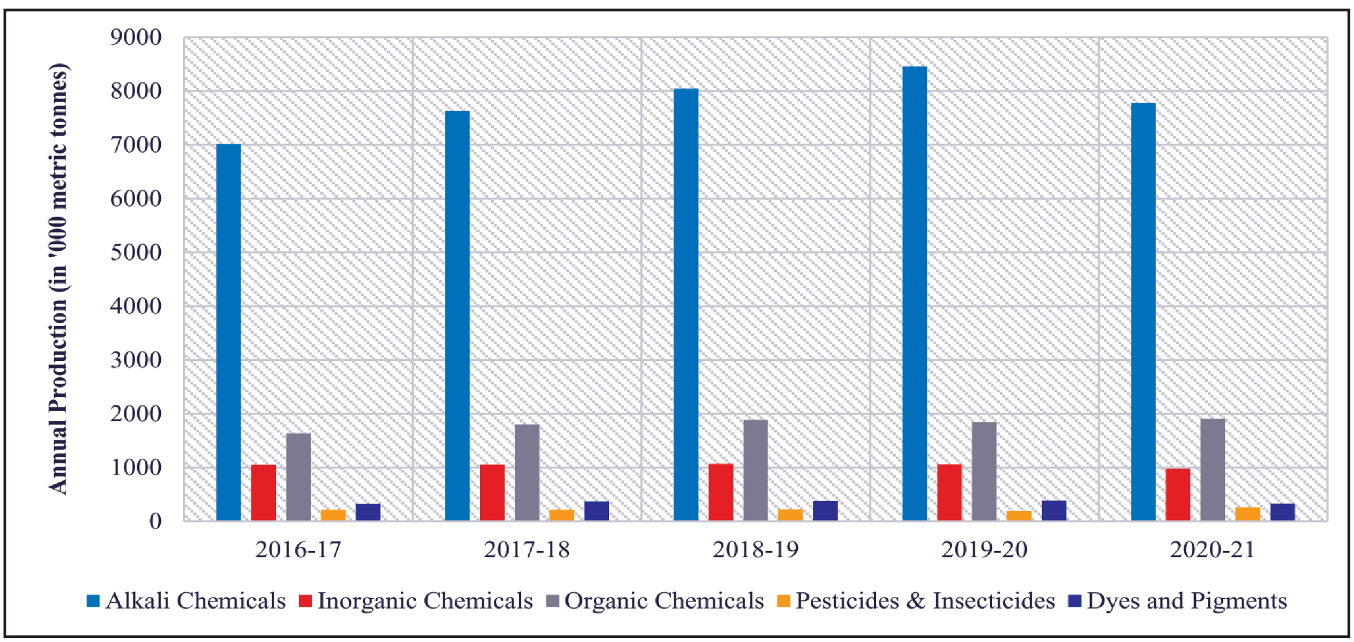

Figure 3.20 Production of major chemicals within the chemical industry (in 000' metric tonnes)

Source: Department of Chemicals and Petrochemicals, Annual Report, 2021-22

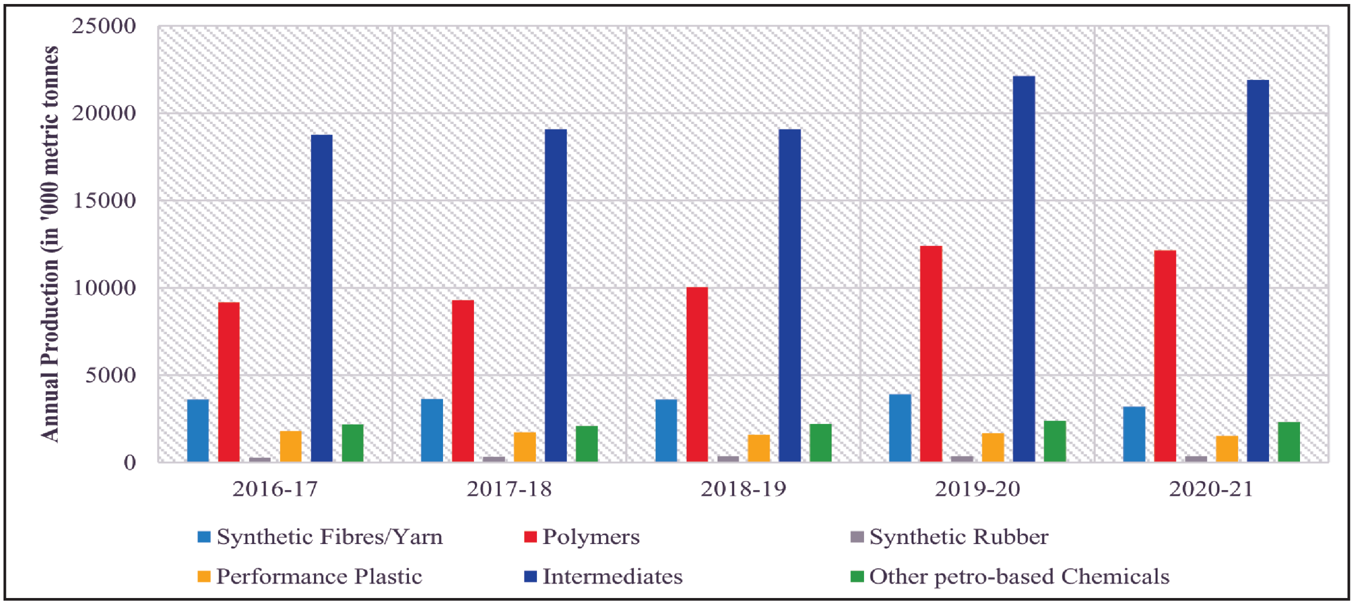

Figure 3.21 Production of major petrochemicals within the chemical industry (in 000' metric tonnes)
Source: Department of Chemicals and Petrochemicals, Annual Report, 2021-22

Alkali chemicals account for approximately 71% of the total production of major chemicals, with the production of chemicals growing at a CAGR of 2.4% between 2016-2020.

3.4.5.2 Energy Use & Fuel Consumption

Energy is consumed in the chemicals and petrochemical sector in the form of coal, naptha and natural gas. The main uses for naphtha are as feedstock for high octane gasolines and the manufacture of olefins in the petrochemical industry Coal consumption in the chemicals industry is demonstrated in the preceding section (in Figure 3.20) coupled with the fuel consumption in the fertilizer industry. Figure 3.22 provides an overview of the status of fossil fuel consumption in the chemicals and petrochemicals industry for the period of 2011-2020.

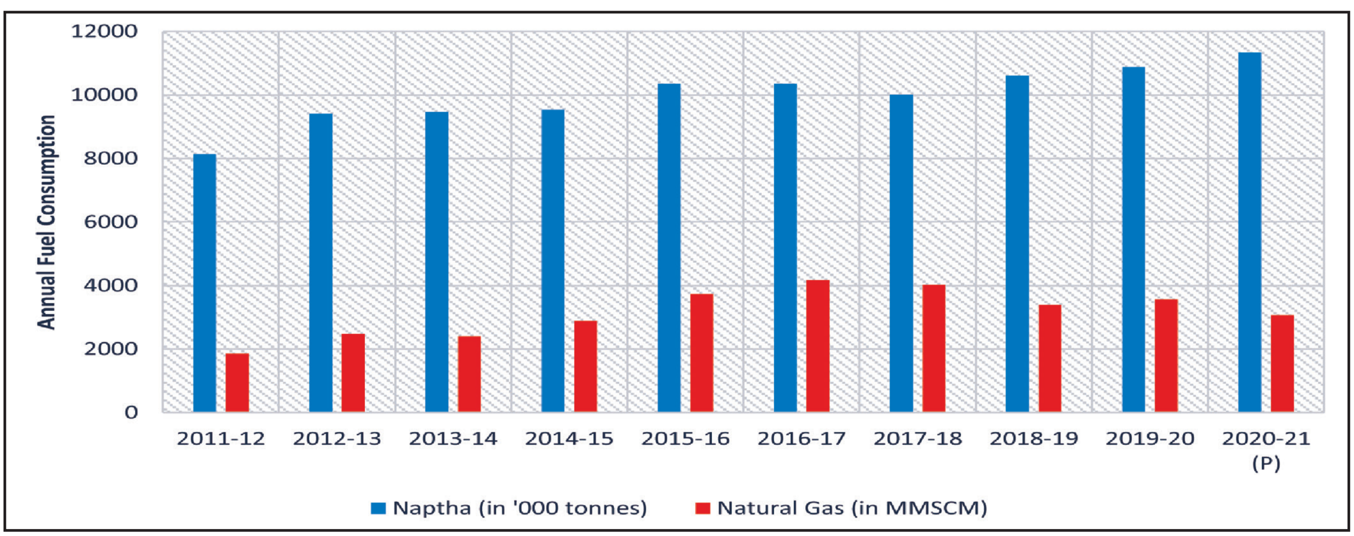

Figure 3.22 Annual Consumption of natural gas (in MMSCM) and naphtha (in '000 tonnes) in the chemical industry over 2011-2020
Source: Department of Chemicals and Petrochemicals, Annual Report, 2021-22

Regarding future demand for chemical and petrochemical products, certain studies have estimated the increased consumption of these products based on past and current patterns of utilization (Hall et. al, 2020; IEA, 2018). Based on current levels of consumption, the demand for primary chemicals is globally projected to increase by around 30% by 2030 and almost 60% by 2050 (IEA, 2018). The demand for methanol is expected to increase rapidly in the coming years, driven by policy support from the government and the continued use of methanol in the chemical industry. The import share for methanol is expected to reverse from the current 80% to 20% by 2050, driven by supportive policy framework (Hall et. all, 2020).

3.4.5.3 Schemes & Interventions undertaken for Climate Mitigation

Developed economies like the United States, Europe, and others currently use up to 20 times as much plastic and 10 times as much fertilizer as India, Indonesia, and other developing economies on a per capita basis, thereby underscoring the huge regional disparity in the levels of consumption amongst nations. Developing nations and LDCs need to increase their consumption of chemical products to move towards their path of industrialisation, while also ensuring that they contribute their fair share in improving their efficiencies and reducing their contribution to carbon emissions as effectively as they can.

Reductions achieved through the implementation of Perform Achieve and Trade (PAT)

In chemical industries, the chlor-alkali sector has been included in successive cycles of the PAT since its inception in 2012 (BEE, 2021). Table 3.18 summarizes these achievements in terms of energy savings and emissions reductions achieved in the chlor-alkali sector

Table 3.18 Achievement under PAT Cycles in the chemical and petrochemical industries

PAT Cycle	Years	Number of Designated Consumers (DCs)	Energy Savings Achieved (in Mtoe)	CO_2 Emissions Reduction ($MtCO_2$)/year*
I	2012-2015	22	0.09	0.62
II	2016-2019	24	0.133	0.55

Source: BEE, 2023

***The emission reduction numbers are for the last year of the respective PAT Cycle.**

Some of the best practices and technology upgrades that are commercially available in India and have been implemented in the chlor-alkali sector within the ambit of the PAT scheme include:

- Zero-gap technology
- Micro-turbine
- Feeding of 48 per cent hot Caustic Soda lye direct to flaker plant
- Change-over of fuel from Furnace Oil (FO) to Hydrogen in process heating/steam requirement

- Utilizing Hydrogen in Captive Power Plant
- PEM Fuel Cell Technology using Hydrogen
- Hydrogen Compressed Natural Gas (HCNG) (Hydrogen blending with CNG)
- Hydrogen Co-firing in Industrial Gas Turbines

Coal-to-chemical Technology

Coal India Limited (CIL) is in process to venture into the Coal-to-Chemicals sector on a stand-alone basis by setting up a Coal-to-Methanol plant of 2050 MTPD (0.676 MTPA) capacity at Dankuni Coal Complex (DCC). Coal from the Raniganj coalfields shall be gasified to produce Syngas, which shall be subsequently converted into methanol. An MOU has been signed between CIL and GAIL (India) Limited to explore areas of cooperation for setting up of coal-to-chemical plants in the vicinity of coalfields of CIL having coal reserves of higher calorific value.

3.4.5.4 Potential Technologies for Substitution & Future Challenges

A variety of carbon and hydrogen-containing materials can be utilised to replace fossil fuels as chemical feedstocks, key among them being bioenergy products, which are a source of both carbon and hydrogen. Some potential technologies which are being explored with respect to their application in the chemicals and petrochemicals sector are discussed below.

Green Hydrogen

Hydrogen can be produced using water and electricity through electrolysis, as an alternative to using fossil fuel feedstocks in the chemical and petrochemical industries. Combined with nitrogen, carbon and oxygen, hydrogen is used directly to produce methanol and ammonia, and indirectly (via methanol-to-olefins/aromatics) to produce the starting materials for the entire range of plastics and other chemical products (IEA, 2018).

CCS/CCUS (Carbon Capture Storage/Carbon Capture, Utilisation and Storage) technologies

Catalytic alternatives to traditional process routes can provide more than 15% of energy savings per unit of production (IEA, 2018). Typically, carbon sequestration projects are expensive and therefore not implemented in isolation in India (MoEFCC, 2021a). A dialogue has been initiated between US-DoE and the DST on clean coal technologies, supercritical carbon dioxide ($scCO_2$) power cycles and carbon capture utilisation & storage (CCUS) technologies which is supposed to initiate the participation of India in the multilateral platform for Accelerating CCUS Technologies (ACT) through which avenues have been generated for possible US - India collaboration (ibid). With regards to storage, it is estimated that there is a vast untapped potential for CO_2 storage in India through Enhanced Oil Recovery, Enhanced Coal Bed Methane Recovery, saline aquifers and basalt storage, amounting to 400-600 $GtCO_2$ (NITI Aayog, 2022).

However, access to relevant, affordable, and scalable technologies, along with improvement of capacities and technical skills, can be a game-changer for the possibility of mitigation, provided adequate financial support and technological transfers are received by developing nations. There is a need to stimulate investment in R&D of sustainable chemical production routes and limit associated risks. It is also necessary to unlock finance in areas with potential for sustainable returns and stimulate independent private investment.

3.4.6 Micro, Small and Medium Enterprises (MSME) Industries

The Micro, Small and Medium Enterprises (MSME) sector consists of manufacturing, trade and service enterprises, and contributes a significant share to India's GDP. For the year 2019-20, for instance, the MSME sector contributed 30% of the national GDP (PIB, 2021b). The 73rd round of the National Sample Survey (NSS) conducted in 2015-2016, estimated that there are 6.3 crore MSMEs in India. Of these, 1.95 crore enterprises are engaged in small-scale manufacturing activities, such as, food products, furniture, paper and plastic products, domestic electrical appliances, organic chemicals. A further 2.3 crore MSMEs are engaged in trade and another 2.06 crore are engaged in services. The MSME sector is highly labour-intensive and generates employment for a large number of people in both urban and rural India. The NSS estimated that 11.09 crore people were employed in the MSME sector, with micro enterprises accounting for 97% of the total employment generated. Small and medium enterprises account for 2.8% and 0.16% of the employment generated respectively (MSME, 2022).

3.4.6.1 Energy Use & Fuel Consumption

Energy consumption by MSMEs is estimated to be around 70 Mtoe, which accounts for 20-25% of the overall industrial energy consumption in India for the year FY 2019-20. (BEE, 2021). As MSME enterprises are usually run-on conventional technologies, they have significant potential in terms of energy savings through the introduction of energy efficient technologies and best operating procedures. However, this potential is constrained by both the scale of production, and the limited financial resources available for investments in conservation and efficiency measures.

3.4.6.2 Schemes & Interventions undertaken for Climate Mitigation

MSMEs, being semi-formal in nature, lack access to credit from financial institutions as well as the technical know-how and capacity to adopt energy-efficient technologies. The Government of India has undertaken various programmatic interventions in the MSME sector focused on financial assistance, technological support, and capacity-building for MSMEs to adopt energy efficient measures. Some of the energy efficient technologies introduced through these interventions include waste heat recovery, induction furnaces, servo motors, Computer Numerical Control (CNC) machines, Variable Frequency Drive plastic moulding machines, and permanent magnet motors for air compression.

BEE–SME 'National Program on Energy Efficiency and Technology Upgradation in Small and Medium Enterprises (SMEs)'

The BEE-SME program 'National Programme on Energy Efficiency and Technology Upgradation in SMEs' was initiated in 2009 for the purpose of developing, demonstrating and disseminating energy-efficient technologies at the cluster-level. Over 400 Bankable Detailed Project Reports for energy efficiency projects were prepared in 35 clusters across India. Few activities undertaken to encourage efficient energy consumption in the MSMEs in India are – energy use and technology analysis, capacity building and outreach awareness, development of innovation financing mechanisms and implementation of energy efficiency measures.

The BEE-SME program includes a mechanism, the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE), for managing credit risk in loans extended to industries for adopting energy efficient measures. It provides a guarantee of up to 50% of the loan amount or INR 10 crore, whichever is less, to participating financial institutions which extend loans for energy efficiency projects. The BEE-SME program has also established an online knowledge management portal, Simplified Digital Hands-on Information on Energy Efficiency in MSMEs (SIDHIEE), for the dissemination of information about best practices and case studies of energy efficient technologies.

BEE-GEF-UNIDO Project 'Promoting Energy Efficiency and Renewable Energy in selected MSME clusters of India'

The United Nations Industrial Development Organization (UNIDO) in collaboration with the Bureau of Energy Efficiency, and in partnership with the Global Environment Facility (GEF), Ministry of MSME and Ministry of New and Renewable Energy (MNRE), is executing this project. The project involves conducting energy audits and assessing operational efficiency, identification of potential technologies for intervention and providing handholding support to MSMEs. The programme is operational in 23 MSME clusters in India from five sectors: Brass, ceramics, dairy, foundry and hand-tools. The project also covers two mixed clusters comprising enterprises from multiple sectors.

Various energy efficiency interventions have been carried out in above-mentiooned MSME clusters. Energy saving obtained from BEE-GEF-UNIDO and BEE-SME Programme being implemented in Selected MSME Clusters in FY 21-22 is showcased in Table 3.19.

Table 3.19 Energy saving from BEE-GEF-UNIDO Programme and BEE-SME Programme in Selected MSME Clusters in FY 21-22

Sector	Cluster	Total Energy Savings (Toe)	CO_2 Reduction (Tonnes)	Monetary Savings (INR Crores)	Investment (INR Crores)
Ceramic	Thangadh	235.238	2443.11	1.85	6.56
	Morbi	1324.62	6888.75	9.13	15.04
	Ahmedabad	77.19	307.03	0.39	0.94
	Khurja	135.3	400.1	0.85	0.85
Hand Tool	Jalandhar	356.44	1384.63	2.05	4.81
	Nagaur	90.14	262.83	0.59	0.79
Dairy	Gujarat	453.18	5764.77	4.25	7.67
	Kerala	186.8	190.32	0.32	1.91

Sector	Cluster	Total Energy Savings (Toe)	CO_2 Reduction (Tonnes)	Monetary Savings (INR Crores)	Investment (INR Crores)
	Andhra Pradesh & Telangana	97.8	820.4	0.54	1.86
	Maharashtra	138.05	1444.69	0.5	5.42
	Tamil Nadu	191.1	729.7	0.87	4.21
	Punjab	67.11	359.1	0.34	0.87
	Haryana	13.04	136.46	0.1	0.32
	Madhya Pradesh	81	524	0.3	1.15
Foundry	Coimbatore	728.68	7096.83	6.155	17.18
	Belgaum	256.45	2466.5	1.97	5.62
	Ahmedabad	167.02	616.79	0.66	1.85
	Eastern Zone	464.23	3814.02	2.35	3.43
Brass	Jamnagar	477.64	1264.71	2.02	5.25
Mixed Cluster	Indore	66.92	421.88	0.61	1.27
	Sikkim	90.02	837.3	0.89	0.86
Total		**5697.96**	**38173.92**	**36.72**	**87.83**

GEF-World Bank-BEE-SIDBI Project Financing Energy Efficiency at MSMEs

This project, based on a grant agreement between the Global Environment Facility (GEF), the World Bank, the Small Industries Development Bank of India (SIDBI) and Bureau of Energy Efficiency (BEE), has focused on boosting the adoption of energy efficient technologies in MSME industrial clusters through financial support and technical assistance. It has been implemented in three phases: Phase I (2011-2015), Phase II (2015-2017) and Phase III (2017-2019), with each phase targeting different regional MSME clusters in India. While Phase I involved 5 clusters, Phases II and III saw an expanded implementation in 25 clusters. The project prepared Detailed Project Reports for energy efficiency measures and provided hand-holding support to MSMEs for their implementation. As of 2019, INR 330 crore worth of energy efficiency investment has been achieved through the project, with estimated lifetime reductions of 2 million tons of CO_2. The project also created a revolving fund to provide financing at concessional interest rates to MSMEs for the adoption of energy efficient measures. More than 630 MSMEs have benefited from the revolving fund. For the year 2019-2020, total energy savings of 12,178 toe were achieved due to Phase II and Phase II interventions across regional MSME clusters.

The project also included a sub-component on the design and implementation of the Energy Management System (EnMS) as per the ISO 50001 standards, which targeted 50 MSME units leading to estimated energy savings amounting to INR 900 lakh. The implementation of this program has enabled MSMEs to regularly monitor and measure energy performance and the identification of in-house energy efficiency measures. Other components of the project involved awareness and capacity building workshops for more than 2500 MSMEs and CleanTech exhibitions that served as an interface between technology vendors and MSMEs.

Key achievements of the scheme till 2022:

- Program footprint to 25 MSME clusters till the third phase.
- Reached out to 5000 MSME units through Capacity Building Workshops, and B2B Exhibitions
- EE Implementations in more than 1250 MSME units
- Resulted in emission reductions of 1.9 $MTCO_2$
- Support to more than 45 MSMEs for implementation of Energy Management System (EnMS) ISO 50001
- Key Performance Indicators (KPI) and Energy Efficiency Benchmarks for MSMEs in various sectors
- Around 200 participants from 20 MSME clusters have participated in ISO 50001 training workshops

EESL-UNIDO – GEF programme 'Promoting Market Transformation for Energy Efficiency in Micro, Small & Medium Enterprises'

Energy Efficiency Services Limited (EESL), with aid from UNIDO and GEF, is implementing the project 'Promoting Market Transformation for Energy Efficiency in MSMEs' in 10 MSME clusters, and the project is in various stages of implementation. For the FY 2021-22 the project has achieved the energy savings in 10 clusters as provided in Table 3.20.

Table 3.20 Energy saving from the EESL-UNIDO-GEF 6 programme in FY 21-22

State	Cluster	Sector	No. of Units	Total Invest-ment (INR Lakhs)	Energy Saved (Toe/yr)	Monetary Saving (INR Lakhs)	Reduction in CO_2 emission (tCO_2/yr)
Gujarat	Chemical	Ankleshwar	9	96.62	141	37	913
Punjab	Forging	BJL	2	64	181	58	335
W. Bengal	Mixed	Howrah	5	96	597	143	2604
Assam	TEA	Jorhat	8	117	126	53	486
Gujarat	Textile	Surat	8	126	840	127	4093
Tamil Nadu	Rice	Vellore	2	56	33	31	158
Uttar Pradesh	Textile	Varanasi	1	3	0.31	0.45	3
Total			**35**	**558.62**	**1918.31**	**449.45**	**8592**

Source: BEE, 2023

3.4.6.3 Future Strategies

The Government of India's Unlocking National Energy Efficiency Potential (UNNATEE) strategy plan for 2017-2031 outlines potential technological interventions for enhancing energy efficiency and savings. According to the report, the MSME sector's energy demands are projected to increase by 500% by the year 2031. Industrial sector, which includes the MSMEs are projected to contribute upto 60% of the total energy savings. To realize the potential of energy savings in the MSME sector, an estimated 14 billion USD of investment is required.

Within the MSME sector, the strategy plan identifies both cross-sector and sector-specific energy efficient technologies that can be adopted in the future. Cross-sector technologies with high energy-saving potential identified by the UNNATEE strategy plan are: installation of variable-frequency drive on motors, improvement of insulation in thermal systems, energy-efficient pumping, installation of energy-efficient boilers, energy-efficient air compressed systems and waste heat recovery in ovens and furnaces. Sector-specific technologies have been identified for both retrofitting as well as replacement in key energy-intensive manufacturing MSMEs (BEE, 2019).

Table 3.21 Technologies identified in the UNNATEE strategy plan 2017-2031 for enhancing energy efficiency in key energy-intensive manufacturing MSMEs

MSME sector	Technologies for Energy-efficient retrofitting	Technologies for Energy-efficient equipment/replacement
Foundry	1. Lid mechanism for induction furnace 2. Replacing cooling tower fan blades from aluminium to Fibre Reinforced Plastic (FRP) 3. Conversion to divided blast cupola	1. Energy-efficient induction melting furnace with energy meter 2. Replacing inefficient conventional cupola by induction furnace 3. Induction ladle refining furnace
Forging	1. Fuel switching from furnace oil to natural gas for forging furnaces 2. Application of veneering module at LPG-fired normalizing furnace	1. Replacement of existing Furnace Oil-fired furnace with energy-efficient induction billet heater 2. Installation of microprocessor-based pneumatic clutch-operated, screw friction presses
Engineering and auto-components	1. Programmable Logic Controller (PLC)-based control system for furnace temperature control 2. Waste heat recovery in ovens and furnaces	1. Computer Numerical Control (CNC) milling/turning/machining centres 2. Servo-controlled die-casting machines

MSME sector	Technologies for Energy-efficient retrofitting	Technologies for Energy-efficient equipment/replacement
Chemicals and Pharma	1. Optimization of excess air in natural-gas-fired boiler 2. Optimization of air circulation pattern of tray dryer to maximum utilization of the heat in the dryer 3. Interlocking of blower with combustion cycle to avoid idle operation and residual heat loss	1. Replacement non-IBR boiler with energy-efficient IBR boiler 2. Replacement of conventional horizontal agitator system with energy-efficient agitator systems 3. Flash dryers or rotary vacuum dryers (product drying)
Ceramics	1. Improvement in insulation in kiln, spray dryer resulting in saving in fuel consumption 2. Installation of recuperator in tunnel kiln thereby preheating combustion air from flue gas	1. Preheating of input slurry of spray dryer through solar energy resulting in saving in spray dryer fuel consumption 2. Installation of natural gas turbine for electricity generation and use of exhaust flue gas of turbine in spray dryer
Plastics	1. Radiant barrel heater for moulding machines 2. Accumulator controllers for hydraulic power packs	1. Shell-in-shell type recuperator for reheating furnace 2. Installation of anti-friction roller bearing and universal spindles and couplings

Source: BEE, 2019.

As demonstrated by the outcomes of the programmatic interventions, the provision of international financial and technological aid will play an important role in meeting these demands for energy efficiency measures in the MSME sector and will contribute significantly to emissions reductions.

3.4.7 Textile Industry

3.4.7.1 Current state of Production

The Indian textile industry is one of the largest in the world with a substantial raw material base and manufacturing strength across the value chain (Ministry of Textiles, 2022). It is the second largest manufacturer and is the sixth largest exporter of textiles & apparel in the world (ibid). India's textiles and clothing industry is one of the mainstays of the national economy with the share of textile and apparel (T&A) including handicrafts in India's total exports standing at a significant 11.4% in 2020-21 (ibid). The textile industry is also one of the largest sources of employment generation in the country with over 45 million people employed directly, and another 60 million people in allied sectors. The following table provides an overview of the production of major products as on 31st December 2020.

Table 3.22 Production of major products in the Textiles industry

Product of Textile Industry	Total Production (as on 31st December 2020)
Cotton	360 lakh bales
Jute goods	512 (in '000 Mt)
Silk	12,796 (in '000 Mt)

Source: (Ministry of Textiles, 2022)

- The Indian technical textiles market is expected to expand to USD 23.3 billion by 2027, driven by increased awareness of goods and higher disposable incomes.
- Cotton production in India is projected to reach 7.2 million tonnes (~43 million bales of 170 kg each) by 2030, driven by increasing demand from consumers.
- Exports of cotton yarns/fabs. /madeups/handloom products stood at USD 8.6 billion between April 2021 and October 2021 (IBEF, 2021b).

3.4.7.2 Energy Use & Fuel Consumption

Energy consumed in the textiles industry is mainly dependent on the consumption of fossil fuels including coal, lignite and petroleum products such as high-speed diesel oil and LPG (demonstrated in Figures 3.23 and 3.24 below). Although textile units might primarily not be considered energy-intensive, however, owing to the large numbers of plants in the industry, the overall consumption of energy becomes significant. Judicious energy utilisation is critical to the processes involved in the production of textiles with the energy costs, next to the material costs, accounting for around 15-20% of the total production cost.

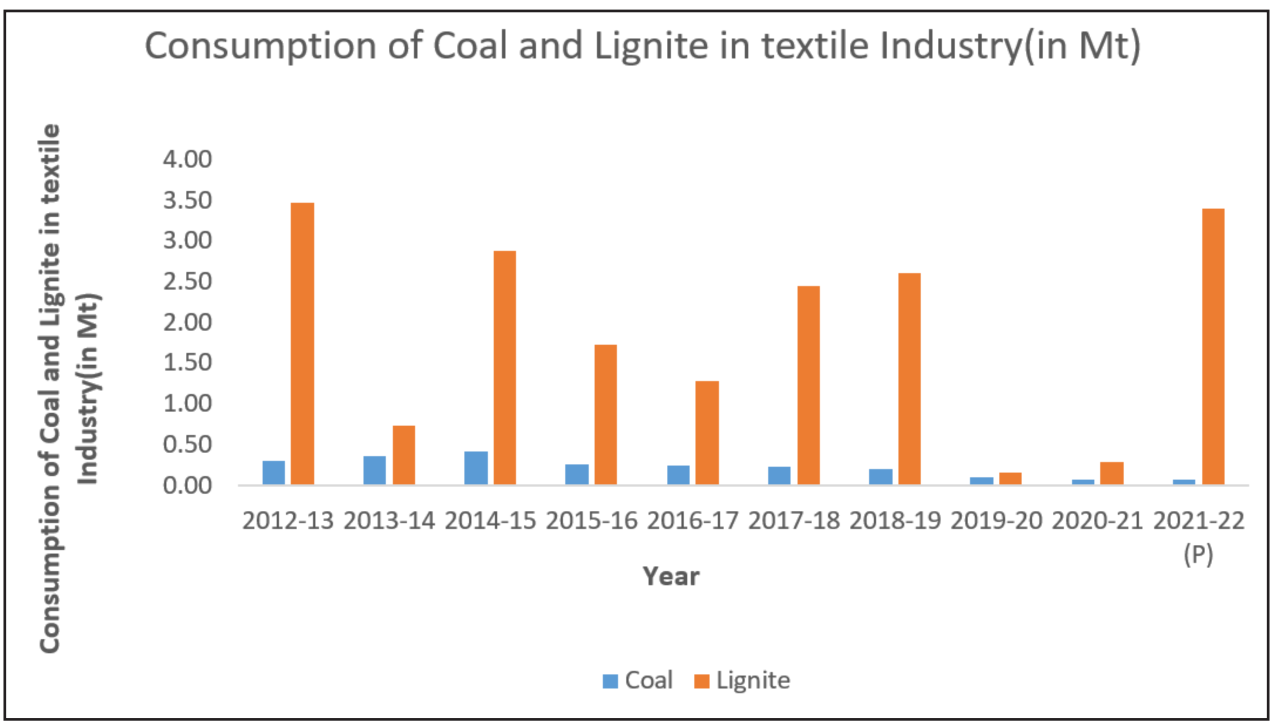

Figure 3.23 Consumption of coal and lignite in the textile industry (in Mt)

Source: MoSPI, 2023a

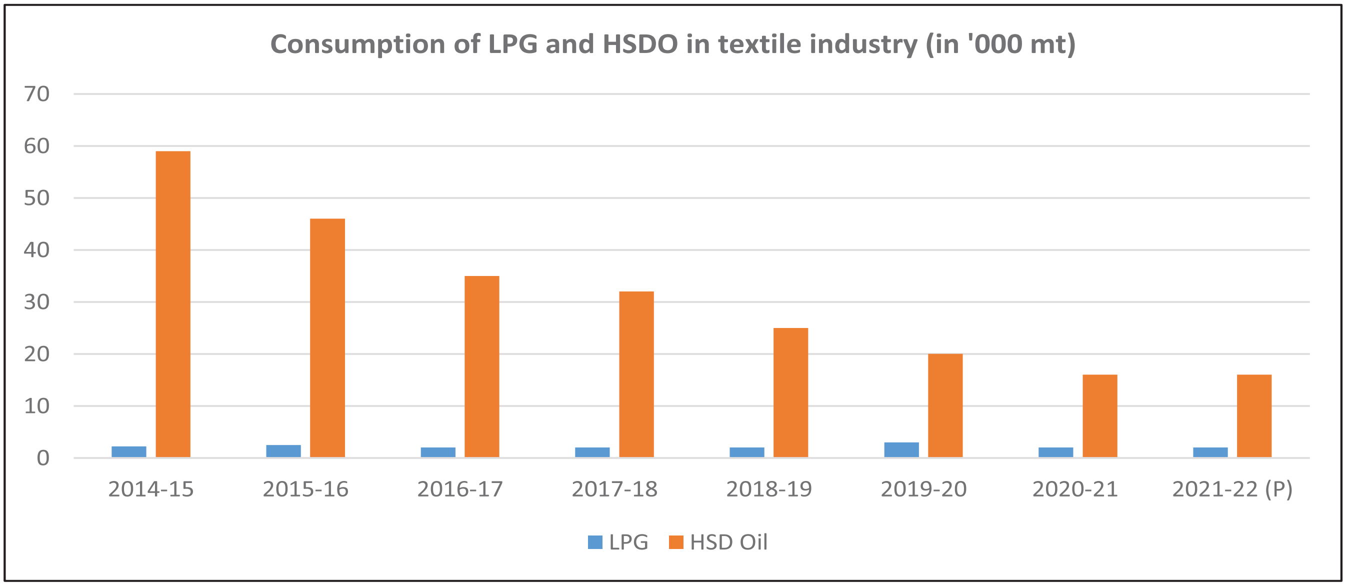

Figure 3.24 Consumption of LPG and HSDO in the textile industry (in ‘000 Mt)
Source: MoSPI, 2023a

The final energy consumption in the textiles industry has increased from 0.647 Mtoe in 2015-16 to 0.869 Mtoe in 2021-22. A report by the BEE, IGEN and CII (2018) assessed and projected future energy savings possible uptil 2030, assuming the current levels of growth in fuel and energy consumption and the continued implementation of PAT. In terms of the future growth of demand in this industry, the total energy consumption for the textiles sector in the year 2030 was estimated to be 1.98 Mtoe, which may reduce to 1.65 Mtoe considering the implementation of energy efficiency measures of PAT.

3.4.7.3 Schemes & Interventions undertaken for Climate Mitigation

The need for energy conservation holds paramount importance and has immense potential in the textile industry. With increases in the efficiency of production processes, the demand for fossil fuels is seen to be reducing in the future. Since operational plants and units in the textile industry are highly varied in terms of their energy consumption ranging from being highly energy efficient to least energy efficient, depending on their size and scale, there arises a need for technology upgradation and improving production efficiencies in the sector. Some of the policies and initiatives undertaken are discussed in the following sections.

Energy Efficiency improvements due to PAT

The textiles industry has been part of the PAT cycles since its inception in 2012 and continues to be a part of every consecutive cycle (currently up till Cycle VI) with new Designated Consumers (DCs) from the industry being included in every cycle. Table 3.23 provides an overview of the energy savings and emissions reduction achieved:

Table 3.23 Achievement under PAT Cycles in the textiles industry

PAT Cycle	Years	Number of Designated Consumers (DCs)	Energy Savings Achieved (in Mtoe)	CO_2 Emissions Reduction ($MtCO_2$)/year*
I	2012-2015	90	0.13	0.62
II	2016-2019	99	0.135	0.66
III	2017-2020	34	0.048	0.261

Source: BEE, 2023
**The emission reduction numbers are for the last year of the respective PAT Cycle.*

Some of the best practices and technology upgrades that are commercially available in India and have been implemented in the textiles industry within the ambit of the PAT scheme include the following:

- Pulser dyeing technique
- Waste heat recovery systems
- Wind recovery turbine from humidification
- Microbial fuel cell technology to generate electricity from textile wastewater treatment
- Solar paint for the textile industries
- Energy recovery from exhaust air by utilising special turbines which generate grid-connected electricity for lighting.

Policies for Technological Upgradation

The Union Ministry of Textiles has initiated several schemes and programmes for the textile and apparel sector aimed at contributing to the increasing growth and development of the sector, ensuring scaling and aggregation of smaller textile units for improvement of production efficiencies. Some of the flagship schemes introduced have been described below.

Table 3.24 Policies and Schemes implemented for Technology upgradation and boosting production in the textiles industry

Policy/Scheme	Features
Amended Technology Up-gradation Fund Scheme (A-TUFS)	Government allocated funds worth INR 17,822 crore (USD 2.38 billion) between FY16 and FY22 were utilised to boost the Indian textile industry and enable ease of doing business.
Mega Investment Textiles Parks (MITRA)	The MITRA scheme envisions setting up 7 Mega Integrated Textile Region and Apparel (PM MITRA) Parks (total outlay of INR 4,445 crore) aimed at helping India to achieve the United Nations Sustainable Development Goal 9 of "Build resilient infrastructure, promote sustainable industrialization and foster innovation". PM-MITRA parks have been proposed for enabling scaling of operations, reduce logistical cost by housing entire value chain at one location, attract investment, generate employment, and upgrade technologies, especially for smaller sized units.

SAATHI	The Union Ministry of Textiles, Government of India, along with Energy Efficiency Services Ltd. (EESL), launched a technology upgradation scheme called SAATHI (Sustainable and Accelerated Adoption of Efficient Textile Technologies to Help Small Industries) for reviving the power loom sector of India in 2018. Energy Efficiency Services Limited (EESL) will replace old inefficient electric motors with energy efficient IE3 motors which will result in energy and cost saving up to 10-15% in the first phase.
Production-Linked Incentive (PLI) Scheme	The Government has launched Production Linked Incentive (PLI) Scheme for Textiles (approved outlay of INR 106.83 billion over a five-year period). The PLI scheme will benefit the textile manufacturers registered in India providing them with incentives under the scheme available for five years from 2025-26 to 2029-30 on incremental turnover achieved from 2024-25 to 2028-29. The scheme proposes to incentivize MMF (Man Made Fibre) apparel, MMF fabrics and other segments of technical textile products.

Sources: (Ministry of Textiles, 2021), (PIB, 2021d), (PIB, 2018b), (IBEF, 2021b).

3.4.7.4 Potential for Substitution & Future Challenges

Reduction of energy consumption involved is also making way for innovations in various operations involved in the chemical processing of textile materials, giving rise to novel technologies at nascent stages of development that are being pursued. A variety of strategies for initiating sustainability into the production of textiles have been implemented by certain companies having the financial and technological capacities (IBEF, 2021b). Some of these strategies and technologies are listed below (ibid).

- Several Indian textile players are opting for sustainable production processes, including BRFL Textiles Private Limited (BTPL), India's largest fabric processing facility, which introduced a new sulphur dyeing process involving continuous dyeing without requiring water. BTPL is the first company in the textile sector to implement this new process of dyeing, making it the pioneer of this innovative sustainable process.
- Sangam India Ltd (SIL) installed two solar power plants of 5 MW that reduced their dependence on fossil fuels for fulfilment of their energy requirements. SIL also plans to increase their utilization of recycled fibres, leading to lesser generation of plastic waste by using it as a raw material.
- Several companies are investing rapidly in the generation and utilisation of solar energy in including the following (Tagra, 2022):
- India's largest exporter Shahi Exports has two solar power plants of 32 MW and 52 MW capacities which cater to around 65 per cent of its electricity requirements.
- Pee Empro Exports has installed solar panels at two of its units

- Matrix Clothing, Gurgaon has installed a solar power plant of 258 KW, KG Fabriks has a 1.05 MW solar power plant and Dollar Industries has invested Rs. 18 crores for setting solar power plant in Tirupur
- Trident Group recently commissioned a 7.6 MW solar power plant at Budhni.

Supercritical Dyeing Technique

Supercritical dyeing technique is an innovation to conserve the thermal energy of the fabric by using supercritical carbon dioxide as a dyeing medium. Dyeings are performed in high-pressure vessels called autoclaves wherein carbon dioxide exists as a supercritical fluid at temperature at about 31ºC and pressures above 72 bars (Gaikwad, 2020). The medium of utilising an anhydrous process offers a number of ecological and economic advantages such as no requirement of processing water and low energy consumption for heating up the dyeing liquor. The method has been established successfully in recent years in practice and is expected to be scaled up as currently, this method is only used for dyeing polyester (PET).

Some of these technologies currently have limited applications due to certain challenges faced by the textiles industry in terms of a lack of scale across the value chain. In the Indian textile and apparel sector, the sub sectors of weaving, processing and garmenting are fragmented and lacking in the requisite scale for success in global markets. Most of the manufacturing units have small capacities and low manufacturing efficiencies which are a disadvantage in the global arena. The advent of large manufacturing plants with economies of scale will help India in achieving global competitiveness and increase the applicability and suitability of larger and medium-level units in improving their efficiencies and adopting cleaner technologies.

3.4.8 Paper & Pulp Industry

The Indian paper and pulp industry is one of the most fragmented sectors with production capacities for different mills ranging from 5 tons per day (TPD) to 1650 TPD (CPPRI, 2021). During the decade 2010 to 2020 the industry registered a substantial growth which resulted in a twofold increase in production from 10.99 Mt to 21.36 Mt by 2020. The consumption of paper in India increased from 16.91 million tons in 2016-17 to 22.83 million tons in 2019-20. During this period India's paper consumption registered a CAGR of 6% compared to the global growth of 3% making India one of the largest growing paper markets in the world.

The Indian paper & paper products market is projected to grow from USD 8.6 billion in 2018 to USD 13.4 billion by 2024, exhibiting a CAGR of 7.8% during 2019-2024 (MoEFCC, 2022a). The growth of the Indian Printing Industry is at a rate of 12% per annum.10-year forecasted CAGR for Paper Industry is 7% to 8% (ibid). In India, paper is produced from three alternate raw materials including wood/bamboo; agro residue (bagasse/wheat straw) and waste paper/Recycled Fibre (RCF) with around 21% of the total paper produced in India using wood as the primary raw material. The sector has unutilized capacity primarily due to acute fiber shortage in the country. Another reason for low-capacity utilization has been the ever-increasing input costs particularly for energy inputs (both coal and non-coal) (CPPRI, 2021).

3.4.8.1 Energy Use & Fuel Consumption - past, present, and future projections

Energy consumption in paper mills varies in accordance with the type of raw material and technology in use with coal, lignite and electricity serving as the main sources of energy used in paper production. The major factors that affect energy consumption in the Indian pulp and paper industry are low level of capacity utilization, quality and type of paper produced, number and multiplicity of machinery, paper machine runnability and down time, finishing losses, boiler type and pressure levels, level of cogeneration, and power generation (MoEFCC, 2022a). The cost of energy is estimated to be 16 to 25% of the total production cost of paper, and the component of energy cost is expected to increase progressively over other inputs in the near future. The consumption of steam and electricity per ton of paper production in India is around 11 to 15 tons and around 1,300 to 1,700 kWh, with the average specific energy being approximately 50 GJ per ton of paper, which is nearly twice the North American and Scandinavian standards (ibid). Figure 3.25 below demonstrated the consumption of fossil fuels in the paper industry over the period of 2012-2021. The industry is likely to consume approximately 1,702 PJ per annum of energy by 2030.

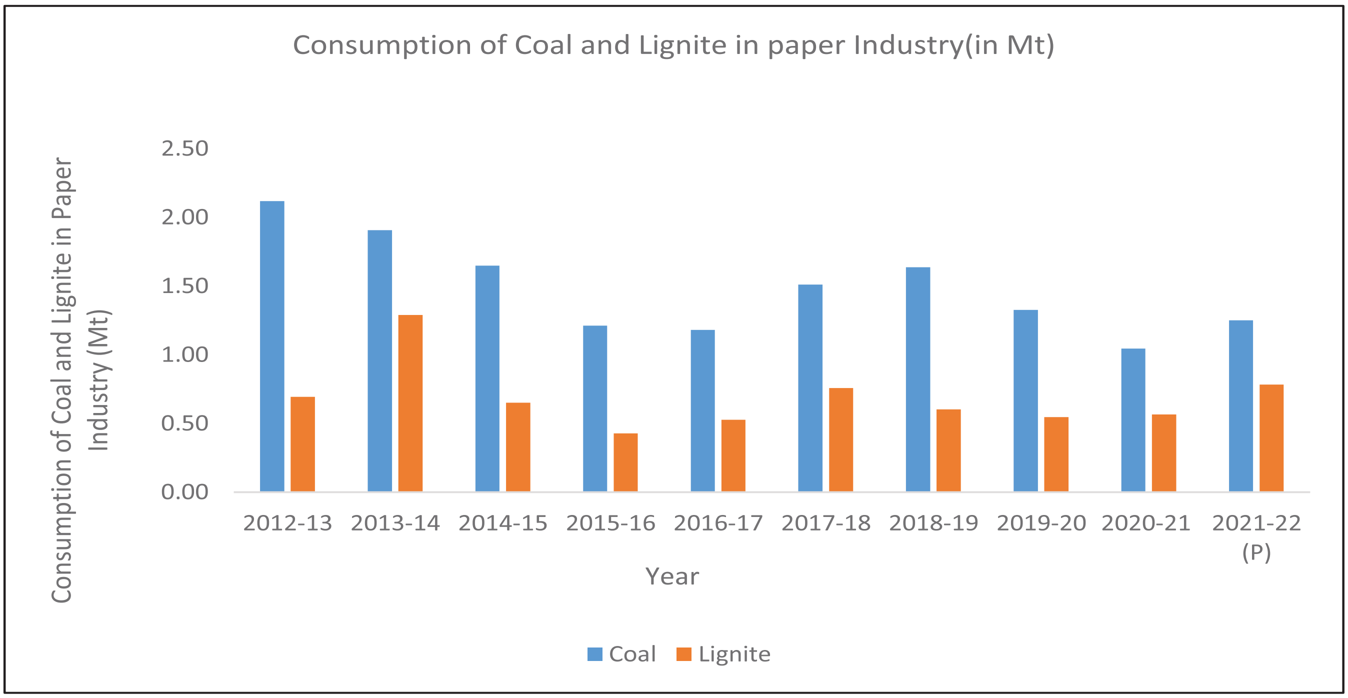

Figure 3.25 Consumption of coal and lignite in the paper industry (in Mt)
Source: MoSPI, 2023a

3.4.8.2 Schemes & Interventions undertaken for Climate Mitigation

As an important energy consumer as well as a sector that plays an important role in India's economic growth and for the creation of employment opportunities, it is necessary to assess the potential for growth in this sector, and to explore the possibilities of moving to greener production of pulp and paper thereby creating more opportunities in interlinked sectors of power, agricultural waste management etc.

The pulp and paper industry accounted for 6% of total global industrial energy consumption, being the fourth largest energy consumer worldwide. As per a study of energy efficiency[4], the specific electrical and thermal energy consumption was estimated at 91.85 kWh/ton and 1619 MJ/ton paper respectively, while the annual energy saving potential was found to be 5.9% of the total annual energy consumption (Pandey & Prakash, 2018). This section provides an overview of the measures and technologies adopted for reducing GHG emissions in the industry including improvements in energy efficiencies and agroforestry.

Energy Efficiency improvements due to PAT

The paper and pulp industry has been part of the PAT cycles since its inception in 2012 and continues to be a part of every consecutive cycle with new Designated Consumers (DCs) from the industry being included in every cycle. Table 3.25 provides an overview of the energy savings and emissions reduction achieved.

Table 3.25 Achievement under PAT Cycles in the paper and pulp industry

PAT Cycle	Years	Number of Designated Consumers (DCs)	Energy Savings Achieved (in Mtoe)	CO_2 Emissions Reduction ($MtCO_2$)/ year*
I	2012-2015	31	0.29	1.24
II	2016-2019	29	0.315	1.35
III	2017-2020	1	0.05	0.015

Source: BEE, 2023

**The emission reduction numbers are for the last year of the respective PAT Cycle.*

Some of the best practices and technology upgrades that are commercially available in India and have been implemented in the textiles industry within the ambit of the PAT scheme include:

- Super Batch Cooking.
- Two Stage Oxygen Delignification – OxyTrac.
- BCTMP Process (bleached chemi-thermomechanical pulp).
- Super Batch Cooking.
- Ultra-Low Intensity Refining.
- Opti Batch Process.
- Biogas firing in rotary lime kiln (Replacement of Furnace Oil)
- Boiler Conversion: Fluidised bubbling to Spouted bed
- Solar Energy Utilization for Process Heating at Low and Intermediate temperature (Replacement of LP Steam) i.e., 50°C to 250°C
- Oxyfuel burning in lime kiln and black liquor boilers
- Installation of Extended Delignification System for cooking of wood (to reduce steam consumption)

4 https://www.researchgate.net/publication/329481483_Energy_Conservation_Opportunities_in_Pulp_Paper_Industry

Agroforestry

The Indian paper is predominantly biodegradable and can be recycled up to 6-7 times; moreover, it is made from resources that are renewable and can be easily regenerated. The industry is not a forest-based industry but is an agro/farm forestry-based industry with over 90% of wood requirement being sourced from industry-driven agro/farm forestry (Indian Paper Manufacture Association, n.d.). The Indian paper and pulp industry is wood-positive, that is, it plants more trees than it harvests and has undertaken research carried for producing high-quality tree clonal saplings (e.g., Eucalyptus, Subabul, Casuarina, Acacia, Poplar, etc.) which are disease and drought-resistant and can be grown in a variety of agroclimatic conditions (ibid). A large part of this wood is grown in backward marginal/sub-marginal land, which is potentially unfit for other use with the paper industry providing technical extension services to grow trees-outside-forests (TOFs) as any other crop and their harvest is sold to paper mills, apart from other industries. In India, an estimated 500,000 farmers are engaged in growing plantations with approximately 125 thousand hectares being brought under agro/farm forestry on an annual basis and around 1.2 million hectares on a cumulative basis across the country due to the efforts of paper mills (IPMA, n.d.). This has generated significant employment opportunities for the local community, especially in the rural areas, and also significantly supplemented the income of farmers while additionally leading to environmental benefits in terms of an increase in the country's green/tree cover, carbon sequestration, restoration of degraded land contributing towards mitigating efforts of the industry (ibid).

3.4.8.3 Potential for Substitution & Future Challenges

Currently, the paper sector is moving towards an era of new opportunities driven by introduction of the biorefinery approach and utilization of possible unique products from the constituents of ligno-cellulosic raw materials produced in a biorefinery (CPPRI, 2021). The Central Pulp & Paper Research Institute is also conducting research for exploring various potential technologies to improve the production efficiency and reduce resource consumption in the paper and pulp industry including the following (CPPRI, 2021):

- Delignification of Agro Residue Raw Materials using Deep Eutectic Solvents or/and Ionic Liquids
- Alternate Auto-causticization Process for Conventional and Non-Conventional Chemical Recovery Systems

Another technology that is being investigated with regards to its applicability in the paper and pulp sector is Cogeneration or Combined Heat and Power (CHP). However, the pulp and paper industry cannot operate with a prolonged unavailability of process steam, and therefore the cogeneration system to be installed must be modular and it should consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply (MoEFCC, 2021a).

The paper and pulp industry is also constrained due to the deficiency in the availability of raw material domestically. Availability of wood domestically at 9 million tonnes per annum (MTPA) is inadequate compared to demand, which is currently about 11 MTPA and is projected to rise to 15 MTPA by 2024-25 (MoEFCC, 2022a). Therefore, current pulp output would be inadequate to meet the increasing demand, particularly in developing countries, thereby leading to an increasing shortage of wood raw materials, thereby necessitating increased production and improved production efficiencies.

Conclusion on Mitigation Actions in Industrial Sector

This section highlights the initiatives that the Government of India has demonstrated in implementing several policy measures for undertaking climate mitigation in the industrial sector. Given that climate change concerns and India's pledge to enhance its mitigation actions, it is essential that industrial development be as green as possible. However, the Indian industrial sector is faced with the challenges of fulfilling the developmental requirements of a large developing country in terms of infrastructure, housing, transport, and meeting the demands of a growing population, while also taking measures to reduce carbon emissions using the financial and technological resources at their disposal. While India is a large producer of high-carbon industrial goods like cement, iron and steel, and aluminium, India's per capita consumption of these goods is well below the global average and the demands in these sectors are projected to increase in the near future. Chemical and petrochemical industries provide important inputs to downstream industries like textiles and pharmaceuticals, and a growing fertilizer industry is essential to meet food security requirements. Industrial activity is an important contributor to the process of development and enhancing the well-being of the population both through the provision of goods as well as the generation of employment. Mitigation efforts in the industrial sector therefore need to be located and understood in the context of the responsibility that India has in terms of fulfilling its developmental priorities.

Mitigation in the industrial sector requires access to advanced technology and finance. Despite having limited access to technological and financial resources, many Indian industries, especially those in the semi-formal MSME sector, have taken important energy efficiency measures and contributed to emission reductions. This chapter has listed, sector-wise, potential technologies that have been identified for deployment in the near future as well as technologies that are currently in the developmental stage. While the Indian industrial sector is on the path to contribute to India's mitigation commitments, there is significantly more mitigation potential that can be realized with the provision of adequate financial and technological support. Existing projects outlined in the chapter that have been implemented with support from international agencies like UNIDO, GEF, and others have shown the importance of international support for mitigation measures in developing countries. The domestic efforts of the Indian industrial sector in achieving energy efficiency and emission reductions will be greatly enabled by the provision of international technological and financial support, which developed countries have committed to in international climate agreements. There is a potential for improvements in production capacities, energy efficiencies and monitoring and verification systems in various industries, but this would impose an additional burden of costs for India, and the speedy implementation of further mitigation action would be dependent on the provision of climate finance and technology transfers.

3.5 Low carbon Initiatives in the agricultural sector

As per India's NDC submitted to the UNFCCC, only the sectors covered in voluntary declarations have to be reported in the National Communications. India's voluntary declaration does not include mitigation activities and emissions reductions in the agriculture sector as the emissions from agriculture are survival emissions for India due to its contribution towards maintaining food and nutritional security (MoEFCC, 2021a). However, India has undertaken several initiatives to proactively promote improvement of energy efficiency and low carbon development in the agricultural sector. These initiatives are discussed in this section.

The agricultural sector in India plays a fundamental role in ensuring food and nutritional security and serves as a primary source of livelihood for about 58% of the workforce in India. Figure 3.26 shows the contribution of the agricultural sector to the Gross Value Added (GVA) between 2011-12 and 2021-22

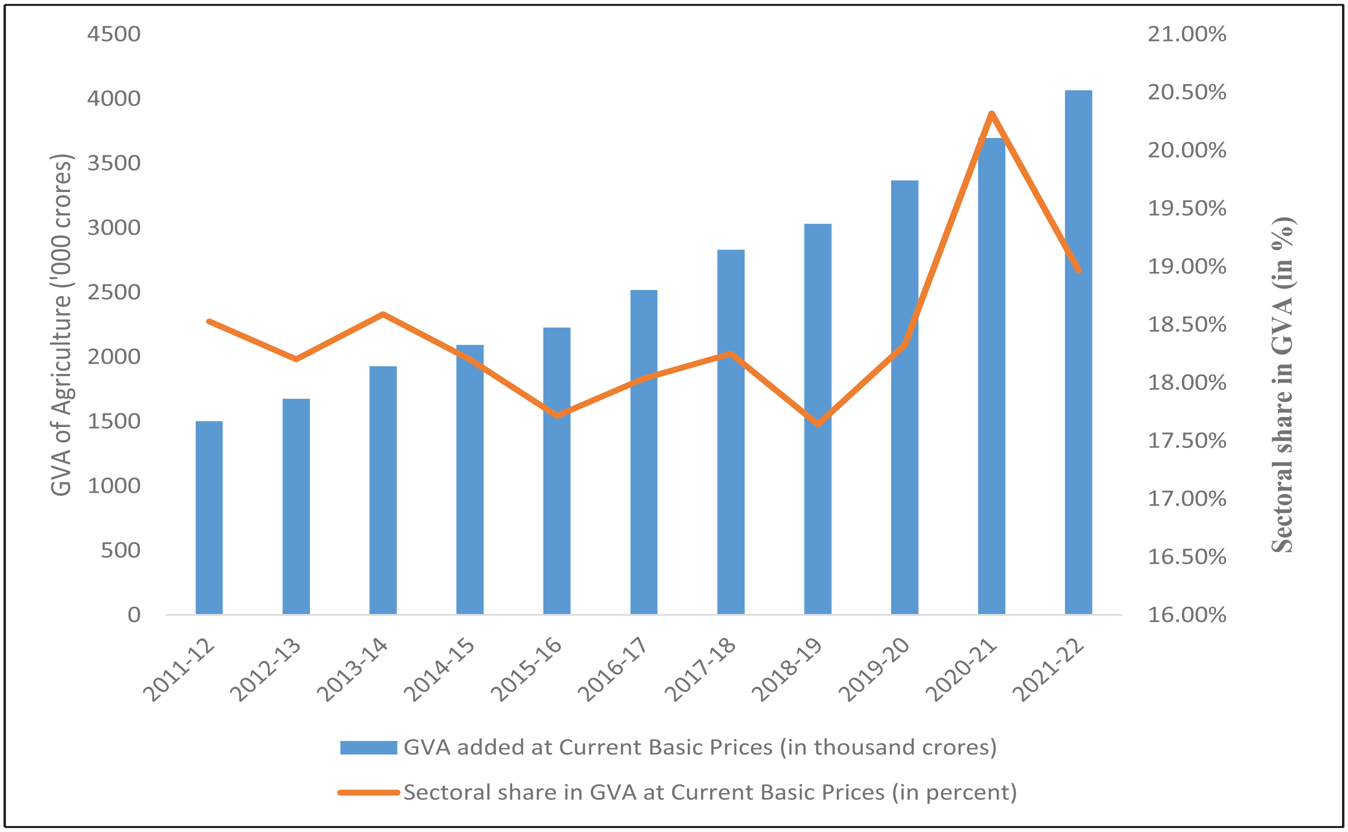

Figure 3.26 Gross Value Added (GVA) and sectoral share of GVA at Current Basic Prices
Source: (MoSPI, 2023c)

The higher contribution of the agricultural sector to the GVA in the years 2020-21 can be partly attributed to the COVID-19 pandemic. The nation-wide lockdown implemented to contain the spread of COVID-19 depressed output from other sectors disproportionately as compared to the agricultural sector (Cariappa et. al, 2021).

3.5.1 Energy Use in agriculture - past, present, and future projections

With the evolution of the agricultural sector in India, various transitions in the patterns of utilisation and sources of energy have also taken place over the years. With the increasing levels of mechanisation, the demand for energy is constantly increasing as the more tedious and labour-intensive crop operations are being mechanised (See figures 3.27 and 3.28). The operation-wise level of farm mechanisation in the country is about 40% for tillage and seedbed preparation, 30% for seeding/planting, 35-45% for plant protection; for harvesting and threshing, the percentage of mechanisation is 60-70% for rice and wheat and less than 15% for all other crops (NITI Aayog, 2018).

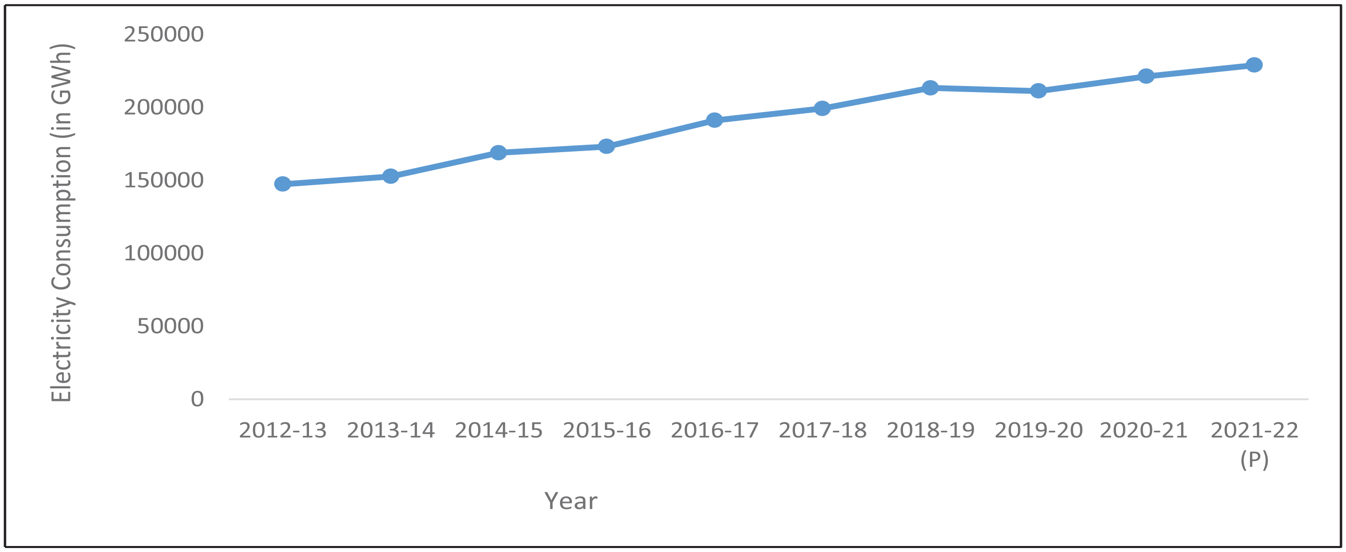

Figure 3.27 Annual consumption of electricity in the Agricultural sector (in GWh)

Source: (MoSPI, 2023a)

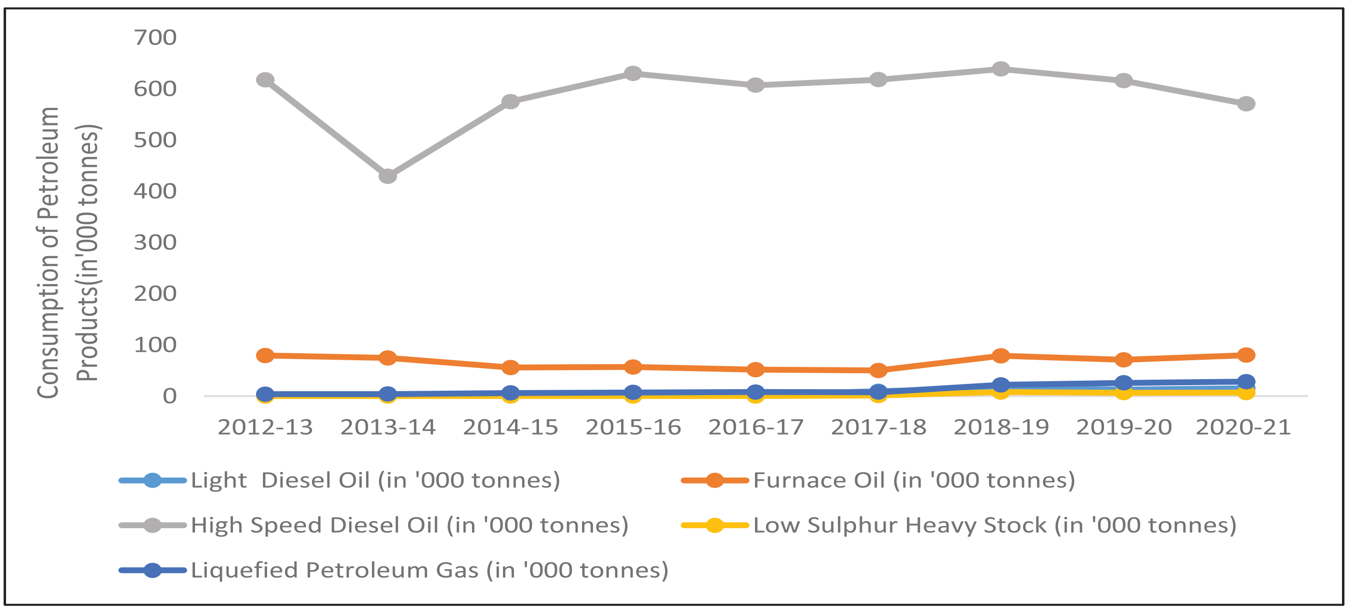

Figure 3.28 Annual Consumption of Selected Petroleum Products in the Agricultural sector (in '000 tonnes)

Source: MoSPI, 2023a

On-farm power availability has grown from 0.28 kW/ha in 1960-61 to 1.83 kW/ha in 2010-11 and is expected to increase to 5.17 kW/ha by 2032-33, with the total farm power availability in 2032-33 being 733.33 million kWh (NITI Aayog, 2018).

3.5.2 Schemes & Interventions undertaken for Climate Mitigation

India's voluntary declaration does not include the agriculture sector. However, India has undertaken several climate-friendly initiatives to proactively promote sustainable development in the agricultural sector. These initiatives are discussed in the following sections.

3.5.2.1 Agriculture Demand Side Management (AgDSM)

The agricultural sector constitutes approximately 18.5 percent of India's total energy consumption with a projected growth in total power consumption of an estimated 54 percent between 2015 and 2022. As of 2018-19, a total of 21.3 million pump sets have been energized, with a majority of the pump-sets being non-standard and inefficient in comparison to the commercially available BEE star rated energy efficient pump sets (MoP, 2020). Agricultural pump-sets of inferior quality used for irrigation are both inefficient and unreliable, leading to higher energy consumption as well as uneconomical groundwater utilization. Under these circumstances, an Agricultural Demand Side management programme has been designed and implemented, for replacing energy inefficient agricultural pump-sets with BEE rated 5-star energy efficient pump-sets. Table 3.26 provides an overview of the progress made under the AgDSM scheme in the period between 2016 and 2022.

Table 3.26 Number of pump-set installations under AgDSM between 2016-2022

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Number of pump-sets replaced/installed	5,109	18,018	40,488	10,784	2,500	2,562

Source: BEE, 2023

A total replacement of 2.1 million pump sets is envisioned under this programme and measures are being taken to achieve this target (MoP, 2020). As on 31st March 2022, 79,975 agricultural pumps have been installed. A total of 6,634,753.14 KWh energy savings and 4,909.74 tCO_2 emission reduction was achieved during FY 2021-2022 under the scheme (BEE, 2023).

Within the purview of the AgDSM scheme, a variety of training and awareness programmes have been conducted in the Krishi Vigyan Kendras (KVKs) which are the local units for agricultural extension set up by the State Governments, for building capacities of farmers. The details of the training programmes conducted in the period 2016-2021 are given below (Table 3.27).

Table 3.27 Training Programmes conducted under AgDSM

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Number of programmes conducted	44,730	45,729	47,000	60,672	52945	55406
Number of farmers trained (capacity building) (in lakhs)	13.21	13.06	13.51	16.82	15.76	16.9

Source: MoA&FW, 2022.

3.5.2.2 National Mission for Sustainable Agriculture (NMSA)

The NMSA is an endeavour by the government to transform the agricultural sector into an ecologically sustainable, climate resilient production system through various adaptation and mitigation measures. The NMSA has been formulated for enhancing agricultural productivity especially in rainfed areas focusing on integrated farming, water use efficiency, soil health management and synergizing resource conservation through the following sub-missions.

Rainfed Area Development

Rainfed Area Development (RAD) is being implemented as a component of the NMSA to establish appropriate farming systems by integrating multiple elements of agriculture, such as horticulture, livestock, fishery, and forestry along with agro-based income generating activities and value addition. Besides, soil test/soil health card based nutrient management practices, farmland development, resource conservation and crop selection conducive to local agroclimatic condition are also being encouraged under this component. RAD focuses on promoting Integrated Farming Systems (IFS) for enhancing productivity and minimizing risks associated with climatic variability. This scheme integrates various crops and cropping systems with allied activities to enable farmers to not only maximize returns from agriculture, but also to mitigate the impacts of droughts, floods and other extreme weather events, by ensuring alternative or additional income opportunities. Table 3.28 provides an overview of the annual progress made by the IFS scheme and the area brought under coverage since inception till 2021-22.

Table 3.28 Area covered under the Integrated Farming System (IFS) between 2014-15 and 2021-22

Year	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	Total
Area covered under the IFS (in hectares)	87232	83211	81943	86289	110802	98695	90642	34595	673409

Source: MoA&FW, 2022.

Sub-Mission on Agroforestry (SMAF)

The SMAF under NMSA have been implemented since 2016-17 as part of the recommendations of the National Agroforestry Policy (2014) to encourage and expand tree plantation in association with crops and livestock to improve productivity, employment, income, and livelihoods of rural households, especially for small and marginal farmers; to protect and stabilize ecosystems and promote resilient cropping and farming systems to minimize the risk during extreme climatic conditions and to increase tree cover to promote ecological stability, especially in the vulnerable regions. Table 3.29 provides an overview of the progress made under the scheme in the period between 2016-17 and 2021-22.

Table 3.29 Area covered under the Sub-Mission on Agroforestry (SMAF) between 2016-17 and 2021-22

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Area covered under the SMAF (in hectares)	43,821.1	50,656.9	77,334.6	92,517.78	87,000	31,419

Source: MoA&FW, 2022.

National Bamboo Mission (NBM)

The NBM was restructured and relaunched in 2018 with a mission to focus on the development and creation of a complete value chain for the bamboo sector to link producers with the consumers. This included creation of a supply chain starting from planting materials, plantations, creation of facilities for collection, aggregation, processing, marketing, micro, small & medium enterprises, skill development and brand building initiatives (DA&FW, 2019). The objectives of the NBM involve increasing the area under coverage of bamboo plantations in non-forest government and private lands to supplement farm income as well as satisfy the requirement of quality raw materials for industry. The mission would also aid in expanding the green cover and enhancing the potential for carbon sequestration (ibid).

Table 3.30 Area covered under NBM in hectares.

Year	2018-19	2019-20	2020-21	2021-22	Total
Area planted under the NBM (ha)	8069	10262	5425	11363	35119

Source: MoA&FW, 2022.

As on 31.01.2022, 70 nurseries for quality planting material were opened, an area of 12,094 hectares for bamboo plantation and 14 bamboo treatment units, 148 product development/ processing units, and 33 infrastructure projects for promotion and development of bamboo markets have been approved as per the Annual Action Plans received from states and institutes.

3.5.2.3 Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)

The PMKSY scheme has been operational since 2015-16 with the purpose of replacing flood methods of irrigation with micro-irrigation systems which reduce electricity consumption required for pumping as well as improve water use efficiency. The adoption of water and energy efficient irrigation technologies help to conserve water by delivering water directly to the root zone, while also having the potential to improve agricultural productivity.

The Department of Agriculture & Farmers Welfare is implementing the Pradhan Mantri Krishi Sinchayee Yojana- Per Drop More Crop (PMKSY- PDMC) component of PMKSY, which primarily focuses on enhancing water use efficiency at farm level through precision and micro-irrigation through the utilization of drip and sprinkler irrigation. Besides, promoting precision irrigation and better on-farm water management practices to optimize the use of available water resources, this component also supports micro level water storage and water conservation and management activities along with the other interventions (DA&FW, n.d.). Table 3.31 provides an overview of the area covered under micro-irrigation under PMKSY-PDMC from 2015-16 to 2021-22.

Table 3.31 Area covered under micro-irrigation, under the under PMKSY-PDMC scheme between 2015-16 and 2021-22

Year	Area covered under micro-irrigation (in lakh ha)
2015-16	5.73
2016-17	8.40
2017-18	10.49
2018-19	11.59
2019-20	11.73
2020-21	9.37
2021-22	10.15
Total	**67.46**

Source: MoA&FW, 2022.

3.5.2.4 Sub-Mission on Agriculture Mechanization (SMAM)

The Sub-Mission on Agricultural Mechanization (SMAM) was launched for the in-situ management of crop residues and to increase the reach of farm mechanization to small and marginal farmers by promoting 'Custom Hiring Centers' to offset the high cost of individual ownership. Tables 3.32 and 3.33 provide an overview of the machines and agricultural equipment (including crop residue management machines, tractors, power tillers) provided to cultivators between 2016 and 2021.

Table 3.32 Number of agricultural equipment provided under the Sub-Mission on Agriculture Mechanization from 2016-17 to 2021-22:

Year	Agricultural machinery distributed including tractors, power tillers & self-propelled machinery (Numbers)
2016-17	151164
2017-18	269062
2018-19	384911
2019-20	201769
2020-21	132741
2021-22	92440

Source: MoA&FW, 2022.

Table 3.33 Total In-situ crop residue management machines distributed under SMAM

Year	Total in-situ crop residue management machinery distributed
2018-19	61679
2019-20	44428
2020-21	51988
2021-22	42475
Total	**200570**

Source: MoA&FW, 2022.

3.5.2.5 Reduction of Energy use and Emissions in Paddy cultivation

Crop diversification programme

Given the higher energy and irrigation intensity of paddy and the subsequent decline in groundwater levels in states such as Punjab, Haryana, and Uttar Pradesh, diversification from paddy to other crops was envisioned. The main objectives of the programme include demonstration and promotion of the enhanced production technologies of alternative crops and the restoration of soil fertility through the cultivation of leguminous crops. Due to the stagnancy in crop yields, decline in soil quality and the incidence of pests and diseases due to continuous paddy cultivation in northern India, diversion of paddy cultivation to other crops has become important. This also enabled a reduction of the methane emissions associated with paddy production.

Table 3.34 Areas covered and cost incurred under crop diversification programme

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Area covered (ha)	17175	55310	26506	3705	68014	22353
Expenditure incurred (in lakh Rs.)	10097.06	3916.03	1903.37	632.74	3272.65	2399.99

Source: MoA&FW, 2022

System of Rice Intensification (SRI)

SRI is a resource-saving method of rice cultivation that is demonstrating promising results in terms of improving yields while reducing input utilization. Studies have indicated a significant increase in rice yields, with substantial savings in the utilization of seeds (80-90 per cent), water (25-50 per cent), and input costs (10-20 per cent) compared to conventional methods of cultivation (Uphoff, 2011), and a reduction in methane emissions. As part of the National Food Security Mission (NFSM) - Bringing Green Revolution to Eastern India (BGREI), SRI is being implemented in 193 districts of 24 states in India. The SRI component under the NFSM – BGREI aims at expanding the area under cultivation and enhancing the productivity in a sustainable manner in identified districts in India, while restoring soil fertility and productivity at the individual farm level, enhancing farm incomes and enhancing post-harvest value addition at farm gate for better price realization to farmers through the creation of efficient market linkages.

Table 3.35 Area covered (in hectares) under the SRI system of cultivation

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22 (Reported up to 2nd quarter)
Target envisaged for coverage of SRI system of cultivation (ha)	36184.6	35056.4	22080.27	12818.8	1823	8053.2
Target achieved for coverage of SRI system of cultivation (ha)	33240	31657.11	21389.6	11515.72	1391	6747
Financial expenditure incurred (INR in Lakhs)	1905.178	1712.048	1511.225	607.056	91	354.09

Source: MoA&FW, 2022

Direct Seeded Rice (DSR) cultivation

DSR is one of the methods of rice cultivation with the objective of doing away with raising nurseries, puddling, and transplanting. Unlike transplanted paddy cultivation, standing water is not maintained in the DSR system and the field is maintained at saturation and a higher cultivable area can be attained under limited water conditions. Due to alternate wetting and drying cycles, the methane emissions can be reduced significantly. The quantum of water application gets reduced significantly thereby resulting in energy savings. As part of the NFSM and BGREI, DSR method of cultivation is being promoted in districts that have been selected for paddy interventions. The extent of coverage of the area with DSR is given in Table 3.36.

Table 3.36 Area covered under DSR cultivation (in hectares)

Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22 (reported up to 2nd quarter)
Target envisaged for coverage of DSR system of cultivation (ha)	42974.8	39962.8	31935.56	23421.8	29774	11090.58
Target achieved for coverage of DSR system of cultiva-tion (ha)	34889	44937.6	34645.46	18671.99	47476	8276
Financial expendi-ture incurred (INR in Lakhs)	2086.239	2566.177	1737.072	1358.428	2447	353.236

Source: MoA&FW, 2022.

3.5.2.6 Mission for Integrated Development of Horticulture (MIDH)

Mission for Integrated Development of Horticulture (MIDH) promotes holistic growth of the horticulture sector, duly ensuring backward and forward linkages. A total of 384 districts in 19 States and 4 Union Territories are covered under MIDH. Sixteen National Level Agencies (NLAs) have also been included for providing support for developmental efforts, which require inputs at the National level. The Mission includes various activities of Coconut Development Board, Horticulture Development Board and Development of Commercial Horticulture through production and post-harvest management, capital investment subsidy for construction, expansion, modernization of cold storages for horticulture produce, technology development and transfer for horticulture produce. This includes provisions for the National Beekeeping and Honey Mission (MoAFW, 2018).

The horticulture sector consists of a wide range of crops such as fruits, vegetables, flowers, spices, and nuts of which the fruit crops produce relatively higher biomass and are retained in the field for a relatively long period. This helps in sequestering carbon both above and below the ground. The area brought under the mission from 2016-17 to 2018-19 is shown in Table 3.37. The quantum of carbon sequestered is estimated to be 108.96 MtCO_2 between 2017-18 and 2018-19.

Table 3.37 Area brought under Mission for Integrated Development of Horticulture

Year	Target envisaged for coverage under MIDH (ha)	Target achieved for coverage under MIDH (ha)
2016-17	157753	142448
2017-18	179695	173491
2018-19	214184	186923
2019-20	213032	154219
2020-21	241352	186154
2021-22	212570	97363
Total	**1218586**	**940598**

Source: MoA&FW, 2022.

3.5.2.7 Energy Substitution: Solarization of Agriculture

Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM)

The PM-KUSUM scheme has been launched since 2019, for the "de-dieselisation of the farm sector and enhancing farmers' incomes by providing energy and water security across India (MNRE, 2021b). The scheme has three primary components in terms of the modes of implementation of solar irrigation systems:

i) Component-A: Setting up of 10 GW of decentralized grid-connected solar or other renewable energy power plants on barren/fallow (leased or owned) land. The power generated is to be procured by distribution utilities (DISCOMs) at feed-in-tariffs determined by respective State Electricity Regulatory Commissions (SERCs). Rural landowners would benefit as it generates an avenue for an additional and continuous source of income through performance-based incentives.

ii) Component-B: Installation of 2 million standalone solar pumps: Within this mode, individual farmers are supported for installing stand-alone decentralized solar pumps of up to 7.5 horsepower (HP) capacity with available state and central subsidies.

iii) Component-C: Solarisation of 15 lakh (1.5 million) grid-connected agriculture pumps: Under this component of the scheme, individual farmers are supported to solarize their pumps of up to 7.5 HP capacity. Farmers would be allowed to use the generated energy to meet their irrigation needs and sell the surplus available energy to DISCOMs, creating extra income for the farmers while supporting the states to meet their Renewable Purchase Obligation (RPO) targets. This component also supports feeder level solarisation by installing a single solar plant for feeding power to single or multiple agriculture feeders. This will provide daytime reliable power to all farmers connected to the grid. Further, in order to strengthen domestic solar manufacturing, use of domestically manufactured solar cells and modules for standalone solar pumps and solarisation of grid connected pumps is mandatory under the scheme (MNRE, 2020).

iv) The states of Andhra Pradesh, Gujarat, Karnataka, and Maharashtra in the recent past have implemented pilot projects which became precursors of the PM-KUSUM scheme to experiment with the possible modes of operation and technology for solarisation of agriculture pump-sets. Table 3.38 provides an overview of the different schemes implemented in India within the ambit of the PM-KUSUM.

Table 3.38 Different schemes implemented in India as components of PM-KUSUM

State	Scheme/ Policy	Components of Scheme	Progress
Andhra Pradesh	BLDC Pump Replacement	Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL) implemented a pilot project wherein all inefficient AC pump-sets on a feeder were replaced with solar BLDC pump-sets as per MNRE specifications. This was implemented for stand-alone solar water pumps along with 5-year insurance and warranty	In the initial phase, the Energy Department installed 250 pump-sets on a pilot basis in the Vizianagaram district. The Andhra Pradesh government is extending the scheme to other districts of the state.
Gujarat	Suryashakti Kisan Yojana (SKY)	PV capacity (in kW) of 1.25 times the pump capacity in HP is allowed to be installed for connection on feeders where normally 70% of the farmers connected on the feeder agree to participate in the Scheme. State and central government subsidies support 60% of the pump cost, with the farmer paying just 5% upfront and the remaining 35% is a loan at a lower interest rate. The scheme is to run for 25 years, with the farmer getting INR 7.00/kWh of production in the first seven years, and INR 3.50/ kWh subsequently.	Since the program's inception in 2018, 91 feeders covering 4,171 farmers across the state's DISCOMS have been solarized.

State	Scheme/ Policy	Components of Scheme	Progress
Karnataka	Surya Raitha	Under the Surya Raitha scheme, older and inefficient pumps are replaced with new energy efficient pumps. Two-third of the electricity generated through solar panels is to be mandatorily used by farmers and the balance energy can be sold to the DISCOM at a proposed rate of INR 7.50 / kWh.	310 solar pump-sets were installed under the pilot programme.
Maharashtra	Mukhyamantri Solar Pump Yojana Maharashtra	In 2018, the Maharashtra government launched its solar irrigation pumps scheme with a target to deploy a total of 125,000 solarised pumps in a phased manner in the three years to FY2021/22.15. A farmer or a group of farmers with land available for deployment of solar panels could apply for the scheme. The beneficiary farmer paid an up-front cost of INR 1,65,594 (USD 2,256) for a 3HP pump and INR 247,106 (USD 3,367) for a 5HP pump.	Against a targeted capacity of 3,654 MW, the Maharashtra Electricity Regulation Commission (MERC) has granted approval for projects totalling 1,826 MW capacity. These projects are at various stages of development (Gambhir et al. 2021). This scheme will result in savings of 27 MtCO_2 emissions per annum across the country (PIB, 2019). Further, it will also result in reduction in consumption of coal by 9.34 million tonnes per annum. As a result of the replacement of diesel pumps with solar pumps, there will be an estimated savings of 1.2 billion tonnes of diesel (PIB, 2019).

Source: (IWMI, 2021), (Rahman et, al, 2021), (BESCOM, 2021), (PIB,2019), (Yashodha et. al, 2021)

Table 3.39 provides an overview of the progress achieved under the KUSUM scheme component-wise.

Table 3.39 Component wise progress made under PM-KUSUM Scheme (as on 31.03.2023)

Component-A (Grid-connected solar power plant in MW)		Component-B (Standalone solar pumps in numbers)		Component-C (Solarization of existing agriculture pumps in numbers.)		
Sanctioned	Installed	Sanctioned	Installed	Sanctioned (IPS)	Sanctioned (FLS)	Installed
4,913	99.95	9,53,791	2,18,539	1,45,930	24,00,279	1,476

IPS: Individual Pump Solarization; FLS: Feeder Level Solarization

3.5.2.8 Convergence of PMKSY and PM-KUSUM demo by Krishi Vigyan Kendra (KVK) and National Commission on Plasticulture Applications in Horticulture (NCPAH)

The scheme gives preference to farmers looking to install standalone solar agriculture pumps and those who are using micro-irrigation systems covered under micro- irrigation schemes, or those who opt for micro-irrigation systems to minimize water usage. Accordingly, while releasing central assistance under the scheme of PMKSY-PDMC, States are advised to converge with the PM-KUSUM scheme for promotion of micro-irrigation systems. Solar pumps are also to be combined with micro-irrigation following the guidelines of the scheme and in coordination with respective implementing agencies. Three solar integrated micro-irrigation projects at Precision Farming Development Centres (PFDCs) namely Ludhiana, Bhopal and Leh are being implemented by NCPAH under the PMKSY-PDMC. A project for the establishment of demonstration units on micro-irrigation systems across 190 Krishi Vigyan Kendras has been approved by the extension division of ICAR under PMKSY-PDMC.

3.5.2.9 Neem Coated Urea

As a matter of policy, all urea, both imported and indigenously produced, available in the country is neem coated since 2016. Total mitigation of 7.529 MtCO_2 was achieved in 2017-18 and 2018-19, with a total production of 47.99 million tonne. Neem-coated urea has higher use efficiency and lower loss of nitrogen due to inhibition of nitrification process in soil compared to prilled urea. For the year 2019-20, the season-wise assessed requirement and production of Neem-coated urea is shown in the following table.

Table 3.40 Production of neem-coated urea

Year	Assessed requirement (in million tonne)	Production of urea (in million tonne)
Kharif 2019	16.407	11.813
Rabi 2019-20	18.204	12.642
Total	**34.611**	**24.455**

Source: MoEFCC, 2021g

3.5.3 Challenges for the future

i) Reduce vulnerability, especially of farmers dependent on rainfed agriculture

Rainfed agriculture in India covers approximately 72 million hectares (constituting 51 percent of the total net cultivated area) practiced across varying agroecological regions and contributing to 40% of the country's food production (Chary, et al, 2020). Despite having witnessed growth in the agricultural sector, the productivity of rainfed agriculture continues to remain low due to multiple risks and constraints relating to biophysical stressors and socio-economic inequalities. Nearly half of all the food grains in India are grown under rainfed conditions, with low-input subsistence agriculture being the predominant mode of cultivation in these regions producing reduced crop yields and degraded soil conditions (Pradhan et. al, 2017). While climate change impacts the agriculture sector in general, rainfed agriculture is more vulnerable due to its high dependency on monsoon and impacts from increased extreme weather events. 76 percent of India's total annual rainfall comes from the monsoon (Gulati et. al, 2013). A large extent of area in the country that depends primarily on the monsoon is highly vulnerable to weather variability. However, sources of irrigation such as tanks, wells, and reservoirs, in most parts of the country, are also dependent on the amount and pattern of precipitation during the monsoon. These, therefore, face significant uncertainty making even irrigated agriculture vulnerable to climatic variability (Vaidyanathan & Sivasubraminiyan, 2004). Endemically low incomes and low levels of mechanisation and input use in agriculture get further compounded by weather variability leading to impacts on agricultural production. This adds to the social and economic vulnerability of cultivators.

A major challenge for India in the immediate future lies in reducing the vulnerability of farmers, increasing land productivity, and ensuring food security. These main objectives must determine policy and technological choices in the agricultural sector. To the best possible extent, synergies with low carbon and climate friendly options should be explored while keeping in mind that there are likely to be climate trade-offs of the most accessible, affordable, and feasible options of meeting the outlined objectives. However, as a developing country, with a large population dependent on agriculture as the main source of income, developmental objectives, and enhancing adaptive capacities must have primacy in the agricultural sector.

ii) Increase mechanisation and input use

According to available census data, out of the 608 million farms world-wide, small farms (i.e., those with less than two hectares) make up 84% of all farms globally. However, they control only around 12% of all agricultural land and generate about 35% of the world's food (Lowder et. al, 2021). Within India, 86% of the small and marginal cultivators (those owning less than 2 hectare of land) cultivate 46% of total cultivated area. Table 3.41 provides a comparison of key agricultural parameters for a few agricultural nations.

Table 3.41 Comparison of key Parameters for Agriculture in Select Countries

Country	Average size of landholding and operational holding (hectares)	Area under cultivation ('000 ha)	Electricity use in agriculture (in terajoules)	Fertilizer used per hectare in 2018 (in kg/ha)	Pesticide used per hectare (tonne/ha)
China	0.6	135675.2	464134.2	393.2	0.013
India	1.08	169317	776039.8	175.0	0.0004
Russia		123442	69556.5	20.8	0.001
UK		6131.5	15894.7	245.6	0.003
USA	179.3	160436.8	174671.3	128.8	0.003

Source: FAOSTAT database, World Bank Indicators database

Improved inputs are required to increase yields and productivity of food grains so as to meet the growing food requirements of the population. Net irrigated area and utilisation of mechanised implements needs to be increased to augment production of food grains. Mechanization and modernization of farming and irrigation practises is therefore necessary while also making an endeavour towards promoting strategies for energy conservation. Various schemes introduced by the government to promote a conducive environment for the growth of solar technology as well as the growth of private enterprises providing decentralized solar energy solutions, especially in rural areas. However, increased transmission and dissemination of decentralised solar irrigation is only possible if a conducive regulatory environment is created which subsidises the installation and capital costs of the technology thereby reducing the overall energy price for the technology. While improved technologies such as renewables are inevitably required, it has to be ensured that their use is accessible and affordable to farmers to ensure a "just growth" in the sector, while planning for the future deployment of low-carbon alternatives.

iii) Need of Agrometeorological Advisory Services (AAS)

Crop production depends upon various direct and indirect inputs in agriculture including climatological parameters, primary inputs such as fertilizers, seeds, irrigation, the use of machinery, the extent of land, and labour, and the relationship between these parameters. This relationship has implications for food supply and crop management policies (Gulati et. al, 2013). Critical weather parameters and the variations in these parameters, such as the changes in minimum and maximum temperatures, the intensity and frequency of rainfall, extent of cloud cover during crucial plant growth periods have a significant impact on crop yield and production (Jayaraman & Murari, 2014). Meteorological parameters also have a significant influence on crop growth, development, yields, pest infestation and diseases, water needs, and fertilizer requirements (CRIDA, 2011). With the change in the climatic scenario as well as changing agricultural production and patterns of production, cultivators require more information about weather parameters during the cropping period (CRIDA, 2015).

Rational decision making in agriculture, especially in times of increased weather variability, depends on factors such as weather forecast services and agrometeorological advisory services (Nesheim et. al, 2017). It is essential to improve management in agriculture in the period of climatic fluctuation. The forecast also requires an effective communication system for the dissemination of relevant information. Dissemination of meteorological information to the farmers at the right time may minimise the risk and losses of agriculture production during the cropping period and will also have a direct impact on farm incomes. The vulnerability of small and marginal farmers can increase considerably with changing and highly variable meteorological conditions (CRIDA, 2015). In this situation, Agrometeorological Advisory Services (AAS) become a necessary intervention to improve risk management strategies of farmers and increase their productive capacities. Across the world, the availability of agricultural extension services as well as agrometeorological services is considered an important strategy in risk mitigation to minimise the potential impacts of climatic uncertainty for agriculture.

Since 2008, the India Meteorological Department (IMD) has started providing the AAS and operated the same through 130 agro-meteorological field units (AMFU) across all agroclimatic zones of the country. Currently, AAS is provided to farmers twice a week (Tuesdays and Fridays) throughout the year. At AMFU level, crop-specific advisories are generated and disseminated through mass media communication systems. In the near term, it would be essential to enhance the provision of these advisories, and also to ensure access to and effective utilisation of the same.

iv) Adaptation in Agriculture

Methane emissions from India are primarily from sub-sustenance activities by marginal and small farmers, required for the cultivation of essential food crops, thereby forming survival emissions, rather than luxury emissions. Indian agriculture consists of a majority of small and marginal cultivators, who already have to bear a disproportionate burden of adapting to climatic changes which they have not contributed to. The primary objective for India in the agricultural sector is therefore to ensure the reduction of vulnerability and enhance adaptive capacities of Indian farmers.

3.6 Mitigation undertaken in the Buildings and Domestic Energy use sector

In 2011, India's urban population stood at 377 million people, which is 31.8 per cent of the total population. This figure is projected to grow to 38.2 per cent by 2036, out of a total projected population of 1.52 billion people (National Commission on Population, 2020). This indicates a trend of further rapid urbanization, which is natural for a fast-developing country like India. This rapid urbanization will lead to an increase in demand for built infrastructure like housing and community infrastructure. Buildings also play an important role in climate change mitigation. The report of Working Group-III for AR6 cycle of IPCC outlines their importance in terms of their potential to lock-in the energy consumption and associated emissions for decades to come due to their long lifespans. India is thus making multiple efforts at mitigating emissions from construction and use of buildings.

Much of the emissions resulting from buildings are indirect, both during construction and use. Indirect sources of emissions during construction are essentially the embodied energy in construction materials resulting from industries that produce building materials. Similarly, the emission factors in electricity production determine the emissions due to final energy use during the life cycle of buildings. Emissions from building post construction can also be reduced by better building design to ensure lower energy use for cooling or heating. Much of the efforts at mitigation efforts in the building sector focus on the demand side management of energy and material use through design and technology. The following sections will give an overview and implementation status of policies and programs being enacted in India aimed at both energy efficiency in domestic energy consumption, encouraging design and construction of green buildings, and adoption of green technology.

India's Long-Term Low Carbon Development Strategy (LT-LEDS) puts forth transitions to low carbon development pathways in seven key sectors. One of these transitions includes "promoting adaptation in urban design, energy and material efficiency in buildings and sustainable urbanization.

The Bureau for Energy Efficiency (BEE) that has undertaken the implementation of most of these policies, was set up by the Government of India in 2002 under the Energy Conservation Act, 2001. Its objective is to develop policies and strategies to reduce the energy intensity of the Indian economy within the framework of the Energy Conservation Act, 2001, with a focus on self-regulation and market principles.

3.6.1 Current Scenario

Electricity consumption by residential and commercial buildings in India between 2011 and 2020 is shown in Table 3.42. There has been an increase of 88% from 2011 to 2020 in the total electricity consumption by buildings. Residential and commercial buildings constituted about 33% of the total electricity consumption in India. Energy demand in this sector is projected to increase by 5 times in the residential sector and 3 times in commercial sector by 2032 (BEE, 2021)[5] .

5 These projections are estimates published by Government of India agencies such as the Bureau of Energy Efficiency and the NITI Aayog.

Table 3.42 Electricity consumption in residential and commercial buildings [Values in GWh]

Year	Commercial	Domestic	Total
2012-13	7279	183700	256494
2013-14	74247	199842	274089
2014-15	78391	217405	295796
2015-16	86037	238876	324913
2016-17	89825	255826	345651
2017-18	93755	273545	367300
2018-19	98228	288243	386471
2019-20	106047	308745	414792
2020-21	86950	330809	417759
2021-22 (P)	107500	334000	441500

Source: MoSPI (2023a)

Table 3.43 illustrates domestic consumption of electricity and fossil fuels. The consumption of oil has increased by over 20% since 2011, while that of Natural Gas by over 60%. Electricity consumption has doubled over the same decade.

Table 3.43 Oil, natural gas and electricity consumption in the residential Sector

Year	Oil Consumption (000 Tonne)	Natural Gas Consumption (MMSCM)	Electricity Consumption (GWh)	LPG Consumption (000 tonne)	Kerosene Consumption (000 tonne)
2011	21090.7	243.462	155300.97	12,369	8722.00
2012	21340.9	397.752	171103.599	13,296	8045.00
2013	20917	410.614	183700.44	13,568	7349.04
2014	21420.5	414.731	199841.8	14,412	7008.86
2015	22957.7	384.73	217404.73	16,040	6917.34
2016	23830.6	388.168	238845.69	17,182	6648.94
2017	24075.48	NA	255826.01	18,871	5204.12
2018	23985.37	NA	273545.03	20,352	3633.59
2019	24959.23	NA	288243.12	21,728	3231.21
2020	25249.8	NA	310151*	23,076	2173.71

Source: India Energy Dashboard, NITI Aayog (2022a)

3.6.2 National Mission on Sustainable Habitat

The National Mission for Sustainable Habitat is one of the nine missions under the National Action Plan on Climate Change and was approved by the Union Cabinet in 2010. The NMSH seeks to promote current and future climate change mitigation and adaptation policies in the built environment, including buildings, waste management and transport. One of the stated objectives of NMSH is "improvements in energy efficiency in buildings through extension of the energy conservation building code - which addresses the design of new and large commercial buildings to optimize their energy demand" (CPHEEO, n.d.). Development of sustainable habitat standards is thus one of the key deliverables of the mission. The revised National Building Code, 2016, which constitutes the guidelines for all construction works in India, incorporated the ECBC in a new chapter. The ECBC for residential and commercial buildings themselves have been revised subsequently.

The NMSH has been implemented through 4 flagship missions - Atal Mission on Rejuvenation and Urban Transformation (AMRUT), Swachh Bharat Mission, Smart Cities Mission, Urban Transport Programme. Various achievements under these missions are summarised below.

Table 3.44 Flagship missions under National Mission for Sustainable Habitat and their achievements till 2021

Mission	Achievements
Smart Cities Mission	• 5,151 projects worth INR 2,05,018 Crore initiated, of which 3,170 projects worth INR 53,370 Crore have been completed (MoHUA, 2021b). • 78 projects in as many cities worth INR 8,808 Crore to implement Integrated Command and Control Centers; 718 projects on Smart Roads worth INR 22,788 Crores; 528 projects worth INR 38,185 Crore on Waste Water; 225 projects worth INR 21,907 Crore being implemented with Public Private Partnership; have been completed or ongoing (MoHUA, 2021b).
Atal Mission on Rejuvenation and Urban Transformation (AMRUT)	• Over 5.8 million watertap connections installed, over 3.7 million sewerage connections installed, 1946 parks developed, and over 6.2 million street lights replaced with LEDs (MoHUA, 2021b)
Swachh Bharat Mission	• In urban areas, over 6.2 million individual household toilets constructed, overtaking the target of 5.8 million; over 620,000 community and public toilets constructed, overtaking the target of 500,000; over 4371 cities have been declared Open Defecation Free, of which 4316 are ODF verified (MoHUA, 2021c). • In rural areas, over 108 million household toilets built in Phase 1 since 2014, and over 6,00,000 villages declared ODF (MoHUA, 2021d).
Urban Transport Programme	• 791 kms of Metro rail line under construction in 27 cities • 82 kms of Regional Rapid Transit System under construction • 319 kms of Bus Rapid Transport System operation • Further 515 kms of BRTS in 11 cities operational (MoHUA, 2021b)

3.6.3 Energy Conservation Building Code

The first ECBC was developed in 2007 and revised considerably in 2017. The 2017 ECBC has also been updated in 2018 and 2019 based on consultations with stakeholders held by the Bureau for Energy Efficiency. Along with ECBC 2017, Government of India has also notified ECBC Rules, 2018 under the Energy Conservation Act, 2001, laying down the procedures for ensuring compliance of future constructions. These Code and Rules are applicable to all buildings with a connected load of 100 kilo watt (kW) or above or a contract demand of 120 kilo-Volt Ampere (kVA) or above. The earlier eligibility criteria for buildings was a connected load of 500 kW or above or a contract demand of 600 kVA or above only, which was amended in 2010 to bring more buildings under the coverage of the guidelines.

ECBC covers all important building components: building envelope; comfort systems and controls (heating, ventilation and air conditioning service hot water system); lighting and controls; and electrical and renewable energy systems. It also prescribes standards in accordance with the five major climatic zones of India. Compliance is determined either through the prescriptive method where the project has to meet all mandatory and prescriptive requirements, or through the Whole Building Performance Method where the project has to meet mandatory requirements in addition to its Energy Performance Index being lower than a standard building.

The minimum level of energy efficiency that an ECBC Compliant building achieves is 20% compared to a standard baseline, by adhering to the mandatory and prescriptive requirements. Buildings achieving energy efficiency of 30-35% are labelled as ECBC Plus and those achieving 40-45% of energy efficiency are labelled Super ECBC Building. The code is implemented by State Governments, which can make necessary modifications to suit local requirements. In the FY 2021-22, 25 building cells have been functional covering all States/UTs. Implementation of ECBC has committed in Andhra Pradesh, Assam, Andaman & Nicobar Island, Haryana, Karnataka, Kerala, Punjab, Sikkim, Telangana, Uttarakhand, Madhya Pradesh, Uttar Pradesh. About 270 ULBs have covered under these states.

As on 31st March 2022, 173 buildings have been registered under ECBC. The 173 constructed and ECBC compliant buildings with total area of 5.51 Million square meter have led to energy savings of 79.19 MU. Countrywide implementation of ECBC is expected to achieve a 50% reduction in commercial building energy use by 2030, translating into energy savings of 300 billion units and peak demand reduction of over 15 GW in a year, and 250 Million Tonnes of CO_2 reduction (PIB, 2017).

3.6.4 Building Energy Efficiency Programme

The Building Energy Efficient Programme, launched in May 2017 by the Government of India, and implemented by Energy Efficient Services Limited (EESL), aims to retrofit existing public, institutional and industrial buildings with energy efficient appliances and systems. The major interventions in buildings are in the lighting and air-conditioning systems by retrofitting energy efficient ceiling fans, ACs and LED lights. EESL also gives access to a Building Management System to building managers to allow them to efficiently manage their electricity consumption using real time data.

BEEP aims to retrofit 20,000 Government and Private Buildings with energy efficient solutions by investing INR 2,000 crore (equivalent to USD 30.8 crore). This will lead to retrofitting of around 2 crore LED lights, 25 lakh energy efficient ceiling fans, and 2 lakh energy-efficient air conditioners. The Government also aims to expand the scope of BEEP to include centralized air conditioning, Energy Audits, and New Generation Energy Management System.

Energy Audits conducted by EESL in these buildings show potential electricity consumption reduction of 30-50%. As on 31st March 2021, over 15,000 buildings have been either completed, under retrofitting, or proposed under BEEP (BEE, 2021). So far, over 1.25 million indoor lights, over 156,000 outdoor lights, over 290,000 fans, and over 34,000 ACs have been installed (EESL, 2021b). The total energy savings from BEEP till November 2021 has been over 653 GWh, leading to avoided emissions of 536,000 tCO_2 (EESL, 2021b).

3.6.5 Star Rating System for Commercial Buildings

BEE launched the Star Rating System in 2009 to encourage private commercial buildings to adopt energy efficiency measures. Four categories of buildings – office buildings, BPOs, shopping malls and hospitals – are covered. The rating is done on the basis of their Energy Performance Index calculated as energy usage in kWh/sqm/year, based on which buildings are awarded between 1 and 5 stars, with the latter being the most efficient. Standards to rate them are formulated for all four categories, with separate values for India's 5 climatic zones. Further differentiation is done on the basis of the ratio of air-conditioned area to the total floor space.

Till the end of March 2022, total 264 buildings have been awarded Star Rating under this programme. On account of the total number of star-rated buildings in the last 5 years, the total energy (electrical) saved by these commercial establishments in the year 2021-22 is 261.57 MU. This has led to a reduction of 0.2065 tonnes of CO_2. Details of the program are shown in Table 3.45.

Table 3.45 Year wise details of energy savings across 4 categories of the Star Rating System, along with their avoided carbon emissions

Building Type	2017-18	2018-19	2019-20	2020-21	2021-22	Total	Avoided CO_2 Emissions (Mn Tonne)
Offices	6.2	7.9	51.5	14.3	12.8	92.77	0.0732
BPO	28.6	40.8	86.2	0.0	0.0	155.6	0.1229
Hospital	0.0	3.5	0.9	0.0	0.0	4.4	0.0034
Mall	0.0	8.9	0.0	0.0	0.0	8.9	0.0070
Total	34.8	61.0	138.6	14.3	12.8	261.57	0.2065

Source: BEE, 2023

3.6.6 Econiwas Samhita for Residential Buildings

The increasing urban population has led to an increased demand for housing in cities, leading to a booming residential real estate sector. By year 2030, around 3 billion m^2 of new area is expected to be added with respect to 2018. Consequentially, electricity demand, which has been increasing at a CAGR of 8% per year on average, will see an increase in electricity consumption from 273 BU in 2017 to almost 700 BU in 2030 (BEE, 2021).

Ministry of Power, Government of India, launched the Eco Niwas Samhita, an ECBC targeted specifically at residential buildings, in 2018. It aims to make the design and construction of residential buildings more energy efficient, as well as reduce the electricity consumption during the life of the buildings. The code is applicable to all residential buildings, including those that are part of mixed-use projects, built on plot areas of more than 500 m^2. The minimum plot area for code applicability is also flexible, where the State and Urban Local Bodies can determine their own criteria based on local conditions.

ENS Part I concentrates on building envelopes, to reduce heat gain and losses, and maximise natural ventilation and daylighting potentials. ENS Part II sets standards for electro-mechanical systems and renewable energy systems and has been launched in 2021. The Government also plans to train over 15,000 professionals in the building sector like architects and engineers in ECBC and ENS. To ensure compliance with ENS, the Government has also launched an online ENS Compliance tool for home owners and ULBs (PIB, 2021f).

Currently, BEE and the Ministry of Power are developing an energy efficiency labelling program for residential buildings under Eco Niwas Samhita to encourage further efforts by private players to achieve energy efficiency. Its estimated cumulative energy saving potential is 388 Billion Units by the year 2030 (BEE, 2021).

3.6.7 Pradhan Mantri Awas Yojana – Urban (PMAY-U) and Pradhan Mantri Awas Yojana – Grameen (PMAY-G)

Launched in June 2015 by the Ministry of Housing and Urban Affairs, PMAY-U is a Central Government Scheme to address the urban housing shortage. The implementation period of PMAY-U scheme which was earlier from 25.06.2015 to 31.03.2022, has been extended up to 31.12.2024, except Credit Linked Subsidy Scheme (CLSS) vertical, to complete all the houses sanctioned under the scheme without changing the funding pattern and implementation methodology. PMAY-U has a technology-sub mission to encourage the use of innovative and green technologies and materials for sustainable and quality construction of houses. It covers the design and planning, technologies and materials, and use of natural resources in construction. Separate guidelines have been issued under this sub-mission to encourage various implementing agencies to adopt these technologies. Construction of Demonstration Housing Projects to disseminate and facilitate adoption of new technologies was also undertaken in collaboration with the Building Materials and Technology Promotion Council. As of November 2022, more than 1.20 crore houses have been sanctioned under the Mission, out of which more than 64 lakhs have been completed and the rest are in various stages of construction/grounding (PIB, 2023).

Similarly, the Pradhan Mantri Awas Yojana – Grameen (PMAY-G), scheme for rural housing, has initiated the adoption of locally appropriate technologies and design in the construction of housing in rural areas. These technologies encourage use of materials with low embodied energy indirectly reducing emissions. Over 130 housing typologies have been documented and developed under PMAY-G, and the range of materials are being validated by the Central Building Research Institute (CBRI), Roorkee (MoRD, 2021).

3.6.8 Regulation of buildings and construction projects

Any building and construction projects covering more than 20,000 sqm. of built up area require to obtain prior environmental clearance from the State Environment Impact Assessment Authority under the provisions of EIA Notification, 2006 and its amendments thereof. The Expert Appraisal Committee (EAC) appraises the proposed project and recommeds grant of environment clearance with environmental safeguards interalia energy efficiency, water conservation, greenbelt, waste management etc.

3.6.9 Non-Government Initiatives in Building Sector

It is pertinent to note that apart from all the government initiatives, the private sector in India has been taking the lead in designing and developing energy efficient green buildings. The LEED, GRIHA and IGBC are best examples of these initiatives, and are described below. Additionally, various State Governments encourage these initiatives by providing incentives such as additional floor area ratio for free across from 3% to 15% depending upon the rating. The Ministry of Environment, Forests and Climate Change also gives a fast-tracked environmental clearance for green rated buildings (BEE, 2021; IGBC, n.d.).

3.6.9.1 Leadership in Energy and Environmental Design (LEED)

Leadership in Energy and Environmental Design (LEED) is an international rating system for green buildings, developed by the US Green Building Council. LEED encompasses the design, construction and operation of buildings, guiding owners and operators to efficiently manage resources. Energy performance, demand response, energy metering, renewable energy production, green power and carbon offsets are some of the relevant criteria for mitigation that LEED covers. India is the fourth largest market in the world under LEED, with more than 2,900 registered and certified projects, covering 1.39 Billion sq. ft. of built space, covering IT Parks, Offices, Airports, and Hotels among others.

3.6.9.2 Indian Green Building Council (IGBC)

The Indian Green Building Council (IGBC), a part of Confederation of Indian Industry (CII), offers a wide array of services which include developing new green building rating programmes, certification services and green building training programmes. Various stakeholders like building industry professionals, developers, product manufacturers, corporate entities, government bodies, academia, and nodal agencies participate in the council activities. Its 24 local chapters facilitate a sustainable built environment at the local level through policy advocacy, capacity building, networking, and awareness programs. The IGBC Green Building rating programs have led to significant benefits like savings of 30 to 40% on energy costs, which is equivalent to 15000 MWh per million sq. ft. per year of built space; and 20-30% savings on water consumption, equivalent to 45000 kL per million sq. ft (BEE, 2021). These ratings systems also comply with all national standards and norms like ECBC, NBC and Pollution Control guidelines.

As on 31st December, 2019, more than 5,723 Green Building projects with a footprint of over 7.09 Billion sq. ft are registered with the IGBC (BEE, 2021). Out of these, 1,932 Green Building projects are certified and fully functional in India.

3.6.9.3 Green Rating for Integrated Habitat Assessment (GRIHA)

GRIHA is an independent green building rating system developed in India by The Energy and Resources Institute, in collaboration with the Ministry for New and Renewable Energy, Government of India. It was adopted as the national rating system for Green Buildings in India in 2007. All buildings with built up area of more than 25,000 m^2 except industrial complexes are eligible for GRIHA, which rates buildings on their Energy Performance Index based on 31 criteria. As on 31st March 2022, 61 Buildings have been rated by GRIHA and these buildings have contributed in energy saving of 88.20 MU (0.082 BU) (BEE, 2023).

3.6.10 Standards and Labeling Programme

The S&L Programme was launched in 2006 by the Ministry of power and is one of the key focus areas of BEE. This program entails setting standards for energy performances of various appliances and rating their performance between 1 and 5 stars. This facilitates the consumers in making an informed choice about energy and energy cost savings. The BEE issues comparative labels like the star-rating system, and endorsement labels which is a certification for highly energy efficient products. Deep freezers and light commercial air conditioners are the latest products added in the programme in March 2020. Currently, 10 appliances have to mandatorily get a star-rating under this program, while 20 can do so voluntarily. Energy savings and avoided emissions due to S&L program are summarised in Table 3.46.

Table 3.46 Year wise energy savings and avoided emissions from the Standards and Labelling Programme

Year	Total Energy Savings (Billion Units)	Total Emission Reductions (Million Tonne CO_2)
2018-19	19.3	15.61
2019-20	20.11	16.29
2020-21	18.90	15.31
2021-22	12.29	9.95
Total	**70.57**	**57.16**

Source: BEE, 2023

3.6.11 Unnat Jyoti by Affordable LEDS for All (UJALA)

Unnat Jyoti by Affordable LEDS for All (UJALA) scheme was launched in January 2015. Under this program, EESL sells LED bulbs, LED tube lights, and energy efficient fans at a highly subsidised price. Apart from promoting efficient use energy at domestic level, this program aggregates demand to reduce the high initial costs to facilitate higher uptake of LED lights by residential users. During the financial year 2021 – 22, EESL has distributed 1.05 million LED bulbs, where cumulative achievement as on 31st March 2022 is 367 million LED bulbs. Total energy savings of 47.78 billion kWh per year with avoided peak demand of 9567 MW and estimated GHG emission reduction of 38.70 million tCO_2 per year (EESL, 2022).

Table 3.47 Achievements under UJALA in the period 2016-2022

Year	LED Bulbs		LED Tube Lights		Energy Efficient Fans	
	Units Distributed (Millions)	Energy Savings (Million Units)	Units Distributed (Millions)	Energy Savings (Million Units)	Units Distributed (Millions)	Energy Savings (Million Units)
2016-17	124.3	15,883	1.57	55	0.59	53
2017-18	79.8	10,195	4.26	153	1.06	99
2018-19	58.2	7,436	1.52	57	0.57	55
2019-20	12.03	1,533	0.24	8.7	0.11	10
2020-21	4.89	630	0.103	4.52	0.043	3.96
2021-22	1.05	135.32	0.052	2.30	0.056	5.25
Total	**280.27**	**35,812**	**7.745**	**280.52**	**2.429**	**226.21**

Source: BEE, 2023

3.6.12 Pradhan Mantri Ujjwala Yojana

Pradhan Mantri Ujjwala Yojana was launched by the Ministry of Petroleum and Natural Gas in May 2016, to make LPG, which is a clean cooking fuel, available to the rural and deprived households. These households otherwise use traditional fuels such as firewood, coal, cow-dung cakes etc., which has negative health and environmental impacts. The initial target of providing 50 million LPG connections was revised to 80 million LPG connections, to be achieved by March, 2020. This increased target was achieved in September, 2019. The Government of India has now extended the scheme in the financial year 2021-22 by making the provision for 10 million more LPG connections and increasing the coverage to include migrant families. LPG connections given to 96 million households under Pradhan Mantri Ujjwala Yojana (PMUY) has led to an increase in LPG coverage from 62% on 1st May 2016 to near saturation in March 2023.

3.7 Mitigation in the transport sector

The transport sector in India comprises roadways, railway, water and airways in decreasing order of value added to the GDP (BERPD, 2018), with the sector contributing around 10% overall to the GDP. Figure 3.29 shows that this trend has remained constant in the past years. Currently, the primary mode of both freight and passenger transport is road-based.

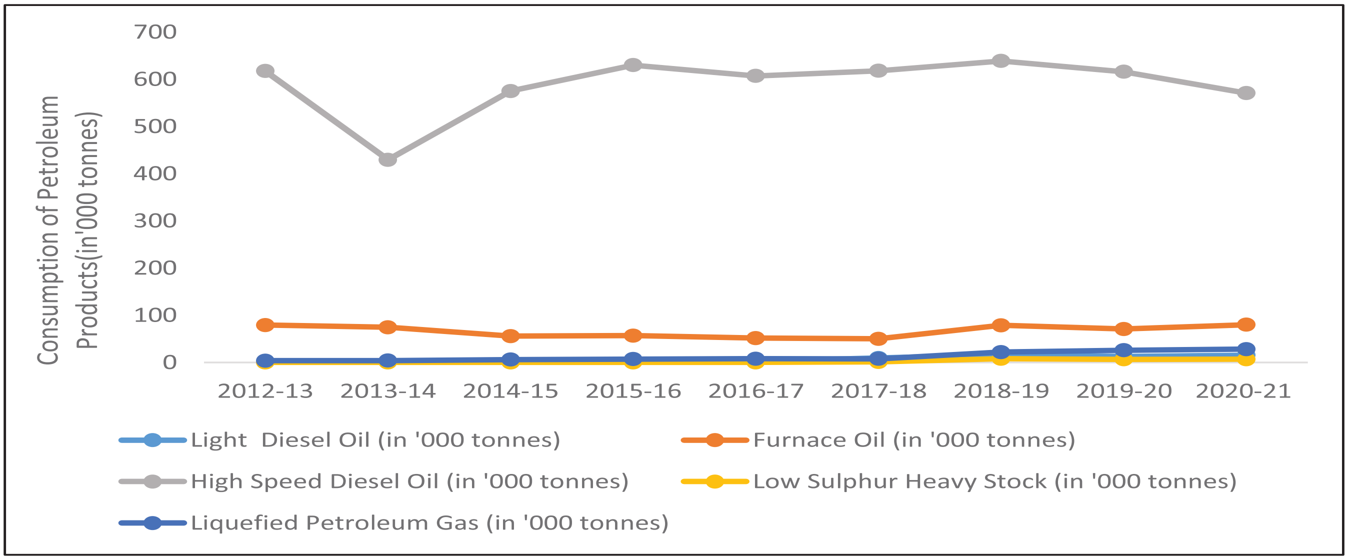

Figure 3.29 Value added by transport sector to GDP in India
Source: BERPD, 2018

However, railways have also expanded in spite of their decreasing modal share. It still remains the main mode of transport for coal, lignite, iron ores, cement etc., thus meeting the daily requirements of the power and industrial sectors (BERPD, 2018).

The National Waterways Act was passed in 2016. With this, 111 inland waterways were declared as 'National Waterways' to promote shipping and navigation. These national waterways measure a total of 20,162 km spread across 24 states in the country as of July, 2021 (MoPSW, 2021b). India also has 12 government-owned ports and approximately 200 notified non-major ports along its coastline and sea-islands (MoPSW, 2021a).

The expansion in airways has also been significant. The number of airports has gone up from 74 in 2014 to 147 in 2022 in India (MoCA, 2023). India has emerged as one of the fastest growing aviation markets in the world. The domestic traffic in India has more than doubled from around 61 million in 2013-14 to around 137 million in 2019-20, registering a growth of over 14 percent per annum (Ministry of Finance, 2022). Figure 3.30 shows the modal split of passenger transportation in India (TERI, 2020).

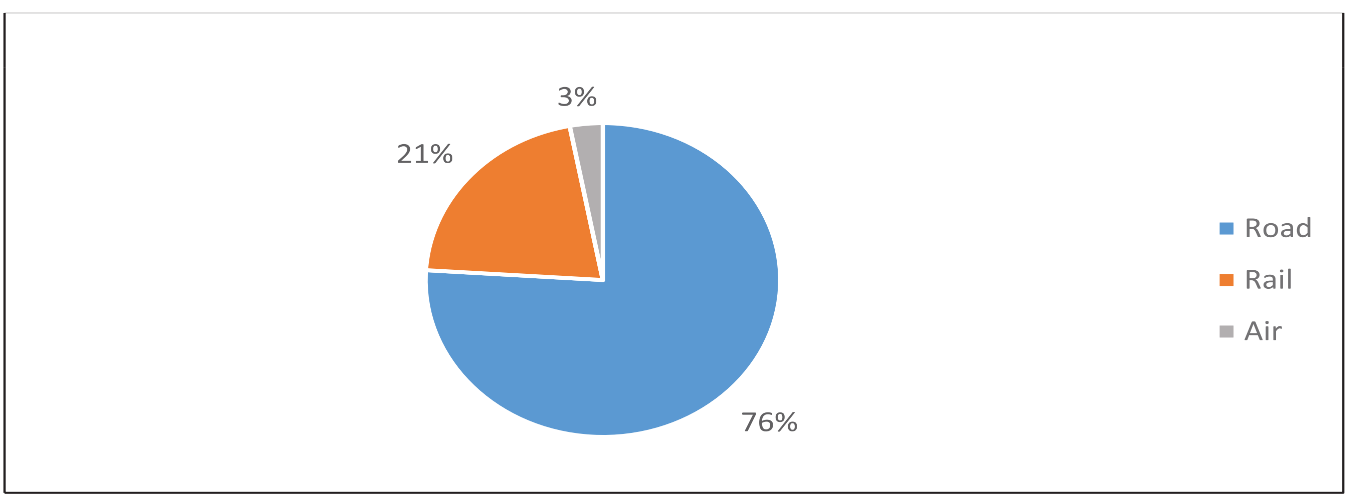

Figure 3.30 Modal split of passenger transport
Source: TERI, 2020

The sector has seen changes in modes, fuel use, and efficiency parameters. The policy initiatives and reductions in CO_2 achieved are discussed in the subsequent sections.

3.7.1 Current Scenario in the Transport Sector

The sector has seen increased electrification and increased energy utilisation. Steps have been taken to promote public transport run on alternative fuel sources to lower emissions. This has increased the share of alternative fuels in total fuel use. Figure 3.31 shows the fuel use distribution of the sector over the past decade (MoSPI, 2022; MoP&NG, 2022b).

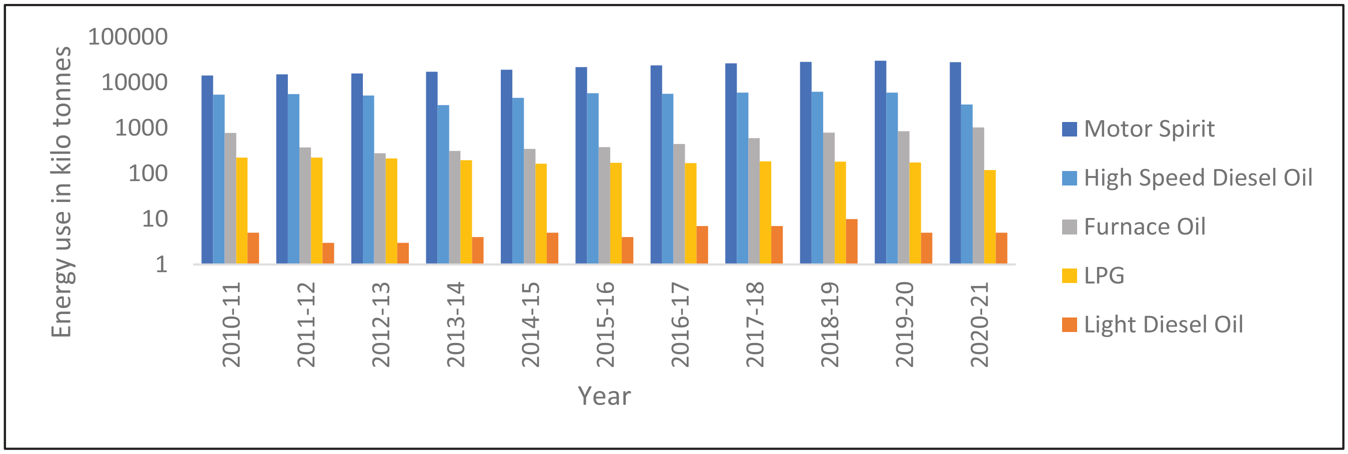

Figure 3.31 Fuel use in transport sector
Source: MoSPI, 2022; MoP&NG, 2022b

3.7.1.1 Electricity Consumption

There is an increasing trend in energy use across the major fuel sources (other than in the pandemic year). A similar trend is also seen for electricity use in transportation (See Figure 3.32). Electricity consumption in railways has also increased alongside the increase in the pace of electrification of the railways (see Figure 3.33).

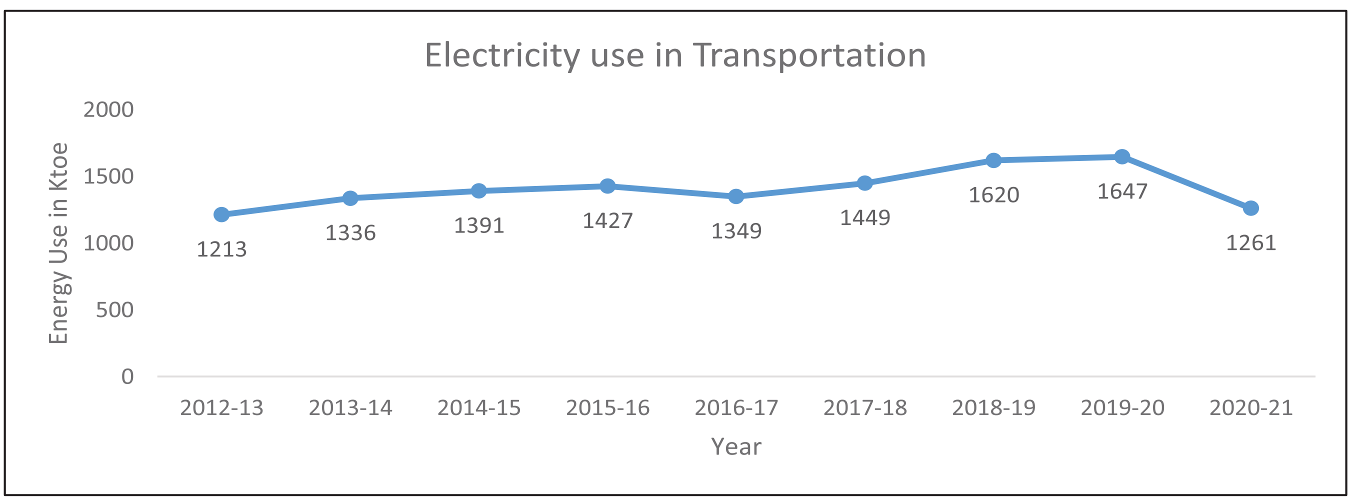

Figure 3.32 Electricity use in transport sector
Source: MoSPI, 2023

Between 2014-15 and 2020-21, about 3400 km of the railway route has been electrified on an average. By 2021, 71% of the total Broad-Gauge network has now been electrified (Ministry of Railways, 2021; Ministry of Railways, 2022).

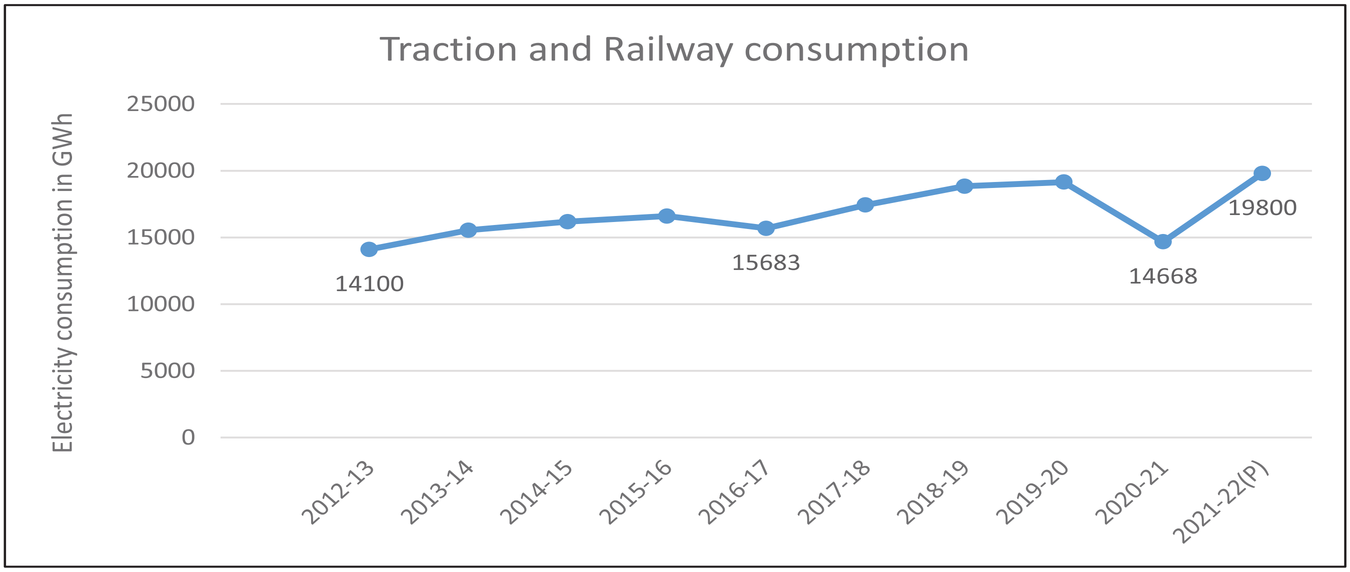

Figure 3.33 Electricity consumption in Traction and Railways
Source: MoSPI, 2023

3.7.1.2 CNG Consumption

About 25 diesel powered cars in the railways have been converted to CNG based dual fuel engines (PIB, 2021c). The use of CNG based three-wheelers has increased significantly in major Indian cities. The overall increase in use of CNG (other than in the pandemic year) is shown in Figure 3.34.

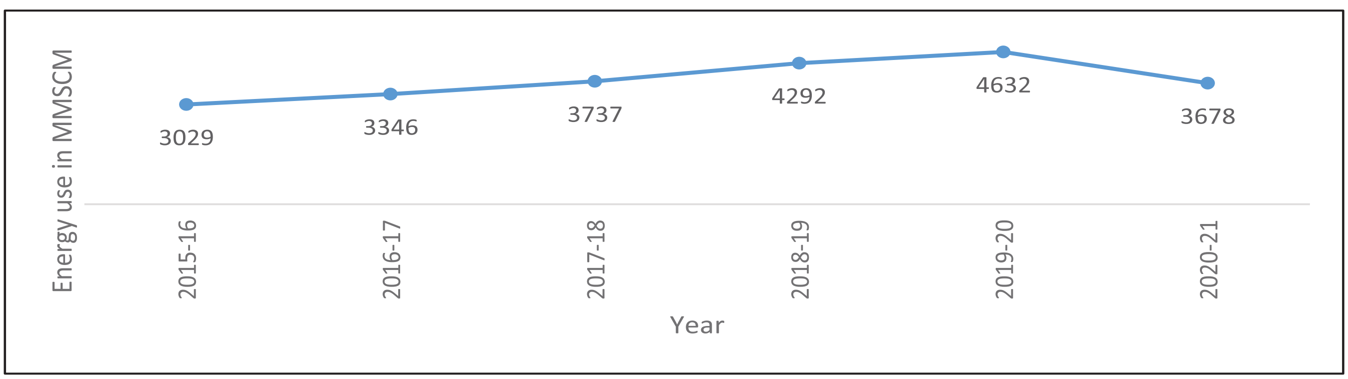

Figure 3.34 CNG consumption in transport sector
Source: MoP&NG, 2022b

3.7.2 Low Carbon Growth Plans and Projections for the Rail, Water, and Air Transport Sectors

3.7.2.1 Railways

Indian Railways plans to achieve 100% electrification of all broad-gauge routes by the end of year 2023. This is expected to reduce dependence on imported diesel fuels and reduce the carbon footprint of the railways. It also plans to improve energy efficiency in traction by inclusion of new energy efficient locomotives. For this, it has already awarded a contract for the supply of 800 electric locomotives with 12,000 HP IGBT based 3 phase propulsion technology (PIB, 2020b). Passenger trains are also being converted to mainline electric multiple units to reduce their carbon footprint.

The Indian Railways have decided that all new locomotives and Electric Multiple Units will be manufactured with three phase technologies with regenerative capability. This is expected to save about 15% energy from locomotives and 30% energy from Electric Multiple Units (BEE, 2021).

The Indian Railways plans to install solar plants on unused vacant railway land – about 20 GW of land based solar plants by 2030 (PIB, 2020d).

3.7.2.2 Waterways

The Government of India plans to expand the use of coastal shipping and inland water transportation as they have been recognised for their fuel efficiency, environmental friendliness, and cost-effectiveness (PIB, 2018a; MoPSW, 2021c). Multiple initiatives have been announced by the Government of India, which are listed below:

- The Coastal Berth Scheme has been introduced where financial assistance is provided to the implementing agency for infrastructure creation. This is to promote the movement of cargo and passengers by sea and national waterways. The estimated cost of implementing this scheme is expected to be INR 1,207 Crore (PIB, 2018a).
- Sagarmala programme: This programme envisions port led development for India. This includes port modernization, port connectivity, port-led industrialization, and coastal community development projects. More than 800 projects have been identified under this programme to be completed by 2035. Estimated cost of INR 5.54 Lakh Crore is expected to be spent on realising these projects. (MoPSW, 2021b)

Cargo handling capacity of major ports has increased over the years. In 2014-15 this capacity stood at 871 MTPA which rose to 1561 MTPA in 2021-21 (MoS, 2020; MoPSW, 2022).

3.7.2.3 Aviation

Many major international airports, including those in Delhi, Mumbai, and Bangalore, have taken initiatives to develop green buildings, terminals, and renewable energy installations. Solar power capacity of 55.49 MW has been commissioned by the Airports Authority of India across 51 airports in the country.

India is also participating in the mandatory phase of the scheme 'Carbon Offsetting and Reduction Scheme for International Aviation'. This is the second phase of the scheme scheduled from 2027 to 2035. Under the scheme, any increase in annual CO_2 emissions from international aviation will be offset through the purchase of carbon credits. This will make Indian carriers liable and will carry financial implications from 2027 onwards (MoCA, 2021a).

3.7.3 Mode-wise Low Carbon Initiatives

India has taken many steps to improve efficient use of fuels and shift to low emitting forms of transportation, over the last decade. These steps mainly focus on regulatory action or infrastructural improvements for each type of freight and passenger transportation (TERI, 2020). Regulatory norms on Emissions standards and Fuel efficiency standards have led to considerable decrease in emissions, albeit at a significant cost (BEE, 2021).

3.7.3.1 Emissions standards

In 2003, The Auto Fuel Policy was implemented to address issues of vehicular emissions and fix standards for the same. Further in 2018, The Central Motor Vehicles Rules, 1989 were amended to ensure that all new motor vehicles manufactured before 1 April 2020 conformed to BS-IV standards (PIB, 2020e).

For vehicles manufactured after 1 April 2020, BS-VI standards have been made applicable. By taking this step, India has leapfrogged from BS-IV to BS-VI efficiency standards which are equivalent to EURO-VI norms. This means that the emissions from diesel and petrol vehicles contain 80% less sulphur ppm than BS-IV standards. Public Sector Undertakings producing oil and petroleum products in India have invested about INR 34,000 crore to upgrade plants for producing BS-VI fuel. This has made India one of the few nations with cleanest EURO-VI compliant petrol and diesel.

Bharat Stage VI Phase II (BS6.2), also known as Real Driving Emissions (RDE) norms, were implemented on April 1, 2023, and have resulted in car prices going up. These new norms require manufacturers to add hardware to cars and SUVs to meet the more stringent emissions norms. Under the RDE norms, all cars need to achieve emissions targets in real-world conditions that co-relate with tests conducted in laboratory conditions under the Modified Indian Drive Cycle (MIDC). In the laboratory, cars follow a fixed set of parameters – speed, time and distance – whereas, in the real world, cars are subjected to bursts of acceleration, frequent changes in speed as well as everyday traffic; hence, an RDE test. These new norms will help to reduce the gap in emissions between laboratory tests and those produced in the real world.

3.7.3.2 Fuel Efficiency

Corporate Average Fuel Economy Norms for Passenger Cars

The first phase of the Corporate Average Fuel Economy (CAFE) Norms for passenger cars was brought in FY 2017-18 to improve fuel efficiency in passenger cars. This phase will be effective till FY 2021-22, following which the second phase of norms would come into effect. These norms are applicable to passenger cars, which are essentially motorised vehicles that run on petrol, diesel, liquified petroleum gas, compressed natural gas, or electricity. These vehicles must have a Gross Vehicle Weight under 3,500 kilograms. Under CAFE 1 and 2, the average fuel consumption norms for the vehicles are determined (See Table 3.48).

Table 3.48 Energy Savings and Emissions Reduction achieved under CAFE norms for 2018-2022

Year	Energy Savings (Mtoe)	CO_2 Emissions Reduction (Million tCO_2)
2018-19	0.43	1.32
2019-20	0.35	1.08
2020-21	0.31	0.92
2021-22	0.38	1.09
Total	**1.888**	**4.41**

Source: (BEE,2023)

From 2018-22, a cumulative emissions reduction of 4.41 $MtCO_2$ was achieved under the CAFE norms (BEE, 2023).

Fuel Economy Norms for Heavy-Duty Vehicles

In 2017 the government of India took steps to establish norms for commercial vehicles with gross vehicular weight equal to greater than 12 tonnes. Under these norms, manufacturers must comply by evaluating vehicles over the “Constant Speed Fuel Consumption” test procedure. This is applicable for all commercial vehicles under this category.

In the CSFC protocol, trucks were driven at constant speed on a test track at 40 and 60 kilometres per hour (kph), and buses are run at 50 kph. Later, Ministry of Road Transport and Highways revised the safe axle weight limits, subsequently the norms for HDVs amended vide S.O. 3215 (E) dated 21st September 2020.

The norms were applicable to the vehicle confirming BS-IV emission norms and implementation date for the norms was 1st April 2020. However due to implementation of BS-VI emission norms by MoRTH a correction factor would be needed to multiply with FE norms, to make it suitable for BS-VI complied vehicles. The correction factor for the norms have been notified through an amendment published vide S.O. 1465(E) dated 29th March 2022.

Fuel Economy Norms for Light and Commercial Vehicles

Similar to standards for heavy-duty vehicles, standards for commercial vehicles with gross vehicular weight between 3.5 and 12 tonnes were also finalised and implemented in 2019. Under these norms, manufacturers must comply by evaluating vehicles over the “Constant Speed Fuel Consumption” test procedure for all applicable vehicles.

In 2020 BS-VI emission norms implemented by MoRTH, and a correction factor was to be derived for BS-VI complied vehicles, to be applied on the BS-IV complied vehicles’ FE norms equation, similar to HDFE norms case.

The correction factor for the norms have been notified through an amendment published vide S.O. 1464(E) dated 29th March 2022.

3.7.3.3 Voluntary Vehicle Fleet Modernization Programme (VVMP)

The Ministry of Road Transport and Highways (MoRTH) has introduced the Voluntary Vehicle-Fleet Modernization Program (VVMP) or "Vehicle Scrapping Policy" which is aimed at creating an Eco-System for phasing out of unfit and polluting vehicles. Older vehicles pollute the environment 10 to 12 times more than fit vehicles and pose a risk to road safety (PIB, 2021). This policy was introduced in the interest of clean environment. A vehicle failing to get a renewal of its registration certificate maybe declared as "end of life vehicle".

3.7.3.4 Standards and Labelling Programs

Agricultural Tractors

This is a voluntary program brought in after a committee was formed in 2018 under the Ministry of Petroleum and Natural Gas. The purpose of these norms is to develop and monitor fuel economy for tractors.

Tyres

This is also a voluntary programme brought in to establish labelling standards for all vehicular tyres manufactured or imported in India. The committee has finalised the labelling bandwidths and drafted a schedule for the implementation of the voluntary phase.

3.7.3.5 Initiatives by Civil Aviation

The Airports Council International has recognised international airports such Delhi, Mumbai, Bangalore, and Hyderabad as Carbon Neutral Airports. The Airport Authority of India has implemented the Airport Carbon Accreditation Programme on "Mapping" Level-1 (by Airports Council International) at the following airports – Kolkata, Bhubaneswar, Varanasi, and Trivandrum. With a target for 2018, these airports were able to lower their carbon intensity per passenger (kgCO_2/passenger) to 2.14 at Kolkata Airport, 1.57 at Bhubaneswar Airport, 1.52 at Varanasi Airport and 2.54 at Trivandrum Airport. As they have delivered on the target, they have been upgraded to the "Reduction" Level-2 category (ACI, 2021).

Recently, 23 more AAI airports have been accredited with ACI-ACA Level-2 (Reduction) certification (August, 2023). Further, more than 50 AAI airports are running on 100% renewable energy.

3.7.3.6 Initiatives by Indian Railways

In the 2nd cycle of the PAT scheme, the Indian Railways was able to overachieve its energy saving target, by more than double the targeted amount. A reduction of 0.27 MtCO_2 was achieved through energy efficiency efforts in traction and non-traction systems. For traction emissions, this includes electrification efforts, inclusion of 3-phase regenerative locomotives, shift from diesel locomotives, and training of loco pilots. For non-traction energy, efforts have been made to shift to low energy use lighting – LEDs, and renewable energy integration at stations (BEE, 2021).

For overall reduction in emission intensity of Indian Railways, IR has already set up 200.48 MW of solar covering 1376 stations and more than 600 service buildings and 103.4 MW of wind Power. In addition, about 5750 MW of renewable capacity has been tied up which also includes 900 MW of 100% renewable power in round the clock (RTC) mode. Further, steps taken for reduction in traction emissions, includes 100% electrification of Board Gauge network, inclusion of energy efficient 3-phase locomotives, shift from diesel locomotives, training of locomotive pilots, use of Head on Generation (HOG) technology in trains, LED lightings. In addition, IR has also adopted comprehensive energy efficiency policy for Non-Traction installations, wherein, an action plan comprising of five action points (Aps) for reducing energy use has been spelt out. The policy broadly centered around 05 action points i.e. Sustainable Buildings, Cloud based data monitoring and management portal, Energy Efficiency in equipment and appliances, Power quality restoration, Capacity building and awareness. The Indian Railways has also prepared a National Rail Plan (NRP) for India to create a 'future ready' Railway system by 2030 (PIB, 2022c). The NRP is aimed to formulate strategies based on both operational capacities and commercial policy initiatives to increase modal share of the Railways in freight to 45%.

3.7.3.7 Initiatives by Coastal Shipping

Some initiatives taken up in coastal shipping are listed below:

- Green port project: Includes multiple initiatives at ports including plantation, renewable energy generation, sustainable design practices, and preparation of Environment Management and Monitoring Plans.
- Renewable power in major ports: Initiatives taken in this area include,
- 20.7 MW wind farm installed at DPT (Kandla).
- 500 kW solar plant, 150 kW solar rooftop, and 5 kW ground solar PV in 2020, at VO Chidambaranar port trust.
- 5.19 MW solar power plant at New Mangalore port trust.
- Paradip port trust has proposed to install a 100 MW solar power plant.
- 240 kW solar power plant installed at Mormugao port trust.
- 401 kW solar power installed at Mumbai port trust. 1030 kW rooftop solar in the project pipeline.
- 10.77 MW solar power installed at Visakhapatnam port trust.
- 500 kW solar power plant installed at Chennai port trust.
- 822 kW rooftop solar panels and 2 MW floating solar plant installed at Jawaharlal Nehru port trust
- 250 kW solar power installed at Kamarajar port. Additional 20 MW wind power along the coast is in the project pipeline.

3.7.4 Initiatives to enhance public transport

Efforts have been made to improve mass transit systems across India. These include expansion and improved efficiencies in modes such as bus-ways, bus rapid transit systems, light rail transit, metros, trams and regional rail. However, there have been issues in ensuring access to public transport in the nation. For example, access to bus-ways in India is much below the developing nation average and largely varies from state to state (NITI Aayog and BCG, 2018). Emissions avoided by these public transportation modes in FY2015 and FY2016 are stated in Table 3.49.

Table 3.49 CO_2 emissions avoided ($MtCO_2$) through implementation of public transport policies

Policy	Start year of implementation	FY2015	FY2016
Metro	2002	0.78	0.86
BRTS	2006	0.039	0.035

Source: MoEFCC, 2021g.

3.7.4.1 Laying of New Metro Lines

Around 754 kms of metro rail is in operation and another 1000 kms of metro and Regional Rapid Transit System (RRTS) is expected to come in the next 5 years (MoH&UA, 2022) The RRTS includes new technologies such as Metrolite and Metro Neo connecting Tier-2 and peripheries of Tier-1 cities.

Since the second national communication, the metro capacity has increased by many folds – from 5 cities in 2014 to 18 cities in 2020. It is expected that by 2025 this service will be available in 25 cities. Currently, around 130 MW of solar power is used to run the metro system. This is expected to increase to 600 MW. Few of the metro systems use regenerative braking which has led to emissions reduction. Essentially, regenerative braking can reduce overall electricity consumption by generating electricity from braking and supplying it back to the grid (UNCTC&N, 2022). This has been adopted in the Delhi Metro system as its first Clean Development Mechanism (CDM) project. About 30% of electricity is regenerated per kilometre. This has led to an annual average reduction of 0.041 $MtCO_2e$ between 2007 and 2017 (DMRC, 2022; UNCTC&N, 2022).

Under the Metro Rail Policy 2017, the Government provides various financial assistance. Some of these are listed here:

- Projects sanctioned under public private partnership mode are eligible for grant of up to 20% under the Viability Gap Funding Scheme of the Ministry of Finance.
- A grant of 10% of the total project cost is admissible for metro projects implemented by State Governments (with conditions).
- Equity is shared equally between central and state governments with a maximum contribution of 20% of the project cost by the Central Government.

3.7.4.2 Bus rapid transit system

The Bus Rapid Transit System (BRTS) is implemented under the Jawaharlal Nehru Urban Renewal Mission launched under The National Urban Transport Policy 2006. This promotes bus transport by financing buses and building bus-only lanes for bus transit. Further it also provides assistance for increasing the number of CNG buses in cities. Overall, this scheme expects to improve capacity and reliability of bus-ways as compared to conventional bus systems.

The first BRTS was established in the city of Pune. Since then, multiple cities have taken up BRTS projects to improve public transportation. Currently, around 11 cities are operating BRTS including in Ahmedabad, Bhopal, Hubli-Dharwad, Surat, Visakhapatnam, and Indore. The Ahmedabad BRTS has been rated silver on BRT standard in 2013. The Hubli-Dharwad BRTS is latest in the list, which has improved mobility. This has been able to shift passengers' transport choice and has increased its daily passengers to 90,000 (Gupta, 2020).

3.7.5 Fuel substitution in the transport sector

3.7.5.1 Ethanol Blended Petrol Programme

The Ethanol Blended Petrol programme was launched to promote the use of biofuels in India, with the intention to encourage the blending of petrol with biofuels of different types. With the introduction of the "National Policy on Biofuels" in 2018, goals to achieve 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel by 2030 have been made official. These efforts have been ramped up and it is expected that 20% blending of ethanol in petrol will be achieved by 2025-26 (MoP&NG, 2022d).

Blending of biofuels is expected to reduce the carbon footprint and decrease dependence on oil imports. The programmes have multiple categorizations of biofuels ranging from basic (first generation biofuels, biodiesel etc.) to advanced biofuels (second generation ethanol, drop-in fuels etc.). The implementation of the programme began with sale of E10 petrol (90% petrol with 10% ethanol) sold by Oil Marketing Companies. Ethanol blending cumulative volumes have increased 8 times from 38 crore litres in 2013-14 to 302.3 crore litres in 2020-21. The average ethanol blending has also increased, i.e., the total percentage of ethanol content in petrol sold. The average was at 1.5% in 2013-14 which has increased to 8% in 2020-21 (MoP&NG, 2022b). The average currently stands at 10% (June, 2022) which is a target achieved 5 months ahead of schedule (MoP&NG, 2022a).

The total reductions in CO_2 emissions achieved in the last 7 years due to the Ethanol Blended Petrol programme have been estimated to be 22.6 $MtCO_2$. In 2020-21 alone, 6.44 $MtCO_2$ of reduction was achieved. This figure will increase with the implementation of E20 norms (80% petrol with 20% ethanol) which is expected to be rolled out by 2023, which has the potential to lead to an annual emissions reduction of 21.64 $MtCO_2$. However, this also requires adoption of new technologies i.e., E20 compatible vehicles, increase in flexi-fuel engines, and doubling of existing production capacities (MoP&NG, 2022b).

The Indian Oil Corporation Limited has been directed by the Government to blend 15% methanol in petrol (M15) for retail sale in Assam and North- Eastern States on a pilot basis. It has declared financial assistance of USD 300 million for the period 2018-19 to 2023-24 supporting second generation ethanol projects that are either at the demonstration or commercial stage. Additionally, multiple projects have been taken up by oil public sector units across the country. These include projects in the states of Punjab, Odisha, Haryana, and Assam which are expected to be operational by 2022 and 2023 (MoP&NG, 2022b). Details of these projects are listed below:

- Project by Hindustan Petroleum Corporation Limited in Bathinda, Punjab
- Project by Indian Oil Corporation Limited in Panipat, Haryana
- Project by Bharat Petroleum Corporation Limited in Bargarh, Odisha
- Project by Numaligarh Refinery Limited in Numaligarh, Assam

Pradhan Mantri JI-VAN Yojana

The government announced the "Pradhan Mantri Jaiv Indhan- Vatavaran Anukool fasal awashesh Nivaran (PM JI-VAN) Yojana" in March 2019 to provide financial support to integrated bioethanol projects for the establishment of Second Generation (2G) ethanol for the years 2018–19 to 2023–24, the plan will cost a total of INR 1,969.50 crore. For improving commercial viability and promoting R&D for the development and adoption of technologies in the field of producing 2G ethanol, the PM JI-VAN Yojana has set a maximum financial assistance limit of INR 150 crores per project for commercial projects and INR 15 crores per project for demonstration projects (PIB, 2022e). Financial assistance of INR 150 crore each has been provided to four commercial Second 2G bioethanol projects at Bathinda in Punjab, Panipat in Haryana, Bargarh in Odisha and Numaligarh in Assam (ibid).

Sustainable Alternative Towards Affordable Transportation (SATAT)

To boost the availability of affordable and clean transport fuels, a MoU was signed today between MoPNG and leading oil & gas marketing companies & technology providers to establish Compressed Biogas (CBG) plants across India under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative (PIB, 2020c). The scheme envisages to target production of 15 MMT (million tons) of CBG by 2023 from 5000 plants (SATAT, n.d.). The initiative aims to produce compressed biogas (CBG) from waste and biomass sources like agricultural residue, cattle dung, sugarcane press mud, Municipal Solid Waste (MSW) and sewage treatment plant waste (ibid).

3.7.5.2 Bio-fuel in Aviation

Given India's commitment to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which will begin by 2027, plans to use bio-jet fuels in military and civilian aircrafts have been made. New standards for aviation turbine fuels were designed from the efforts of the Bureau of Indian Standards in collaboration with the Indian Air Force, research organisations and the industry. These specifications align Indian standards with current international standards. Indian Standard IS 17081:2019 Aviation Turbine Fuel (Kerosene Type, Jet A-1) containing synthesised hydrocarbons has been formulated and released in 2019. Following the standard, oil companies will be able to manufacture bio-jet fuel for the aviation industry, which would reduce carbon emissions and help the industry deliver on its commitments for CORSIA (MoCA, 2021b).

3.7.5.3 E-Mobility

The Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme was launched in 2015 under the National Electric Mobility Mission by the Ministry of Heavy Industries. The scheme's primary objective is to develop and promote electric vehicles and electric charging infrastructure. Launched in 2 phases, FAME-I and FAME-II have led to emissions reductions, albeit at a significant cost. Phase 1 of the scheme was launched in 2015 and it targeted demand creation, technology platforms, pilot projects, and constructing charging infrastructure. The total budget allocated for this phase was USD 122.4 million over the time period of 2015 to 2017 (BEE, 2020). This has led to saving of 97 million liters of fuel and reduction of about 242 million Kg of CO_2 as on 25th January 2022 (BEE, 2023).

Phase 2 of the scheme was launched in 2019 for a period of 3 years. The budget allocated for this phase stands at INR 10,000 crore. This phase of the scheme promotes the following

- electrification of public transport
- subsidies for advanced batteries
- localization of manufacturing and assembling
- advanced charging and RE inter-linking (BEE, 2020)

India expects to achieve a much higher market penetration of electric vehicles, given the results from FAME-I and II. India aims at realising electric vehicles sales at penetration rates of 30% for private cars, 70% for commercial cars, 40% for buses and 80% for two and three-wheelers by 2030 (NITI Aayog and RMI, 2019).

3.7.5.4 National Hydrogen Mission

The Ministry of Petroleum and Natural Gas (MoPNG) is taking steps to increase the contribution of hydrogen in the energy mix. The integration of hydrogen into the fuel mix of the transport sector is expected to bring in reductions in CO_2 emissions. The government of India has already started initiating pilot projects such as that of the grey hydrogen initiative, which involves the mixing of up to 18% hydrogen in CNG for transportation. A trial run began in October, 2020 to operate 50 buses with this fuel at the Rajghat bus depot, Delhi (MoP&NG, 2022c; MoP&NG, 2020). Other pilot projects based on green hydrogen (hydrogen produced from solar, biomass etc) are listed below:

- 2 pilot projects for setting up solar hydrogen refuelling stations for demonstration of fuel cell vehicles.
- 1 pilot project for production of green hydrogen and its blending with CNG for dispensing at retail outlets.

- 1 pilot project for setting up of green hydrogen infrastructure and pipeline injection of green hydrogen in the City Gas Distribution network.

Ambitious research and development projects such The Multiple Pathways project have also been initiated. This project has an investment of INR 296 crore and is expected to address all aspects of the value chain of hydrogen-based mobility (MoP&NG, 2022c).

3.8 Mitigation in the forestry sector

India's forest cover has increased from 6,92,027 sq.km in the year 2011 to 7,13,789 sq.km in the year 2021. Also, the total tree cover has increased from 95,027 sq.km to 95,748 sq.km, leading to an increase in the total area under tree and forest cover from 23.81% of the country's geographic area in 2011 to 24.62% in 2021. There is a net increase in forest cover by 26,666 sq.km from 2011 to 2021 (FSI, 2021).

Table 3.50 Area under Forests

Year	Total Forest Cover		Total Tree Cover		Total Forest and Tree Cover	
	Area (sq.km)	Percentage (%)	Area (sq.km)	Percentage (%)	Area (sq.km)	Percentage (%)
2021	7,13,789	21.71	95,748	2.91	8,09,537	24.62
2019	7,12,249	21.67	95,027	2.89	8,07,276	24.56
2017	7,08,263	21.54	93,815	2.85	8,02,078	24.39
2015	7,01,673	21.34	92,572	2.82	7,94,245	24.16
2013	6,97,898	21.23	91,226	2.78	7,89,164	24.01
2011	6,92,027	21.05	90,844	2.76	7,82,871	23.81

Source: (FSI 2021), (FSI, 2019b), (FSI, 2017), (FSI, 2015), (FSI, 2013) (FSI, 2011)

Total carbon stock in country's forest is estimated to be 7,204 million tonnes in 2021 and there is an increase of 79.4 million tonnes in the carbon stock of country as compared to the last assessment of 2019. The annual increase in the carbon stock is 39.7 million tonnes. The following table gives the assessment in different years.

Table 3.51 Forest Carbon Assessment done by FSI

Sl No	Years	Forest Carbon (in million tonnes)
1.	2021	7204
2.	2019	7125
3.	2017	7083
4.	2015	7044
5.	2013	6,941
6.	2011	6663 (Data Calculated for 2004)

Source: (FSI 2021), (FSI, 2019b), (FSI, 2017), (FSI, 2015), (FSI, 2013) (FSI, 2011)

The LULUCF sector, which includes GHG emissions and removals associated with forestry and land-use change, is the only sector in the country that consistently absorbs CO_2, making it one of the most important sectors from the mitigation perspective. This sector removed 20 per cent of the country's carbon dioxide emissions in 2019. In the same year, its emissions reached -4,85,472 $GgCO_2e$, increasing its status as a sink by 58 per cent since 2016. Between 2000 and 2019, the sector of LULUCF reported a growth in GHG removals of 118 per cent.

Table 3.52 CO_2 economy-wide emissions and removal by LULUCF compared

Year	CO_2 Emissions (Gg)	CO_2 Removals By LULUCF (Gg)	Total Economy-wide CO_2 Emissions, including emission from LULUCF (Gg)	LULUCF Removals as % of Total CO_2 Emissions
2019	9,725	-4.96,655	24,89,042	19.95%
2016	21,289	-3,30,765	22,52,356	14.68%
2014	17,616	-3,19,860	20,15,108	15.87%
2010	58,261	-3,14,587	16,32,624	19.27%

Source: MoEFCC, 2021g.

In India, forests are not just carbon sinks, but also enduring sources of livelihood for the millions of people who live in close proximity to them. Approximately 275 million people directly depend on forests for their livelihood (World Bank, 2005). The estimated economic value of carbon retention service provided by India's forests, using the social cost of carbon approach, is estimated as INR 546.95 thousand crore Crores in 2019-20 (MoSPI, 2022). Despite its vast population, and at a time when many countries around the world are losing forest cover due to anthropogenic factors, India has been able to increase its forest cover.

3.8.1 Initiatives for mitigation in the forestry sector

3.8.1.1 National Forest Policy and the Forest (Conservation) Act, 1980

India's National Forest Policy promulgated in 1988 has laid an ambitious target of bringing one-third of the country's geographic area under forest and tree cover. India continues to pursue this target in the long run and has included it in the new Draft National Forest Policy, 2019. The new draft Policy also emphasizes climate change mitigation through sustainable forest management.

The Forest (Conservation) Act, 1980 was promulgated to conserve the country's natural forests and reduce the rate of deforestation. The Act of 1980 regulates the diversion or use of forest land for non-forestry activities such as industrial or development projects. This Act also rests the authority to give clearance for such diversions of forest lands for non-forestry use with the Central Government, establishing a dedicated Forest Advisory Committee for the same. Between 1951 and 1980, 0.14 million ha per annum of forest land was diverted for non-forest purposes, whereas between 1980 and 2019, this figure declined to 0.024 million ha per annum on an average. From 2014-15 to 2018-19, 69141 hectares of Forest land was diverted for non-forestry purposes (MoEFCC, 2020d).

Table 3.53 Diversion of forest land before and after the Forest (Conservation) Act, 1980

S.no	Years	million ha per annum
1.	1951-1980	0.14
2.	1980-2020	0.024

Source: MoEFCC, 2020d; MoSPI, 2020

3.8.1.2 Compensatory Afforestation Fund and Compensatory Afforestation Management and Planning Authority (CAMPA)

An important provision laid down by the Forest Conservation Act, 1980 is that of Compensatory Afforestation, which is mandatory for all diversions of forest lands for non-forestry purposes. According to this Act, for every forest area converted to non-forestry purposes, a parcel of non-forest land equivalent to the diverted forest area should be afforested, or a degraded forest area twice the diverted forest area should be restored. The cost of afforestation is to be borne by the 'user agency'. Since the afforested and restored forests cannot provide ecosystem services immediately, the Supreme Court of India ordered an expert committee in 2007 to calculate the Net Present Value (NPV) of the diverted forest. This value is recovered from the 'user agency' to compensate for the losses experienced in the interval during which the afforested or restored forest area regrows. The NPV value varies depending upon the type of forests, ranging from INR 0.43 million per ha for low-quality to INR 1.04 million per ha for very dense forests (Chopra et. al, 2005).

The Compensatory Afforestation Fund Act, 2016, has operationalized this mechanism under the Forest Conservation Act, 1980, with the setting up of National and State Level Compensatory Afforestation Management and Planning Authorities (CAMPAs). The National CAMPA receives funds contributed by user agencies towards compensatory afforestation, additional compensatory afforestation, penal compensatory afforestation, catchment area treatment plant etc., in lieu of forest land diversion for various non-forestry activities/projects, and deposits them in the Compensatory Afforestation Fund. This is subsequently disbursed to State CAMPAs, which are responsible for the implementation of Compensatory Afforestation. Cumulatively till January 2021, over INR 48,000 Crore have been disbursed to carry out afforestation activities.

Cumulatively from 2015-16 till 2020-21, over 44,943 Ha of non-forest land has been afforested, whereas 1,36,259 ha of degraded forest land has been restored, under the Compensatory Afforestation mechanism. From 2009-10 to 2018-19, 0.382 billion trees were removed and plantation of more than 8.016 billion trees has been stipulated under compensatory afforestation (MoEFCC, 2020c). The following table gives year wise details of afforested non-forest lands and restored degraded forest lands.

Table 3.54 Plantation Works carried out under CAMPA

Year	Plantation Area (Ha)	
	Non-Forest land	Degraded Forest land
2015-16	7450	17015

2016-17	4717	6584
2017-18	9489	17509
2018-19	9504	30990
2019-20	6842	40529
2020-21	6941	23632

Source: MoEFCC, 2021b; MoEFCC, 2020b

3.8.1.3 National Mission for Green India

The National Mission for a Green India was launched in 2014 and is one of the nine missions under the National Action Plan on Climate Change. The Mission aims at responding to Climate Change through a combination of mitigation and adaptation measures aimed at forests. The mitigation component aims to enhance India's forest carbon sinks. The overarching goal of the Green India Mission (GIM), as it is commonly referred to, is to increase the forest and tree cover on 5 million Ha of forest/non- forest lands and improve the quality of forest cover on another 5 million Ha of lands. This should lead to improved ecosystem services including carbon sequestration. Additionally, the mission aims to increase forest-based livelihood income of about 3 million households, living in and around the forests. The Mission, taking a holistic approach, has also included enhancement of tree cover in urban and peri-urban areas, social and agroforestry, and restoration of wetlands within its purview. Specific targets include provisions to cover degraded lands, scrublands, abandoned mining areas, ravines, grasslands, open and moderately dense forests, and degraded mangroves.

Activities under the Green India Mission began in the financial year 2015-16. The State Government submits the Annual Plan of Operation (APO) for taking up various activities as per Implementation Guidelines of GIM to the Central Government. The Ministry examines the APO and after approval, releases the fund to the State Governments. Up to 2020-21, an area of 1,67,151 ha was sanctioned for afforestation (MoEFCC, 2021c) along with distribution of 68,707 alternative fuel energy devices, like LPG, solar devices, improved stoves, etc., to rural households (MoEFCC, 2021f). The total funds released amount to over INR 450 crores (MoEFCC, 2021c).

Table 3.55 Total afforestation and funds released under Green India Mission

Name of the State	Afforestation being taken up (in ha.)	Funds Released (INR in crore)
Andhra Pradesh	2737	4.1675
Chhattisgarh	20191	66.62667
Himachal Pradesh	5480	17.085
Jammu & Kashmir	5680	25.727
Karnataka	1360	6.6145
Kerala	12297.77	25.46633
Manipur	23358	38.39164
Mizoram	6766	69.95651
Odisha	17080	49.57125

Punjab	19643	15.5183
Uttarakhand	16634.24	48.1
Madhya Pradesh	4304	54.81198
Maharashtra	1509.2	10.302
Sikkim	11045	8.64067
West Bengal	18666	9.426488
Total	**166751**	**450.406**

Source: (MoEFCC, 2021c)

3.8.1.4 National Afforestation Programme

The National Afforestation Program was launched in 2000-02, implemented by the National Afforestation and Eco-development Board (NAEB). The NAEB is responsible for promoting afforestation, tree-planting, ecological restoration and eco-development activities in the country, and comes under the MoEFCC. Over the years, the NAP had acquired a pan-India coverage, being implemented by all the 28 states. A three-tiered institutional mechanism implements the program - State Forests Development Agency (SFDA) at the state level, Forest Development Agency (FDAs) at the district/forest division level and Joint Forest Management Committees (JFMCs) at the village level.

NAP Scheme stands merged with Green India Mission as per Order dated 30th January, 2018. However, during the year 2020-21, INR 39.54 crore has been released to carry out committed liabilities of plantation activities taken up during previous years under the NAP scheme. Advance work of 750 hectares has been sanctioned for new afforestation.

Table 3.56 Progress made under the National Afforestation Program

Year	Project Area approved (ha.)	Funds Released (Rs. in crores)
2000-02	71068	47.53
2002-03	404799	151.26
2003-04	282536	207.98
2004-05	106743	233
2005-06	54432	248.12
2006-07	221035	292.75
2007-08	272026	392.95
2008-09	173436	345.62
2009-10	103556	318.17
2010-11	57126	309.99
2011-12	141448	303
2012-13	55529	193.37
2013-14	80583	257.62

2014-15	74435	243.78
2015-16	35986	94.16
2016-17	2359	59.35
2017-18	39847	80
2018-19	16636	95.38
2019-20	19724	21.98
2020-21	750	39.54

Source: (MoEFCC, 2021d)

3.8.1.6 National Mission for Clean Ganga

A crucial aspect of the National Mission for Clean Ganga (NMCG) under the Namami Gange Programme is implementing Forestry Interventions in the Ganga basin. The Forest Research Institute, Dehradun, has prepared an afforestation plan for 1.34 lakh hectares of land at an estimated cost of INR 2,294 Crores. From 2016-20, the NMCG has allocated INR 337.20 crores under afforestation and biodiversity component to the five States falling in the Ganga basin - Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal for plantation. Out of 1,34,104 hectares proposed, plantations on 26,764 Ha. has been carried out by the respective State Forest departments till FY 2019-20 (NMCG, 2020).

Table 3.57 Progress made under the National Mission for Clean Ganga (NMCG)

State	Area planted so far (in ha.)	Fund sanctioned by NMCG from yr. 2016-20 (INR in Cr.)
Uttarakhand	8295	85.62
Uttar Pradesh	7531	102.85
Bihar	4836	73.86
Jharkhand	636	29.41
West Bengal	5466	45.46
Total	**26764**	**337.2**

Source: NMCG, 2020

3.8.1.7 Green Highways Policy and National Green Highways Mission

The Government of India came out with the Green Highways (Plantation, Transplantation, Beautification and Maintenance) Policy in 2015 to develop India's road network, especially the National Highways, sustainably and collaboratively with other stakeholders. Its objectives are to reduce air pollution, noise pollution, and soil erosion along the national highways, with significant mitigation co-benefits. Salient features of this policy include:

- setting aside and pooling of one percent of total project cost of new projects for raising and maintaining plantations

- detailed guidelines and specifications for the manner in which plantations along the highways and in their medians should be raised
- the institutional framework for implementing and monitoring the same.

The policy also specifies that transplantation of trees for expansion/construction of roads should be taken up wherever feasible. Following the promulgation of this policy, the National Green Highways Mission was launched by the Ministry of Road Transport and Highways. The Government has also started implementing the Green National Highway Corridors (GNHCP), which is partially funded by a loan from the World Bank. There are three components of this project:

- Component A: Green Highway Corridor Improvement and Maintenance
- Component B: Institutional Capacity Enhancement
- Component C: Road Safety

The component A has a total Cost of USD 1,001 million, consisting of a loan of USD 423.95 million from International Bank for Recontruction and Development (IBRD). It includes upgradation and maintenance for 5 years of about 781.3 km of selected existing National Highways in the states of Rajasthan, Himachal Pradesh, Uttar Pradesh and Andhra Pradesh as Green Highways. It also includes pilot projects demonstrating resource efficiency, climate resilience, green and safety aspects. Component B focuses on Institutional Capacity Enhancement to support MoRTH in its pursuit to conserve natural resources and improve climate vulnerability of National Highways network and GHG emissions from the transport sector. Out of total length of 781 km, as of July, 2021, work on 287.96 km having Civil Cost of INR 1,664.44 cr. has been awarded. The scheduled date of completion is December, 2025 (MoRT&H, 2021).

National Highway Authority of India (NHAI) has created a separate Division i.e., Green Highways Division (GHD) to facilitate the planning, implementation and monitoring of plantation activities. More than 345 Lakhs plants planted on National Highways from 2016-17 onwards by way of Annual Plantation Action Plans. To monitor the survival and growth of plants, NHAI launched a Mobile App "Harit Path" in August 2020 and 237 lakhs plants have been geotagged.

MoRTH has ensured that the bare minimum tree felling is carried out for widening of existing National Highways. For greenfield projects, under the PM Gati Shakti National Master Plan, NH alignment is reviewed by the Network Planning Group to ensure overlap with any protected zones viz. forests, reserves, etc. are avoided to the extent possible.

3.8.1.8 Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)

The Mahatma Gandhi National Rural Employment Guarantee Scheme, started in 2005, is one of the world's largest social security programmes with an investment of INR 730 billion during 2021-22 (PIB, 2021g). The bulk of the MGNREGS activities are focused on natural resources such as land, water and trees, providing an opportunity for enhancing carbon sequestration, as a co-benefit. A study by the Indian Institute of Science estimated the carbon sequestration achieved by MGNREGS programme in

2017-18. The total mean carbon (biomass and soil organic carbon) sequestered at the national level, considering all the Agro-Ecological Regions (AER) and Natural Resource Management (NRM) activities, for the year 2017-18 (for cumulative number of works implemented) is estimated to be 102 $MtCO_2$, and projected to increase to 249 $MtCO_2$ by 2030 (Ravindranath & Murthy, 2021).

3.8.1.9 Nagar Van Yojana

Nagar Van Udyan was a pilot scheme that ran from 2015 to 2018, where 46 urban forests were created across 16 states on over 3,663 Ha of land with an expenditure of over INR 50 Crores. On World Environment Day in 2020, the scheme was restructured as Nagar Van Yojana, with an aim of creating 200 Urban forests over the next five years till 2024-2025. These forests will range in area from a minimum 10 Ha up to 50 Ha. Preference will be given to proposals that entail rejuvenation of degraded forest lands within city limits or on their fringes, by planting a mix of shrubs and trees according to local site conditions, and according them protection from anthropogenic pressures. Every year, 40 such urban forests are envisaged to be developed. The total estimated cost of Nagar Van Yojna is INR 415.00 crore for the period of 2020-21 to 2024-25, which will be drawn from the National Funds under Compensatory Afforestation Fund Management and Planning Authority (CAMPA). The Nagar Vans are proposed to be developed in collaboration with the Forest department, other departments and agencies in the State/ Union Territories like NGOs, Corporate bodies, Industries, Civil Societies etc. The financial support from the Central Government is to meet the cost of fencing, soil and moisture conservation, maintenance of plantations, etc.

Table 3.58 State-wise details of projects sanctioned under Nagar Van Yojana (2020-21 & 2021-22)

S.No.	Name of State/UT	No. of Approved Proposals	Approved Total Cost (Rs. In lakhs)	Funds Released (Rs. In lakhs)
1	Madhya Pradesh	11	1,758.46	1,230.92
2	Maharashtra	6	449.88	314.92
3	Tamil Nadu	5	847.30	593.11
4	Goa	1	205.30	143.71
5	Nagaland	3	184.70	129.29
6	West Bengal	2	145.80	102.06
7	Andhra Pradesh	2	167.72	117.40
8	Gujarat	4	425.00	297.50
9	Himachal Pradesh	2	237.80	166.46
10	Mizoram	2	405.80	284.06
11	Punjab	4	374.40	262.08
12	Tripura	4	504.80	353.36
13	Jharkhand	4	463.20	324.24
14	Chhattisgarh	7	1,186.82	830.77

S.No.	Name of State/UT	No. of Approved Proposals	Approved Total Cost (Rs. In lakhs)	Funds Released (Rs. In lakhs)
15	Assam	3	242.30	169.61
16	Jammu & Kashmir	2	197.80	138.46
17	Haryana	5	641.46	449.02
18	Manipur	1	205.30	143.71
19	Uttarakhand	4	446.30	312.41
20	Rajasthan	5	501.50	351.05
21	Bihar	2	261.28	244.49
22	Karnataka	3	509.10	356.37
23	Odisha	40	2,905.95	2,034.17
24	Uttar Pradesh	25	2,811.85	1,968.30
25	Kerala	25	1,507.54	1,055.28
26	Andaman & Nicobar	1	80.50	56.35
Total		**173**	**17,667.86**	**12,429.09**

3.8.1.10 Sustainable Forest Management

India accounted for 2 per cent of the total global forest area in 2015, as per the Global Forest Resources Assessment (FRA) by Food and Agriculture Organization (FAO). India also has among the lowest rates of gross deforestation, both in absolute terms, in per capita terms, and in annual rates (MoEFCC, 2021g). Annual rates of deforestation have also been consistently coming down in the country in recent decades, with an estimated annual average loss of 1476 km^2 during 1975–1985, coming down to 209 km^2 during 2005–2013 (Reddy et al., 2015). Policies aimed at sustainable forest management have played a key role in achieving the reduction in rates of deforestation along with improving the quality of the forest cover. ICFRE has estimated that sustainable management of India's forest cover, can potentially lead to an annual addition of 62 $MtCO_2eq$ carbon stocks every year (ICFRE, 2015). Various programs explained above already have provisions for restoring degraded forests like CAMPA. Protected Areas which help conserve existing forests, community-based forest management, and REDD+ strategies to sustainably manage existing forests to check deforestation and degradation and improve forest quality are explained below.

3.8.1.11 Protected Areas

India currently has 106 National Parks and 567 Wildlife Sanctuaries, which are notified under the Wildlife (Protection) Act, 1972. This is an increase from 102 National Parks and 518 Wildlife Sanctuaries a decade earlier in 2011. Together, these two categories of protected areas cover around 1,66,967 Sq Km of area, which is approximately 5.08% of India's total geographical area. The area under National Parks and Wildlife Sanctuaries has increased by over 12,687 Sq. Km since 2011. Further, the Wildlife (Protection) Amendment Act, 2002 introduced the categories of Conservation reserves and Community

Reserves. There are currently 105 Conservation Reserves and 220 Community Reserves, covering an area of 5,206 Sq. km and 1,455 Sq. Km respectively, which together constitutes 0.20% of the country's total area (WII, 2022a). ICFRE has estimated that India's protected areas have the potential to add 47 $MtCO_2eq$ to India's forest carbon sink every year (ICFRE, 2015).

During 2020-21, India added 10 Ramsar Sites to the List of Wetlands of International Importance, thus increasing the overall national wetlands network from 39 to 49 sites, and area from 1.07 million ha to 1.09 million ha. (WII, 2022b). Further, in 2023, the number of Ramsar Sites increased to 75, covering an area of 1.33 million Ha across the country. From 1982 to 2013, a total of 26 Sites were added to Ramsar Sites. From 2014 to 2023, the country added 49 new wetlands to the list of Ramsar Sites. During 2022 itself, a total of 28 sites were declared as Ramsar Sites (PIB, 2023a). India also introduced the Wetlands (Conservation and Management) Rules, 2017 which have been framed under the Environment (Protection) Act, 1986 and guidelines for implementation in 2020. These rules provide for decentralized regulation through creation of wetlands authorities within states and union territories, and their wise use as the basis of regulation and management decisions. Due to the importance of wetlands, Forest Survey of India (FSI) has carried out an exercise at the national level to identify wetlands of more than 1 ha within Recorded Forest Area (RFA). There are 62,466 wetlands covering 3.8 per cent of the area within the RFA of the country.

Wetland conservation is deeply ingrained in Indian Conservation ethos as a part of culture and heritage. Acknowledging the importance of conservation of Ramsar Sites, the Government of India has announced 'Amrit dharohar' initiative as a part of 2023 budget announcement to promote conservation values of Ramsar Sites.

3.8.1.12 REDD+

In accordance with various COP decisions and requisites of the UNFCCC, India prepared and released its National REDD+ strategy in 2018. India has also submitted its national forest reference emission level or forest reference level (FREL/FRL) in 2018, which was revised as per the inputs from the Technical Assessment. In 2021, India released its Safeguards Information System for public consultation, a process that was finished in October 2021.

The proposed strategy currently covers only forests and trees outside forests (TOF), and envisages future coverage of grasslands, blue carbon, etc. There are three phases in which REDD+ Strategy will be implemented, with Phase 1 being the development of national strategies or action plans, policies and measures, and capacity-building. Several states like Himachal Pradesh, Uttarakhand and Mizoram have already released their REDD+ Action Plans. The strategy also covers all five activities defined under REDD+ (including reduction of emissions from deforestation and forest degradation, conservation of carbon stocks, sustainable management of forests and enhancement of carbon stocks) along with listing approaches to address forest degradation, and needs for finance, infrastructure, and capacity-building. Importantly, India's existing legal frameworks, programs and policies such as the National Forest Policy, afforestation programs, and Joint Forest management, are already aligned with the goals of the REDD+.

3.8.1.13 Forest Rights Act and Joint Forest Management

India has made an effort to decentralize its forest management policy since the 1990s. In 1990, the Government of India had released the guidelines for Joint Forest management, envisaged in the National Forest Policy 1988, which recognized the important role played by local communities in conserving, protecting, and managing forests. The JFM guidelines formally involved these local communities in the co-management of India's forests along with the State Forest Departments. In 2006, India promulgated the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, which laid the framework for formally recognizing the rights of all forest dwelling communities in India.

Coming into force in 2008, as of December 2021, 19,75,743 individual claims over 42,47,168 acres of forest land, and 1,01,501 community forest rights claims over 1,16,56,947 acres of forest land have been recognized (Ministry of Tribal Affairs, 2021). The community forest rights claims present a significant opportunity for sustainable management of forests, as India has recently released the Draft Guidelines for Conservation, Management and Sustainable use of Community Forest Resources under the purview of this act, to allow decentralized management of these forests, presenting a significant opportunity to enhance carbon stocks while supporting livelihoods of local forest-dwelling communities.

3.8.1.14 Mangrove Initiative for Shoreline Habitats and Tangible Income (MISHTI)

MISHTI was announced in the Union Budget 2023-24 to promote and conserve mangroves. Mangroves are unique, natural eco-system having very high biological productivity and carbon sequestration potential, besides working as a bio-shield. The Programme will cover approximately 540 sq km area across nine coastal States and four UTs in five years (2023-2028). It will create around 22.8 million man-days with estimated carbon sink of 4.5 million tons of Carbon (PIB, 2023b).

3.8.2 Potential for mitigation in the forestry sector

A 2019 technical paper by the Forest Survey of India finds that India's current policies are sufficient to meet its NDC target of creating 2.5 to 3.0 billion tonnes of carbon equivalent sink through forest and tree cover by 2030 (FSI, 2019a). The detailed study has listed all assumptions, various activities that need to be implemented and their magnitude in different scenarios, magnitude of potential areas of intervention and of areas that need to be treated under different scenarios, and projected unit and total costs state-wise and activity-wise. In the projections, the study finds that restoration of degraded and open forests can make the biggest contribution in improving India's forest carbon stocks. Some other listed activities needed to pursue to achieve the target are afforestation on wastelands and other available lands, plantations along highways, railways lines, and rivers and canals, agroforestry, and greening of urban spaces. It also projects that to achieve the NDC goal, these activities would be carried out over 75 million hectares or 23% of the country's geographical area. The projected increase in the forest and tree cover ranges between 2.38% and 4.49%. The NDC goal is thus in alignment with the goal of achieving forest and tree cover on one-third of total area stated in National Forest Policy. The study estimates the cost of implementing all activities to be ranging from INR 1,01,848 Crores to INE 2,68,568 Crores.

3.9 Waste Sector

The waste sector contributed 2.34 percent to total GHG emissions in 2019, predominantly due to emissions from wastewater treatment and discharge. More than three fourth (77.31 percent) of the emissions from the waste sector come from wastewater treatment and discharge, followed by 22.69 percent from solid waste disposal. The waste sector contributed 73,189 Gg CO_2e to total GHG emissions in 2019, dominated by emissions from wastewater handling, which account for more than 77 percent of the sectoral emissions and remaining ~23 per cent emissions from solid waste disposal.

The government has been undertaking several initiatives for the scientific management of municipal waste. As of January 2020, India produced 147,613 metric tonnes (Mt) of solid waste every day (MoEFCC, 2022a). The government aims at including principles of circular economy which sustainably combine economic growth and environmental protection in solid and liquid waste management (MoHUA, 2021a). The introduction of the regulations such as the Swachh Bharat Mission-Urban (SBM-U) and AMRUT have provided a major impetus to promotion of the circular economy agenda for municipal solid & liquid waste at the national, state, and local levels.

3.9.1 Current and Future Generation and Utilisation of Waste

Municipal solid & liquid waste has been further divided into five sub-categories viz. dry waste, wet waste, construction and demolition waste, wastewater and treated sludge (MoHUA, 2021a). A significant increase in Municipal Solid Waste (MSW) generation has been recorded globally, with average waste generated per capita per day at around 0.74 kilogram (MoEFCC, 2022a). Global MSW generation is anticipated to increase from the current 2.01 billion tonnes yearly to 3.40 billion tonnes by 2050. (Kaza et. al., 2018). In India, 377 million people live in urban areas, producing an estimated 55 million tonnes of municipal solid waste each year (MoHUA, 2021a). It is projected that India's urban population would increase to 600 million by 2030 and to 814 million by 2050 leading to a production of 165 million tonnes of trash by 2030 and 436 million tonnes by 2050, respectively (ibid). By 2030, it is anticipated that the yearly emissions of greenhouse gases from municipal solid waste will increase to 41 million tonnes (ibid).

3.9.2 Schemes & Interventions undertaken for Climate Mitigation in the Waste Sector

Specific laws and regulations devised for efficient waste management for diverse types of waste have been enacted and amended over time to accommodate the changing environmental conditions, including the following:

- Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989.
- Hazardous and Other Wastes (Management, Handling & Transboundary Movement) Rules, 2016, amended in 2022
- Fly Ash Notification 1999, amended in 2016 and 2021
- E-Waste (Management) Rules, 2016, amended in 2022
- Bio-medical Waste (Management & Handling) Rules, 2016, amended in 2018

- Construction and Demolition Waste Management Rules, 2016, amended in 2021
- Solid Waste Management Rules, 2016, amended in 2020
- Plastic Waste Management Rules, 2016 amended in 2016, 2018, 2021 and 2022

More recently, National Resource Efficiency Policy (NREP), 2019 was prepared to create a facilitative and regulatory environment to mainstream resource efficiency across various sectors. Recently, the MoEFCC released the Draft Battery Waste Management Rules, 2020, which provide details for handling and management of batteries under the Environment (Protection) Act, 1986. The sections below provide an overview of the major schemes and interventions undertaken by the government in the recent years.

3.9.2.1 Atal Mission for Rejuvenation and Urban Transformation (AMRUT)

The Atal Mission for Rejuvenation and Urban Transformation (AMRUT) mission was launched as the first national urban water-focused mission in June 2015. AMRUT 2.0 was launched on 1st October 2021, as a step towards new urban India, to make the cities 'AatmaNirbhar' and 'water secure'. AMRUT 2.0 is aimed at extending universal coverage in water supply as well as providing 100% coverage of sewerage and septage management in 500 AMRUT cities (MoHUA, 2022). The following targets have been achieved under the AMRUT mission till date:

- 92 lakh household sewer connections/ coverage with septage management have been provided currently contributing to making cities open defecation-free contributing to better hygiene and reducing pollution of water bodies.
- Sewage Treatment Plants (STPs) of more than 6,000 MLD treatment capacity are being developed, of which 1,980 MLD treatment capacity has already been created. 907 MLD of treated used water being reused for agriculture, industries, rejuvenation of water bodies, and parks, reducing water pollution.

3.9.2.2 Swachh Bharat Mission (SBM)

One of the implementation components of this flagship programme is SBM which includes setting up of wet waste processing facilities (municipal waste to compost, waste to biogas), and dry waste recycle and recovery facilities including for plastic waste, with Central support of 35 per cent of project cost (MoHUA, 2021d). The estimated potential to generate power from MSW is about 500 MW which would be increased to 1,075 MW by 2031, as urbanisation grows (UNCRD, 2018). The Indian Railways had established a goal to install bio-toilets in every train coach by 2021–2022 as part of the Swachh Bharat Mission, which has been met earlier than anticipated. From April 2020 onward, all coaches that carry passengers will be equipped with bio-toilets, eliminating the direct disposal of human waste from trains.

3.9.2.3 Plastic Waste Management (PWM)

The MoEFCC notified the PWM Rules in 2016 which detail the improved waste management system, a part of the framework of "Extended Producer Responsibility". The Ministry notified the Plastic Waste

Management Amendment Rules, 2021, on 12th August 2021, prohibiting identified single-use plastic items, which have low utility and high littering potential, from 1st July 2022 and also notified the Guidelines on the Extended Producer Responsibility for plastic packaging vide Plastic Waste Management Amendment Rules, 2022 (PIB, 2022d). The following actions have been made to improve the application of the 2016 Plastic Waste Management Rules and to decrease the usage of specific single-use plastic products (ibid):

- Thirty-Two States/UTs have constituted the Special Task Force under the chairpersonship of the Chief Secretary / Administrator for elimination of identified single use plastic items pursuant to the directions of the Ministry in this regard. A National Level Taskforce has also been constituted by the Ministry in this regard.
- The State /UT Governments and concerned Central Ministries/Departments have also been requested to develop a comprehensive action plan and implement it in a time bound manner, while 14 States/UTs and twelve Central Ministries have developed their comprehensive action plans.
- Under Swachh Bharat Mission 2.0, additional Central Assistance is also provided to States and Union territories for solid waste management including plastic waste management
- Directions have been issued by Central Pollution Control Board (CPCB) utilizing the power under Section 5 of the Environment (Protection) Act, 1986 for setting up of institutional mechanisms for the enforcement of provisions of Plastic Waste Management Rules, 2016 to all State Pollution Control Boards / Pollution Control Committees. Directions have also been issued by CPCB to E-commerce companies, leading single use plastic sellers/users, and plastic raw material manufacturers with respect to phasing out of identified single use plastic items.

3.9.2.4 Programme on Energy from Urban, Industrial and Agricultural Wastes/Residues

The objective of the programme is to support the setting up of Waste to Energy projects for generation of Biogas/ BioCNG/ Power/ producer or syngas from urban, industrial and agricultural wastes/residues. The programme provides Central Financial Assistance (CFA) to project developers and service charges to implementing/inspection agencies in respect of successful commissioning of Waste to Energy plants for generation of Biogas, Bio-CNG/Enriched Biogas/Compressed Biogas, Power/ generation of producer or syngas. The total estimated energy generation potential from urban and industrial organic waste in India is approximately 5690 MW (MNRE, n.d.).

NTPC Limited has commissioned 24 TPD thermal gasification-based demonstration scale Waste to Energy (WtE) plants at Varanasi to support technology development in India. As on September 2020, a total of 216 Waste-to-Energy plants with aggregate capacity of 370 MWeq have been set up in the country to generate power or biogas or Bio-CNG from agricultural, urban, industrial and municipal solid wastes (MoHUA, 2021a).

3.9.2.5 Circular Economy

The Government has been actively formulating policies and promoting projects to drive the country towards a circular economy. An economic approach aimed at eliminating waste and the continual use of resources, circular economy offers a new paradigm that emphasizes on the need to take a comprehensive view of products and processes. The ability to maximize resource efficiency, minimize the consumption of finite resources as well as the impetus to the emergence of new business models and entrepreneurial ventures will spur transition towards self-reliance.

The Central Government has notified rules on Extended Producer Responsibility (EPR) for four categories of wastes i.e. plastic packaging waste, battery waste, e-waste and waste tyre. These rules promote circular economy principles through Extended Producer Responsibility (EPR) based market mechanism and have set targets for recycling, recovery and use of recycled content. Also, the Ministry of Road, Transport and Highways has notified the Vehicle Scrappage Policy that aims at bringing in circularity in end-of-life vehicle segment. Ten (10) identified priority waste streams for which Circular Economy Action Plans have been developed include End-of-Life Vehicles, Toxic and Hazardous Industrial Waste, Tyre and Rubber Recycling, Electronics and Electrical Sector, Lithium-ion batteries, Gypsum, Scrap Metal (ferrous & non-ferrous), Solar Panels, Used Oil and Municipal Solid Waste. The aforementioned rules are outcomes of these Circular Action Plans.

The Resource Efficiency Circular Economy Industry Coalition (RECEIC) was launched in July 2023 to facilitate and foster greater company-to-company collaboration, build advanced capabilities across sectors and value chains, bring learnings from diverse and global experiences of the coalition members, and unlock on-ground private sector action to enhance resource efficiency and accelerate circular economy transition. The coalition is structured around the three guiding pillars of partnerships for impact, technology cooperation and finance for scale.

3.9.3 Potential Technologies & Future Challenges

A judicious choice of technology is essential for resource recovery and processing and disposal of municipal solid waste. It is important to utilize the resources by employing a combination of technologies suitable for treating various components of dry waste. Some of the technologies for dry waste processing which are being developed and utilised are enumerated below:

- Material Recovery Facilities
- Mechanical Recycling
- Refuse-Derived Fuel (RDF) for Coprocessing
- Plastic to Road Construction
- Pyrolysis
- Gasification
- Waste Incineration

In the Indian context, enacting mitigation in the waste sector is faced with several challenges. There is a need to achieve the objective of waste minimisation while also ensuring that attention is given to the social and economic factors which promote the formation of waste recovery and recycling linkages (Nagarajan, 2022). Further, the needs of the informal sector must also be addressed in the context of their specific-role in material recovery and recycling, in achieving a just transition in the waste sector (ILO, 2015). This would necessitate the industrial development of the unorganised sector, the improvement of its technical and productive capacities, and addressing the concerns of workers employed within it, forming the basis of the sustainable transition to waste minimisation.

3.10 Water Sector

3.10.1 Current and Projected Scenario

India receives an average annual precipitation of about 3,880 BCM. The average annual water resources potential in the country is assessed as 1,999 BCM. Due to topographic, hydrological and other constraints, the utilizable water availability is 1126 BCM which comprises of 690 BCM of surface water and 436 BCM of replenishable ground water resources.

In view of growing population, the per capita water availability in India is reducing progressively. The per capita availability of water has reduced from 5,177 m^3/ year in 1951 to 1,486 m^3/ year in 2021 and it is decreasing further due to rising population. Due to high temporal and spatial variation of precipitation, the water availability in many regions of the country is much below the national average and are facing water stress / scarce conditions.

The latest assessment of Dynamic Ground Water Resources of India for the year 2022 shows that the average 'Stage of ground water extraction' for the country as a whole is about 60%. Out of the total 7,089 assessment units in the country, 1,006 units (14%) have been categorized as 'Over-exploited'; 260 units (4%) as 'Critical'; 885 units (12%) as 'Semi-critical'; 4,780 units (67%) as 'Safe' and 158 units (2%) as 'Saline'.

In view of the above, country needs to ensure water security through all possible options including source augmentation, supply augmentation, demand side managemnet, water conservation, waste water management, reuse of treated waste water and also to take up all necessary actions for food security. Some of the actions in water sector, to achieve water-food-energy securities, are relevant to be discussed under climate change mitigation.

3.10.2 Initiatives in water sector

Agriculture fields and Forests act as sinks for greenhouse gases. Increasing forest cover and agriculture can be an effective way to fight increasing greenhouse emissions. India has taken a multi thronged approach for mitigation of climate change through suitable interventions in water sector to improve water use efficiency in agriculture for mitigating the adverse impact of climate change. Major initiatives include:

1. Increasing Water Use Efficiency: Increasing irrigation efficiency and water productivity will help in two ways: (i) Reducing water requirements will reduce the demand for pumping, thereby reducing energy consumption leading to reduced greenhouse emissions; and (ii) With increased water-use efficiency, more area can be brought under irrigation thereby increasing green cover, which act as carbon sinks. Micro irrigation such as drip, sprinkler, pressurized pipe irrigation etc. are proven methods for improving irrigation efficiency. The micro irrigation potential of the country is 72 million ha. and present coverage is 13.4 million ha.

   A dedicated organization was set up as Bureau of Water use Efficiency (BWUE) in October, 2022 to work on mission mode to act as a facilitator for promotion, regulation and control of efficient use of water in irrigation, industrial and domestic sectors in the country.

2. Environment Management Plan: For the development of new water resources projects, the authorities are legally bound to prepare environement managenemnet plan which include all the mitigation measures for likely environmental damage due to development of the water resources projects. The mitigation measures include catchment area treatment, compensatory afforestation, etc.

3. Namami Gange Programme: was launched in June 2014 to rejuvenate River Ganga and its tributaries. Under Namami Gange Programme, a comprehensive set of interventions such as wastewater treatment, solid waste management, river front management (Ghats and Crematoria development), e-flow, afforestation, biodiversity conservation and Public Participation etc. have been taken up for rejuvenation of river Ganga and its tributaries. Majority of the projects under the programme pertain to creation of sewage infrastructure as the untreated domestic/industrial wastewater is the main reason for pollution in the river.

Many of India’s rivers are facing pollution, encroachment, and over-extraction of water, leading to ecological imbalances and water scarcity issues. Implementing programs similar to Namami Gange for other rivers could help address these issues, promote sustainable water management, and ensure the well-being of both the environment and communities that depend on these rivers. However, the approach might need to be tailored to the unique characteristics and challenges of each river basin.

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Impacts, Vulnerability and Adaptation

IMPACTS

VULNERABILITY

ADAPTATION

IMPACTS, VULNERABILITY AND ADAPTATION

Chapter 04

4.1 Introduction

India is experiencing full range of climate change impacts, ranging from floods and droughts to heat waves and glacier melt. This chapter elaborates on the climate change impacts India is facing, the extent of its vulnerability and the adaptation measures undertaken by the Government of India to combat the impacts of climate change. The methods for assessing the vulnerability, impacts, and adaptation are complex and require thorough investigation, data collection, and assessment of various scientific and research studies. During the preparation of the Third National Communication, 52 research studies were undertaken in various sectors on the aspects of identifying vulnerabilities, assessing impacts, and subsequently adopting adaptation strategies. This chapter synthesizes the results of these 52 studies, spread across all natural and socio-economic systems of the country.

As per Decision 17/CP.8 of the United Nations Framework Convention on Climate Change (UNFCCC), Parties are encouraged to include a description of approaches, methodologies, and tools used, including scenarios for an assessment of the impacts of, and vulnerability and adaptation to, climate change, as well as any uncertainties inherent in these methodologies in their National Communications. In this background, the chapter covers the impact of climate change in eight sectors – biodiversity and forests; agriculture; water resources; coastal and marine ecosystems; human health; gender; urban and infrastructure; and economic costs, the vulnerabilities in each sector and respective adaptation strategies. The chapter also describes the context of India's adaptation challenge and ends with a brief conclusion. The section on biodiversity and forests assesses the impact and vulnerability of climate change on natural ecosystems and biodiversity in India. Climate change is an additional threat to the Indian agricultural system that is stressed by several factors such as reduced availability of land, and water, yield stagnation, and the attack of pests and diseases, and issues of soil health, apart from several socio-economic stressors. The section on agriculture evaluates the associated risks and adaptation strategies adopted by the Indian agriculture system. Climate change impacts hydrological resources and water availability through various climatic parameters leading to changes in seasonal and inter-annual water availability, changes in streamflow and runoff, and changes in the occurrence of droughts and floods. The section on water resources focuses on some of the impacts and vulnerabilities associated with hydrological resources in India. The coastal ecosystems in India, as everywhere in the world, are significantly vulnerable to climate change. Many of these ecosystems are also under severe anthropogenic stress. The section on coastal and marine ecosystems assesses some of the critical impacts on India's coastal ecosystems. The section on human health elaborates on diseases accentuated because of the rise in temperature and the associated risks in India. Globally, it is well recognised that climate change impacts are not 'gender-neutral'. The section on gender discusses the specifically enhanced vulnerability of women to climate change. The section on urban settlements and infrastructure considers the risks posed to manmade infrastructure and adaptation strategies adopted. Lastly, the chapter elaborates on economic cost projections for different sectors required for adapting to climate change.

4.1.1 Contextualising India's Adaptation Challenge

Before we proceed with detailed considerations of impacts, vulnerability and adaptation, it is essential to note that adaptation too, like mitigation, has a global and differentiated contextualisation that must be taken note of and that frames India's view of the adaptation challenge.

Like most developing countries, India's adaptation challenge is one that arises out of a climate crisis in whose making it has had little or even negligible contribution. As the Summary for Policymakers of the Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has noted, South Asia has contributed only about 4 percent of global CO_2 emissions (IPCC, 2022). Global surface temperature has already increased by 1.1^{0}C above pre-industrial levels, which is more than two-thirds of the way to the 1.5^{0}C goal.

At the current rate of annual emissions of the Annex-I countries, which was 17.01 $GtCO_2$ (UNFCCC, 2023) in 2017, their emissions alone would take the world over the 1.5^{0}C limit before 2050, by exhausting the remaining carbon budget of 500 $GtCO_2$ by the year 2047. Even according to their projected long-term emission reduction targets and net zero target years, they will consume far more than their fair share of the remaining carbon budget. Hence, the adaptation goals need to be cognizant of the full temperature goal of the Paris Agreement (which states in Art. 2.1(a): "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels").

India's experience clearly shows that the fundamental pre-requisite of development is adaptation, especially reducing vulnerability and exposure. In contrast to the claims of some sections of the literature, it is essential to note that reducing vulnerability and exposure is a challenge across the entire economy and society of developing countries and cannot be restricted to only particular categories of vulnerable nations, or particularly marginalized communities. Our experience in India, as well as the scientific literature shows clearly the fundamental role of basic social and economic development in managing vulnerability and promoting adaptation.

In this connection, it is pertinent to recall that the Summary for Policymakers (SPM) of the IPCC Working Group II contribution to AR6 notes in B.1.6: "Regions and people with considerable development constraints have high vulnerability to climatic hazards (high confidence)." Further in B.3.2 it is noted: "In the near term, climate-associated risks to natural and human systems depend more strongly on changes in their vulnerability and exposure than on differences in climate hazards between emissions scenarios (high confidence)."

Further it is essential to note that adaptation is an unwelcome additionality to development and increases the cost of development. It would be facile to consider development as a co-benefit to adaptation or vice-versa without any reference to costs.

References to the IPCC terminology of "climate resilient development" cannot obscure two fundamental points. First that adaptation cannot be conflated with mitigation and it is especially important where and how adaptation and mitigation take place. Within countries it is important to recognize the economic, political and social inter-dependence of different regions and hence a simplistic view of adaptation and mitigation occurring together equally at all scales, in all regions and sub-regions is incorrect.

As the IPCC has itself noted in SPM of Working Group II, AR6: "Climate resilient development pathways are progressively constrained by every increment of warming, in particular beyond 1.5°C, social and economic inequalities, the balance between adaptation and mitigation varying by national, regional and local circumstances and geographies, according to capabilities including resources, vulnerability, culture and values, past development choices leading to past emissions and future warming scenarios, bounding the climate resilient development pathways remaining, and the ways in which development trajectories are shaped by equity, and social and climate justice." And again: "Opportunities for climate resilient development are not equitably distributed around the world. Climate impacts and risks exacerbate vulnerability and social and economic inequities and consequently increase persistent and acute development challenges, especially in developing regions and sub-regions."

These findings further indicate that one of the major constraints on adaptation is the scarcity of the remaining carbon budget, with the Annex-I countries having consumed a disproportionate share of the global carbon budget (See for instance, Climate Equity Monitor, https://climateequitymonitor.in and data therein), and that this is not to be considered a purely mitigation question. The need for equitable access to the global carbon budget for adaptation clearly follows from the IPCC's finding, cited above, that "past development choices leading to past emissions and future warming scenarios, bounding the climate resilient development pathways remaining, and the ways in which development trajectories are shaped by equity, and social and climate justice."

Another reason why it is essential to emphasize the global aspect of the adaptation challenge is the question of the provision of the means of implementation. While adaptation action is undoubtedly local, it is universally recognized that communities and regions require assistance, support, knowledge and means of implementation from outside, from beyond the region and from beyond national borders. Developing countries in particular require finance, technology transfer and capacity building support for adaptation.

The most damaging consequence of the failure of the provision of these means of implementation has been on adaptation. In particular, while climate finance has fallen far short of the promised USD 100 billion for several years now, the proportion going to adaptation has been a minor fraction. Once again, as in mitigation, means of implementation is also a cross-cutting issue and forms a fundamental element for every thematic issue on which further considerations need to be built upon. Globally, the share of climate finance going to adaptation has been miniscule, especially compared to the needs of developing countries. Appropriate consideration of adaptation finance as part of the overall issue of climate finance can be found in chapter 6.

The residual due to climate change and climate extremes after adaptation is taken into account is what must be referred to as loss and damage. Loss and damage arises if adaptation is inadequate or the nature of the hazard is such as to overwhelm the adaptation currently undertaken. Dealing with loss and damage is a necessity, as is adaptation to current climate variability, which is an essential pre-requisite to learning for the future. India has invested in both these aspects of climate action, driven predominantly through domestic resources.

The following sections illustrate the challenges of adaptation in key sectors for India, focusing on the impacts and some of the key adaptation initiatives in each of these sectors.

4.2 Biodiversity and Climate Change: An Indian Perspective

India is a biodiversity-rich nation that supports 18% of the world's population with only 2.4% of the world's total land mass (Bhatt et al., 2018). The country also experiences a wide range of climatic conditions as can be expected due to its sheer size and varied geography. The country can be divided into various biogeographic zones based on the climate and geographical variations from the lofty Himalayas in the North, rainforests in the Northeast, vast desert expanse in the Northwest, the biodiversity rich Western Ghats, the Central Semi-Arid Deccan Plateau, and the Islands of Andaman and Nicobar in the Bay of Bengal. These varied biogeographic zones encompass a variety of ecosystems - mountains, plateaus, rivers, forests, deserts, wetlands, lakes, mangroves, coral reefs, coasts, and islands (Mani, 1974). India hosts four global biodiversity hotspots with high concentrations of endemic taxonomy. India represents 12% of the world's known floral diversity, with over 50,200 plant species, of which 18,800 taxa are angiosperms and 82 taxa are gymnosperms (BSI, 2020). In terms of faunal biodiversity, over 1,02,700 animal species including protozoa are found in India (ZSI, 2020). The country hosts 8% of the world's mammal species (including some of the most significant wild populations of the larger, wide-ranging mammals), 13% of the world's bird species, 9% of the world's fishes, 5% of the global amphibians and 5% each of the world's reptiles and insects (Pullaiah, 2018; BSI, 2015). India is also one of Vavilov's eight centres of global crop diversity (Vavilov et al., 1992). India has a significant proportion of the rural population which is reliant on natural resources and agriculture.

The country faces the challenge of balancing conservation and sustainable use of biological diversity with economic growth and overall human wellbeing. This is further exacerbated by climate change as India is already experiencing the ecological, economic, and social consequences of global warming (Bawa et al., 2021). In 2021, Indian Meteorological Department (IMD) reported an increasing trend of 1^{0}C/100 years in annual mean temperature over India during the period 1901 to 2021 (IMD, 2022). The diverse species of plants and animals found in India experience varied environmental conditions both spatially and temporally ranging across different climatic zones – from warm & humid to cold regions (Bhatnagar et al., 2019), to altitudinal zones and seasonality (winter, pre-monsoon, monsoon, and post-monsoon). The crisis of climate change, however, is expected to change environmental conditions, with predicted increases in temperature, sea levels, and frequency of extreme events like heatwaves, floods, and droughts across various parts of the country. Additionally, there is a projected change in habitat types, such as forest vegetation cover, due to climate change (Ravindranath et al., 2006).

Changing hydrological cycles, extreme heatwaves, heavy rainfall and flooding events, storms, and rising sea levels are also damaging lives, livelihoods, and natural assets across the country (Vittal and Karmakar, 2019; Mohanty, 2020; Singh et al., 2020). There is emerging scientific evidence of the impact of climate change on ecosystems and landscapes in India, with the observed changes in species composition, productivity, and biodiversity. In other words, India, relatively has a low to moderate adaptive capacity to withstand the adverse impacts of climate change due to the high dependence of the majority of the population on climate-sensitive sectors, coupled along with developmental challenges and limited financial resources (Srinivasan et al., 2019; Mall et al., 2019). India is, therefore, concerned with the possible impacts of climate change and growing incidences of extreme weather events.

This section assesses the impact and vulnerability of climate change on natural ecosystems and biodiversity in India. These assessments cover the period between India's submission of Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) (i.e., 2012) till 2022. The assessment of climate change impacts, vulnerability, and adaptation to climate change requires a wide range of physical, biological, and socio-economic models, methods, tools, and data. The methods for assessment have significantly improved between India's Second National Communication (SNC) and now TNC, as may be seen in this chapter.

4.2.1 Impact of Climate Change on Forest Ecosystems

Forests have a substantial role in the global carbon cycles, support livelihoods, and supply goods and services that are part of sustainable growth. Climate change can exacerbate many land and forest degradation processes and introduce additional issues such as permafrost thawing and biome shifts. Sustainable land management activities can be adopted to avoid, reduce or reverse such degradation processes (IPCC, 2021).

India has formulated various strategies and undertaken programmes for the conservation and sustainable use of biodiversity. Enforcement of the Forest Conservation Act and Environment Protection Act, large-scale afforestation and reforestation, and community participation have contributed immensely to the conservation of forest areas. However, forest ecosystems in India, as in most parts of the world, are subject to anthropogenic stresses of various kinds. In addition, increasing climate extremes and variabilities such as heat extremes, floods, drought, altered monsoon cycles induce water stress impacting water security. Furthermore, the projected changes in mean climate and climate extremes constitute additional vulnerabilities for the Indian forests. Adaptive management of forests can reduce their vulnerability to climate change (IPCC, 2021). Developing a framework for the adaptation of forests and forest plantations to climate change is fundamental to the preservation of forests. This should be undertaken with due regard to the time needed for adaptation measures become effective (Ravindranath et al., 2019; Chaki et al., 2022).

4.2.1.1 India State of Forest Report1 (ISFR) 2021

As can be expected for a country of India's size, complex terrain, and climatic regimes, India's forests are very diverse - ranging from tropical wet evergreen forests in the Andaman & Nicobar Islands, the Southern Western Ghats, and the North-Eastern states, through tropical dry deciduous forests across large swathes of the country to temperate forest and dry alpine scrub in the North-Western Himalaya (Figure 4.1). The Forest Survey of India (FSI) has been monitoring India's forests and tree resources through periodic assessments. As per the latest ISFR (2021), the total forest and tree cover[2] of the country is 8,09,537 sq. km which is 24.62% of the total geographical area of the country. In terms of canopy density classes, the area covered by Very Dense Forest (VDF) is 3%, Moderately Dense Forest (MDF) is 9.3% and Open Forest (OF) is 9.3%. VDF and MDF together constitute 57% of the total forest cover of the country. A net increase of 1,540 sq. km in the forest cover at the national level has been reported for 2021 as compared to the previous assessment in 2019 which may be attributed to better conservation measures, protection and afforestation activities, tree plantation drives, and agro-forestry (Table 4.1). At the same time, in many Indian States, there has been a loss in forest cover and reduction of forest canopy which may be attributed to both natural calamities and anthropogenic causes.

The State of Madhya Pradesh has the largest forest cover in the country followed by Arunachal Pradesh, Chhattisgarh, Odisha and Maharashtra. The North-Eastern States have the highest percentage of forest cover with respect to the total geographical area of the State. Mizoram (84.3%) has the highest forest cover percentage, followed by Arunachal Pradesh (79.3%), Meghalaya (76%), Manipur (74.3%) and Nagaland (73.9%).

1 Forest Survey of India (FSI) initiated assessment of forest cover of the country for the first time in the year 1987 and since then wall-to-wall forest cover mapping of the country is carried out using remote sensing-based methodology at biennial interval. So far, 16 cycles have been completed and the current assessment is 17th in the series of continuous forest cover mapping in the country.

2 Forest cover refers to the extent of land area that is covered by forest resources in the country. All lands more than 1 hectare in area, with a tree canopy density of more than 10 percent, including tree orchards, bamboo, palm etc., occurring within recorded forest and other government lands, private community or institutional lands, are included in the assessment of forest cover.

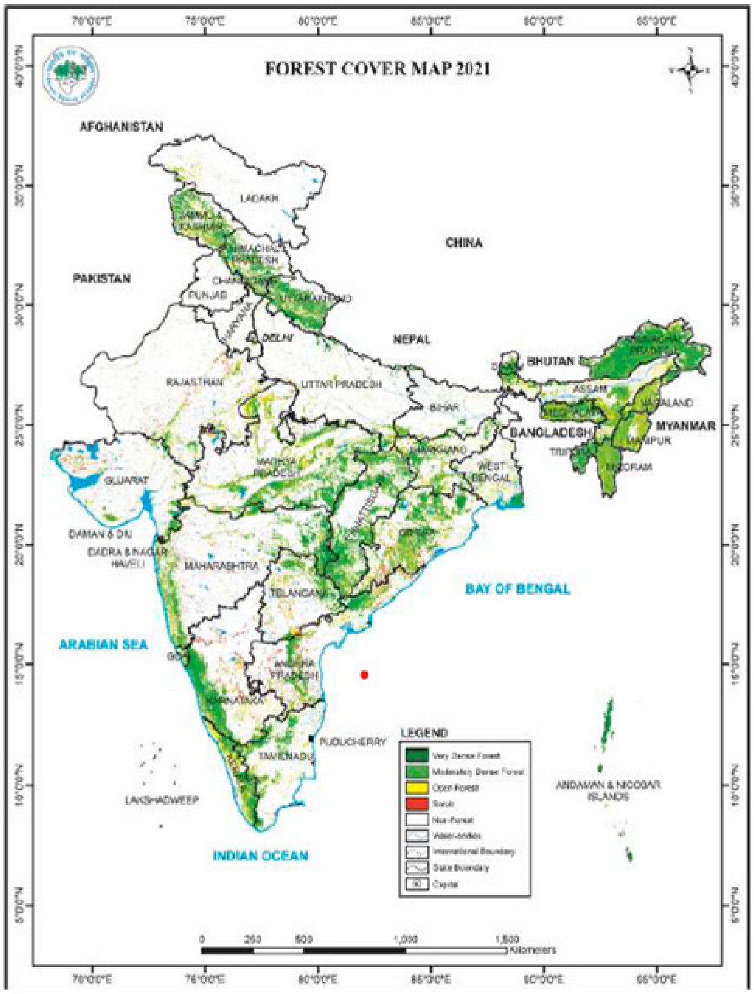


Figure 4.1: Forest types of India

(Source: FSI, 2021)

Table 4.1: Forest Cover change matrix for India between 2019 and 2021 assessments (area in sq km).

Class	2021 Assessment					Total ISFR 2019
	VDF	MDF	OF	Scrub	NF	
Very Dense Forest	97,770	982	348	28	150	99,278
Moderately Dense Forest	1,696	3,02,216	2,736	331	1,493	3,08,472
Open Forest	245	2,939	2,94,200	1,491	5,624	3,04,499
Scrub	31	241	3,048	40,977	2,000	46,297
Non Forest	37	512	6,788	3,712	25,17,874	25,28,923
Total ISFR 2021	**99,779**	**3,06,890**	**3,07,120**	**46,539**	**25,27,141**	**32,87,469**
Net Change	501	-1,582	2,621	242	-1,782	

● Gain ● Loss

(Source: FSI, 2021)

Carbon Stocks in Indian Forests

The carbon stock for 2021 in Indian forests has been estimated to be 7,204 million tonnes. There is an increase of 79.4 million tonnes of carbon stock as compared to the estimates of the previous assessment for 2019. The annual increase of carbon stock during 2019-21 is estimated to be 39.7 million tonnes which is 145.6 million tonnes of CO_2 equivalent. Soil organic carbon is the largest pool of forest carbon accounting for about 55% of the total carbon (Figure 4.2) followed by Above Ground Biomass (AGB; 32.2%), Below Ground Biomass (BGB; 9.98%), Litter (1.49%) and Dead wood (0.66%). On comparing the changes between the 2019 and 2021 assessments, the maximum changes have been observed in the AGB pool which has increased by 63.4 million tonnes, and the litter pool which has decreased by 20.6 million tonnes. Over the last five biennial assessments, the carbon stock of India's forests has shown an increasing trend. The carbon stock has risen from 6,663 million tonnes in the 2004 assessment to 7,204 million tonnes in the 2021 assessment showing an increase of 541 million tonnes between the period 2004 to 2021.

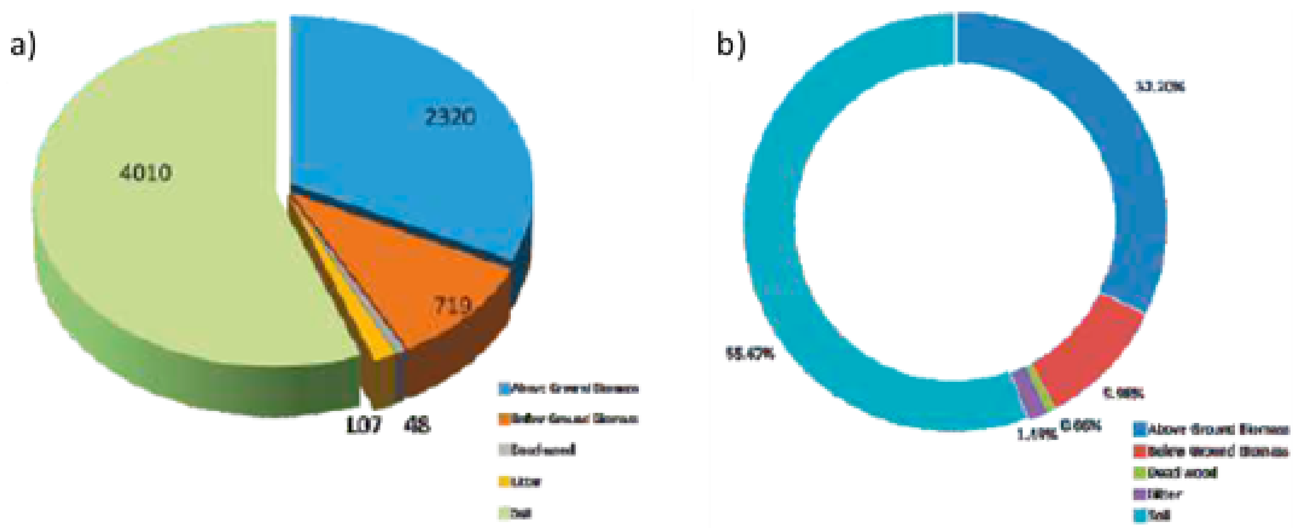


Figure 4.2: Forest carbon stocks in different pools, a) in million tonnes, b) in percentage.

Mangrove Forests in India

Mangroves are salt-tolerant plant communities found in tropical and sub-tropical intertidal regions. They are important refuge for coastal biodiversity, harbour high density of carbon stocks, and also act as bio-shields against extreme climatic events. In India, large populations, primarily rural, depend on mangrove ecosystems for a wide variety of biomass-dependant livelihoods. As per Forest Survey of India (FSI) assessment, the mangrove cover in the country is 4,992 sq. km or 0.15 % of India's total geographical area of which 29.55 % is Very Dense Mangrove, 29.67 % is Moderately Dense Mangrove and 40.78 % is Open Mangroves. The states of Odisha and Maharashtra have shown significant gains in mangrove cover, due to natural regeneration and plantation activities near estuaries and intertidal mud-flats. As per 2021 assessments, there has been a net increase of 17 sq. km in the mangrove cover of the country as compared to the 2019 assessment.

Climate change hotspots in India

FSI, in collaboration with Birla Institute of Technology & Science (BITS) Pilani, Goa Campus, also mapped climate hotspots[3] in the forest areas of India using projections of temperature and rainfall in three timestamps i.e., 2030, 2050 and 2085 (Figure 4.3) for RCP 4.5 and RCP 8.5 scenarios. It was observed that the Northern states, Union Territories of Ladakh, Jammu and Kashmir, Himachal Pradesh and Uttarakhand are projected to witness the highest temperature increase while Andaman and Nicobar, West Bengal, Goa, Tamil Nadu and Andhra Pradesh are projected to witness the least temperature rise over these periods. The North Eastern States and Upper Malabar coast of India are projected to experience the highest increase in rainfall; whereas, parts of Northeastern states like Arunachal Pradesh, Sikkim; parts including Ladakh, Jammu and Kashmir and Himachal Pradesh are projected to experience the least increase and even a decline in the rainfall.

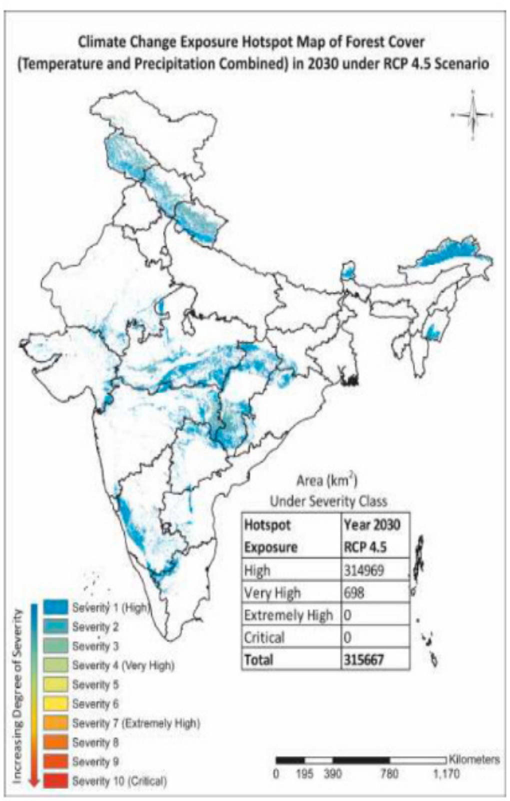


Figure 11.3 Climate change hotspot in 2030 in terms of combined temperature rise and precipitation change for RCP 4.5 (Resolution: 1km X 1km)

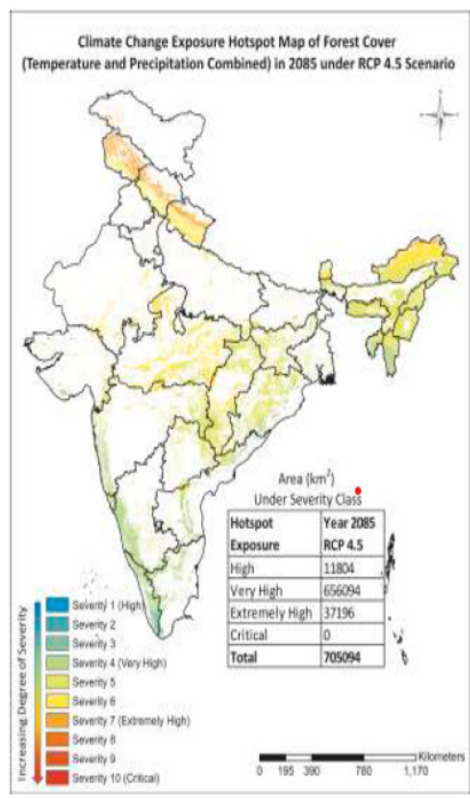


Figure 11.7 Climate change hotspot in 2085 in terms of combined temperature rise and precipitation change for RCP 4.5 (Resolution: 1km X 1km)

3 A climate hotspot refers to an area which is likely to face severe impacts of climate change.

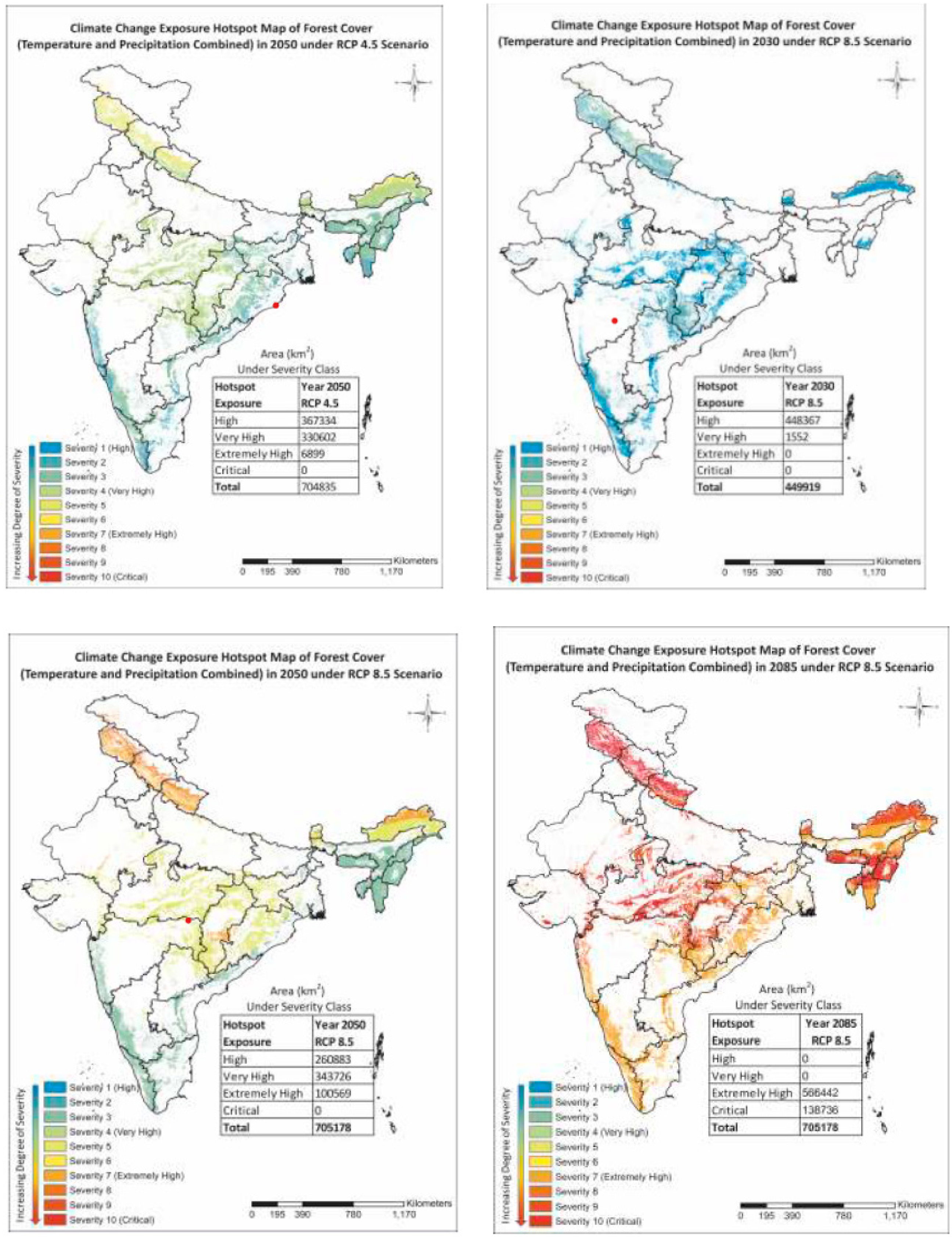


Figure 4.3: Climate change exposure hotspot map of forest cover (temperature and precipitation combined) in three time-horizons (2030, 2050 and 2080) and under two RCP scenarios (RCP 4.5 and RCP 8.5)

4.2.1.2 Findings of Other Forest Assessment Studies

During the Second National Communication (SNC), impact studies of climate change on forest assessment were conducted using climate projections from a single climate model (the regional climate model PRECIS) and a single GHG emission scenario (A1B), and a single impact model, the Integrated Biosphere Stimulator (IBIS) v.2 (Foley et al., 2005). The impact assessment during SNC showed that, at the national level, about 45% of the forested grids are likely to be impacted by climate change, potentially leading to shifts in forest types and forest dieback. For the TNC, climate change impacts, vulnerability and adaptation assessments were carried out for the forestry sector in India by national expert institutions which are presented in this report. Most of these studies primarily focused on two of the four RCP scenarios - one moderate emission scenario (RCP 4.5) and the other high emission scenario (RCP 8.5). The two future scenarios are mainly assessed for the mid-term (2030s - average from 2021 to 2050) and the long-term (2080s - average from 2071 to 2100). Climate outputs from CORDEX (Coordinated Regional Climate Downscaling Experiment; Giorgi et al., 2009; Jones et al., 2011) models are used for impact modelling. The dynamic global vegetation model used is the Lund-Postdam-Jena Model (LPJ) model (Smith et al., 2001; Sitch et al., 2013) which is one of the extensively used vegetation models globally and has been validated for India (Ravindranath et al., 2019).

According to the study by Ravindranath et al. (2019), under the short-term (2030) RCP 4.5 scenario, the percentage of forested grids to be impacted is projected to be 18% (Figure 4.4). Among the forested regions, the Western Himalayan and Northwestern Indian regions are likely to be impacted by climate change. These regions include the Himalayan temperate forests, sub-tropical broad-leaved hill forests, and sub-tropical pine forests. Forested grids that are not projected to be significantly impacted by climate change in this scenario are the tropical deciduous forests in North-Eastern India and tropical evergreen and deciduous forests in the Western Ghats regions. Under RCP 8.5 scenario, the percentage grids with forests to be impacted in the short-term is 20% (Figure 4.4). The grids projected to be impacted are spread over the Himalayan and the North-Eastern region, and a few additional grids in Central and Western Ghats.

Under the long-term (2080s) RCP 4.5 scenario, 25% of the forested grids of India are projected to be impacted by climate change (Figure 4.4). It can be observed that apart from the Himalayan and North-Western region, forested grids in the North-Eastern and a few grids in the Western Ghats are projected to undergo vegetational change. Whereas under RCP 8.5 scenario, the percentage of forested grids to be impacted by climate change is highest – i.e., 28% (Figure 4.4). Himalayan and Northeastern regions, have a higher number of forested grids that are projected to be impacted under RCP 8.5 scenario, leading to vegetation change. Forests in arid and semi-arid regions seem to be at a higher risk of being impacted by climate change.

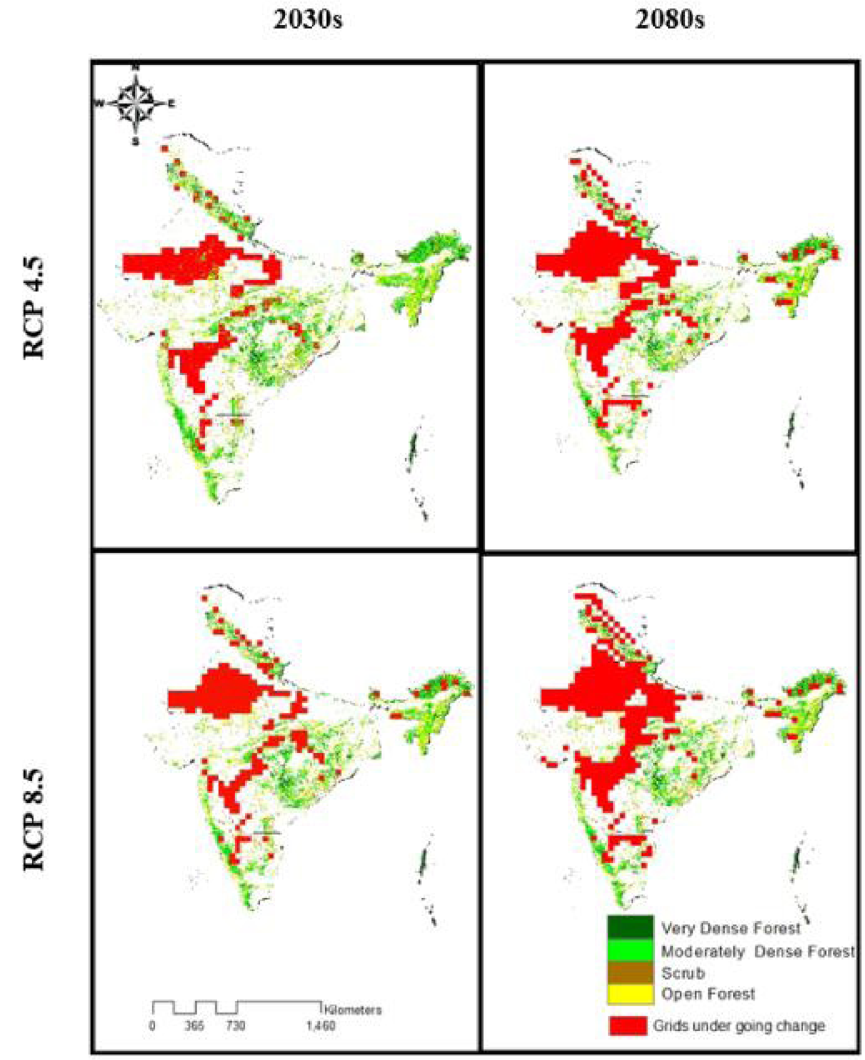


Figure 4.4: Grids projected to undergo change in vegetation type overlaid on forest density categories of FSI for the 2030s (2021-2050) and the 2080s (2071-2100) with respect to the historical baseline from 1975-2005 for RCP 4.5 and RCP 8.5 scenarios. Red color indicates that grids will undergo vegetation change.

Overall, the percentage of forested grids that will be impacted by climate change lies in the range of 18% to 25% under RCP 4.5 scenario (short and long-term), which increases to 20% to 28% under RCP 8.5 short and long-term scenarios, respectively. The major forested and biodiversity rich regions of Western Ghats and the North Eastern are likely to be less impacted by climate change, particularly in the short-term. However, the impact is relatively higher in the long term under both RCP 4.5 and RCP 8.5 scenarios. Temperate and sub-tropical forests in the Himalayan region and the tropical deciduous forests in the North Eastern region are more likely to be impacted by climate change, particularly in the long term. The impact of climate change seems to be highest in the arid regions of Rajasthan, and semi-arid regions of Maharashtra and Gujarat (Ravindranath et al., 2019).

4.2.2 Vulnerability of the Forestry sector to Climate Change

The IPCC 2014 framework on Risk-Impact was adopted to assess the vulnerability of the forests of India. According to this framework vulnerability is determined by sensitivity and adaptive capacity and the proxy indicators used to determine these properties were biological richness, disturbance index, canopy cover, and slope. The assessment shows that in India, about 40% of the assessed forested grids belong to 'High' and 'Very High' vulnerability classes (Figure 4.5). Except in pockets, the forests in the biodiversity rich hotspots in the Western Ghats in peninsular India, North-Eastern India, and North Himalayas have low to medium inherent vulnerability. A 'Very high' vulnerability is estimated for parts of southern Karnataka, Tamil Nadu, eastern parts of Andhra Pradesh, and Rajasthan. Majority of the plantation forest area (65% grid points) is classified under high and very high inherent vulnerability classes. Plantations have higher vulnerability as compared to the natural forest-types (except for tropical thorn forests for which 100% grid points have been classified under high and very high inherent vulnerability). For the dominant forest-type in India, the dry deciduous forests – 35% and 19% grid points are classified under high and very high inherent vulnerability classes, respectively. This has livelihood and social implications for the forest-fringe communities and biophysical implications for the forests, which are already under stress. None of the grids for littoral and swamp forests, montane wet temperate forests, and Himalayan dry temperate forests, show high or very high inherent vulnerability (Ravindranath et al., 2019).

The percentage of grid points under high and very high inherent vulnerability classes for Himalayan moist temperate forests, sub-alpine and alpine forests, tropical wet evergreen forests, tropical moist deciduous forests, and tropical semi-evergreen forests is low. Low inherent vulnerability of these forests has important significance as most of the forest biodiversity and endemicity is hosted by these forest-types in the biodiversity 'hotspots' of Western Ghats in peninsular India, Northern Himalayan region, and the Northeast India (Ravindranath et al., 2019).

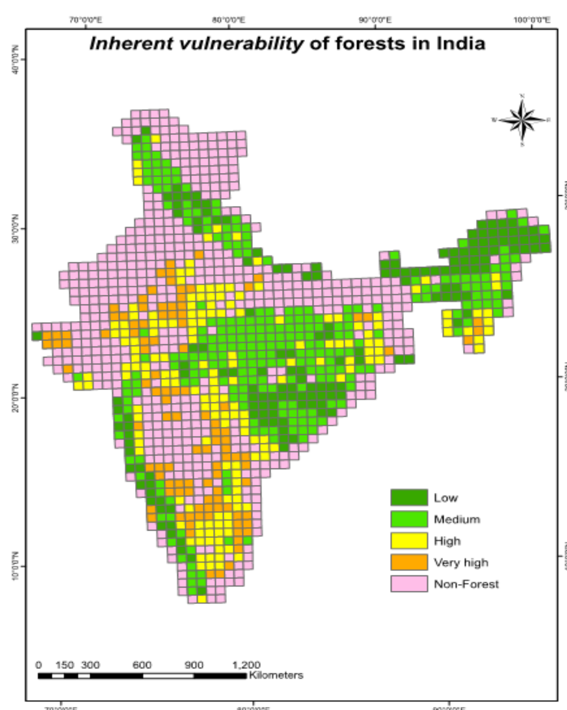


Figure 4.5: Spatial distribution of forest grid points according to inherent vulnerability classes at national scale under climate scenario

Vulnerability of forests depends on the status of biophysical attributes of forests (e.g., biodiversity, forest structure and canopy cover), socio-economic factors (e.g., biomass harvesting, forest management and policy-related factors) and climatic factors (warming temperatures and precipitation). Of these factors, while biophysical attributes and socioeconomic factors can be addressed through forest management, climatic factors leave limited options and can only be adjusted indirectly, e.g., by use of drought-tolerant genotypes in plantations under projected warming (Ravindranath et al., 2019).

Box-1: Case Study - Tropical Dry Forests

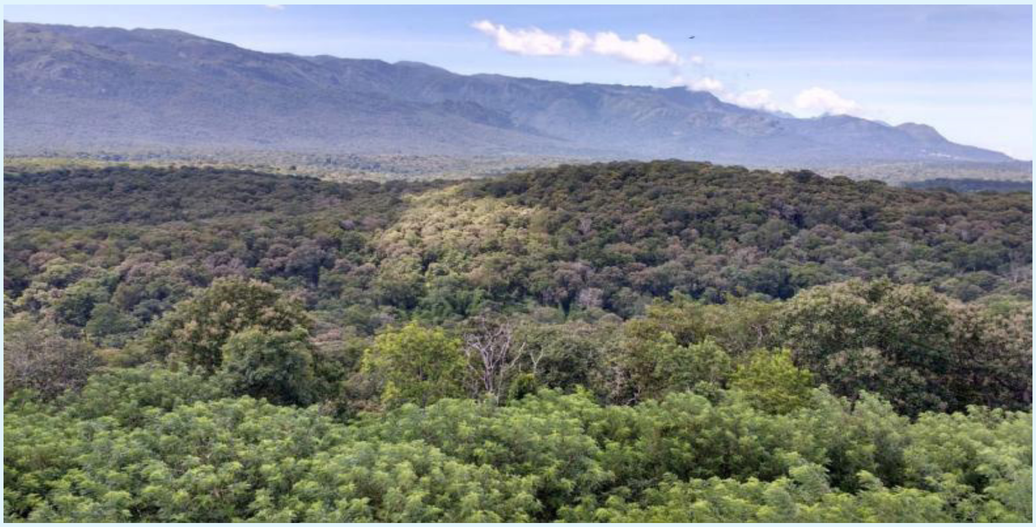


Figure 4.6: Tropical dry forest landscape from Mudumalai Tiger Reserve, Tamil Nadu. (Photo: Sandeep Pulla)

Tropical dry forests occupy large areas of the country including the eastern rain-shadow slopes of the Western Ghats in peninsular India. The seasonally dry forests of Mudumalai (Tamil Nadu) in the Western Ghats have been monitored for over three decades through permanent forest plots established since the 1980s (Sukumar et al., 1992); this study has provided unprecedented empirical data on the sensitivity of tree species dynamics to climatic variables. The effect of key environmental variables, including fire, rainfall, and temperature, on species recruitment, mortality and growth was examined in a large 50 ha plot (Pulla et al., 2021)but can inform both our fundamental understanding of plant communities as well as community-ecology theory. We studied the dynamics of a woody plant community in a southern Indian seasonally-dry tropical forest (SDTF. The time since the last fire burn, precipitation, and minimum and maximum temperatures were the strongest predictors across all three processes, with recruitment, survivorship, and growth of several species lowered during periods of low precipitation and immediately following fires (Pulla et al., 2021). Recruitment increased, but growth and survival largely decreased, with increasing temperatures. Six dominant species, including large canopy dominants with high carbon sequestration capacity such as *Lagerstroemia microcarpa* and *Tectona grandis*, have exhibited decreased mortality with increasing time since last fire burn. Resource-acquisitive species such as *L. acrocarpa, Helicteres isora, Cassia fistula,* and *Catunaregam spinosa* have recruited more in response to increasing rainfall or temperatures. Other positive responses among the dominant species to increased rainfall included increased growth in *Anogeissus latifolia,* a species more abundant in the drier parts, and reduced mortality in the understorey shrub *Helicteres isora*. At the landscape scale, species diversity in these seasonally dry forests is positively correlated with mean annual rainfall and negatively correlated with fire frequency (Dattaraja et al., 2018)which, in turn, affect plant diversity. We examined how precipitation, fire and soil properties jointly determine woody plant diversity. Specifically, we asked how woody plant diversity varies along a sharp precipitation gradient (about 600–1,800 mm mean annual precipitation [MAP]within a 45-km distance.

One of the important findings from this long-term monitoring programme is that tropical dry forests are relatively resilient to carbon stock changes with stability during periods of extreme stress such as drought and fire, and an overall increase was observed over three decades. This underscores the role of tropical dry forests in carbon sequestration under a changing climate.

4.2.3 Wetlands

Wetlands have an important role in regulating ecosystem functioning as well as buffering humans from the impacts of climate change. They are located at the interface of terrestrial and aquatic ecosystems and typically arise when inundation by water produces soils dominated by anaerobic processes, forcing the biota, particularly rooted plants to adapt to flooding. The range of ecosystems that are referred to as wetlands include inland aquatic ecosystems (such as swamps, marshes, lakes and peatlands); coastal and near-shore marine (such as coral reefs, mangroves, seagrass beds and estuaries) and human-made ecosystems (such as reservoirs, irrigation channels, fish ponds and others). Wetlands International South Asia (2020) conducted a trend analysis of wetlands extent in India for the period 1980-2015, based on data from 240 wetlands from ten biogeographic zones of India. During this period, the extent of natural wetlands declined by 41%, whereas the human-made wetlands increased by 44% (Figure 4.7).

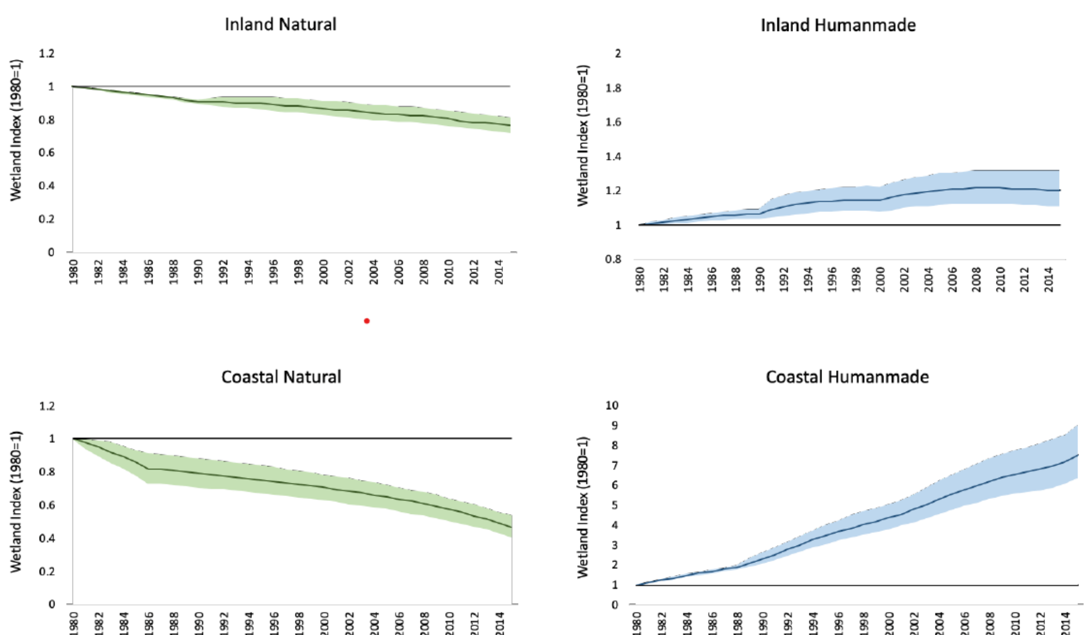


Figure 4.7: Trends in Wetlands Index (1980-2014)

Source: WIS 2020

Natural inland wetlands increased in Trans-Himalayan Zone (by 87%) and declined in all other zones (minimum loss of 5% in the Desert zone, and maximum loss of 71% in the Gangetic Plains). Inland human-made wetlands have increased in all biogeographic zones (minimum in Deccan Peninsula by 3% and maximum in the Desert by 257%). Coastal natural wetlands have declined by 51% with an increase in area under mangroves (71%) and a decline in mudflats (73%), lagoons (62%) and beaches (39%). Coastal human-made wetlands have increased by 619%, the maximum increase being in aquaculture ponds (2908%).

The drivers of the change observed in wetlands were also evaluated in the same study. Physical regime change (in terms of water quantity, water frequency, sediment and salinity regimes), introductions (of nutrients, chemicals, solid waste and alien species many of which are invasive) and structural modifications (drainage and conversion) are the prominent direct drivers. In terms of biogeographic zones, wetlands along the coast and Western Ghats face a higher intensity of direct drivers of adverse change, followed by wetlands of the Gangetic Plains and Deccan Peninsula.

A vulnerability analysis of wetlands in India was also performed where sensitivity to climate change and other anthropogenic pressures were assessed. The results show that the natural wetlands located in Trans-Himalaya, Himalaya, Desert, Coasts and Islands are most vulnerable in the country. Wetlands in Semi-arid and Indo-Gangetic plains biogeographic zones are moderately vulnerable, while wetlands of Deccan Peninsula, North East and Western Ghats have low vulnerability to climatic changes. As a case study, vulnerability of Chilika lagoon in Odisha was assessed using a hydrological model for two emission scenarios- RCP 4.5 and RCP 8.5 under three-time horizons (short-term, medium-term and long-term). Under most scenarios, a reduction in annual freshwater inflows was observed except in the RCP 8.5 short-term scenario (2020-2049) where an increase was observed. Changes in freshwater inflows have a direct consequence on salinity regimes. The reduction in freshwater inflows observed especially in RCP 4.5 scenarios, also indicates relatively higher increases in salinity levels. The findings of the hydrological modelling indicate that climate change is highly likely to shift the lagoon towards higher salinity conditions, especially with a reduction in monsoon rainfall periods. Such trends will be reinforced by high rates of sea level rise in the Bay of Bengal as compared to other parts of the Indian coastline, increasing frequency of cyclones, lagoon surface warming, and high likelihood of flow reduction from the Mahanadi River. Such changes can have a high impact on the breeding and spawning of various fish species, especially the ones that require freshwater conditions.

4.2.4 Climate Change and Forest Fires in India

In India, forest fires are more severe in some forest types, particularly in tropical dry deciduous forests, while evergreen, semi-evergreen and montane temperate forests are less prone (FSI, 2015). According to the long-term trend analysis performed by Forest Survey of India (FSI) for the 2021 report, nearly 10.6% of forest cover in India is under the extremely to very highly fire-prone zone. States under the North-Eastern regions showed the highest tendency and probability of frequent occurrence of forest fires. Parts of Western Maharashtra, Southern Chhattisgarh, Central Odisha and a few parts of Andhra Pradesh also show patches of extremely to very highly fire-prone zones.

Although wildfires are mostly ignited by human actions, they need favourable environmental factors including weather conditions for them to spread. Fire extent, frequency and intensity are determined by the interplay of climatic factors (moisture in the forest fuel load) and standing vegetation (quantity and quality of fuel) (Mondal and Sukumar, 2016). A hybrid process-based and Neural Net Fire Model developed by one of the studies undertaken for this communication was used to project wildfires under RCP 4.5 and 8.5 scenarios, after independent calibration with the Global Fire Emissions Database (GFED4.1s) and Climate Change Initiative (CCI) data (J. Joshi and R. Sukumar, inputs to TNC). The CCI dataset appears to better capture the spatial patterns of burned areas in the subcontinental part of India while severely underestimating burned areas in North-East India. The GFED dataset better captures fire-prone areas in North-East India but fails to capture the spatial variability in burned areas. The CCI-trained model predicts a drastic increase (Figure 4.8; 82.2–195.0% in subcontinental India and 27.5–83.5% in Northeast India) in burned areas in the future. By contrast, the GFED-trained model predicts only a modest increase (Figure 4.8; 17.6–34.5% increase in the subcontinent and a 9–14.9% decrease in the North-East). Therefore, the reconciliation of different burned area datasets is crucial to reduce uncertainty in future fire projections. A study on the incidences of forest fire in the Western Himalayan states of Himachal Pradesh and Uttarakhand suggests that the predicted increase in April temperatures and decrease in mean annual precipitation under future climate change scenarios is likely to result in increased fire incidences (Ahmad and Goparaju, 2018). Carbon emissions from forest fires in India are negligible on a global scale. For all types of fires in India, Rao et al. (2019) estimates this to be ~87 Tg/y over a 110y period (1901-2010). National Remote Sensing Centre estimated emissions of 98 Tg/y for the year 2014 from forest fires (Reddy et al., 2017). If these are matched against the estimated global emissions of 2.2 Gt C/y during 1997-2016 (van der Werf et al., 2017), forest fires in India are responsible for only 1.0-1.5% of global fire-related emissions.

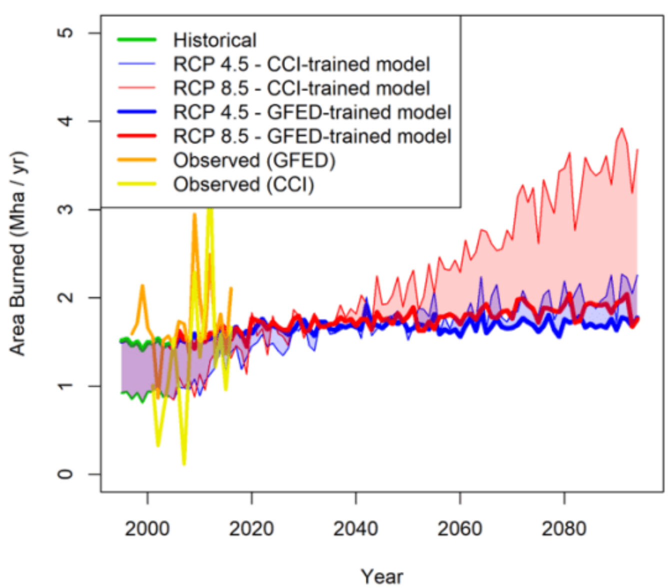


Figure 4.8: Timeseries of projected burned area for India from the two (GFED- trained and CCI-trained) models, showing burned area (Million Ha/yr) for the historical period (1975-2005) and projections for the future (2006-2100), under the RCP 4.5 and RCP 8.5 scenarios. Also shown is the observed burned area from the GFED dataset between 1997-2016 and the CCI dataset between 2001-2016.

4.2.5 Impact of Climate Change on Ecosystem Services

The effects of climate change on ecosystem services accrue through changes in both abiotic and biotic components. A review of 102 studies during 2000-18 on the state of current knowledge on the effects of climate change on ecosystem services in India has been conducted (Osuri et al., 2018). The frequency of research on climate change and ecosystem services increased from around one study per year during 2000-2005 to over 13 studies per year since 2015. The majority of studies (68%) employed modelling approaches to examine potential responses of ecosystem services to future climate scenarios, while empirical studies comprised 16%, and reviews comprised 13% of all studies. The body of research suggests a substantial impact of climate change on fisheries, with increasing temperatures being associated with reductions in spawning, altered distribution and ecology of commercially important fish species in inland and coastal ecosystems.

Supply and regulation of water are also expected to alter with climate change in India. Water plays an important role in regulating Earth's climate and environment but changing climatic patterns have directly and indirectly influenced water resources by altering the hydrological cycle further accelerating climate risks and impacting water quantity (Singh et al., 2022). The glaciers in the Himalayan mountains, which are widely regarded as the 'water towers' of Asia, are shrinking which can lead to a significant reduction in water availability in India (Kumar et al., 2007; Mehta et al., 2014). The increased evapotranspiration due to rising temperatures is likely to reduce stream flow in river basins (Immerzeel et al., 2010). In areas that are likely to experience an increase in rainfall, the ability of hydrological systems to regulate disturbances such as floods might also be reduced. Increased temperatures are also likely to alter the quality of water by altering the concentrations of oxygen and other nutrients like nitrogen and phosphorous and changing the salinity of water (Gupta et al., 2011). These can have a profound impact on both water resources and food production.

In India, the primary source of income of 58% of the population is agriculture which contributes 15.4% of GDP (Rao et al., 2019). Agricultural yield can be negatively affected by the loss of beneficial arthropods like pollinators, predators and parasitoids due to changes in abiotic conditions with respect to climate change. Elevation range shift of different pollinators like butterflies due to temperature changes was reported in multiple areas of the Indian Himalayan range (Acharya and Chettri, 2012, Chandra et al., 2019).

In a literature survey conducted by Borges et al. (2020), the vulnerability of pollinators and pollination services in India in the context of climate change was examined. The survey of 56 plant species reported that very few studies have recorded pollinator activity in relation to temperature of which 7 studies were assembled in the report. A case study for the foraging behaviour of pollinators (flies, stingless bees and wild Asian dwarf honey bee) of an important horticulture crop of India, mango (*Mangifera indica*), has been presented in detail. Mango production is heavily dependent on pollination- a decrease in fruit set by 63% was recorded upon insect exclusion compared to open pollination in the Alphonso cultivator of mango (Rajan and Reddy, 2019). One study showed that temperature is the single most important abiotic variable that influenced the foraging activity of pollinators of mango (Reddy et al., 2012). From these studies, it is clear that above the thermal limits for the species, the pollinator foraging activity declines. Consequences of such results in terms of fruit yield and food availability for primary consumers under climate change scenarios are thus extremely important.

4.2.6 Climate Change, Animal Movement and Human-Wildlife Conflict

India is one of the few developing countries where the populations of several wildlife species are on the rise. India has nearly two-thirds of the population of wild tigers in the world, while the population of Asiatic lions has risen from 177 in 1968 to over 675 in 2020. Similarly, the Asian elephant population numbers which were less than 20,000 in 1970s and 1980s has risen to nearly 30,000 in 2017. Similarly, the population of the one-horned Indian Rhino, which was on the brink of extinction during the early 20th century, has increased to almost 3000 in 2023.

Changes in abiotic conditions (reviewed in Bhatnagar et al., 2019) and projected habitats such as forest vegetation cover (Ravindranath et al., 2006), due to climate change are bound to exacerbate the challenges these animals face and force them to change their habitat use patterns or disperse to suitable regions to meet their requirements (Sukumar, 2018). Currently, evidence from India of species changing their movement strategies or shifting their distribution in response to climate change are few (Jose and Nameer, 2020; Raman et al., 2020).

An added complication for animals moving into suitable habitats to overcome climate change is anthropogenic habitat modifications. Such mismatches in space available for animals are especially relevant in India where protected areas are surrounded by human-modified landscapes. According to the Forest Survey of India (2021), 21.71% of the country's land area is forested but only 5.2% of the total area falls under Protected Areas (PAs). This restricted area for protection in the country is bound to exert different pressure on animals that live and move inside PAs, those that move in and out of them, and those moving outside PAs. For example, tigers showed higher displacement outside PAs as compared to displacement inside PAs (Habib et al., 2021). Such movements may have consequences for species dispersal. Habitat generalist species, such as the golden jackal and jungle cat, tolerate human-modified landcover types and, thus, may be better buffered against future climate-driven changes to agricultural patterns as compared to a habitat specialist such as the Indian fox, which requires native grasslands that are already limited in availability (Katna et al., 2021).

Along with the impact on plant and animal population dynamics and their distribution, climate change is expected to impact aspects human-wildlife behaviour as well. The interaction between these two is often manifested in the form of human-wildlife conflicts where the role of climate change is largely unknown and has received poor attention so far. Changes in the movements and behavior of elephants and lions have been observed following severe droughts triggered by El Nino events. Elephants have migrated to regions where they had not been seen for hundreds of years, resulting in multiple casualties when they crossed paths with humans who were not used to them (Sivaganesan and Bhushan, 1986; Rao, 1995; Prasad and Reddy, 2002; Manakadan et al., 2009). A combination of environmental factors was responsible for the dispersal and persistence of elephants in Southwest Bengal. The changes in natural habitats in the state of Jharkhand due to mining, plantations and deforestation and regeneration of Sal (Shorea robusta) trees aided elephants in raiding nearby paddy fields in Southern Bengal. The ensuing conflicts with agriculture and people have been described in several anecdotal accounts and reports, but severe droughts caused as a result of the El-Nino Southern Oscillation (ENSO) event were the probable climatic trigger for the elephants to disperse (Sukumar, 1995).

Similarly, drought triggered an increase in human-lion conflict in Gir Forest, leading to human deaths (Saberwal et al., 1994). Poorer villages close to the park boundary suffered higher losses of livestock during the drought, thus forcing the Asiatic lions to move further away from the park in search of prey. Lion attacks on people increased during the monsoon period when both lions and people were active during the day. It is speculated that climate change may exacerbate such conflict with wildlife. Mitigating wildlife-human conflicts is an important facet of biodiversity conservation in changing climate. However, filtering the causality between climate variability and human-wildlife conflict is often complex, context-specific, and received poor attention. Long-term time series of conflict observations can enable us to see the influence of climate variability on conflict.

4.2.7 Adaptation to Climate Change

IPCC Working Group II SPM (2014) concluded, "A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability".

The projected impact of climate change would require development of a hierarchy of adaptation strategies across governance tiers. The adaptation measures need to be location specific and based on a range of factors such as forest or plantation type, level of degradation, biodiversity status, forest management practices, community pressure, climatic factors, and vulnerability. Thus, there is a need for Forest Division and Forest/ Plantation-specific adaptation measures and practices.

The key adaptation strategies envisaged include the promotion of climate resilient afforestation and reforestation practices, anticipatory planting of tree species along the latitudinal and altitudinal gradients, conservation of forests and biodiversity, linking of protected areas, corridors and fragmented forests, creation of Climate Change Cells at Forest Departments, incorporation of climate change under the Working Plans and promotion of long term research and observation on impact of climate change and the response of forests and plant species.

The Government of India revised the National Working Plan Code in the year 2014. The new code recognizes climate change as a phenomenon that "seriously affects and alters the distribution, type, composition, quality, and mitigation potential of forests of the country, especially in the realm of anthropogenic stressors". Such recognition of the impacts of climate change and anthropogenic stressors on forests prompts devising adaptation strategies and action to deal with the risks. Management of forests according to the Working Plan has been sanctioned in policy, law and governance provisions in India. The sanctioned Working Plan provides an accepted, efficient and effective mechanism for implementing forest adaptation measures, as it includes monitoring as well as evaluation of the measures undertaken. Such a mechanism also benefits by providing feedback information for developing an adaptation strategy in the succeeding cycle.

The State Action Plan on Climate Change (SAPCC) developed by the States and UTs identify measures to adapt to climate change vulnerability while improving ecosystem resilience through various measures. The Indian Western Himalayan region states/UT viz., Jammu & Kashmir, Himachal Pradesh and Uttarakhand developed their respective SAPCCs in 2011 while identifying the following thrust areas - management of forests, soil and water conservation, estimation of soil carbon, stabilizing emissions, enhancing ecosystem resilience, eco-restoration, improving the livelihood of forest-based communities, wetland development, monitoring of forest encroachment, agrarian economy, networking the fragmented protected area, buffering ecosystem services, sustainability of hydro economy, management of fire, securing livelihoods, and capacity building among others. The priorities thus identified are being implemented through various schemes funded by the Central and State Governments. The establishment of inter-relations between parameters of climate change and the evolution of the climate change adaptation strategy for forestry and allied sector will strengthen the implementation, monitoring and reporting of the on-ground initiatives.

For adaptation strategies to be effectively devised, focusing on addressing critical knowledge gaps, particularly due to the complexity at every level of organization and the inherent stochasticity of natural systems, leading to considerable uncertainty in our ability to predict how these entities will respond to climate change, requires long-term observatories and monitoring networks. The Ministry of Environment, Forest and Climate Change has established a network of Long-Term Ecological Observatories (LTEO) as part of the Climate Change Action Programme (CCAP) of India to understand the various anthropogenic and biophysical drives that result in ecosystem change while considering social and ecological perspectives (GoI, 2018). The Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC) following a consultative process has set up a National Mission on Biodiversity and Human Well-Being with the aim of comprehensive documentation of India's biodiversity with the potential for cataloguing and mapping all lifeforms in India. The mission's program on "Biodiversity, Climate Change and Disaster Risk Reduction" will work to assess the vulnerability of ecosystems and different biomes in India to climate change and climate disasters by evaluating both historic trends in responses and future projections for different climatic stressors, including extreme events, and develop strategies for integrating ecosystem and eco-based solutions for enhancing resilience to climate change (Bawa et al., 2020).

Apart from domestically addressing the challenges related to disaster management, India launched the Coalition for Disaster Resilient Infrastructure (CDRI) at the 2019 Climate Summit at a global platform. This international partnership of National Governments, UN agencies, Multilateral Development Banks, the private sector, and knowledge institutions will promote the resilience of new and existing infrastructure systems to growing climate risks and disasters. The Government of India has allocated INR 480 crore (approx. 58 million USD) to support the work of the CDRI over a period of five years from 2019 to 2023-24.

4.3 Agriculture in India under the Changing Climate

Agriculture is one of the major drivers of the Indian economy. Good monsoon years drive market demand spurring growth rates in various sectors significantly. India has come a long way from the 'ship to mouth' condition of the 1960s to the Food Security Act of 2018. Total food grain production reached an estimated record 305.44 MT in the year 2020-21 which is about 3.7 times the food grain production in 1960-61 compared to a population increase of 3.25 times in the same period. Even during the COVID-19 pandemic, food grain production in 2020-21 was 7.94 MT higher than the production in 2019-20, and 26.66 MT higher than the previous five years' (2015-16 to 2019-20) average production. Horticultural production has also increased to 326.58 MT from 320.48 MT in 2019-20. Milk production has increased to 208 MT from 198.4 MT in 2019-20. In addition, annual meat production is about 5.3 MT, egg production is about 75 billion eggs. The fish production in 2019-20 was 14.16 MT, a 31.6% increase over 10.76 MT produced in 2015-16. Indian agriculture is the primary source of livelihood for approximately 58% of India's population. As per 2020-21 land use statistics from Ministry of Agriculture and Farmers Welfare, the net sown area is 141.54 million Ha and the gross cropped area is 216.10 million Ha million with a cropping intensity of 152.7%. The net irrigated area is 77.7 million hectares. The share of agriculture and allied sectors in GVA of the Indian economy was about 17.8% (Rs. 19.48 lakh crore) in 2019-20 with a major contribution from crops followed by livestock (Economic Survey of India, 2020-21). The export contribution from agriculture and allied sector in 2019-20 was about Rs 252 thousand crores. A major share of this came from marine products, rice, spices, meat, sugar, cotton, etc. India stands first in the production of rice, wheat, and milk and second in vegetables.

Notwithstanding the above achievements, there is considerable scope to increase productivity levels in Indian agriculture and allied sectors. Against this background, climate change is an additional threat to the Indian agricultural system that is stressed by several factors such as reduced availability of land, and water, deteriorating soil health in many regions, yield stagnation, and the attack of pests and diseases, apart from several socio-economic stressors. Indian agriculture has always faced climate risks, however, the frequency of some risks has begun to significantly increase. Analysis of yield and weather data from 1966-67 to 2017-18 indicated that the yield of food grains was negative in the Kharif season during 1968-69, 1974-75, 1982-83, 1984-85,1991-92, 2004-05 and 2013-14 as compared to the preceding year. Similarly, the Rabi season yield of food grains yield showed a decrease in 1973-74, 1989-90, 1992-93, and 2014-15. Yield decline in both seasons as compared to respective season yields of the preceding year was noted in 1972-73, 1976-77, 1979-80, 1986-87,1995-96, 1997-98, 2000-01, 2002-03 and 2009-10. Correlating past temperature and rainfall data with the yield of major crops for 1980-2008 period, Lobell et al. (2011) indicated a net positive impact of climate change of about 1.5% on maize yield in India while rice and wheat yields suffered a negative impact of about 2 and 6% respectively (though overall yield growth was positive).

4.3.1 Climate change scenarios for agricultural seasons in India

Climate change is projected to increase the risk of food insecurity in South-Asia due to warming and an increase in extreme temperature and rainfall events, droughts and skewed monsoons (IPCC, 2014, IPCC, 2022a). The IPCC report however notes that the risk level can be moderately minimized with current adaptation measures and can be significantly minimized with high and/or intensive adaptation.

From an agricultural perspective, an analysis of the ensemble probabilistic scenarios for India was carried out at the environmental modeling lab of Indian Council of Agriculture Research (ICAR) based on the 33 CMIP5-GCMs climate projections for 2020, 2050 and 2080 in RCP 2.6, 4.5, 6.0 and 8.5 scenarios. The analysis projected 1) more increase in minimum temperatures than in maximum temperatures; 2) more increase in temperatures during Rabi (October-April) than during Kharif (June-September); 3) an increase in the minimum temperatures by 0.946 - 4.067^{0}C in 2020 to 2080 period over baseline (1976-2005 period) in Kharif; and by 1.096-4.652^{0}C in Rabi across RCPs and climate scenarios; 4) an increase in maximum temperatures by 0.741 - 3.533^{0}C (2020 to 2080) during Kharif and by 0.882- 4.01^{0}C in Rabi; 5) more increase in temperatures in northern parts of India as compared to that in southern parts; 6) an increase in rainfall by 2.3-3.3% (2020), -10.1% (2050) during Kharif; and an increase by 12% (2020), 12-17% (2050) during Rabi, and 9) variability in minimum and maximum temperatures during Rabi projected to be significantly more than during Kharif; variability in rainfall projected to increase future climates. These climate change projections have significant spatio-temporal variations with significant impacts on agriculture in India (IARI Annual Report, 2017-18; NICRA Annual report, 2017).

4.3.1.1 Bias corrected, ensemble climate change scenarios for agricultural seasons in India

The bias-corrected models for the Indian region were developed based on Regional Climate Models (RCM) for RCP 4.5 and 8.0 and were subsequently bias corrected against IMD gridded data for 1976-2005. RCP 8.0 is however not truly a business-as-usual scenario and has been clarified in this regard by the IPCC. These were used for creating the ensemble scenarios and further analyzed to derive the climate change scenarios for agricultural seasons in India. Results indicate spatial and temporal variations in the rise in temperature and change in rainfall. Overall, the seasonal trends are similar to that of GCMs trends, but the magnitudes differed and, in some regions, the direction also differed. Detailed information on the RCM projections for the Indian region is reported by Krishnan et al. (2020). The projections indicate an increase in the annual and summer monsoon rainfall, the frequency of heavy rain events and inter-annual variability over most parts of India (Kulkarni et al., 2020). The CORDEX mean surface air temperature changes over India are also projected to increase in the range of 1.39–2.70 °C in 2050 and in the range of 1.33–4.44 °C in 2080 (Sanjay and Revadekar, 2020), though the upper end of these relate to RCP 8.0 scenario. These trends are broadly similar to the projections of CMIP5 GCMs. The study also projected an increase in the frequency of heatwaves and their extent of coverage during pre-monsoon season. Increases in temperatures are also projected to rise more during Rabi season as compared to the monsoon season. All these are likely to make Indian agriculture more vulnerable to climate change.

4.3.2 Vulnerability of Indian agriculture to climate change

4.3.2.1. Vulnerability and risk assessment

The vulnerability and risk analysis were conducted at the district level for Indian agriculture following the AR5 IPCC 2014 framework by the Indian Council of Agricultural Research (ICAR)/ Central Research Institute of Dryland Agriculture (CRIDA)/ National Innovations on Climate Resilient Agriculture (NICRA) (Rama Rao et al., 2019).

4.3.2.2 Method

Several approaches and methods are available for vulnerability and risk assessments ranging from indicator-based methods to local-level participatory assessments (Cardona et al., 2012). The 'Indicator method' was used because of its simplicity, and usability in monitoring and evaluation for policymakers (Crane et al., 2017). Indicators were selected based on earlier studies (e.g. Esteves et al., 2013, 2016; Ravindranath et al., 2011; O'Brien et al., 2004; O'Brien et al., 2007; Rama Rao et al., 2013; Upgupta et al., 2015), with considerations of underlying determinants of risk, and stakeholder consultations. In this analysis, hazard was represented in two forms: future climate hazard and historic hazard. The future climate hazard was captured in terms of indicators relevant to agriculture sector, derived from the climate projections for RCP 4.5 for 2030s (2020-49) from a subset of 30 GCMs. Several exposure indicators and vulnerability indicators were appropriately selected and included in the analysis. Different components of risk included historical hazard, future hazard and exposure (20% each), and vulnerability (40%).

4.3.2.3 Risk and Vulnerability for Indian agriculture due to climate change

Amongst various drivers of exposure, high proportion of Net Sown Area (NSA) in relation to the geographical area has contributed the most to exposure in 134 of 310 districts (Figure 4.9). High NSA is a surrogate for high pressure on land for agricultural use. It also indicates high fertility and productivity of soils in districts of Uttar Pradesh, Rajasthan, Madhya Pradesh, Haryana, Punjab, Karnataka, etc. Social, human development and economic factors, literacy, income levels, access to economic infrastructure) are the main causes of vulnerability in 71 districts, primarily in North-Eastern states, making them more susceptible to hazard. Lack of economies of scale, weak bargaining power, difficulties in accessing information and capital associated with small farm size are a cause of vulnerability particularly in 52 of 310 districts, that are identified as having 'very high' or 'high' risk (Figure 4.10). The existence of high-value capital assets in places of occurrence of a hazard also pose a high risk. The presence of a high proportion of cross-bred cattle is driving risk in 29 districts of which 10 are in the state of Kerala and a few in the states of Tamil Nadu, Karnataka, Jammu & Kashmir, etc. High population density is a cause of high risk in 14 districts of Bihar and a few in Uttar Pradesh, West Bengal and Kerala.

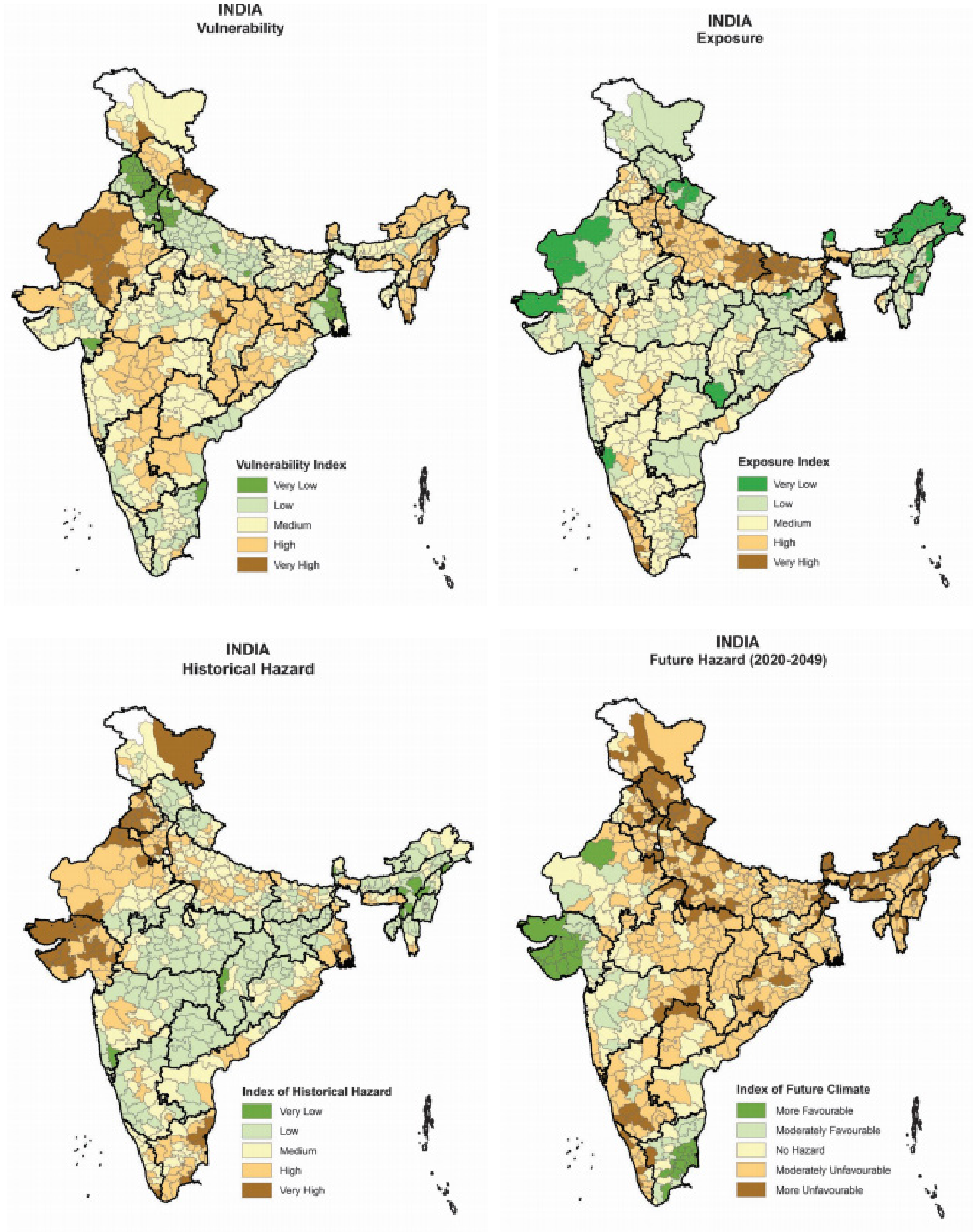


Figure 4.9: District-wise exposure, vulnerability, historical hazards and future hazards over India in RCP 4.5 2030 (2020-49) scenario.

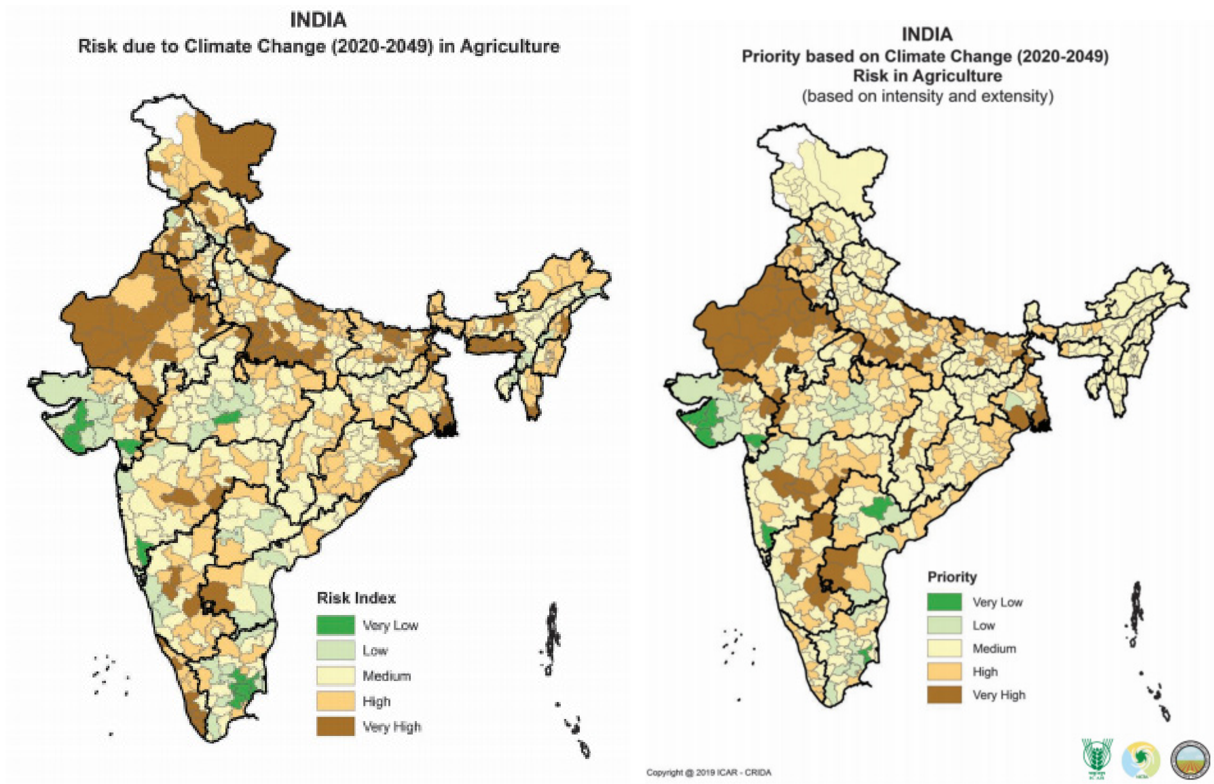


Figure 4.10: District-wise risk over India and b) and intesity and extensity-based priority of dirticts in RCP 4.5 2030 scenario.

In warming conditions, low access to irrigation is the most prominent vulnerability-related driver of risk in 116 districts. Low annual rainfall is an important source of risk in 91 districts. The low water holding capacity of soils and low groundwater availability has contributed to high risk in 56 and 13 districts respectively. Degraded lands are the major cause of vulnerability in 13 districts. High frequency of droughts in 156 districts, cyclones in 93 districts and floods in 61 districts have been major factors contributing to risk. Rise in minimum temperature is the most significant factor in determining risk in 271 districts. Similarly, rise in maximum temperature was identified as a key driver of risk in six districts, while the increase in drought incidences is a cause of high climate change risk in 24 districts.

Identification of major crops for further assessments

Statistical time-series modelling approach was followed to examine the crop's weather sensitivity for each state over the 1969-2009 period. In general, an increase in temperature reduced yield for several cereals and pulses, groundnut and rapeseed, and mustard across States. On the other hand, where there is a significant association between precipitation and yield, such as in rice, bajra, ragi, gram, groundnut, sesamum and sugarcane, the relationship is mostly positive. But for maize and jute yields, a significant negative relationship with rainfall was noted across several states. A significant positive relationship between mean temperature and rice yield was found for several States. Like the cereal crops and pulses, oilseed crops responded more adversely to increasing mean temperature, although in many States the relationship is statistically insignificant. However, non-food crops like jute and cotton responded more adversely to both higher mean temperatures and higher rainfall. For the oilseeds, sugarcane, jute and cotton crops, the influence of maximum and minimum temperature tends to be negative for several states. For a few crops and states, higher rainfall also tends to reduce the crop yield. Based on the nutritional relevance of major food items across each zone and their assessed sensitivities across states of India, the following set of crops, emerge as the ones that require focus from a climate change impact assessment perspective.

Table 4.2: Region-wise list of crops requiring special focus

Zones	Critical Crops
East	Rice, Wheat, Rapeseed & Mustard
North	Rice, Wheat, Maize
North-East	Rice, Maize
South	Rice, Wheat, Ragi, Jowar, Gram, Tur, Sunflower
West	Wheat, Bajra, Maize, Jowar, Groundnut, Rapeseed & Mustard
Central	Wheat, Rapeseed, Mustard

Specific crops that emerge as critical ones need impact assessment and adaptation planning to be carried out not only from a climate sensitivity perspective but also from nutritional security under changing climate. Therefore, the climate change impacts assessments are carried out for a total of 12 crops.

4.3.3 Assessment of impacts of climate change on Indian agriculture

4.3.3.1 Global studies on impacts of climate change on agriculture in India

Climate change impacts on the productivity of major crops have been studied at the global level. Such assessments are largely confined to major crops such as wheat, rice, maize, and soybean. Based on the historical (1966–2011) relationship between inter-annual variations in temperature and rainfall and rainfed yield variability, rice yields were found to be more sensitive than the yields of finger millet, maize, pearl millet, and sorghum (Davis et al., 2019). The national yields in the 2000s were 13% higher than they would have been without irrigation trends since 1970 and as constraints on expanding irrigation become more binding, furthering yield gains in the face of additional warming is likely to be a difficult challenge (Zaveri and Lobell, 2019). Studies indicate that tropical regions such as South Asia, along with Africa, are likely to be the most impacted in future (IPCC, 2014). Temperature rise, change in rainfall distribution, frequent and intense floods and droughts are projected to increase stress on food production (Lobell et al., 2012; Schellnhuber et al., 2013; Rosenzweig et al., 2014). Increasing climatic variability may further complicate agricultural production and food security as almost one-third of yield variability is related to climatic variability (Ray et al., 2016).

A meta-analysis of over 1700 published studies indicates that without adaptation, losses in aggregate production are expected for wheat, rice, and maize in both temperate and tropical regions by 2°C of local warming (Challinor et al., 2014). Crop-level adaptations increase simulated yields by an average of 7-15%, with adaptations more effective for wheat and rice than maize. Projected yield loss trends are similar irrespective of the methods followed (Asseng et al., 2013; Liu et al., 2016). As indicated earlier, climate change has already started affecting crop production in the range of 1- 10%, as compared to no climate change situation (Lobell et al., 2011; Lobell and Field, 2007). Most of the impact assessments carried out to date have highlighted regions such as South Asia, Africa and Latin America as being particularly vulnerable to the effects of climate change on agriculture. In another meta-analysis of approximately 27,000 data points from studies published over the last four decades revealed a yield loss of up to 10% for rice, wheat and maize due to climate change in South Asia (Aggarwal et al., 2019). The study also identifies India as a country with high food production gap and high climate change impacts on wheat and maize. Agricultural productivity in South Asian countries is particularly vulnerable to climatic extremes (Kira Vinke et al., 2017).

4.3.3.2 Experimental evidences on impacts of climate variables on Indian agriculture

Several multi-year field experiments and controlled experiments using Open Top Chambers (OTC), Temperature Gradient Tunnels (TGT), Free Atmospheric CO_2 Enrichment (FACE) and Free Atmospheric CO_2 and Temperature Enrichment (T-FACE) facilities were conducted under National Innovations in Climate Resilient Agriculture programme, other major projects in several ICAR-Institutes and State Agricultural Universities. These studies were conducted to delineate the effects of climate variables on soil systems and crops.

Soil carbon and soil system

The Indian soils are estimated to have an organic carbon stock of 63 Pg in the top 150 cm (Bhattacharya, 2000). Based on the soil survey data, the topsoil (up to 20cm) in Indo-Gangetic Plain (IGP) is estimated to have a soil organic carbon (SOC) stock of 1.1 Pg by the year 2030 (Bhattacharyya et al., 2007). The long-term fertilizer experiments indicated that soils under cropping systems receiving nitrogen, phosphorous and potassium (NPK) and farm yard manure (FYM) are having higher SOC than those receiving just NP and K (Pal et al., 2014). Land use and management are the important factors for soil organic carbon changes in North-Eastern region of India (Sahoo et al.,2019). In Pushkar valley region of Rajasthan, land use changes induced loss of area under vegetation resulted in a net loss of SOC stock by 8.29 MtC during 1993-2003 and 2.76 MtC during 2003-2014 (Sharma et al., 2019).

Studies on changes in SOC in Madhya Pradesh indicated that in a 16-year period (2000-2015), cropped land had significantly lower carbon and nitrogen stocks in the surface and subsurface soil layers than native forest sites (Figure 4.11). Mean annual temperature, the ratio of potential evapotranspiration to mean annual precipitation, soil bulk density and clay content were important covariates for SOC stocks within land use. The SOC content of the surface layers (0-15 cm) was mainly determined by climatic factors, but the SOC content of the deeper soil layers (>15 cm) was more affected by texture factors. Soil carbon and nitrogen stocks under land uses were strongly negatively related to mean annual temperatures while positively correlated to PET: MAP. In the year 2015, almost 50% of the districts of Madhya Pradesh have become low in carbon partially or fully compared to the year 2000 where only 7 districts of 51 were only partially low in carbon. These changes may pose significant impacts on crop productivity and sustainability. Increased temperature and conversion from forest to cropland could decrease the existing SOC sink, but improved soil management and increased water availability may help offset these losses in Madhya Pradesh.

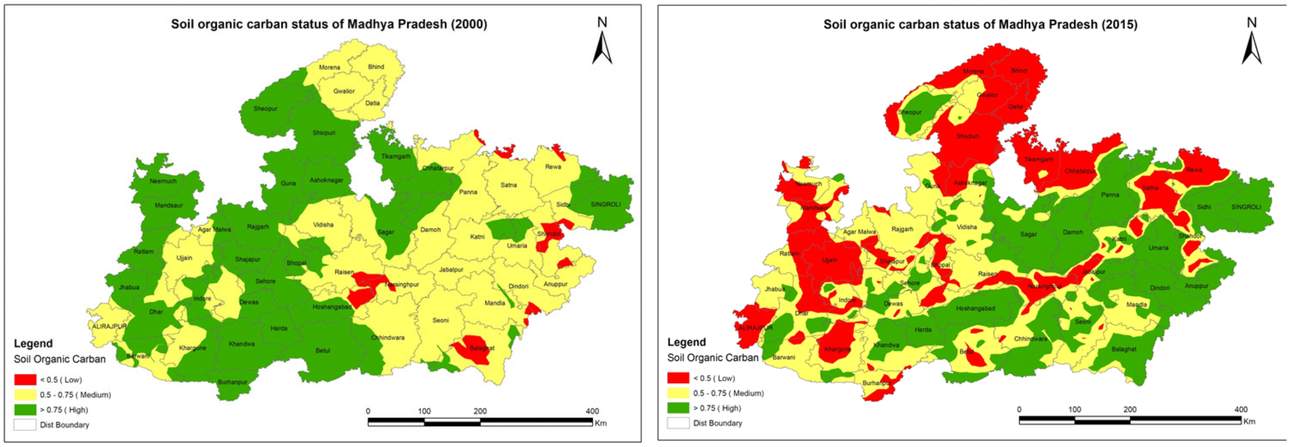


Figure 4.11: Surface soil organic carbon map of Madhya Pradesh for the year a) 2000 and b) 2015

In open-top chamber (OTC) experiments, the elevated CO_2 (550 and 700 µmol mol^{-1}) 2019 significantly contributed to a higher C: N ratio and increased the carbon stock in the soil (Rao et al., 2016). The incubation studies on alfisols and entisols indicated that a rise in maximum temperatures beyond 36^{o}C led to an increase in microbial biomass carbon and the ratio of labile carbon: total organic carbon. The activity of soil enzymes such as dehydrogenase, fluorescein diactate hydrolisase and β-glucosidase increased significantly, while phsophomonoesterase and arylsuphatase activity decreased (Chatterjee et al., 2019).

Crops

Studies conducted at ICAR-Indian Agricultural Research Institute (ICAR-IARI) and ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA) indicated that rise in atmospheric CO_2 concentration from current levels to 550 µmol. mol^{-1} benefited the crops in terms of yield (Figure 4.13-a). However, the quality of grains was affected in terms of protein concentration. On the other hand, a rise in temperature (beyond optimum) caused a significant reduction in the yield (Figure 4.13-b). The detrimental effect on yield was more pronounced with a rise in temperature despite the increase in CO_2.

Nitrogen (N) fixation by legume crops increased significantly under high CO_2 conditions, leading to higher fixation of N helping in soil N status. Both nitrogen and phosphorous uptake by crops increased under high CO_2 conditions. Better N management either by providing additional N dose or by enhancing N use efficiency will alleviate faster depletion of soil N under future climatic conditions.

Figure 4.12: Overview of the climate change research facilities (FACE, T-FACE, O_3-FACE, OTC and TGTs) and Eddy flux tower at ICAR-Indian Agricultural Research Institute, New Delhi (top) and at ICAR-Central Research Institute for Dryland Agriculture, Hyderabad

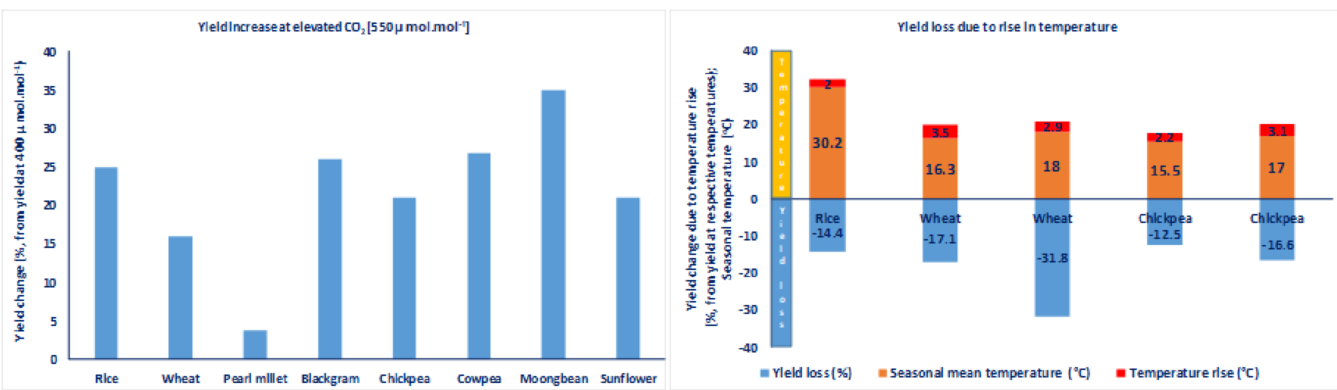


Figure 4.13 (a-b): a) Yield gain in different crops with elevated CO_2 at 550 μmol. mol^{-1}over 400 μmol. mol^{-1} b) Yield loss due to elevated temperature in different crops.

4.3.3.3 Projections on climate change impacts and adaptation gains for major crops

The projections on impacts and adaptation gains are important because they provide the key information on 1) yield changes in future climates, 2) relative sensitivity of crops and varieties, 3) relative sensitivity of regions, 4) areas that require more attention for adaptation to minimize or offset losses, and 5) areas that can be focused to maximize positive impacts of climate change. These studies help in prioritizing research, development and financial investments, policy setting for intra- and inter-national trades, negotiations, and developmental strategies, among many other applications. Impacts on crop yields are projected to have significant inter-annual variation. The impacts and adaptation gains on 12 crops are based on the mean of a 30 years' time-slice.

Approaches for assessing the climate change impacts on agriculture

In order to assess the impacts of climate change on major crops at regional and sub-regional levels, to map the adaptation gains, and to identify the vulnerable regions for specific crop production, the approaches followed include i) past data analysis, ii) the use of multi-location, multi-seasonal experiments data, iii) surveys, iv) data from controlled environment experiments and v) meta-analysis.

All these are eventually assimilated into the simulation modeling (hydrological, crop modeling, crop-pest modeling, economic modeling) frameworks for deriving the impacts and adaptation strategies. These methods were employed alone or in combination to meet the objectives. Further, specific studies conducted in other major projects such as NICRA under National Mission on Sustainable Agriculture; Department of Science Technology–Major Research & Development Programme (DST-MRDP) Project entitled 'Agricultural Productivity in Climate Change Scenarios: Impacts and adaptation pathways' under National Mission on Strategic Knowledge on Climate Change and World Bank-GEF funded project entitled 'Strategies to Enhance Adaptive Capacity to Climate Change in Vulnerable Regions' also are presented.

The present Integrated Vulnerability Assessment (IVA) is based on the Regional Climate Models (RCMs) data available at the CORDEX ESGF node for South Asia (Figure 4.14). The bias corrected ensemble outputs on daily temperatures (maximum and minimum) and rainfall from the 17 RCMs were developed and are input into the crop models at 0.5 x 0.5-degree grid scale along with atmospheric CO_2 levels to quantify (IVAs) for crops in RCP 4.5 and 8.5 for 2020 (2010-2039), 2050 (2040-2068) and 2080 (2070-2099) climate scenarios with IMD gridded data for 1976-2005 as the baseline. Soil data is taken from National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur and the varietal coefficients are derived from experimental data. Representative crop management data for each district was taken from various sources.

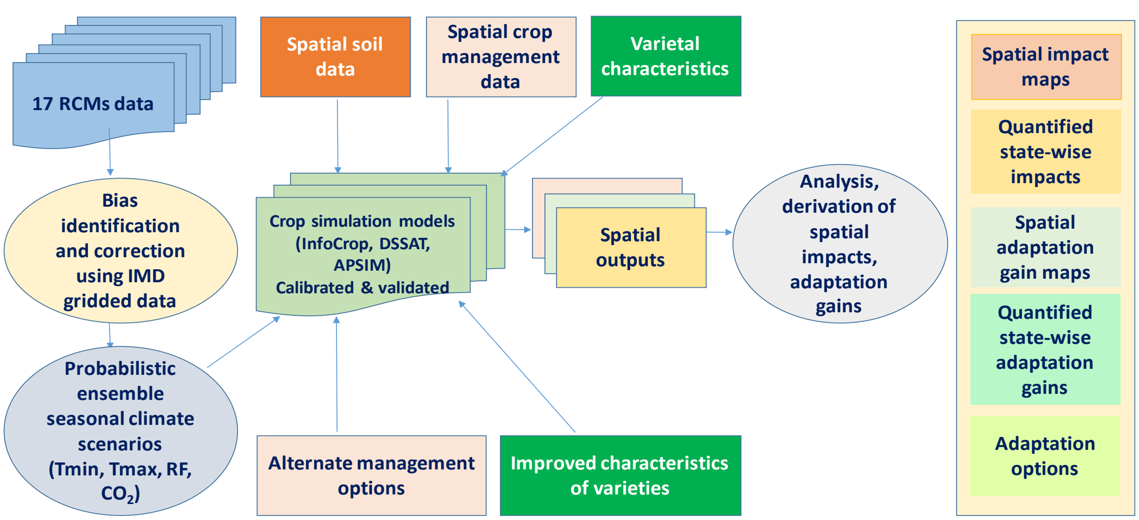


Figure 4.14: Modeling framework for IVA assessments on crops using simulation models.

All the impacts and adaptation gains are presented as percent change from the mean productivity of 2010-2015 period. The uncertainty is addressed following a globally accepted methodology. Impacts are derived based on the current level of technological adoption by farmers. For deriving the best adaptation, about 300 low-cost, easy-to-adopt management combinations of variety, sowing time, irrigation, nitrogen, and organic matter management are considered for each grid cell for each crop. Inputs from 8 stakeholder meetings conducted in different parts of India were also considered while simulating the adaptation options. For this entire Integrated Vulnerability Assessment, as many as 8.12 billion simulations for 12 crops were carried out. Integrated modeling (climate-hydrological-crop modeling) studies conducted under NICRA on Ramganga and Brahmani river basins are also included.

Projected impacts on cereals and millets

The cereal crops such as rice, wheat, maize, sorghum and pearl millet contribute to about 91% of total food grain production in India. Among these, major contributions come from rice (40%), wheat (36.3%) and maize (9.65%). In addition, the nutri-cereals contribute 16% to total food grains, the major ones being sorghum (1.6%) and pearl millet (3.36%). The climate change impact assessment projected a reduction in all India wheat yield by -9.1% (2020), -7.7% (2050) and -6.5% (2080) in RCP 4.5 emission scenarios, as compared to the mean yield of 2010-2015 period; and by -21.1% (2020), -17.3 (2050) and by -25.9 (2080) in RCP 8.5 emission scenarios, with the current level of technology adoption by farmers. In case of Kharif season irrigated rice, the projected reduction in yield is by -12.3% (2020), -7.9% (2050) and -2.7% (2080) in RCP 4.5 emission scenarios, as compared to the mean yield of 2010-2015 period, and by -1.7% (2020), -10.8% (2050) and by -29.5% (2080) in RCP 8.5 emission scenarios. Similarly, Kharif season irrigated maize yields are projected to reduce by -18.4% (2020), -21.1% (2050) and -26.6% (2080) in RCP 4.5 emission scenarios as compared to the mean yield of 2010-2015 period, and by -21.2% (2020), -25.6% (2050) and by -47.5% (2080) in RCP 8.5 emission scenarios. In contrast to the earlier cereal crops, beneficial effects of climate change are projected for Kharif season sorghum. The yield of Kharif season sorghum is projected to increase by 17.1% (2020), 20.9% (2050) and 26.6% (2080), as compared to the mean yield of 2010-2015 period, in RCP 4.5 emission scenarios and by 8.4% (2020), 14.2% (2050) and by -16.2% (2080) in RCP 8.5 emission scenarios, even with current management. However, Kharif season pearl millet yield is projected to reduce by - 6.0% (2020), -2.5% (2050) and -9.5% (2080), as compared to the mean yield of 2010-2015 period, in RCP 4.5 emission scenarios and by -4.3% (2020), but with a marginal benefit of 10.0% in 2050 and by 1.5% (2080) in RCP 8.5 emission scenarios (Figure 4.15).

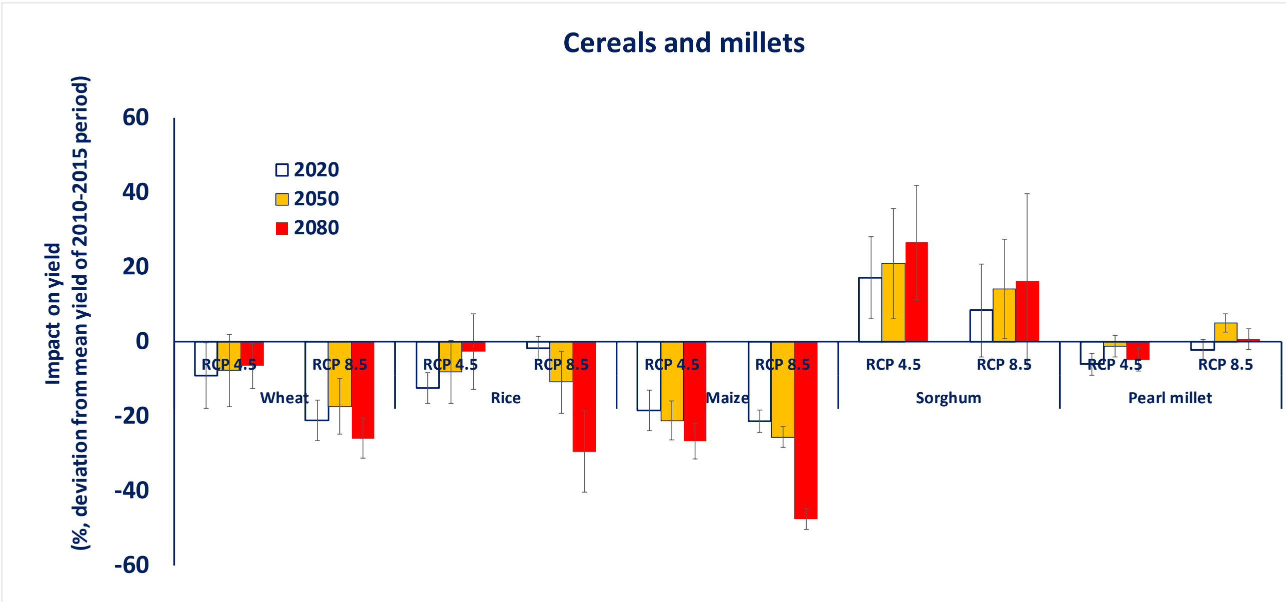
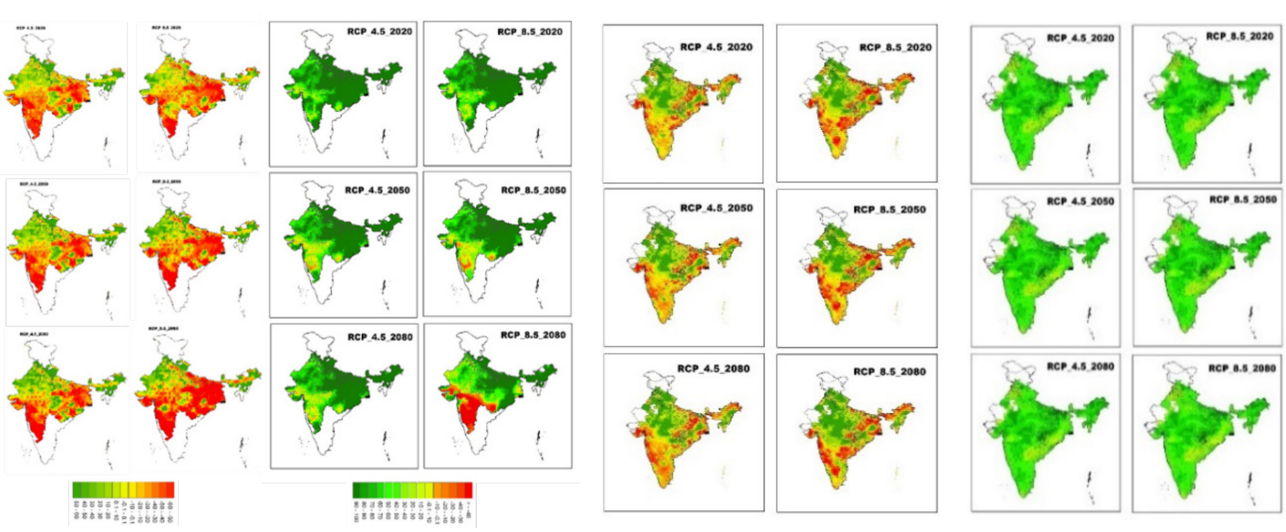


Figure 4.15: Impacts of climate change on major cereals and millets in India, with current level of technological adoption by farmers, in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

Impact with		Impact with	
Current management	Adaptation	Current management	Adaptation
Wheat		Rice	



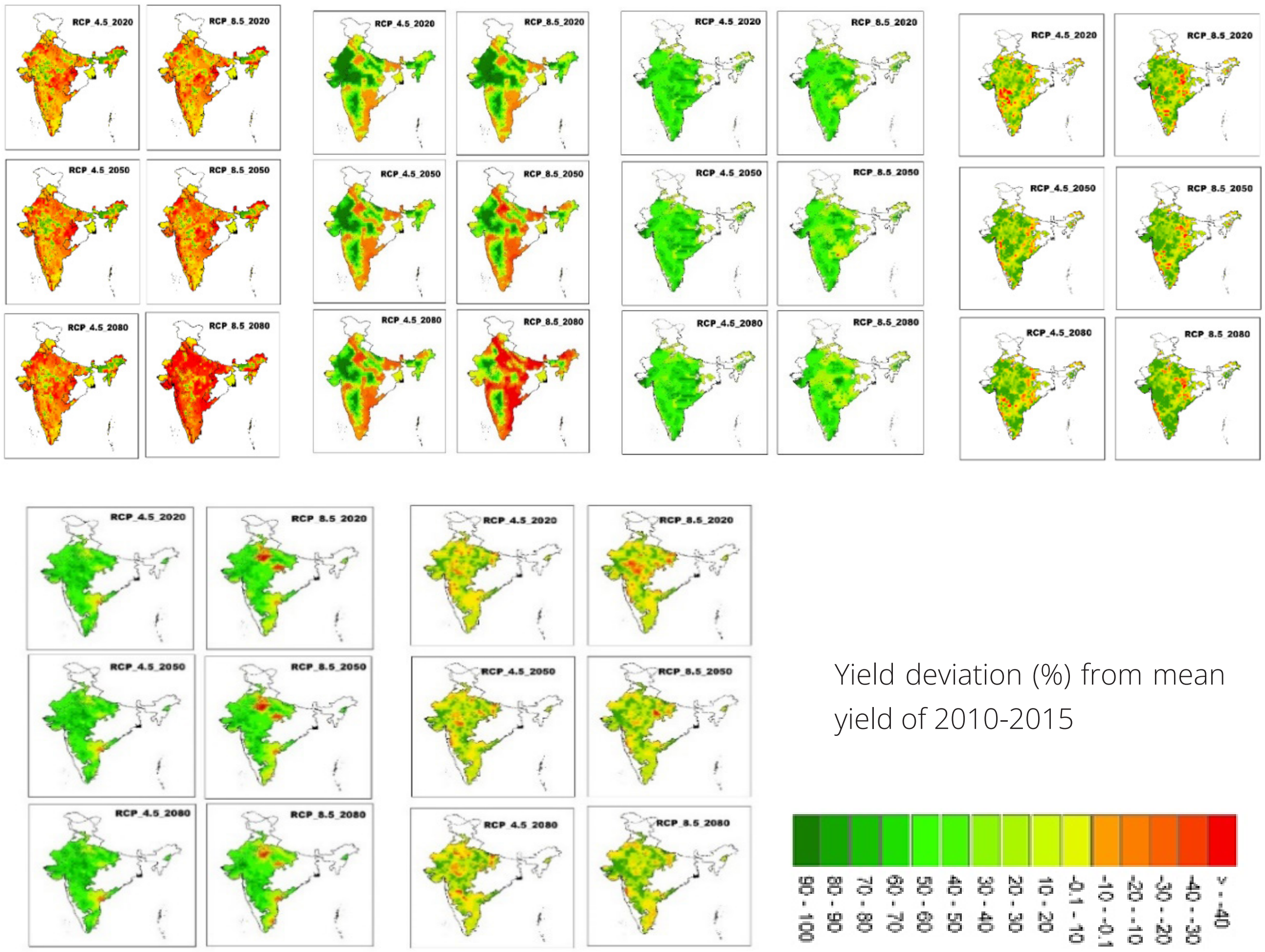


Figure 4.16: Spatial distribution of impacts (with current level of technological adoption by farmers) and adaptation gains in cereal and millet crops in India in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

Impacts on pulses and oilseeds

Climate change is projected to increase all India pigeon pea yield by 14.9% (2020), 20.9% (2050) and 24.0% (2080) from the mean yield of 2010-2015, in RCP 4.5 emission scenario, and by 9.2% (2020), 15.3% (2050) and 13.3% (2080) in RCP 8.5 emission scenario. Climate change is projected to marginally affect the all-India chickpea yield by -2.9% in the 2020 climate scenario but increase by 5.4-7.3% (in 2050) and 12.1-17.1% (in 2080) from the mean yield of 2010-2015 with the current level of technological adoption by farmers.

Climate change is projected to affect the all-India mustard yield by -12.1% (2020), -15.4% (2050) and -18.4% (2080), as compared to the mean yield of 2010-2015 period, in RCP 4.5 emission scenarios and by -11.1% (2020), -21.0% (2050) and by -35.6% (2080) in RCP 8.5 emission scenarios with the current level of technological adoption by farmers. Climate change is projected to marginally affect the all-India soybean yield by -3.2% (2020) but benefit it by 6.1% (2050) and 11.6% (2080), as compared to the mean yield of the 2010-2015 period, in RCP 4.5 emission scenarios; and by 0.2% (2020), 12.2% (2050) and 16.1% (2080) in RCP 8.5 emission scenarios. Climate change is projected to maintain the all-India kharif season ground nut yield as the change from the mean yield of 2010-2015 is marginal by -0.5% (2020) but may marginally benefit by 3.2% (2050) and 5.1% (2080) in RCP 4.5 emission scenarios and by 1.9% (2020) and 6.7% (2050) but may reduce by -4.2% (2080) in RCP 8.5 emission scenarios (Figure 4.17).

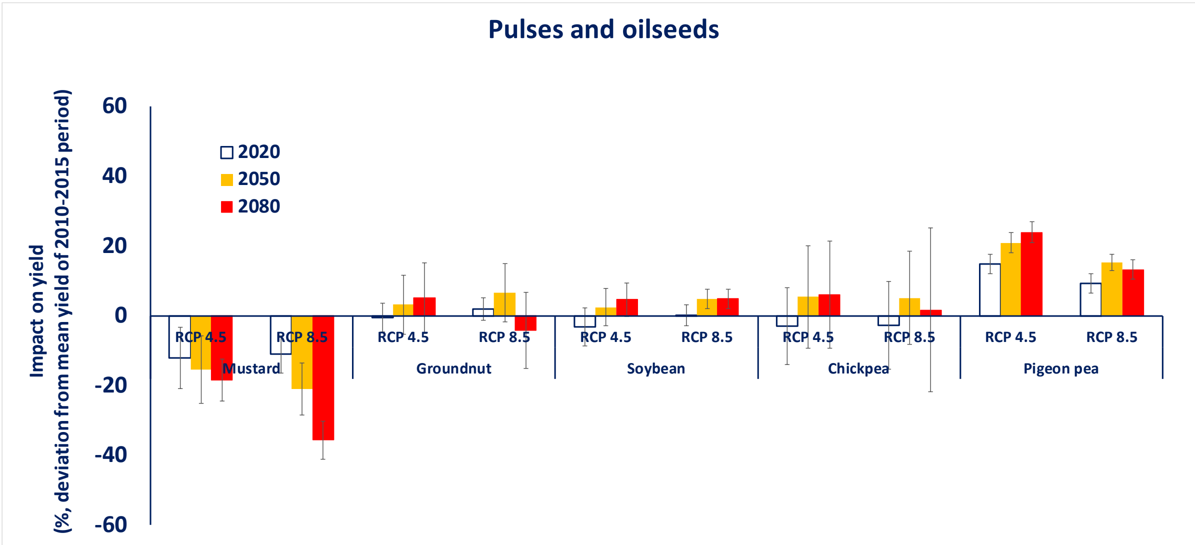


Figure 4.17: Impacts of climate change on pulse and oilseed crops in India, with current level of technological adoption by farmers, in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

Impacts on potato and cotton

Climate change is projected to reduce the all-India potato yield from the mean yield of 2010-2015 by -13.4% (2020), -7.2% (2050) and by -8.6% (2080) in RCP 4.5 emission scenarios and by -10.7% (2020), -16.4% (2050) and by -19.1% (2080) in RCP 8.5 emission scenarios with current level of technological adoption by the farmers. Climate change is projected to increase all India cotton yield by 8.4% (2020), 13.6% (2050) and 23.6% (2080) in RCP 4.5 emission scenarios, but marginally reduce by -4.0% (2020), and increase by 21.1% (2050) and by 20.1% (2080) in RCP 8.5 emission scenarios (Figure 4.18 & 4.19).

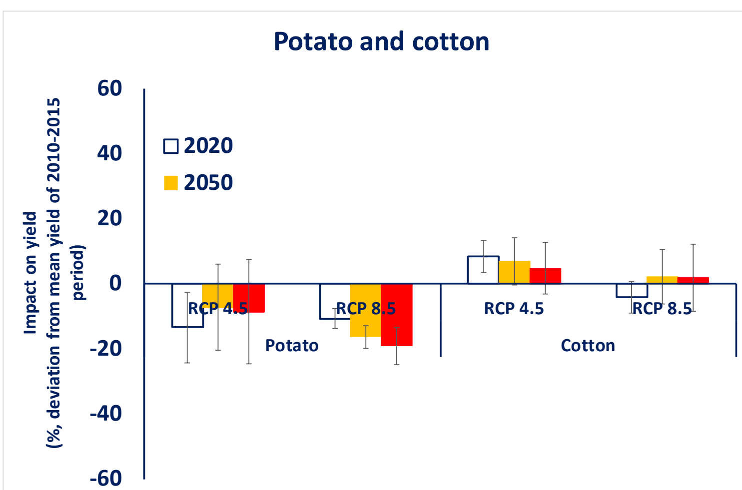


Figure 4.18: Impacts of climate change on potato and cotton crops in India, with current level of technological adoption by farmers, in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

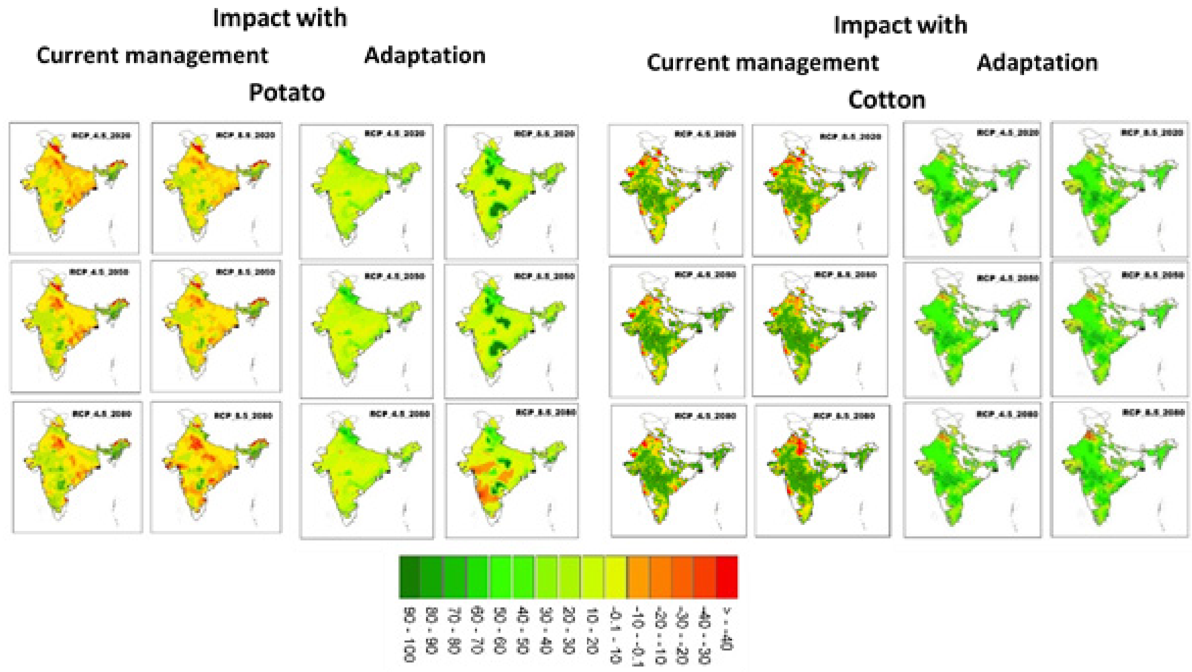


Figure 4.19: Spatial distribution in impacts (with current level of technological adoption by farmers), and adaptation gains in potato and cotton crops in India, in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

Relative positive impacts and vulnerability of States for the productivity of major crops in climate change scenarios

Significant spatial variations in the magnitude and direction of impacts are projected for major crops. Three types of impacts of climate change could be possible for regions and crops viz., i) positive impacts with current management ii) vulnerable with current management but can gain significantly with adaptation and iv) remain vulnerable despite adaptation. Crop yields in many states are projected to be affected to different magnitudes and remain vulnerable despite simple adaptation (Table 4.3).

Table 4.3: Vulnerable states to climate change for the productivity of major crops.

Crop	Vulnerable states
Climate scenario	RCP 4.5 and RCP 8.5
Wheat	Parts of Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam, Parts of Madhya Pradesh, Maharashtra and Gujrat
Rice (kharif irrigated)	Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Telangana, Chhattisgarh, Maharashtra and Gujrat
Maize (kharif irrigated)	Bihar, Chhattisgarh, Maharashtra, Telangana, Tamil Nadu, Uttar Pradesh and Andhra Pradesh
Sorghum	Karnataka, Telangana and Maharashtra
Pearl Millet	Punjab, Haryana, Gujarat and Jharkhand
Mustard	Gujarat, Jharkhand, Uttar Pradesh Bihar, West Bengal and Assam

Crop	Vulnerable states
Soybean	Parts of Madhya Pradesh, Uttar Pradesh and Rajasthan
Ground nut	Bihar, Haryana, Jharkhand, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh, parts of Gujarat
Pigeon pea	Karnataka, Telangana, Andhra Pradesh and Odisha
Chick pea	Andhra Pradesh, Gujarat and Telangana
Potato	Bihar, Chhattisgarh, Gujarat, Jharkhand, Telangana, Uttar Pradesh and West Bengal
Cotton	Haryana and Punjab

However, as mentioned above, climate change is projected to benefit some crops in a few regions and the magnitude of positive impacts varies across regions. For instance, wheat in states like Punjab, Haryana and Rajasthan are projected to gain in yield despite climate change in RCP 4.5 scenario. Similarly, Kharif season irrigated rice is projected to gain in parts of Punjab, Haryana and Uttar Pradesh; while in Orissa, rice yields may be maintained in future climates even with the current level of management. In this state, the current yield levels are very low. Like-wise, Kharif sorghum in parts of Madhya Pradesh, Rajasthan and Telangana may gain more than the other states. Kharif season pearl millet is projected to gain despite climate change even with current management in parts of Karnataka, Madhya Pradesh, Tamil Nadu and Telangana. In the case of mustard, Rajasthan may maintain the yield levels despite climate change till 2050 scenario. Ground nut yields are projected to increase in parts of Andhra Pradesh, Karnataka, Tamil Nadu and Telangana. Soybean yield in parts of Karnataka, Maharashtra and Telangana is projected to gain. Climate change is projected to increase the chickpea and cotton yield in most of the states, with different magnitudes while, pigeon pea yield is projected to gain in Gujarat, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh. Potato yields are projected to increase in Punjab, Haryana and Assam. However, all these gains are generally marginal and need technological and investment backup to harness significant gains.

4.3.4 Projected adaptation gains in climate change scenarios

Adaptation gains in cereal and millet crops

The location-specific adaptation interventions such as adjusting sowing time, suitable variety with terminal heat tolerance, nutrient and irrigation management can significantly improve the wheat yield up to almost 60% in 2020 scenario, up to 45% in 2050 scenario and up to 35% in 2080 scenario. For rice these adaptation gains are projected up to almost 38% in 2020 and 2050 scenarios and up to 28% in 2080 scenario (Figure 4.20). Maintaining the crop duration as that of current varieties in North West India, and short duration and heat tolerant varieties in central India will be key for yield improvement in wheat in future climates. For rice, growing short-duration varieties with improved nutrient and water management can enhance productivity but with significant inter-annual and spatial variations. Further, the strategy of growing shorter duration varieties than the current ones in Northwest India may not prove beneficial even in the near future.

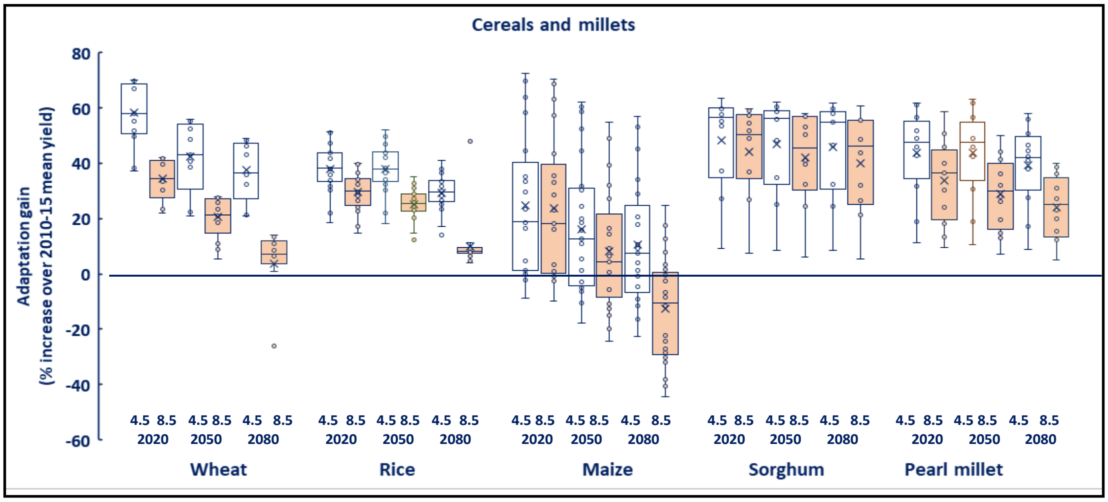


Figure 4.20: Adaptation gains in wheat, rice, maize, sorghum and pearl millet yield in India in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

In rainfed rice, growing short-duration stress-tolerant high-yielding varieties can improve the yield by up to 28% in rainfed rice regions till 2050. But to sustain rainfed rice yield further, heat and water-stress tolerant varieties with high yield may need to be developed. In addition, managing the water sources at the field level will become crucial.

In the case of Kharif maize, location-specific adaptation interventions can significantly improve yield by up to 20% in 2020 and 2050 and up to 7% by 2080. Location-specific adaptation interventions can significantly improve the sorghum yield by up to 57% in 2020, 2050, and 2080 inspite of climate change equivalent of RCP 4.5. Location-specific adaptation interventions can significantly improve Kharif pearl millet yield by up to 47% in 2020, 2050, and 2080.

Adaptation gains in pulse and oil seed crops

Location-specific adaptation interventions can significantly improve mustard yield by up to 40% in 2020, up to 28% in 2050 and 2080 at the all-India level, while ground nut yields are projected to gain by up to 48% in 2020 and up to 35% in 2050 and 2080 under both RCPs. Location-specific adaptation interventions can significantly harness the positive impacts of climate change and improve soybean yield by up to 38% in 2020 and 2050 and by up to 30% in 2080 despite climate change. Similarly, chickpea yield is projected to improve by up to 40% in 2020, 32% in 2050 and 27% in 2080 and pigeon pea yield is projected to improve by up to 53% in 2020, 48% in 2050 and 37% in 2080 at all India level with location-specific adaptations despite climate change (Figure 4.21). The adaptation options considered included adjusting sowing time, growing short-duration varieties, providing lifesaving irrigation, and growing crops in raised beds to minimize the losses due to climate extremes. As the suitable period for mustard cultivation may reduce in the future, short-duration (<130 days) cultivars with a 63 % pod-filling period will become more adaptable (Kumar et al., 2014).

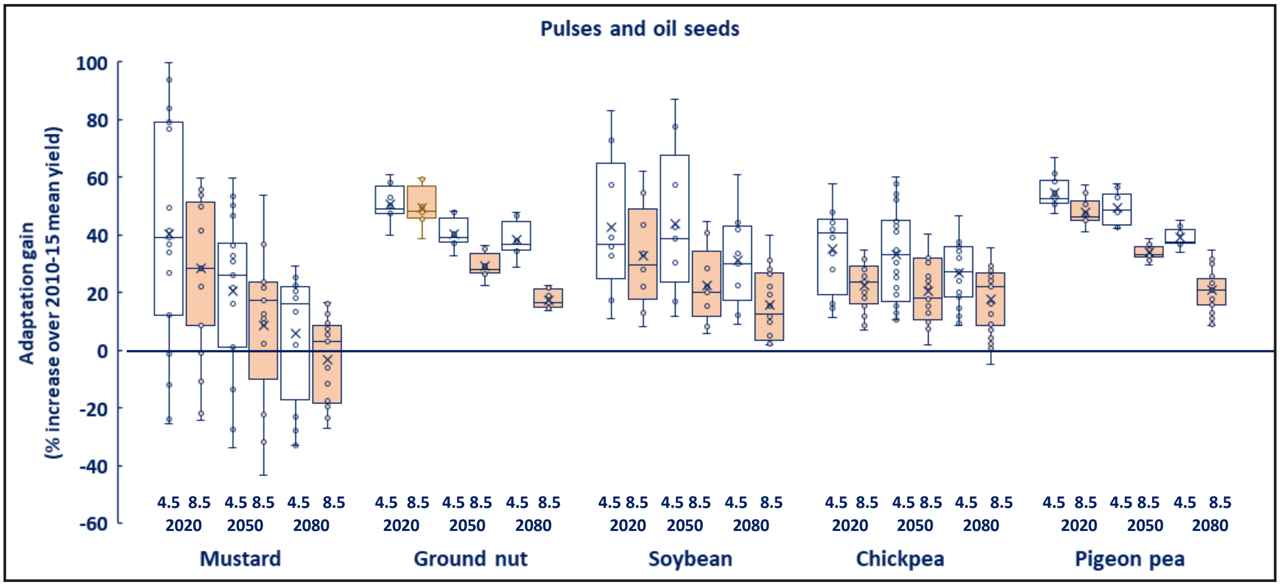


Figure 4.21: Adaptation gains in pulses and oilseeds yield in India in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069), and 2080 (2070-2099).

Adaptation gains in potato and cotton

Location-specific adaptation interventions can improve the all-India potato yield in the range of 12-16% under climate change scenarios of 2020, 2050, and 2080. However, significant spatial variations in adaptation gains are projected. In the case of cotton, yield in Punjab and Haryana is projected to reduce significantly, and location-specific adaptation interventions can improve the all-India cotton yield in the range of 16-24% in climate scenarios of 2020, 2050, and 2080 (Figure 4.22). For potato, a change in planting time is identified as the single most important adaptation option which may lead to significant yield gains when combined with improved variety and/or application of additional nitrogen.

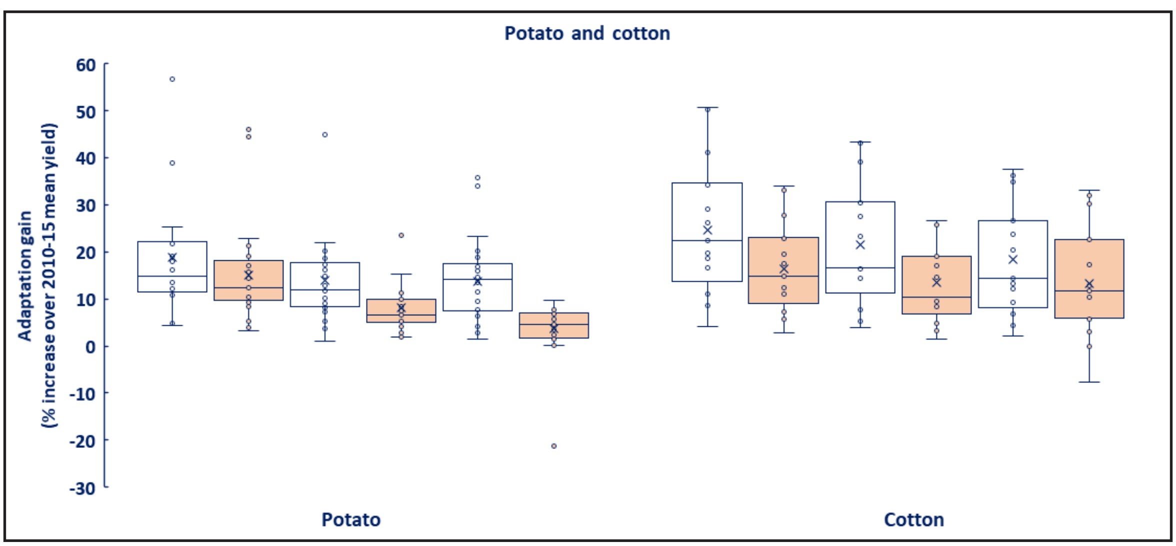


Figure 4.22: Adaptation gains in potato and cotton yield in India in RCP 4.5 and RCP 8.5 scenarios of 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

4.3.5 Adaptation strategies, technologies and results from adaptation experiments and evidence

Several strategies of adaptation are being developed based on approaches that include i) vulnerability assessment ii) resilience targeting and iii) sustainable development. While developing the adaptation strategy, either a 'top-down' or a 'bottom-up' approach and/or a combination of both are used. The bottom-up approach includes several location-specific and locally preferred interventions. However, a combination of both is preferable where the convergence of local needs with national goals is achieved through several mechanisms to i) reduce vulnerability, ii) achieve resilience and iii) sustain food production systems.

Since climate change impacts are location and situation-specific and adaptation options need to be modified to suit agroecological conditions, socioeconomic contexts, and farmers' priorities (Rosenstock et al., 2015). So, the adaptation options and resultant gains will also have significant spatial and temporal variations. Thus, an approach that contextualizes adaptation options becomes important (Kumar et al., 2014). This approach involves participatory adaptation planning. Under this, firstly the needs, technologies, and aspirations of the farming community as desired by them are listed. Then the best technological alternatives to increase productivity and optimize input use in a sustainable manner are identified using experimental or simulation approaches in current and future climate scenarios. The shortlisted technological options are once again matched with the farmers' needs/ aspirations before they are implemented in their field for performance testing in pursuit of developing 'Climate Resilient Agriculture'. Thereafter, the scope for out-scaling and up-scaling of successful technologies is analyzed.

Though several adaptation technologies are already available to cope with the current climatic risks, many experiments are still being undertaken to find more alternate solutions that are low cost, easy to adopt, and more sustainable in several ICAR Institutes and State Agricultural Universities (SAUs) to meet the challenges of climate change. Broadly these include genotypic improvement, alternate cropping systems and crop diversification, improved agronomy, improved natural resource management, and extension efforts to take technologies to farmers at a faster pace.

4.3.5.1 Genetic improvement-climate resilient varieties

Due to the concerted efforts in crop improvement programme at various ICAR Institutes and SAUs, several stress tolerant varieties have been identified and popularized among the farming community. More than one thousand such varieties of cereals, millets, pulses, oilseeds, forage, fruit and vegetable crops as well as livestock breeds and fish breeds are identified/developed (Figure 4.23). These are tolerant to heat, drought, water logging/flood/submergence, salinity stress tolerant. Some of them are also short duration varieties, while some are suitable for delayed sowing in late onset of monsoon conditions. In addition, several indigenous heat stress tolerant breeds of livestock and fish species are identified.

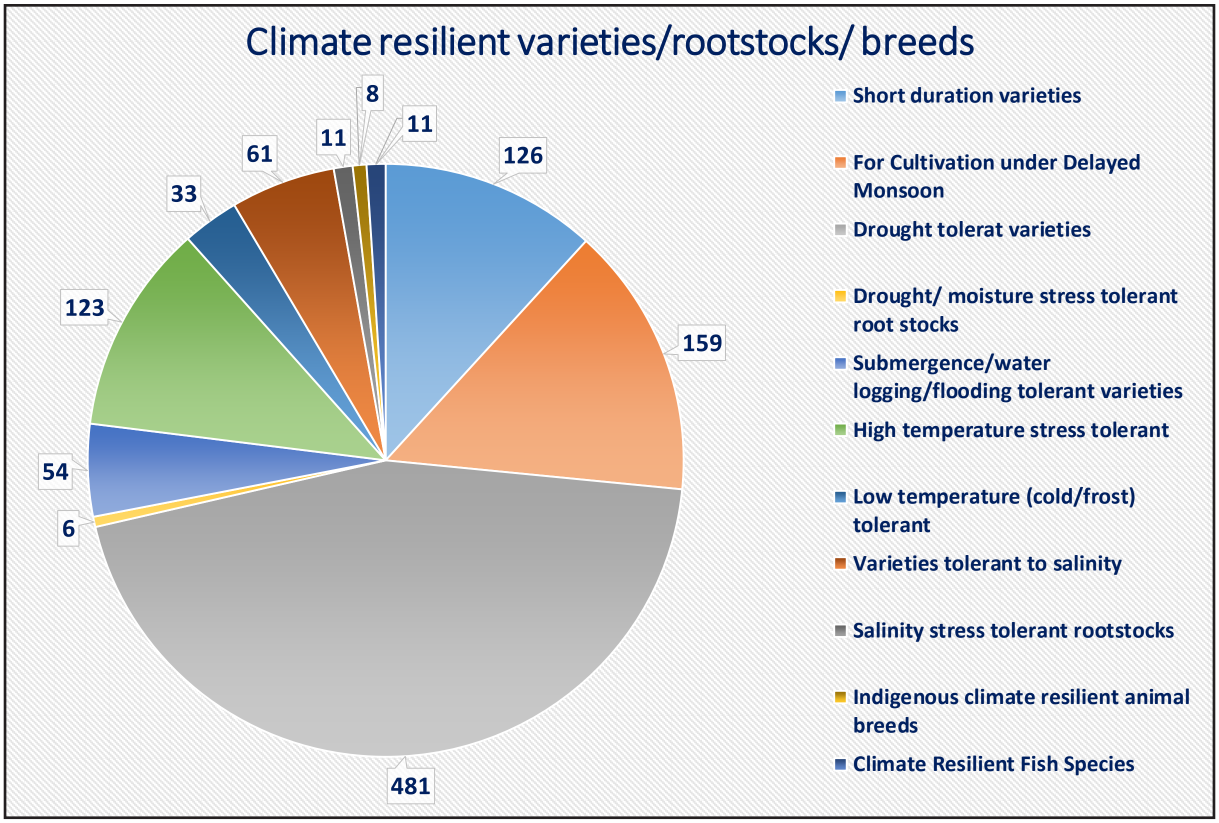


Figure 4.23: Summary of climate resilient varieties/ root stocks of field crops, vegetables, fruits, and breeds of livestock and fish (Source: Maheshwari et al., 2019 and Boraiah et al., 2021).

In addition to these, a number of high-yielding varieties are being released for several crops almost every year. Seventy-one bio-fortified varieties of 16 crops a released. Recently, in 2021 ICAR released 21 more climate-resilient and bio-fortified special varieties of rice, maize, sorghum, millets, soybean, peas, pigeon pea, buckwheat, and quinoa crops making it to 92 to strengthen support in meeting the Sustainable Development Goals 2 (Zero Hunger) and SDG 3 (Good Health and Well-being). Fodder and feed availability for livestock is being improved by developing multi-cut fodder sorghum, dual-purpose pearl millet varieties, etc. In addition, the short-duration varieties are found to be more suitable for delayed monsoon/deficit rainfall ex rice, finger millet, etc as they provide an opportunity to shift the sowing time (late sowing) in the event of late onset of rainfall.

4.3.5.2 Agronomic and natural resource management

Broadly these include alternate cropping systems and crop diversification, improved agronomy, and improved natural resource management. Numerous experiments are being conducted to develop new agronomic practices, crop diversification options, alternate cropping systems, integrated farming systems, agroforestry-based technologies, soil, and water conservation technologies, technologies for enhanced nutrient and water use efficiency, pest and disease management, value addition and farm income augmentation. A summary of some of these technologies (indicative, not exhaustive) is listed in the Table 4.4 for quick comprehension.

Table 4.4: Indicative list of crop and natural resource management technologies

Type of intervention	Description (indicative)	Relevance to climatic stress and livelihood security
Crop diversification	Alternate cropping systems Short duration vegetable crops	• Improved water use efficiency in system, utilize crops that can withstand higher temperatures; increased income/ diversification • To fit in cropping sequence window; increased income
Cropping pattern	Fallow-early mustard-wheat/ vegetables	Minimizes loss due to erratic and delayed monsoon
Crop-management	• Improved seeds, seed replacement rate and timely sowing • Recommended sowing rate • Zero-till sowing where feasible • Crop residue mulching and incorporation, avoiding burning • Timely and recommended irrigation • Recommended fertilizers • Pest management • Shade nets	• Reduced in-breeding loss in yield • Avoid terminal heat stress in wheat; avoid water stress in monsoon crops • Avoid inter-plant competition and lodging due to heavy winds • Reduces the soil carbon loss • Soil moisture conservation, increased soil organic carbon. Application of PUSA decomposer hastens the paddy straw decomposition within three weeks. Reduced burning of crop residues to reduce pollution load in atmosphere • Improve water use efficiency and reduce diesel/ electricity for pumping water; reduce GHG emissions • Avoid excess fertilizer application; reduce GHG emissions • Pheromone traps – eco-friendly, reduce pesticide load and GHG emission • Disease free nursery of horticultural crops for main- and off-season; improved income
Water harvesting & saving technologies	• Laser levelling • Sprinkler • Rain gun • Drip irrigation • Underground pipeline for water conveyance • Mulching • Farm ponds	• Reduced water loss; increased water use efficiency by over 50% by saving 450-650 m^3 water per ha; 20% additional area under irrigation with same amount of water; reduced emission of 65-120 kg CO_2/ha; • Soil moisture conserved • Life-saving irrigation, improved water use efficiency
Horticultural and fruit plants	Back-yard horticultural and fruit plants such as guava, sapota, pomegranate, papaya, etc.	Carbon sequestration; nutritional security

Type of intervention	Description (indicative)	Relevance to climatic stress and livelihood security
Agroforestry	Location specific agroforestry systems	Micro-climate modification, carbon sequestration, income diversification
Livestock management	• Increased availability of fodder and feed • Regular health check-up; immunization; mineral nutrient mix supplement • Shelter management	• Improved fodder led to increase in milk yield (1.5-2 L/animal/day) • Reduced calf mortality; improved the health of livestock; increased climatic risk coping ability due to availability of a greater number of male calves for distress or other-wise selling, improved income insurance in stress conditions • To minimize the heat stress on animals; minimize extreme rain/hail storm effects
Value addition	• Wheat flour making • Grading of tomato • Pickle making • Dhal-dhalia making, etc	Improved income for farm produce; self-employment
Secondary skill development	Tailoring, mushroom culture, poultry, etc.	Income augmentation; self-employment
Information and weather-forewarning	Mobile based information system on weather, crop management, market and training	Weather-based crop management; information on markets, training, etc.; enabled farmers with information on climatic risk management.
Seed villages/ seed banks	Mobile seed processing units Community seed banks	Increased income to seed-selling farmers; rapid improvement in seed replacement rate, income enhancement
Village resource centres	• Information sharing, dissemination and custom hiring machinery • Small farm mechanization through custom hiring centres	Availability and application of agricultural machinery, improved cultivation, drudgery reduction
Rice crop management	• Community paddy nursery • Direct seeded rice • Drum seeding of rice • Drought tolerant cultivars • Flood and water-stagnation tolerant varieties ex Swrna-sub1, etc.	• Contingency measure for delayed planting • Reduction in GHG emission by about 40%, improved water use efficiency • Water saving and timeliness in planting • Deficit rainfall situations • Water stagnation in flood-prone areas
Village ponds/ community tanks/ ponds	• Renovation, desilting, deepening, bunding, etc • Recharge of wells	Rain water harvesting, increased ground water table, prolonged availability of water

Type of intervention	Description (indicative)	Relevance to climatic stress and livelihood security
Reclaiming cultivable wastelands	Ecological restoration measures	Improved yield and resilience
Captive rearing of fish seed	In flood-prone areas	Reduction of loss due to floods, income augmentation/ diversification.
Cage cultivation	For cultivation of marine fish in coastal areas	Reduces the uncertainty due to shift in potential fishing zones, reduced deep see exploration, reduces the GHG emissions due to deep sea boating
Directed marine fishing	mKRISHI FISHERIES is a mobile app developed in PPP mode which is used for alerting the marine fisherfolk regarding potential fishing zones for directed navigation.	Reduced deep see exploration, reduces the GHG emissions due to less time spent for deep sea boating
Poultry management	Shed management	To reduce cold stress/ heat stress related mortality
Land shaping in cyclone and flood prone coastal agro-ecosystems	Land shaping	In land shaping-20% model, the excavated soil is used to convert the land from lowland to medium land and strengthen the embankments around the field and around the newly developed water harvesting pond, which is used for fish culture, to augment the income
Solar power-based water pumps	Solar-power based water pumps help the farmers to provide irrigation in areas not having access to electricity	This technology is useful in making farmer independent of the electricity supply. But enough care must be taken to ensure judicious use of water to avoid over-exploitation of ground water. This also avoids the GHG emissions by replacing diesel-based water pumps
Contingency plans	District level contingency plans	Helping in case delayed onset of monsoon, dry spells, etc.
Weather forecast based forewarning	Weather forecasts Weather-based pest forewarning Weather based mobile apps	Weather forecasts being increasingly used for scheduling irrigation/ other farm operations Pest forewarning-based management of pests/ preventive actions The farmers are using the mobile-based apps for seeking information on various aspects of farming, markets, inputs etc.

Source: NICRA Annual reports 2012-2020; Kumar et al., 2014; Rao et al., 2016

Several technologies that have shown promise to substantially increase the yields of many crops may also contribute to more GHG emissions. Such technologies indicate the need for an adequate share of the carbon budget for developing countries, even for adaptation to climate change. Though, they may not be completely sufficient to overcome the emerging new and challenging climatic extreme events at a large scale can contribute significantly to reducing the losses to productivity and income. However, more innovations for developing adaptation technologies need to be continued to find technologies that are resource-conserving, productivity-enhancing and sustainable while meeting the challenges of extreme climatic events. In addition, it is important to find a combination of technologies that have synergistic effects and are location specific.

4.3.5.3 Simple, ready-to-adopt adaptation options

Many current management options may become unsuitable in future climates to sustain crop yields. However, simple, low-cost, and easy-to-adopt technologies such as improved high-yielding varieties, line sowing, adjustment of sowing time, organic matter addition, and nitrogen and irrigation management can significantly improve the yield despite the challenges of climatic stresses. The raised bed cultivation of wheat has proved to be beneficial in farmers' fields to overcome heavy rainfall events coinciding grain development period and maturation. Short-duration varieties of crops without yield penalties for many crops including rice are becoming important. As maize is very sensitive to water stagnation, ridge sowing of maize has also proved to be beneficial to prevent the heavy rainfall events led water stagnation resulting in crop loss. Heat and water stress-tolerant hybrids will be a very important part of the synchronizing tasseling and the active silking period becomes an important adaptation strategy. Providing proper drainage of water and assuring irrigation depending on crop water requirements are crucial water management options. Ridge sowing of sorghum heat and water stress-tolerant hybrids will be very important for the adaptation strategy for sorghum and pearl millet. For mustard, apart from heat and water-stress-tolerant varieties, varieties of 120-day crop duration with about 63% pod filling period will be more suitable in changing climates. For soybean, heat and water stress tolerant short duration varieties, sowing on ridges and providing spilt application of nitrogen (at sowing and about 25 days after sowing) are some of the adaptation strategies. Heat and water stress tolerant varieties (for ground nut, soybean and cotton), heat and water stress, and frost tolerant varieties (for chickpea, potato), and sowing on ridges are some of the adaptation strategies. For cotton, adopting pest-tolerant varieties and water-stress tolerant varieties are some of the adaptation strategies.

4.3.5.4 Technological interventions for enhancing resilience of framers to climatic stresses

Since the modeling studies have indicated the significant impact of climate change on several crops, regions with differential magnitude and direction and also the gains due to adaptation, it is imperative to implement available technologies and develop new, low-cost, easy-to-adopt green technologies to minimize the negative impacts and maximizing the positive gains. Adaptation in agriculture is multi-dimensional that includes the farmers, Government Departments, Research Organizations, Non-Governmental Organisations (NGOs), Private Companies, Markets, and State and National Governments, apart from the Global trends. All of these play a major role in determining the overall agricultural performance. At the farmer's level, autonomous adaptation becomes challenging due to several factors like attitudinal disposition, resource endowments, services, etc. Under National Innovations in Climate Resilient Agriculture Project, situation-specific participatory adaptation planning is followed to develop '*Climate Resilient Agriculture*' in '*Climate Resilient Villages*'. Simulation studies have indicated that significant improvement in the yield of several crops can be achieved by adopting simple and low-cost adaptation technologies like adjusting sowing time, change in variety, and improved water and nitrogen management with national-level out-scaling.

4.3.5.5 Adaptation gain evidence from farmers' fields for livelihood and food security and resilience to climate change

In India, considerable evidence of farmers' adaptation to climatic risks and climate change has begun to emerge. Under National Network Project on Climate Change (2004-2013), National Initiative on Climate Change (2011-2015), National Innovations in Climate Resilient Agriculture (2015 onwards), World Bank-GEF project (2009-2014), and Department of Science & Technology-Major Research and Development Programmes (DST-MRDP) (2018 onwards) project, and several other projects, adaptation technologies are being demonstrated in farmers' fields for climate risk minimization. Under these projects, the 'Climate Resilient Villages (CRVs)' are being developed (NICRA Reports, 2011-2016; 2017-2020; Kumar et al., 2014; Rao et al., 2016). The concept of CRVs and the details of adaptation options and their performance in various agroecosystems in different parts of India are extensively dealt in Srivasa Rao et al., 2016. Apart from these, the Climate Change, Agriculture Food Security (CCAFS) programme also has contributed to developing CSVs (CCAFS reports at *https://ccafs.cgiar.org/flagships/climate-smart-technologies-and-practices).* These concepts use the basic approach of managing the resources and knowledge for reducing the climatic risks to agriculture and farm income.

The adaptation interventions in farmers' fields are based on the analysis of past and projected climatic risks and resources analysis. The interventions have been based on crop varieties, crops, agronomical management, and the use of weather information apart from income augmentation activities for livelihood security (Kumar et al., 2014, Rao et al., 2016, CCAFS reports). In addition, the convergence of line departments (such as agriculture, horticulture, animal husbandry, etc), financing institutions and knowledge hubs (ex. KVKs) as well as capacity building plays an important role in developing climate-resilient villages. Adaptation interventions that include conservation agricultural practices indicate huge potential in improving the yields from the current level and averting climatic risks. The summary of results indicates the availability of technologies and their potential in minimizing climatic risks in different agricultural systems in various parts of India (Table 4.5).

Table 4.5: Summary of results from adaptation interventions and their potential in minimizing climatic risks in different agricultural systems in various parts of India. The information is synthesized from (NICRA Annual reports 2012-2020; Bandyopadhyay et al., 2013; Kumar et al., 2014; Rao et al., 2016)

Type of stress	Adaptation options and observed improvements in yield			
	Crop	**Adaptation option**	**Improvement in yield over farmers practice (%)**	**Details (indicative)**
Drought stress	Rice Wheat Maize Mustard Ground nut Soybean Chick pea Pigeon pea Green gram Black gram Cotton	Tolerant / improved varieties and increase in seed replacement rate	20-35 20-28 25-41 8-25 5-10 22-40 25-35 30-40 15-25 25-30 5-10	Short duration drought tolerant varieties
Submergence <1m for <10 days	Rice	Tolerant varieties	30-35	Swarna-sub 1, MTU-1010, 1100, 1064, 1140, 7029, BPT-5204; Dehangi, Gitsh, Sahasrang
Submergence >1m for >10 days	Rice	Tolerant varieties	20-25	Jalashree, Rajashree, Karjat-2, GAR-13 Lalat,
Drought prone areas with areas <750mm	Intercrops	Altering the intercrops	4-47	Soybean+Pigeon pea Pigeon pea+pearl millet/ sunflower Rabi sorghum+safflower/ chickpea Maize + balckgram
Drought prone areas with areas >750mm	Intercrops	Altering the intercrops	11->50	Groundnut + pigeon pea/ castor Maize+ pigeon pea/ cow pea/ black gram/ green gram Pigeon pea+ black gram/sorghum/ maize/soybean/okra Soybean+ pigeon pea Ground nut + castor Finger millet +pigeon pea Cotton+ Pigeon pea
Regions with <500 mm rainfall	Different crops	In situ water conservation	11-61	Bunding and levelling Conservation furrow Land levelling

Type of stress	Adaptation options and observed improvements in yield			
Regions with more than 500 mm rainfall	Different crops	In situ water conservation	8->50	Compartmental bunding, Mulching, Conservation furrows Trench cum bunding, Bunding, Land levelling, Contour sowing Ridge and furrow, summer ploughing, Set furrows
Regions with <500 mm rainfall	Different crops	Water harvesting and irrigation	5->50	Farm ponds, Furrow, Sprinkler, Drip, Rain-gun
	Different crops	Planting methods	4-43	Broad-bed and furrow, Raised bed
	Wheat	Tillage method	23-34	Zero tillage
Drought prone areas	Different crops	Improved crop management	12-15 25% & 30% reduction in CO_2 emission / ha & water saving respectively	Recommended seed rate, sowing method, dose and scheduling fertilizer and irrigation
	Different crops	Water management	~ 40% water saving, 25% irrigation-time saving and 25% reduction in CO_2 gas emission; Water Users groups	Laser levelling, underground pipeline, sprinkler/ rain gun, drip irrigation; open-well deepening, de-silting and renovation of community ponds

4.3.6 Eco-friendly adaptation: Indigenous Technological Knowledge for Sustainable Adaptation Strategies

Traditional and local knowledge systems are a way of life in India. This is not only the case for the tribal and forest-dwelling communities, but also across the country. Different communities have adopted a myriad of practices and systems, the core of which is ingrained in sustainability. A review of the available and documented Indigenous Technical Knowledge (ITK) on agricultural activities was undertaken through a Mission Mode Project on Collection, Documentation and Validation of Indigenous Technical Knowledge. A total of 4880 ITKs are categorized under 24 technological aspects (Figure 4.24). The majority of these ITKs fall under the veterinary and animal husbandry aspects followed by those for pest and disease management. Out of these, 111 ITKs have been validated by the ICAR institutes and State Agriculture Universities (SAUs). These ITKS fall under i) Rain Water Management ii) Soil and Water Management iii) Pest and Disease Management iv) Horticultural Crops, v) Farm Implements, vi) Fishery, and vii) Veterinary Science and Animal Husbandry (Figure 4.25). Some of the 37 validated ITKs are directly related to climatic risk management aspects including rainwater management in arid and semi-arid regions, rainwater measurement using an indigenous rain gauge, and rainwater management in mountainous landscapes. In addition, the ITKS for soil and water conservation in hills along with several other ITKS for animal management, pest management, and weather forecast indicators form a strong repository for testing and their implementation in relevant areas as sustainable approaches to address the challenges of climatic risks in the farmers' fields.

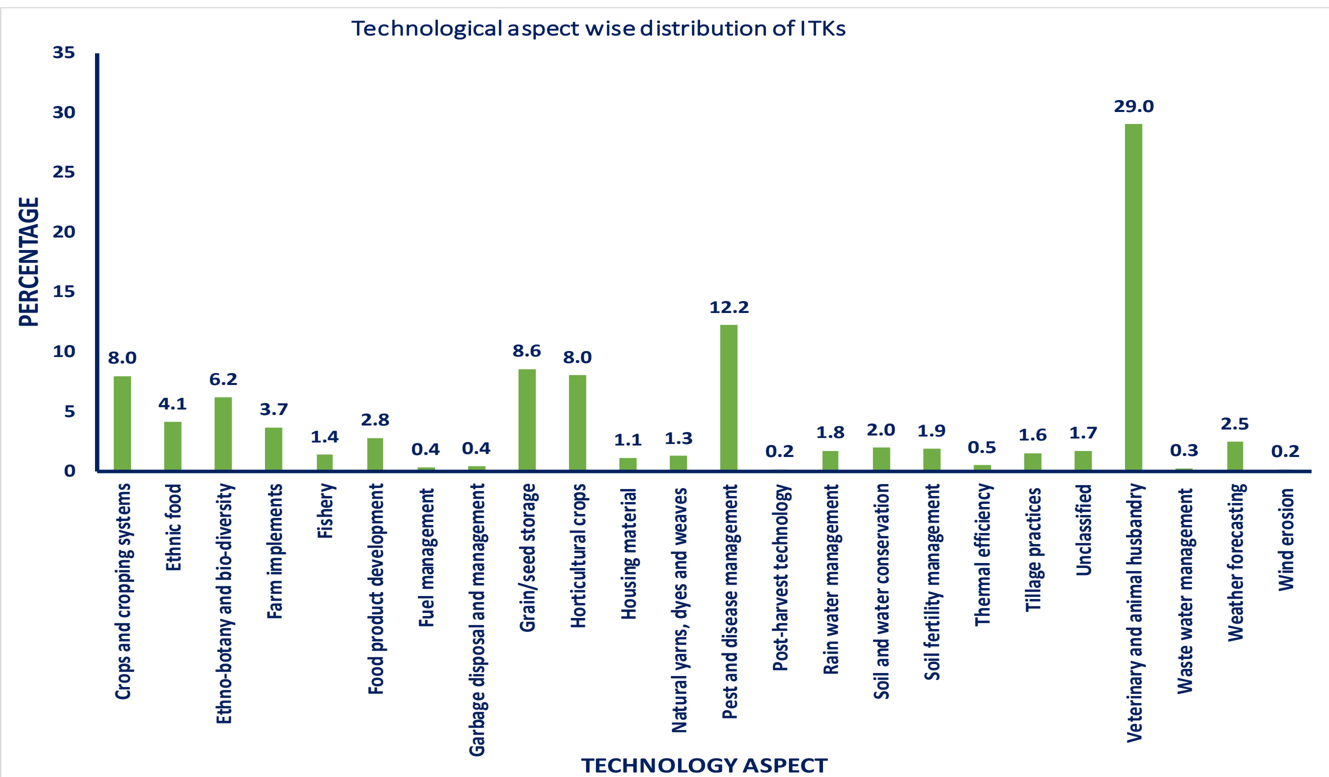


Figure 4.24: The distribution of ITKs based on the technology aspect

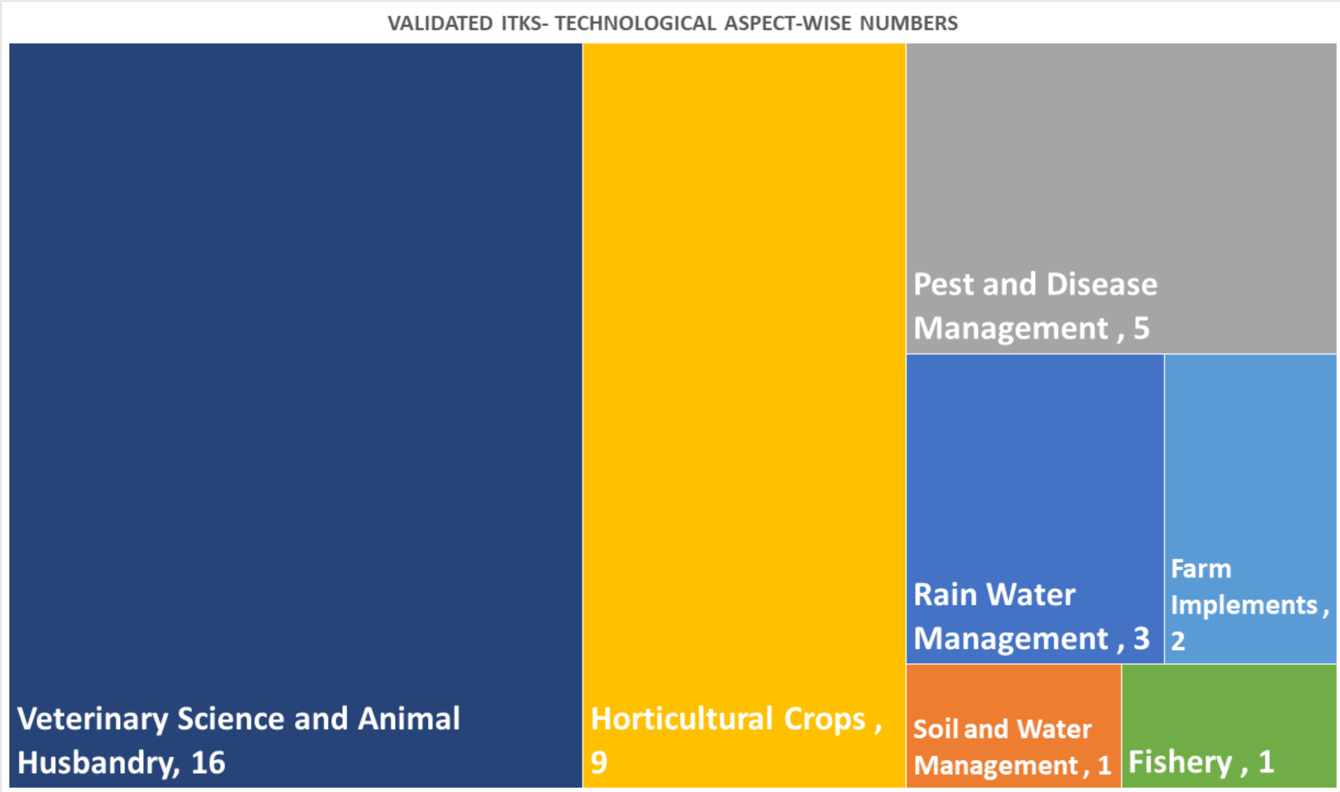


Figure 4.25: The distribution and number of validated ITKs based on the technology aspect.

4.3.7 Observed and estimated losses to agricultural productivity due to climatic stresses in the past

Analysis of data on summer monsoon precipitation and food grain production in Kharif and Rabi seasons in India during 1966– 2010 indicated that negative anomalies of seasonal precipitation and the number of rainy days is highly correlated with negative anomalies of Kharif and Rabi food grain yield (Prasanna, 2014). An analysis of all India Kharif and Rabi seasonal rainfall and mean maximum and minimum temperatures in reference to the productivity of major crops from 1951-2017 while discounting the technology effects, indicated that rice productivity change in successive years is positively correlated to normalized change in Kharif rainfall during 1951-2017 period. But, it negatively correlated to normalized change in Kharif mean maximum temperature. Analysis of wheat indicated that an increase in Rabi rainfall and minimum temperatures negatively affected yield. An increase in Kharif rainfall positively influenced maize, sorghum, pearl millet, pigeon pea, groundnut, soybean and cotton yields, while the increase in temperatures have a negative impact on maize, pearl millet, groundnut, soybean and cotton yields and had positive impacts on sorghum yields. The coincidence of heavy rainfall during pod maturation significantly affected soybean and many other pulse crops in parts of Madhya Pradesh, and rice in coastal Andhra Pradesh. Kharif rainfall has a marginal positive influence on the yield of chickpea and mustard since they were sown immediately after the Kharif rains to exploit the benefits of residual moisture. Another study also indicated changes in temperature and rainfall in the past (1969-2005) impacted the crop yields in India (Birthal et al., 2014). Temperature extremes coinciding with the flowering and grain filling period are affecting the wheat yield in Northern parts of India (Lobell et al. 2012; Duncan et al. 2015). An analysis of the sensitivity of rice yield in India to climatic conditions during 1969–2007 indicated that high daytime temperatures have a larger negative impact on rice yield as compared to higher night-time temperatures. This resulted in an estimated annual average loss of rice yield to the tune of 4.4 Mt/year (Kumar and Pattanayak, 2014). Internal variation in summer (JJAS) rainfall and intra-seasonal rainfall distribution influence crop production during monsoon as well as in Rabi season. The Economic Survey (2017-2018) by the Government of India estimated a significantly higher loss in farm revenue due to extreme rainfall events during the monsoon season. Whereas, the losses due to extreme temperature events are almost similar in monsoon and winter season crops. In addition, India in the past 20 years has witnessed incidences of several invasive insect pests such as Asian fruit fly, American tomato moth, blackfly, desert locust, eriophyid mite, fall armyworm, mango fruit borer, red banded mango fruit borer, rugose spiralling whitefly, winged plant bug, etc. (Chakravarthy et al., 2013; Vennila et al., 2018). Between 1964 and 2020, 19 events of locust plagues that have occurred in India. These can be directly or indirectly attributed to climate change.

Recent yield losses due to climatic risks

The frequency of climatic risks has been increasing over the years, causing severe yield and income loss to the farming community. In 2018 unseasonal rains in February affected crops in large areas. A powerful storm with a damaging hailstorm hit parts of Central and Southern India destroying more than 1.25 lakh hectares of crops, particularly in parts of Maharashtra and Madhya Pradesh apart from killing several people. The unseasonal rains also affected coffee in Karnataka. The country has seen widespread drought every year since 2015, except for 2017. Heavy monsoon rains in 2018, 2019, and 2020, were the highest in 100 years in Kerala, and resulting floods caused widespread devastation. Between 1953 and 2017, the overall damage to crops is reportedly estimated to be over 1.1 lakh crore and over 6 million cattle dead. Such numerous examples exist. In every season some portion of farmers get affected despite the increase in production and productivity at the macro-level, warranting more research to understand impacts, develop adaptation technologies and strategies, and their deployment to minimize the climatic risks. In addition, rainfall intensity, prolonged active/break episodes, floods, and droughts have a negative relationship with food grain yield. Further, extreme weather events such as floods, droughts, cyclones, cold and heat waves have been adversely affecting agricultural productivity leading to increased risk of food insecurity. In 2020 desert locust outbreak affected cumin, rapeseed and mustard, particularly in Rajasthan and Gujarat, possibly due to prolonged monsoon. Fall armyworm affected maize, paddy, and sugarcane crops in Karnataka, western Maharashtra Gujarat and Eastern states in 2018 and 2019.

Estimated losses due to climatic change: past studies

At the aggregate national level, climate change impacts on agriculture are likely to be adverse. Studies have estimated total agricultural net revenue losses to the tune of 8 – 12% for India, for a 2°C rise in temperature and 7% increase in precipitation (Kumar and Parikh, 2001; Sanghi and Mendelsohn, 2008). While some regions or sections of the agricultural population could benefit, others may lose. Between 1953 and 1982, the loss suffered due to damaged crop was the biggest contributor to India's flood-related losses. But from the 1980s onwards, the share of loss due to damaged crop was overtaken by the loss due to damages to public property.

An analysis of 10 previous studies shows that over short-, medium- and long -time scales, economic impacts are projected to be negative at an aggregated, all-India level (Figure 4.26). Further, over time, economic impacts are projected to be more severely pronounced. Over the long-run time scale (i.e., by the end of the 21st century), most of these studies project various economic outcomes to be lower by 25%. The median economic impact, in the long run, is projected to be approximately 12.5%.

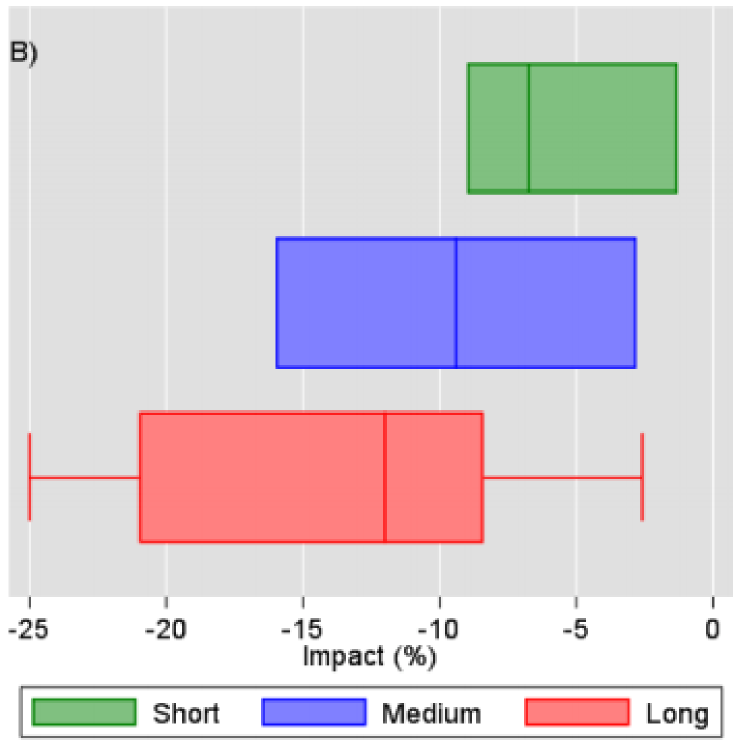


Figure 4.26: Economic impact assessment studies on Indian agriculture in future over the short-, medium- and the long-run time scale. (Compilation from 10 scientific and research studies).

Agriculture production loss related economic costs and crop prices across Indian states due to climate change

Agriculture is the main source of livelihood for 58% of the population of India and under no climate change scenario this rate will be steady (ESI, 2018-19). Indian Agriculture is beset with a host of challenges for the future. Continual subdivision of land holdings, increasing costs of agriculture, stagnant farm gate prices, low capital formation in agriculture, non-willingness of youngsters to take up agriculture and the threat from climate change are the major challenges. The focus of the government has shifted to dry lands from irrigated lands and these have given better returns from the (quote the year). Irrigation has made major advances and now more than 90% of wheat and 50% of paddy is irrigated and almost 20% of pulses are irrigated as well. As climate change is projected to negatively impact the productivity of Indian agriculture in many areas with a likely increase in adaptation costs, the economic impacts of climate change on Indian agriculture are analyzed.

Adaptation costs for farmers, limits and limitations

Adaptation is a necessary response to deal with climate change in agriculture and other sectors such as infrastructure, urban planning, and public health (Wamsler, 2015). Indian farmers have been adapting to climatic risks. Though several efforts have been going on to test the adaptation options at the farm level, only a very few studies have analyzed the cost of adaptation at the farm and at the household level. A detailed household-level analysis in a village indicated that the cost of adaptation and gains vary with the type of agriculture and farm size (Kumar et al., 2014). In this study, adaptation options that included crops (such as improved varieties, crop diversification, crop water, pest management), farm (includes livestock management), off-farm (value additions, etc), non-farm (income augmentation) and knowledge (weather forecast) have improved resilience of crop, farm, farmer and household to climatic risks and increased the livelihood security. The analysis indicated that income from agriculture alone could not support the small and marginal farm families. However, adaptation to climatic risks can improve income sustainability. As mentioned in earlier sections, crop diversification, improved varieties, and growing of horticultural crops are found to increase profits from agriculture despite small land holdings. Growing one-grain crop and at least two vegetable crops during a year can be highly profitable. Small-holder and marginal farmers incur adaptation costs, but it is not always the case particularly for middle- and large-farm holdings. Middle- and large-holding farmers may have to rationalize their farm expenses. Science and technology-based crop management can rationalize the costs of adaptation to climatic risks (Kumar et al., 2014). The study further shows that though the additional cost is not imperative for adaptation, the cost of adaptation is not directly proportional to gains across different strata of farmers (Figure 4.27).

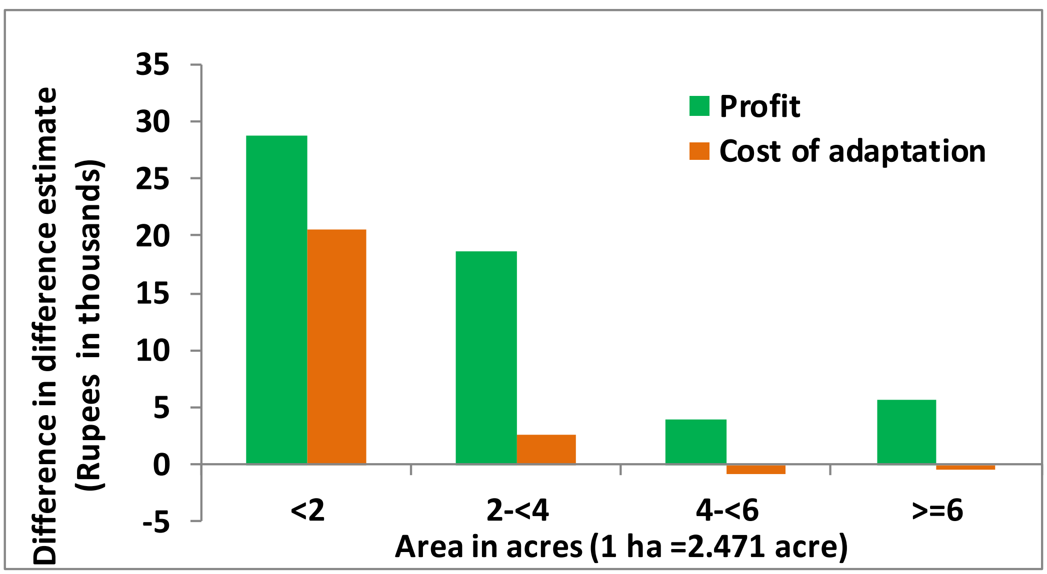


Figure 4.27: Adaptation costs and profits in different strata of farmers

Source: Kumar et al., 2016

Analysis of livelihoods due to socioeconomic and other environmental stresses in the current climate and its likely exacerbation due to climate change for the short, medium and long-term were conducted (Kumar et al., 2014; Kumar et al., 2016). Analysis indicated that the average surplus income per person per acre in a year decreased as the land holding size increased, while the reverse trend was observed when the income is expressed per capita in a year (Figure 4.28). Adaptation to climatic stresses could improve the income of farmers with a land holding of <0.8 ha, supporting their family expenses. However, the agriculture income alone could not meet the family expenses of non-adapted farmers. These families had to depend on non-farm income for sustenance. Though these results are specific to the situation where the joint family culture prevails, they indicate the significance of non-agricultural income in sustaining the family expenses, particularly that of small and marginal farmers. The joint families also have abundant family members to manage bigger farms.

Since climate change is projected to increase climatic variability and climatic risks to agriculture, it is important to underline that small and marginal farmers are at greater risk of losing income and livelihoods. Therefore, it is essential to provide adequate safety nets such as crop insurance, value addition, market support, and rural infrastructure to provide the impetus for not only agricultural income but also for improving avenues for income from other sources in villages.

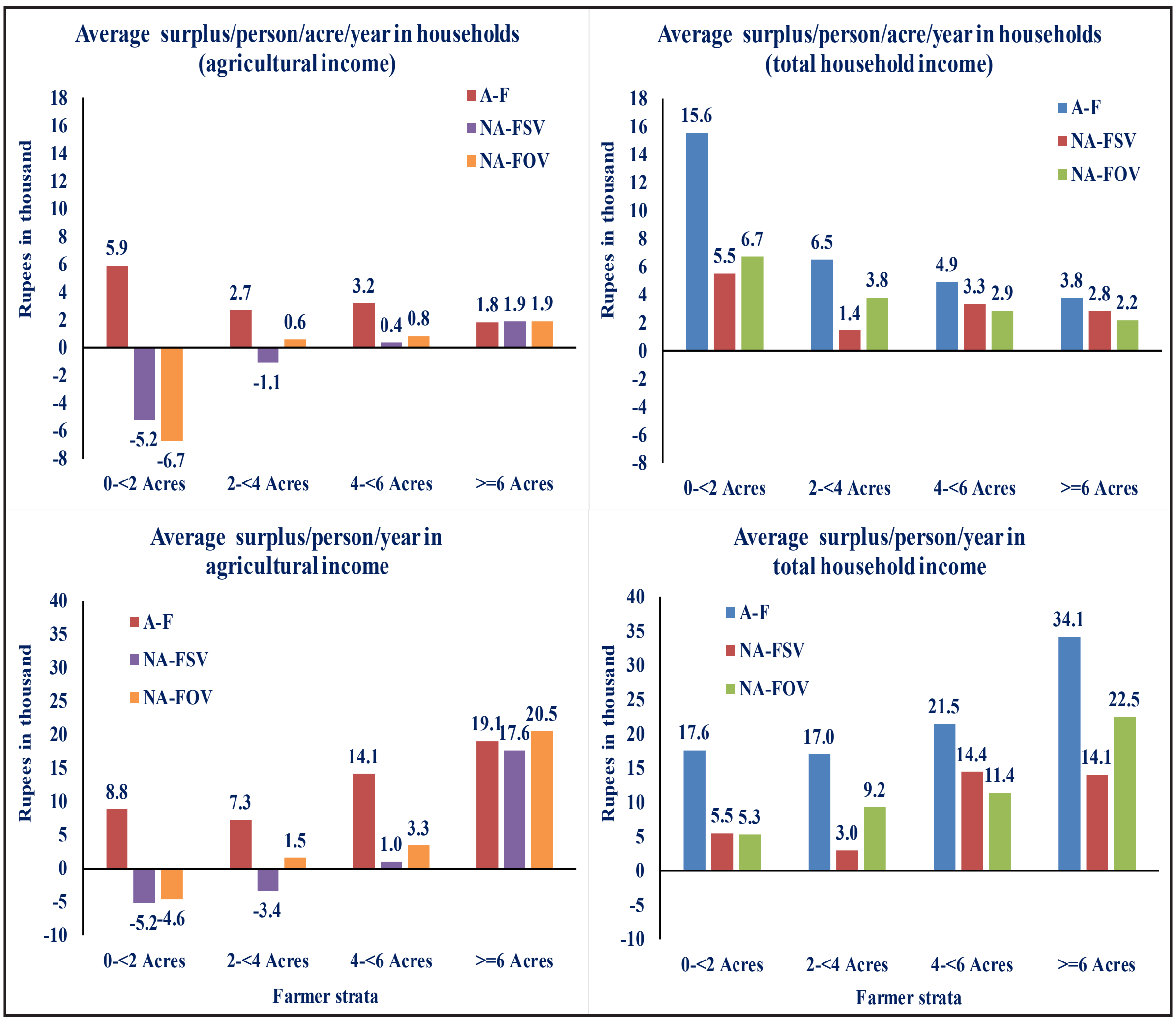


Figure 4.28: Variation in average surplus per person per acre in a year in different groups of households based on a) agricultural income and b) total household income. Lower graphs indicate variation in average surplus per person in a year in different groups of households based on c) agricultural income and d) total household income. A-F-adapted farmers; NA-FSV-non-adapted farmers from same village; NA-FOV-non-adapted farmers from the other village. (Adopted from Kumar et al., 2016).

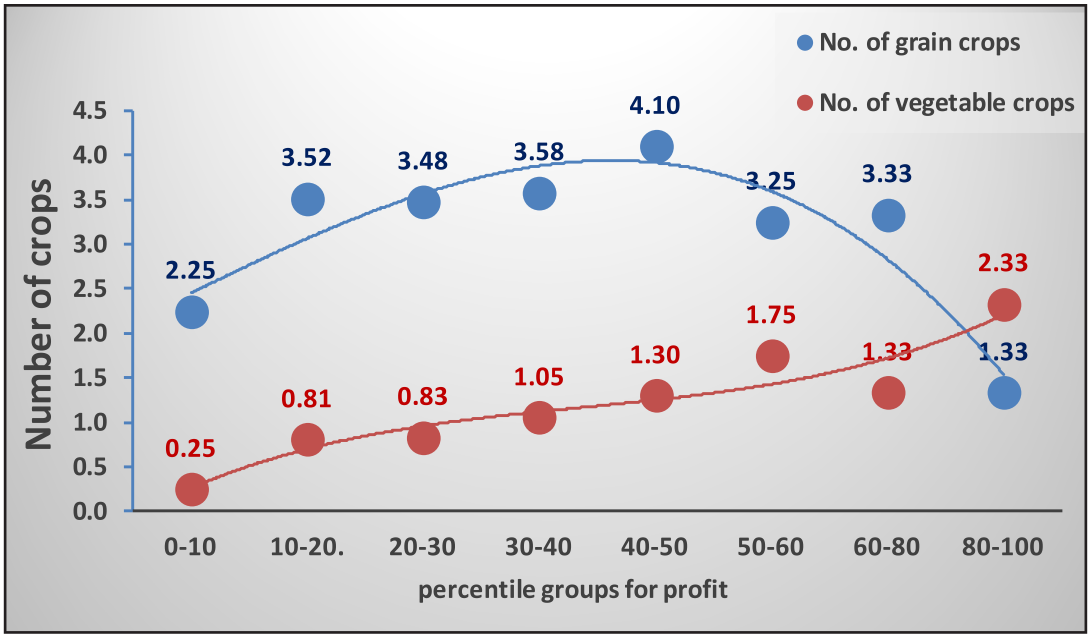


Figure 4.29: Change in profits from agriculture due to cultivation of crops and vegetables in various combinations. The Y-axis indicates number of crops and X- axis represents percentile groups for profit with 80-100 indicating top percentile for profit (Adopted from Kumar et al., 2016)

Adaptation has potential limits and limitations that can be successfully overcome. The limits to adaptation can arise from ecological, economic, technological and social limits. The technological options have a limit on uniform utility, and efficiency under different conditions. For example, in a drought-prone area, ecological constraints limit the choice of a variety of crops only to those requiring less water and tolerating high temperatures and oxidative stresses. In addition, the costs of technologies influence the preference of the farmer. The social limits include society's cultural, behavioral and attitudinal aspects. Thus, tailoring to suit location-specific needs becomes the most important component for the success of a technology. Technologies that are too specific or too rigid or too costly have more limits than those which can be modified to suit location-specific needs and are low-cost. Adaptation limitations arise due to constraints of farming communities in knowing and finding availability, and access and implementing the adaptation options. The adaptation limitations- though there are many— ranging from technology, finance, land, behavioral and attitudinal factors, information, accessibility, availability, and to local governance system, — can be overcome with convergence and prioritization.

4.3.8 Impact of Climate Change on Crop Prices

The analysis also indicated that a reduction in crop production will lead to an increase in crop prices relative to the Business-As-Usual (BAU) (Table 4.6). The price of wheat and sugarcane could increase by 30% in the RCP8.5 scenario by 2050, relative to BAU price. Oilseeds and maize could increase by at least 20% in 2050, relative to BAU. By the end of the century, prices could increase by at least 100% relative to the BAU for most crops, even the price of rice would increase by 70% relative to its price in the BAU scenario in 2100, if the world is not able to limit its emissions below RCP8.5 pathway.

Table 4.6: Increase in crop prices under various climate impact scenarios, relative to BAU prices

		2030	2050	2100
Maize	RCP4.5H	1.04	1.10	1.15
	RCP4.5L	1.03	1.06	1.09
	RCP8.5H	1.08	1.20	2.00
	RCP8.5L	1.05	1.11	1.28
Cotton	RCP4.5H	1.02	1.05	1.10
	RCP4.5L	1.01	1.02	1.04
	RCP8.5H	1.04	1.12	2.08
	RCP8.5L	1.01	1.05	1.15
Oilseeds	RCP4.5H	1.05	1.11	1.20
	RCP4.5L	1.03	1.07	1.12
	RCP8.5H	1.09	1.26	5.60
	RCP8.5L	1.06	1.14	1.41
Rice	RCP4.5H	1.01	1.04	1.09
	RCP4.5L	1.01	1.02	1.06
	RCP8.5H	1.02	1.11	1.72
	RCP8.5L	1.02	1.07	1.16
Sugarcane	RCP4.5H	1.04	1.09	1.30
	RCP4.5L	1.02	1.04	1.16
	RCP8.5H	1.08	1.33	2.59
	RCP8.5L	1.04	1.17	1.52
Wheat	RCP4.5H	1.04	1.09	1.30
	RCP4.5L	1.01	1.03	1.10
	RCP8.5H	1.07	1.30	2.40
	RCP8.5L	1.03	1.11	1.57

Note: BAU prices imply price for a given crop in the given year

The price increase under RCP4.5 scenario, relative to BAU, is already significant. The increase becomes significantly higher under the RCP 8.5 scenario. In the RCP4.5 scenario, the prices of these three crops could be higher by 9%-10% in 2050, and 30% (for wheat and sugarcane), 15% for maize, and 20% for oilseeds in 2100 relative to the crop prices in the BAU, which will itself be higher than today. The price increase, relative to BAU, will be lower in rice and cotton, a maximum 9%-10% in 2100. In the RCP8.5 scenario, price increases are very high. As in the case of RCP4.5, the four crops (wheat, sugarcane, oilseeds and maize) will see the highest impact on their prices relative to the BAU. Interestingly, this impact will be felt even in the near term, i.e. 2030. Prices for these crops could be higher by 7%-9% relative to BAU under this scenario in 2030. The price increase relative to BAU prices would be much higher for wheat and sugarcane (11%-30% and 17%-33% respectively in 2050) as compared to oilseeds and maize (14%-26% and 11%-20% respectively in 2050). In the long run, when a temperature increases under the RCP8.5 scenario would have a significant impact on crop productivity, the price impacts would also be much more pronounced. Even the price of rice will be higher by 70% relative to BAU price in 2100. The price rise could be as high as 100% for maize, 108% for cotton, 140% for wheat, 159% for sugarcane, and over five times for oilseeds in 2100, relative to their respective prices in the BAU scenario.

Need for adaptation finance and development of adaptive capacity

Adaptive capacity needs to be enhanced in the first instance in the knowledge domain, particularly in specific studies on climate change impacts on key crops. Second, research is critical to enhance the adaptive capacity of crops. India's crop productivity, considering the overall picture, is low compared to many regions of the world and across several crops. It is expected that the crop productivity of all crops will keep rising over the long-term. Such growth will counter the impact that climate change will have in terms of lowering the growth potential. Climate resilient agriculture will ensure that India's agriculture productivity truly achieves its growth potential. Finally, there is an important role for international adaptation finance. Research has shown that the cumulative contribution of India to the GHG emissions and concentrations is going to be low compared to the developed nations which have cornered most of the global carbon budget. Adaptation efforts, such as the development of climate resilient high productivity crops, need significant finances to undertake research across the length and breadth of the country. It is imperative that developed countries financially support India to enhance the adaptive capacity of its agricultural systems. Only through these collective interventions can India reduce the imminent climate risks its agriculture and agriculture dependent communities face in the near and long-term future.

Box-2: Climate change and plantation crops in India

Plantation crops such as coconut (grown in 2.2 Million Ha producing 16.3Mt nuts), rubber (0.82 Million Ha, 0.69 Mt), arecanut (0.47 Million Ha, 0.77 Mt), pepper (0.12 Million Ha, 0.046 Mt), cocoa (0.09 Million Ha,0.02 Mt) and cardamom (0.075 Million Ha, 0.02 Mt) directly or indirectly support the livelihoods of about 13 million people in India. Climatic stresses such as excess rainfall events, dry spells, droughts and high and low-temperature stresses are the major abiotic factors affecting plantation crops' survival and production and decide the crop vulnerability in a region presently under cultivation as well as the emergence of alternate areas likely to become suitable under future climate. Experiments on coconut indicate that temperatures more than 35^{o}C affect the pollen tube growth causing fertility loss (Figure 4.30).

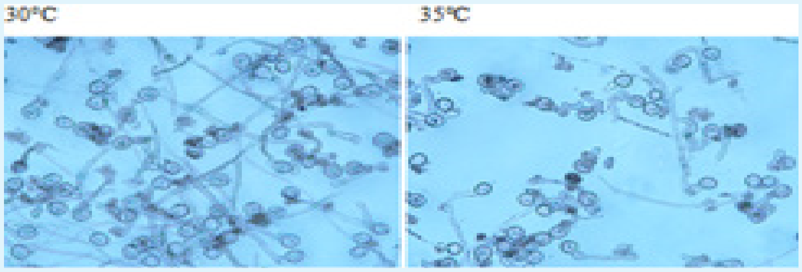


Figure 4.30: Pollen tube growth at 30^{0}C and 35^{0}C

The assessment of the impact of climate change on coconut, a plantation crop, is challenging. Using the simulation model, InfoCrop-COCONUT (Kumar et al., 2008), the potential impacts of climate change on coconut productivity in India has been carried out (Figure 4.31). Climate change is projected to increase coconut productivity in western coastal region, Kerala, parts of Tamil Nadu, Karnataka and Maharashtra (provided the current level of water and management is made available in future climates as well) and also in north-eastern states, islands of Andaman and Nicobar and Lakshadweep while negative impacts are projected for Andhra Pradesh, Orissa, West Bengal, Gujarat and parts of Karnataka and Tamil Nadu. On all-India basis, even with current management, climate change is projected to increase coconut productivity by 4.3% in 2030 and 1.9 to 6.8% in 2080 climate scenarios (Kumar and Aggarwal, 2013). Agronomic adaptations like soil moisture conservation, summer irrigation, drip irrigation, and fertilizer application in addition to genetic adaptation measures like growing improved local tall cultivars and hybrids under improved crop management is needed for long-term adaptation of plantation to climate change, particularly in the regions that are projected to be negatively impacted by climate change. Such a strategy can increase the productivity by about 33% in 2030, and by 25–32% in 2080 climate scenarios. Productivity can be improved by 20% to almost double if all plantations in India are provided with the above-mentioned management even in current climates. In places where positive impacts are projected, current poor management may become a limiting factor in reaping the benefits of CO_2 fertilization, while in negatively affected regions adaptation strategies can reduce the impacts. Thus, intensive genetic and agronomic adaptation to climate change can substantially benefit coconut production in India (Kumar and Aggarwal, 2013).

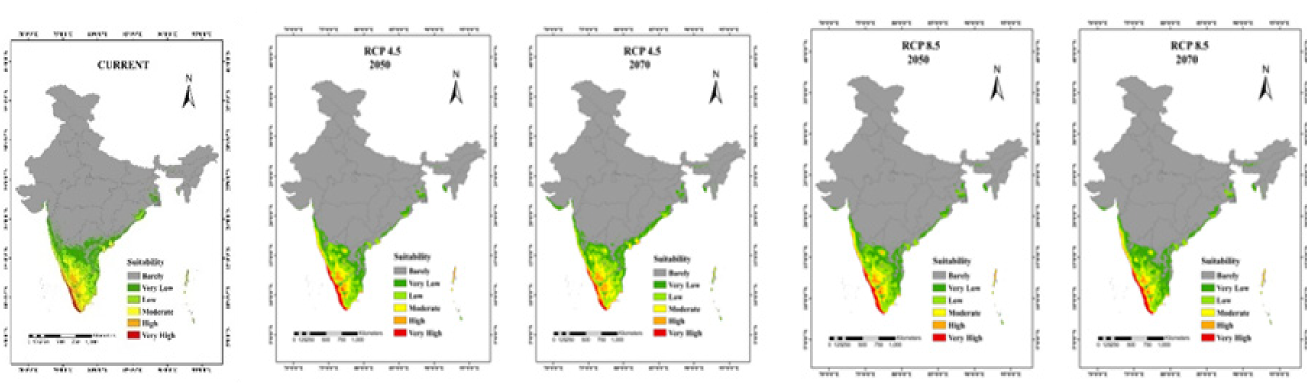


Figure 4.31: Modelled current and projected coconut area distribution in 2050s and 2070s under RCP 4.5 and RCP 8.5

The Maxent model was used to assess the crop suitability response to climate change using current climate data (1979 – 2013) and 19 Global Climate Models and climate change projections for 2050s and 2070s. The analysis focused on the specific regions mostly coastal and hilly tracts of South India and North Eastern states where the crop is currently-grown (Table 4.7). Results project a shift in climatic suitability for different plantation crops in by RCP 4.5 and RCP 8.5 2050 and 2080 scenarios.

Table 4.7: Shift in climate suitability for plantation crops in India in future climates

Crop	Suitable to unsuitable	Unsuitable to suitable	Highly suitable to moderately suitable	Moderately to highly suitable
Coconut	Tamil Nadu (Madurai, Virudhnagar)	Andhra Pradesh-Karnool	Karnataka (Davanagere, Chitradurga, Tumkur, Shimoga); Tamil Nadu (Salem, Namakal, Pudukot-tai); Andhra Pradesh (East Godavari and Krishna)	-
Arecanut	Southern districts of Kerala; Tamil Nadu (Kanyakumari, Nilgiris); Assam		Kar- Shivmogga, chikma-galuru, Hassana Tamil Nadu - Coimbatore	Ker-Palakkad
Cocoa	Some parts of Uttarakhand of Karnataka Tamil Nadu-Nilgiris, Theni, Erode		Parts of Coimbatore East & West Godavari	Western Karna-taka and Kerala
Black pepper		Western coast of Karnataka & Kerala Kanyakumari		Western coast of Karnataka & Kerala
Cardamom		Western coast of Karnataka & Kerala Western region of Tamil Nadu		Southern Kerala
Rubber		Brahmaputra valley	Western Ghats	

4.4 Climate Change and Water Resources in India

Climate change impacts the hydrological resources and water availability through various parameters leading to changes in seasonal and inter-annual water availability, extreme events of droughts and floods, and changes in streamflow, and runoff. India witnessed major droughts (Bundelkhand 2017-2018, Gujarat 2016, and Maharashtra 2013) and floods (Kerala 2018, Gujarat 2017, and Madras 2015) during the recent years. These events cause significant loss to agriculture in the affected region, and the local and regional economy.

Various studies indicate the increase in frequency of both droughts due to weaker summer monsoon precipitation as well as increase in floods due to increase in frequency of extreme precipitation. Under various scenarios of future climate change, these effects are projected to rise. In the following the vulnerability of water resources, and the impact of future climate change on water resources as well as the corresponding adaptatiton strategies are discussed in this section.

4.4.1 Vulnerability assessment of water resources

India has 18% of the world's population about, 17% of world's cattle population but only 4% of world's renewable water resources and 2.4% of world's geographical area. Availability of water is highly uneven in both space and time, with monsoon confined only to four months in a year. Precipitation varies from about 100 millimeter (mm) in the western parts of Rajasthan to over 10,000 mm in Meghalaya.

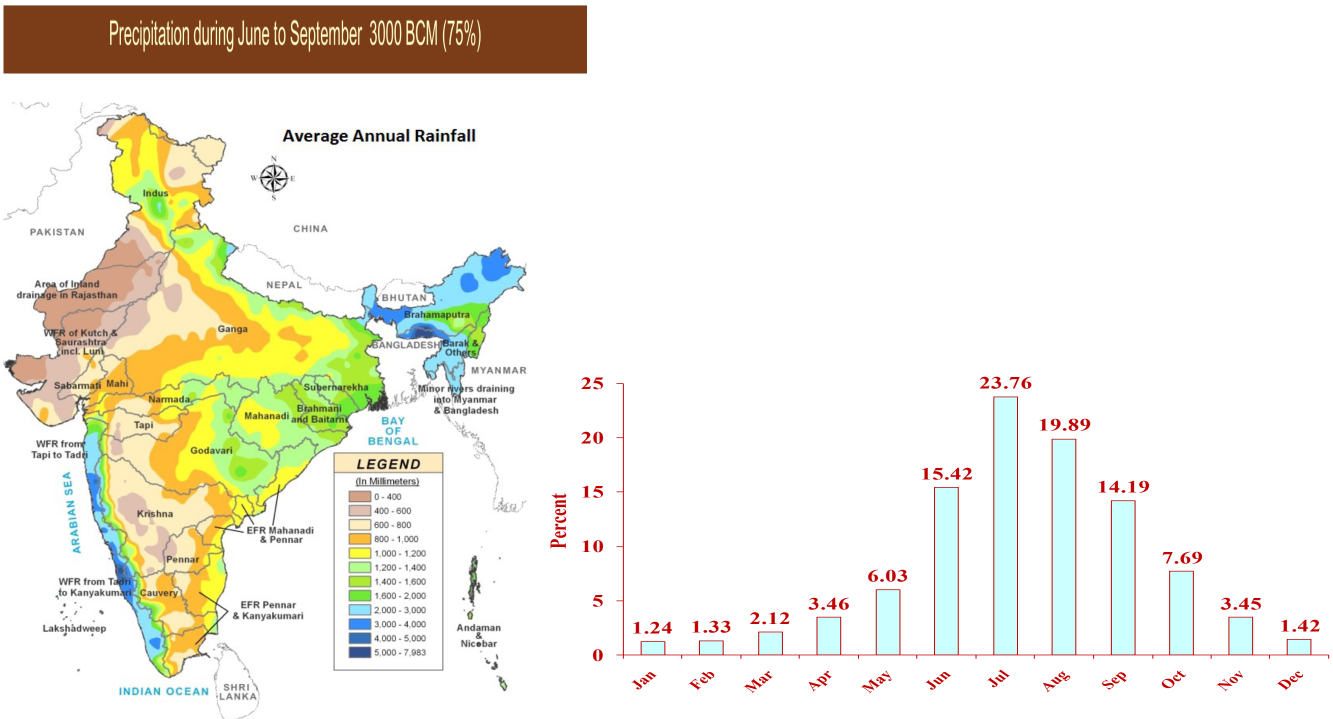


Figure 4.32 Spatial & Temporal Variation in precipitation over India

In view of growing population, the per capita water availability in India is reducing progressively. The Central Water Commission (CWC) has conducted a study titled 'Reassessment of Water Avialability in India using space inputs' wherein wide variability has been observed in per capita water availability amongst different basins of India. Annual water availability below 1,700 and 1,000 cubic meters per person per year are considered as water stressed and water scarce condition, respectively. Due to high temporal and spatial variations in precipitation, water availability in many regions of the country is much below the national average (CWC, 2019).

It has been estimated that around 40 million hectare (mha) of area is flood-prone, which constitute about 12% of total geographical area of the country. It has been found that around 51 mha. area is drought prone, which constitutes about 16% of total geographical area of the country. Various climate change studies indicate that the likely impact of climate change on water resources could contribute to further intensification of the extreme events.

Although more than 75% of water is used for agriculture, a large area remains rain-fed. Coverage of more area under assured irrigation and increased irrigation efficiency is needed for increasing food production, thereby enhancing rural prosperity and national food security.

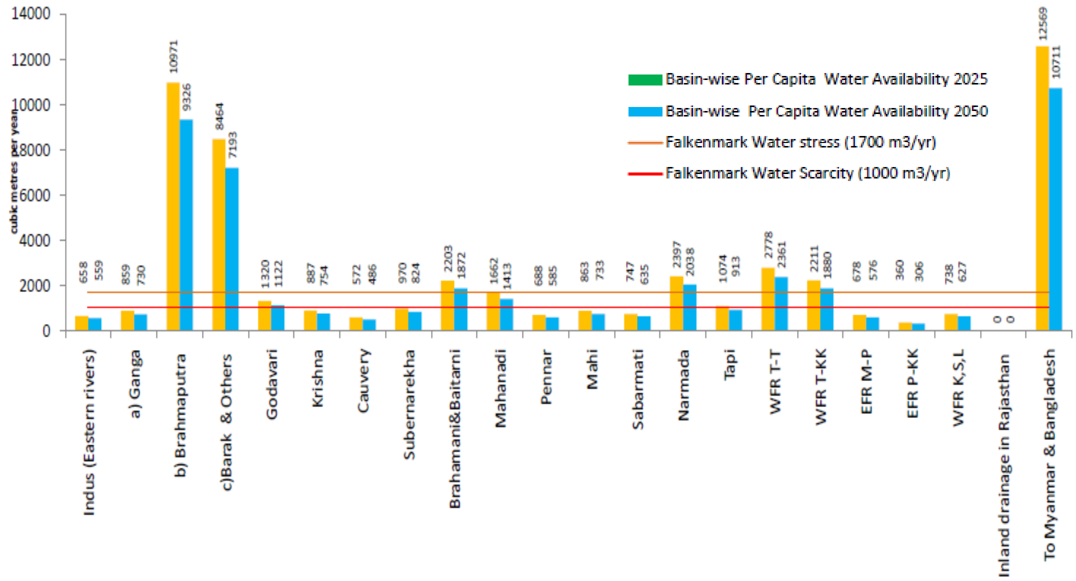


Figure 4.33 Basin wise per capita annual water availability in India

There is tremendous pressure on ground water in the areas where surface water is not readily available leading to unsustainable overexploitation of ground water in such areas.

The water use efficiency in the country mainly in irrigation sector is very low as compared to international standard. Some of the reasons for low irrigation efficiency are dilapidated irrigation systems, unlined canal systems, lack of field channels, lack of field drainage, improper on-farm practices field and levelling etc. Irrational water pricing & poor realization of water charges is also responsible for low efficiency in irrigation sector.

Water pollution is a major environmental concern in India. The main sources of water pollution are discharge of untreated/ partial treated domestic sewage and industrial effluents, (which contain organic pollutants, chemicals & untreated heavy metals and emerging pollution) and run-off from land-based activities such as agriculture and mining. Decrease in lean flow in the rivers further deteriorates the condition.

In view of above, dynamic assessment of climate change scenarios, assessment of its effect on water resources development and management practices, research/ studies to find adaptive and combative measures to avert adverse effect, formulation/ modification of guidelines implementing adaptive and combative measures, providing necessary guidance/ consultation to various agencies in this regard are needed.

4.4.2 Climate change impact projection on water resources

Global warming due to increase in greenhouse gas emissions is likely to have significant effects on the hydrological cycle. Impacts of climate change on hydrological cycle will affect nearly every aspect of human well-being. Assessing the impact of climate change on hydrology, essentially involves projections of climatic variables into local scale hydrologic variables and evaluation of risk of hydrologic extremes in future, for water resources planning and management.

In order to assess the impact of climate change on water resources in India, a study on "Statistical Downscaling for hydro-climatic projections with CMIP5 simulations to assess Impacts of Climate Change" was carried out by the Ministry of Jal Shakti through IIT Bombay as lead institute along with other institutes namely IIT Guwahati, IISC Bangalore, IIT Gandhinagar & IIT Kanpur. Objectives of the study are as under:

- Inter-comparison of IPCC climate model outputs (CMIP5) for assessing their relative skill in simulating rainfall patterns in Indian River Basin.
- To project regional meteorological variables with statistical downscaling for future with different RCP scenarios.
- Use of multiple downscaling techniques to understand the uncertainty
- To understand the capability of statistical downscaling in simulating spatial variability
- Development of statistical downscaling and analysis model for extremes
- Modelling uncertainty resulting from multiple models, scenarios and downscaling methods.
- To prepare database of simulated data for further use in hydrologic models.

Various models were setup under the study for downscaling the data. An ensemble of results of one grid point depicting variability and results of various models is given in the graphs below for RCP 4.5 & RCP 8.5 scenarios.

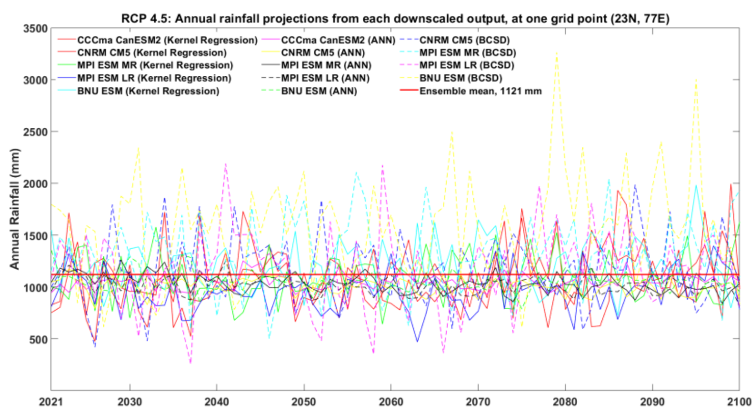


Figure 4.34 Time-series plot for projected annual rainfall (RCP 4.5), corresponding to each downscaled output, at one grid point.

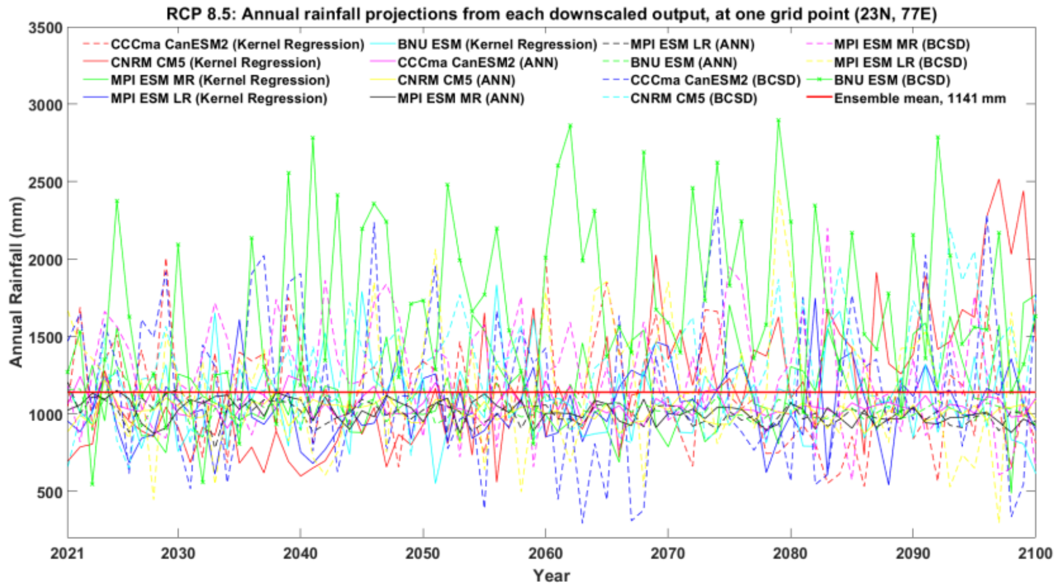


Figure 4.35 Time-series plot for projected annual rainfall (RCP 8.5), corresponding to each downscaled output at one grid point.

High resolution climate projections serve as key input not only in planning and management programs but also for obtaining future patterns of extreme events pertaining to different climate variables. These projections can play crucial role for the country (characterized by rainfed agriculture and high population density regions) in formulating different strategies regarding water-food-energy nexus, disaster mitigation planning etc. Hence, the research reported in this report contributed towards the main objective of obtaining rainfall projections for India using data driven models.

The research work, referred in this report contributes towards obtaining climate projections at fine resolutions, generating future patterns of hydro-meteorological variables. Focus of the cited research is on temperature and rainfall, which are the most important 'impact relevant' climate variables. The major conclusions derived are:

- Daily maximum, mean, and minimum temperature show positive trend indicating rise in temperature in entire India.
- The Rainfall projections for future show non-uniform changes in mean rainfall as compared to the historic period simulations. Effect of orography is clearly seen even in future changes.
- There is a wide variation in projections across models and hence uncertainty modelling is a must before using the projections for planning.

4.4.3 Adaptation framework adopted and implemented in India

The current adaptive actions in the water resource sector are identified from the National Action Plan on Climate Change (NAPCC), State Action Plans on Climate Change (SAPCCs), union budgets, and India's five-year plans. NAPCC addresses nine sectoral missions including National Water Mission (NWM) which was established in 2011 with the objective of "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management". National Water Mission has been working on the five goals which are as follows:

i. Comprehensive water database in the public domain

ii. Assessment of the impact of climate change on water resources

iii. Promotion of citizen and State action for water conservation, augmentation, and preservation with a focus on vulnerable and over-exploited areas

iv. Increasing water use efficiency by 20%

v. Promotion of basin-level integrated water resources management

Various programs of both the central & state governements and by the peoples' participation in order to address the adaptation to climate change impacts on water sector are briefly outlined below:

Namami Gange

This flagship programme was initiated by the Government of India in June 2014. This progamme has created a paradigm shift in the approach to river rejuvenation, pollution abatement and a holistic approach to river basins. The Ganga River basin represents a system of closely interconnected dynamism between the biotic (plants, animals, microorganisms) and abiotic (soil, water) components. Hence, adequate magnitude, timing, frequency, and duration of flows are essential to sustain river dependent ecosystems. Ganga River Basin Management Plan recommends eight important areas where restorative actions need to be carried out in Mission mode viz., Aviral Dhara, Nirmal Dhara, Ecological Restoration, Sustainable Agriculture, Geological Safeguarding, Basin Protection Against Disasters, River Hazard Management and Environmental Knowledge-Building & Sensitization.

Under Namami Gange Programme, a comprehensive set of interventions such as wastewater treatment, solid waste management, river front management (Ghats and Crematoria development), e-flow, afforestation, biodiversity conservation and Public Participation etc. have been taken up for rejuvenation of river Ganga and its tributaries. Till June, 2023, a total of 442 projects have been taken up at an estimated cost of Rs. 373.95 billion, out of which 254 projects have been completed and made operational. Majority of the projects pertain to creation of sewarage infrastructure as the untreated domestic/industrial wastewater is the main reason for pollution in the river. 192 sewerage infrastructure projects have been taken up with a cost of Rs. 303.87 billion for creation & rehabilitation of 6030 million litres per day (mld) of Sewage Treatment Plant (STP) capacity and laying of around 5250 km sewerage network. Among these, 106 sewerage projects have been completed resulting in creation

& rehabilitation of 2664 MLD of STP capacity and laying of 4436 Km sewerage network.

Implementing programs similar to Namami Gange for other rivers would help in addressing these issues, promote sustainable water management, and ensure the well-being of both the environment and communities that depend on these rivers. However, the approach might need to be tailored to the unique characteristics and challenges of each river basin.

National River Conservation Plan

National River Conservation Directorate (NRCD) has been supplementing the efforts of the State Governments in abatement of pollution of identified polluted stretches of rivers under the Centrally Sponsored Scheme of National River Conservation Plan (NRCP) on cost sharing basis between the Central and State Governments. Various pollution abatement works relating to interception & diversion of raw sewage, construction of sewerage systems, setting up of sewage treatment plants, low-cost sanitation, river front/bathing ghats development, etc. have been taken up under this plan.

Jal Jeevan Mission

To ensure safe drinking water supply to all rural households of the country, an ambitious Jal Jeevan Mission (JJM) was announced on 15th August, 2019. The mission is under implementation in partnership with States to provide tap water connection to all rural households by 2024. In addition to the households, aim is to provide piped water supply to public institutions in villages viz. schools, anganwadi centres, ashramshalas (tribal residential schools), PHCs/ CHCs, Gram Panchayat building, community hall, etc. In four years time about 127.5 million rural households out of total about 194.1 million rural households have been provided Functional Household Tap Connection (FHTC).

Following the bottom-up approach, JJM is being implemented as a decentralized, demand-driven community-managed programme. More than 0.524 million Paani Samitis/ Village Water and Sanitation Committees (VWSC) have been formed and over 0.512 million Village Action Plan have been prepared under Jal Jeevan Mission to manage, operate, and maintain in-village water supply infrastructure with an active participation of people especially women, and rural communities working together. For long term drinking water security, local communities and Gram Panchayats are coming forward and taking responsibility to manage village water supply systems, their water resources and grey water.

Atal Bhujal Yojana

Climate change is expected to exacerbate current pressures on groundwater resources, particularly in a scenario where users increasingly turn to groundwater. Sustainable groundwater management initiatives offer significant drought resilience and climate adaptation opportunities, as the resultant improvement in natural storage can be used to play an important ‘stabilization role’ in coping with mid-season dry spells, a ‘buffering role’ during monsoon failure, and a role as ‘carry-over storage’ during multiyear droughts. Improvement in groundwater conditions and consequent rise in water levels hold great promise for significant reduction in carbon emissions from pumps used for irrigation.

Atal Bhujal Yojana (ATAL JAL) is a World Bank aided Central Sector Scheme of the Government of India with an outlay of Rs 60 billion, with focus on community participation and demand side interventions for sustainable ground water management in identified water stressed areas. The scheme is being implemented from year 2020. The scheme is being implemented in select areas in 80 districts, 22 administrative blocks, and 8,562 water stressed Gram Panchayats of seven states, viz. Haryana, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh.

Strategies to manage groundwater sustainably under Atal Bhujal Yojana

i. ***Managing demand through informed water use:*** The scheme aims at ensuring long term sustainability of ground water resources through a combination of demand and supply side interventions through community led, Gram Panchayat-wise Water Security Plans, by way of convergence of ongoing /new schemes. It also aims at inculcating behavioral changes at the grass-root level toward optimal use of available water through improving the availability of real time ground water data as well as through awareness creation. Further, States shall also be incentivized for adopting practices for improvement in ground water management in target areas.

ii. ***Involving the community and behavior change:*** Atal Bhujal Yojana hinges upon the active participation of grass root level stakeholders to improve ground water management. A well-informed grass root level community, armed with traditional wisdom and an improved understanding of the status of availability of local ground water resources, is expected to contribute positively toward long-term sustainability of available resources by way of reducing wastage and ensuring optimal utilization of ground water.

iii. ***Demand side Measures:*** The demand side measures primarily include introduction/expansion of efficient irrigation methods, change of cropping patterns to suit water availability and installation of dedicated feeders for irrigation power supply. Improved irrigation technologies such as drip/ sprinkler systems and shifting to low-water/high-value crops are crucial in the context of climate change because these practices significantly reduce groundwater use and CO_2 emissions. They also have the potential for significantly increasing agricultural productivity per cubic meter of groundwater used and reduce evaporation and conveyance losses. Availability of high-quality power for fixed durations through dedicated feeders are expected to substantially reduce wastage of ground water as it will encourage farmers to optimize their pumping schedules.

iv. ***Supply side interventions:*** To be implemented in the scheme areas are expected to supplement the gains accrued from demand side measures by way of augmentation of ground water resources through strategically located water conservation/ artificial recharge structures. The additional storage created through these structures are also expected to soften the impact of extreme precipitations likely due to climate change to some extent.

v. ***Incentives:*** The prospect of incentives for improving ground water management is also likely to be a key driver for encouraging best practices for ground water management in the participating States, thereby contributing toward adaptation to and mitigation of climate change impact.

Swachh Bharat Mission (SBM)

The mission was launched in October 2014 with the objective of universalizing sanitation coverage, and has, in the process, improved the water security of communities by reducing the contamination of surface water and ground water sources. The SBM, with its two components – SBM-Grameen (SBM-G) and SBM-Urban (SWM-U) – brought drastic changes in India's sanitation sector. Under the SBM-G, all villages, Gram Panchayats, Districts, States and Union Territories in India declared themselves "open-defecation free" (ODF) by 2 October 2019, which was made possible by construction of over 100 million toilets in rural India. To ensure that ODF behaviours are sustained and that solid and liquid waste management facilities are accessible, the Mission has moved towards the second phase called ODF-Plus. ODF Plus activities under Phase II of Swachh Bharat Mission (Grameen) will reinforce ODF behaviours and focus on providing interventions for the safe management of solid and liquid waste in villages.

The Mission has enabled access to safe sanitation, which has enhanced dignity of women while also providing employment opportunities to women in the area of sanitation and waste management. Under the Mission, women have participated in operating material recovery facilities, initiating waste-to-wealth startups and managing sewage treatment plants. The country is now poised to make a transformational shift from 'Women in Swachhata' to 'Women led Swachhata'.

Under SBM-Urban, Urban India have declared themselves Open Defecation Free (ODF), with all 4,715 Urban Local Bodies (ULBs) completely ODF, 3,547 ULBs are ODF+ with functional and hygienic community and public toilets and 1,191 ULBs are ODF++ with complete faecal sludge management.

Pradhan Mantri Krishi Sinchayi Yojana (PMKSY)

It is a centrally sponsored scheme which addresses convergence of investments in irrigation at the field level and targets expansion of cultivable area under assured irrigation. PMKSY is an umbrella scheme, consisting of two major components – Accelerated Irrigation Benefits Programme (AIBP) and Har Khet Ko Pani (HKKP). HKKP consists of four sub-components –Command Area Development & Water Management (CAD&WM), Surface Minor Irrigation (SMI), Repair, Renovation and Restoration (RRR) of Water Bodies, and Ground Water (GW) Development. CAD&WM is being implemented pari-passu with AIBP. PMKSY aims to enhance physical access of water on farm and expand cultivable area under assured irrigation, improve on-farm water use efficiency, introduce sustainable water conservation practices, etc. The scheme further aims to increase ground water recharge, increased availability of drinking water, improvement of catchment of tank commands etc. The positive impact of Irrigation/ Storage projects on climate change are in the areas of flood control, generation of hydropower and ground water recharge, apart from providing security of livelihoods through assured irrigation.

Dam Rehabilitation and Improvement Programme (DRIP)

India ranks third globally after China and the United States of America, with more than 5,700 large dams in operation. In addition, about 400 dams are under construction. There are also several thousand smaller dams. These dams are vital for ensuring the water security of the country. Apart from structural measures to improve hydrologic safety, hydro-mechanical measures, seepage reduction, structural stability etc., non-structural measures, such as dam break analyses, emergency action plans, and operation and maintenance manuals, were put in place for the selected dams. In addition, Dam Health and Rehabilitation Monitoring (DHARMA), a system to monitor the health of dams, has been developed. A Seismic Hazard Analysis Information System (SHAISYS) has also been developed. Improving the operation of existing dams, enhancing their efficiency and life, and addressing sedimentation are important and sustainable ways to combat floods and enhance water security. The first Dam Rehabilitation and Improvement Programme (DRIP) took up the rehabilitation of a select number of dams, as well as the capacity building of dam operators. Based on the success of this programme, DRIP phase-II was approved in 2021. This would be the largest dam rehabilitation programme in the world.

In December 2021, Government of India has enacted "Dam Safety Act". Under the act, Institutuional framework has been setup at the central level and at the state level. These institutions are taking up the Dam Safety Issues of all the dams in the country.

Jal Shakti Abhiyan

The Jal Shakti Abhiyan was launched in 2019 across 256 water stressed districts of the country to enhance water recharge and conservation and arrest depleting water levels to ensure water security. The efforts included the establishment of structures for water storage and conservation as well as intensive afforestation activities that led to plantation of about 123 million saplings with a resultant increase in India's carbon sinks. Ministry of Jal Shakti took up the "Jal Shakti Abhiyan: Catch the Rain" (JSA: CTR) with the theme "Catch the Rain - Where it Falls When it Falls". The aim of this campaign is to nudge all stakeholders to create appropriate rainwater harvesting structures, suitable to the soils substrata and climatic conditions, with people's participation. it led to the development of 16,22,957 water conservation and rainwater harvesting structures, renovation of 2,96,958 traditional water bodies and 36,75,68,460 afforestation activities with increased mitigation co-benefits across the country within the last one year (2021-22). It involved the participation of over 29 million people in its over 1.63 million activities.

Bureau of Water Use Efficiency

In order to address the goal of increasing water use efficiency by 20 percent, to help stem the adverse impact of spatial and temporal variation in rainfall and reduce water stress the Bureau of Water Use Efficiency has been constituted under the National Water Mission in October 2022. The Bureau will inter-alia make necessary regulatory directions to promote water use efficiency, assessment of water footprint and water auditing in agriculture sector, showcasing national/international best practices and evolving innovative mechanism to secure community participation. A campaign viz. "Sahi-Fasal" has been launched by NWM to nudge Indian agriculture to promote crops which use less water but more efficiently, have high nutritional quality and are economically remunerative to farmers.

Flood Management

Floods are natural calamity that the country faces almost every year, in varying degrees of magnitude. The occurrence floods can be attributed to various factors, including wide variations in rainfall both in time and space with frequent departures from the normal pattern, inadequate carrying capacities of rivers, river bank erosion and silting of river beds, landslides, poor natural drainage in flood prone areas, snowmelt and glacial lake out-bursts. Climate change is adversely affecting the situation of floods in the country and it has been observed that frequency of short duration heavy rainfall has increased and is causing flash floods in one or other part of the country leading to serious damage to human lives and property. The flood management and anti-erosion projects are planned, investigated and implemented by the State Governments with their own resources as per priority within the State. The Union Government supplements the efforts of the States by way of technical guidance and promotional financial assistance for flood management in critical areas.

The Government of India is implementing "Flood Management and Border Area Programme" with an objective to enable the State Governments to provide reasonable degree of protection against floods/erosion by adopting structural measures including anti-sea erosion works in critical reaches. It will protect valuable land from flooding and erosion across the country. This scheme also aims to enhance bilateral co-operation in the field of water resources with neighboring countries and includes hydrometeorological observation, flood forecasting, flood management works.

Water resource planning and flood forecasting

Central Water Commission (CWC) has a network of 1,543 hydrological observation stations in all river basins for water resource planning and flood forecasting. The water data monitored above is uploaded to Water Information Management System (WIMS)/ India-WRIS to have a comprehensive water database in the public domain. Forecasting system is essential to predict likely increase in water level in rivers. CWC is currently providing near real time seven-day advisory flood forecast on its web portal through pan India rainfall-based mathematical modelling for 20 major river basins of the country covering 200 water level and 138 reservoir inflow forecast stations. This is a major paradigm shift from the conventional Gauge-to-Gauge correlation to a more scientific modelling technique for flood forecasting.

India-WRIS portal

India-WRIS portal has been created with the aim of dissemination of data in public domain constitute the most important aspects of the water resources management. Water related data is monitored/ observed by various agencies under different schemes of central/state governments including river flows, ground water levels, reservoir levels, water quality, glaciers & glacier lakes for the purpose of water resources planning, assessment, development and management.

Ground Water Management & Regulation (GWMR)

Major objective of the GWMR scheme is to provide scientific inputs for sustainable ground water management. Following major activities are being taken up under the scheme.

National Aquifer Mapping & Management (NAQUIM) Programme has been taken up with the objective to delineate the aquifers, characterize the aquifers and develop management plans. As a part of the NAQUIM program, the entire mapable area of the country (2.5 milllion sqkm) has been covered.

Ground water level monitoring is being carried throughout the country with a network of nearly 26,000 monitoring stations. It has been envisaged to increase the monitoring stations with addition of 9000 more piezometers. It is also planned to automate ground water monitoring by installing digital water level recorders with telemetry systems.

Ground Water Resource Assessment is being done periodically for quantifying availability and utilization of ground water resources. Such assessments help in prioritizing areas for ground water management and assessing impacts of changing rainfall as well management interventions. Ground Water Resources Assessments used to be carried out in 2 to 3 years interval. From 2022, such assessments are being done on annual basis.

Central Ground Water Authority (CGWA) has been constituted under Section 3(3) of the "Environment (Protection) Act, 1986" for the purpose of regulation and control of ground water development and management in the Country. In the states, state ground water authority has been formed, ground water extraction is managed by respective states. Such regulatory measures help in conservation of ground water resources, which in turn, help in climate change adaptations.

Research & Development in Water Sector

At present, most of the research and development activities in water sector in country are undertaken by Central or State Government research and academic institutions. In recent times, some NGOs, private sector have also taken up some studies and research projects in water sector.

Three organizations under Department of Water Resources, River Development and Ganga Rejuvenation namely, Central Water and Power Research Station (CWPRS) Pune, Central Soil and Material Research Station (CSMRS) New Delhi and National Institute of Hydrology (NIH), Roorkee are fully devoted to R&D activities. Other organisations of the department namely, Central Ground Water Board (CGWB), Central Water Commission (CWC), Ganga Flood Control Commission (GFCC) are also actively associated with studies in the field of water resources management.

Indian Council of Agricultural Research (ICAR) in the Ministry of Agriculture and Farmers' Welfare is also a major contributor to the research in water sector. The aspects dealt by ICAR institutions include Integrated Soil-Water-Nutrient Management, Watershed Management, climate resilient agriculture, waste water utilization, etc. National Remote Sensing Center (NRSC) has a Water Resources Division dedicated to remote sensing applications to water resources. Several Indian Institute of Technology (IIT), National Institute of Technology (NIT), Agricultural Universities, State Institutes also conduct research in water sector.

Department of Water Resources, River Development and Ganga Rejuvenation implements a scheme known as 'Research & Development Programme in Water Sector and Implementation of National Water Mission' under which it provides funds to promote research in the field of water resources. This financial assistance is provided by way of grants to academicians/ experts in the Universities, IITs, recognized R&D Laboratories/Institutes, Water Resources/ Irrigation Research Institutes of the Central and State governments.

The studies conducted by CWPRS, CSMRS, NIH, CWC and CGWB have been the basis for formulation of guidelines/manual for practicing engineers in water sector. These documents are extensively utilized by State agencies / project authorities as a reference material in planning, design, construction, operation and maintenance of water resources projects.

Apart from the efforts at Central level, few initiatives have been undertaken by State goverments for water conservation and management, which inter-alia include:

1. Mission Kakatiya (Telangana)
2. Jal Jeevan Hariyali Yojana (Bihar)
3. Sardar Sarovar project – undergeound pipeline network (Gujarat)
4. Community-based Micro Irrigation – Kerala
5. Mera Pani, Meri Virasat – Haryana

4.5 Coastal and Marine Ecosystems

4.5.1 Climate change connect of the sector

Climate Change impacts on the coastal and marine sector are caused primarily by warming seas. Thermal expansion of the seawater as well as increased amounts of water due to ice melt in the Arctic and Antarctic regions has led to rising sea levels. Increase in the Sea Surface Temperature (SST) has also resulted in changing storm patterns/intensities. Further, due to increased absorption of CO_2 by the oceans, the pH levels are going down impacting the carbonate balance in the ocean and affecting marine organisms with calcareous skeletons. There is also an interplay between the various environmental variables that result in changed water quality affecting marine organisms, especially fish.

Sea level rise

The latest report from the Intergovernmental Panel for Climate Change (IPCC-AR6 WG1) noted that the global mean sea level has been rising at an unprecedentedly rapid pace in recent decades. The average sea level rise increased from 1.3 mm/year between 1901-1971 to 3.7 mm/year between 2006-2018. It also noted that the sea level will continue to rise at an increased rate over this century and may rise by more than a meter by the year 2100 under the SSP5-8.5 (high-emission) scenario. Owing to this rapid warming, the sea level of the north Indian Ocean experienced a rapid rise over the last few decades. Based on scientific studies and the recent climate assessment report of the Ministry of Earth Sciences, the sea level in the Indian ocean was observed to be rising at a rate of 1.06-1.75 mm/year during the last century (1874–2004) and ~3.3 mm/year in the recent decades (1993-2015). It also noted that extreme sea level events are projected to occur more frequently along the Indian coast due to the rise in the mean sea level and extreme climate events. The rate of sea level rise may also include manifestations in sea level change due to the subsidence or uplift of land at those locations. Since no long-term data on land subsidence or upliftment is available for these locations, the rate of increase of sea level due to the changes in climate could not be separated.

Sea surface temperature

The tropical Indian Ocean has experienced a rapid increase in ocean warming with an average rise in SST of about 1 deg C over the period of 1951-2015. It is also found that the warming is spatially non-uniform, with the strongest warming seen in the Arabian Sea (Climate Change Assessment Report- 2020 by the Ministry of Earth Sciences). A recent estimate based on NOAA OISSTv2 datasets indicates a maximum SST warming trend of up to 0.4 deg C/decade during 1982-2019 in the northern Arabian Sea off the coast of Gujarat (Chatterjee et al., 2022).

Storm patterns

The Indian Meteorological Department (IMD) has classified storms following the Saffir-Simpson scale and modified for the Indian Ocean. Seven classes are recognized ranging from low-pressure areas to super cyclonic storms (CSs). The comparison of storm frequency (Depressions + Cyclonic storms + Very severe CSs) over the North Indian Ocean in the Arabian Sea and the BoB shows that the BoB storms are much higher than the Arabian Sea and there is a bi-modal behaviour in the Arabian Sea storm occurrence, whereas over the BoB the number of storms in the post-monsoon period of the climatology is higher compared to pre-monsoon period. Analysing the trends for individual categories of tropical cyclones showed that though the number of depressions forming over the BoB were higher than Arabian Sea, their frequency remains more or less constant with no significant increase in the span of 100 years. While the Arabian Sea, though maintaining a lower number shows a linear increase in the frequency. Cyclonic storms show a constant decrease in the BoB while their numbers remain more or less stable for the Arabian Sea. Seasonal analysis shows that the high-intensity tropical cyclones over the Arabian Sea are relatively more pronounced in the pre-monsoonal months while it's the opposite for the BoB. Storm surges are often generated by cyclonic storms and are described as an abnormal rise of water level generated by cyclonic storms over the predicted astronomical tide. Storm surges wreak havoc because high-velocity winds push water beyond the coastline and inundate the coastal regions.

4.5.2 Vulnerability Assessment

4.5.2.1 Vulnerability assessment of coastal population

Vulnerability assessment of the coastal populations focused mainly on the physical impacts of the rising sea levels, which is a slow and steady phenomenon and the impact of episodic events such as storms (of various strengths).

Sea Level Rise

Mainland coast

Many cities on both the east and west coasts are highly vulnerable to SLR. Panaji, the capital of Goa, India's smallest state located on the west coast has been identified as highly vulnerable to flooding due to predicted SLR. The trend for Panaji (1875-2010) shows an increase in the sea level based on the tide gauge data. A smoothening filter was applied to overcome the missing gaps in data. The trend estimated from the dataset is about 0.83mm/year, which after Glacial Isostatic Adjustment (GIA) correction comes out to be 1.26mm/year. The Mumbai/Goa coast shows a trend of around 0.3mm/yr.

Visakhapatnam, located on the east coast is highly vulnerable to climate change induced extreme events like cyclones and storm surges. The observed sea level trend for Visakhapatnam (1935–2010) shows an increase in the sea level based on the tide gauge data, estimated from the data set as 0.7mm/year, which after GIA correction comes to 1.09 mm/year. An exercise similar to the one for Panaji, the models projected an increasing trend of almost 0.2mm/year for Visakhapatnam coast.

Islands

Small islands are amongst the most vulnerable to SLR and climate change related impacts. Measuring the vulnerability of each island is a first step towards a risk analysis to identify where the impacts of climate change are the most likely and what may be their consequences on biodiversity, particularly the coral reefs. Since the loss of land through erosion is critical for small islands, analysis of shoreline change rates (long-term and short- term) was carried out for assessment of possible erosion and/or accretion rates based on the statistical computation of three inhabited islands (Kavaratti, Kalpeni, Minicoy) of Lakshadweep over different time periods during 1972–2015. Multiple shorelines extracted from satellite images were used to calculate shoreline change rates using the Digital Shoreline Analysis System (DSAS) model developed by the US Geological Survey (USGS) in ArcGIS software. More than 50% of the studied islands showed shrinkage in planform on both the ocean and lagoon sides. However, large parts of these eroding shorelines are mostly protected with various artificial structures.

Storm Surge

Studies on the impact of very severe cyclonic storms such as Phailin (2013) and Hudhud (2014) along the eastern coast (from Odisha to Andhra Pradesh) were carried out using ADCIRC, a model used extensively to predict storm surge-related inundation. It was found that the presence of waterbodies or inlets near the coastline led to greater inundation. The wider and gentle slope of the Odisha coast also promoted higher storm surge heights and greater inundation.

The total inundated area associated with the storm surge in Odisha was estimated to be 33.03 km^2 under high risk, 325.65 km^2 under medium risk and 1290.34 km^2 under low risk. The locations that were found vulnerable included 6 in Puri district, 4 in Bhaleswar, 3 in Ganjam district, 2 each in Jagatsinghpur, Bhadrak and Kendrapara and 1 in Khorda district.

In the case of Andhra Pradesh, the total inundation area under high risk category was zero, whereas 114.00 km^2 were estimated to be under medium risk and 245.53 km^2 under low risk. In Andhra Pradesh, 7 locations in West Godavari district, 6 each in East Godavari and Krishna districts, 3 in Nellore, 2 each in Vizianagaram and Srikakulam and 1 in Prakasam district were found to be vulnerable.

4.5.2.2 Vulnerability Assessment of Coastal Ecosystems

The coastal ecosystems in their entirety are highly vulnerable to climate change. Many of these ecosystems are also under severe anthropogenic stress and hence the vulnerability to climate change is of a lower significance or masked by more dominant anthropogenic impacts. The best documented are the coral reefs because of the mass bleaching events which have been directly related to rising SST. The model identifies priority locations where the reefs are predicted to suffer from severe annual bleaching. Under a 'business as usual' emissions scenario (RCP 8.5) all islands in the Gulf of Mannar (GoM) will experience annual severe bleaching (ASB) prior to 2070 and bleaching twice per decade prior to 2060. The onset of ASB showed a clear east to west gradient, with reefs towards the eastern end of the GoM all predicted to experience ASB before 2045.

4.5.2.3 Vulnerability Assessment of Fisheries

Reports are available on the distribution of fishes with changes in various oceanographic parameters for understanding the impact of SST, chlorophyll and precipitation on the catch of vulnerable fish species (vulnerable in the Indian Ocean region) from the Indian Ocean region.

As per the RCP 8.5 scenario, SST and SLR projections show a significant rising trend in 2030, 2050 and 2080 whereas, Sea Surface Salinity (SSS), chlorophyll 'a' concentration and pH show a declining trend. Precipitation shows an increase in 2030, 2050 and 2080 relative to 2015 in RCP 2.6 and RCP 8.5 scenario, however, a significant rising trend was not observed, as it shows variations in each time slice. Multiple models of CMIP5 and RCP-based projections have to be analyzed further in the future for the Indian Ocean for 2030, 2050 and 2080 to assess the quality of projections, reasons for variation and effects in each oceanographic variable.

The major vulnerabilities of marine fisheries sector identified are skeletal deformities in fishes, changes in spawning habits, increased metabolic rate in farmed fish and shellfish (10% increase for 10ºC rise in temperature), reduced life span and extension of boundaries of fish stocks, phenological changes, fish migration and habitat changes, uneven proportions of fish population, fish food security and livelihood related challenges, changes in direction and speed of winds, migration of fish species for reasons other than spawning, dispersal and growth, tsunami and its recurrence effect, changes in phytoplankton species composition and abundance which largely affect structure and functions of the marine ecosystems, fluctuations in abundance and reduction of a particular variety of fish species due to reasons which are climate-related, reduction and extinction of estuarine associated habitats and many related issues.

4.5.3 Impact prediction

4.5.3.1 Impacts of Sea Level Rise

Physical impacts of SLR can be of two kinds:

a) Primary impacts:
   i. inundation and displacement of wetlands and lowlands,
   ii. increasing vulnerability to coastal storm damage and flooding,
   iii. shoreline erosion, and
   iv. saltwater intrusion into estuaries and freshwater aquifers.

b) Secondary impacts
   i. altered tidal ranges in rivers and bays,

ii. increase in the height of waves
iii. changes in sedimentation patterns, and
iv. decrease in light penetration to benthic organisms.

Primary impacts include crop loss, loss of land, and damages to residential and commercial buildings facilities and infrastructure. Secondary impacts include interruption/loss of business, migration, dislocation, disability-adjusted life years (DALY), loss of tourism, etc. Due to difficulty in quantifying all the reported impacts, only selected impacts which include (i) loss of agricultural productivity (ii) loss of income from major commercial activities and income loss of casual labours were considered. The risk was estimated from the exceedance probability curve. These probabilities were then coupled with annual losses to estimate the economic losses due to impacts (see section on economic impacts).

Impacts of climate change on islands are seen through increased wave action, especially during monsoons, which increases erosion rates. Though many islands appeared to show low erosion rates or even accretional trends in the near term, long-term results indicate that more than 50% of the ocean-side shoreline of these Islands will experience erosion.

4.5.3.2 Impacts on Coastal Ecosystems

Coastal ecosystems such as coral reefs have been found to respond to increasing sea surface temperature through bleaching events. Following reduction in human impacts, coral cover in the Gulf of Mannar (south-eastern coast of India) increased till the first bleaching event in 2010 when the coral cover dropped from an average of 42.9% (SE+2.4%) in 2009 to 33.2% (SE+2.3%) in 2010. A second and larger bleaching event occurred in 2016 with an average bleaching of 23.9% (SE+2.3%) of the corals. Following this second event, the reefs in GoM suffered significant reductions in coral cover and increased levels of macroalgae. A multivariate analysis of the benthic communities showed a regional shift in benthic community structure over time, including changes in the coral communities. Digitate forms of Acroporidae (ACD) (predominantly *Montipora digitate* and *M. divaricata*) underwent the greatest mortality over time whereas the encrusting form of Acroporidae (ACE) (*Montipora hispida*) and sub-massive corals (CS) (*e.g*. *Platygyra sinensis*, *Symphyllia radians*) had increases in coral cover. This reflects the differences among coral types in tolerance to bleaching events and is an important component in understanding reef resilience.

4.5.3.3 Impacts on Marine Fisheries

India's Exclusive Economic Zone has a potential of 5.31 million tons for conventional fishery resources and 1.85 million tons for non-conventional resources. The region within 100 m depth zone is currently fully exploited with little scope for near-shore expansion and hence potential in deeper waters needs to be explored. The fishery potential of India's Island territories is quite untapped. Most of the island resources are constituted by high-value fishes such as tunas and allied species, barracudas, bill fishes, elasmobranchs and squids. The development priorities in fisheries in the islands are quite different from that of the mainland. Islanders are mainly dependent on the reef and deep-sea resources for their livelihood.

The fish populations are affected primarily by changes in the environmental conditions (Figure 4.39). Varying environmental conditions can induce changes in foraging, growth, fecundity, metamorphosis, endocrine homeostasis and migratory behaviour of fish species. Changes may be at the population and community level due to effects on performance, patterns of resource use, and survival. Climate change has direct effects on fish stocks and productivity and indirect through changes in the diet and habitat.

Sea Surface Temperature (SST): Trend analysis during the last 40 years has shown that SST is increasing over the period (Hossain et al., 2015). An increase in temperature will reduce the amount of dissolved gases in liquid, and a decrease with leads to the expansion of the low oxygen zones in the water.

pH (Ocean acidification): The pH in the Bay of Bengal (BoB) has fallen by 0.2 units between 1994 (pH 7.95) and 2012 (Bandyopadhyay, *et. al*., 2013). This can decrease the calcium carbonate saturation which threatens calcareous marine organisms. The study's results indicated that the chemical composition of shells and oysters was reduced by 17% (the range varied from 7-22% from a standard composition of those species).

Sea Level Rise: Rising sea levels will lead to the submergence of important coastal habitats such as mangroves which act as a buffer between the sea and land as well as serve as spawning and nursery grounds for commercially important fin and shellfish species.

Sea Surface Salinity (SSS): Ocean salinity varies regionally and is dependent on the balance between precipitation and evaporation. Hence, the eastern Indian Ocean (Bay of Bengal) is less saline than the western (Arabian Sea). Salinity changes affect osmoregulation in marine species.

Rainfall: The Indian monsoons are related with the El Niño and La Niña. The warm phase (El Niño) is associated with weakening of the Indian monsoon, while the cold phase (La Niña) is associated with the strengthening of the Indian monsoon. Studies on the change of rainfall pattern over India by the Indian Meteorological Department identified changes in the frequency of days of rainfall with different intensities for various geographical regions of India. Significant change/turning points are also detected in the southwest monsoon rainfall. Reports also indicated a reduction in the frequency of moderate rainfall events (5 mm ≤daily rainfall<100 mm) during the period 1951–2010 over the monsoon core region of India (Guhathakurta et al., 2015).

Chlorophyll: Changes in chlorophyll composition, which are the primary producers will affect the fish species composition and catch availability. These are influenced by the availability of nutrients in the ocean. The decadal seasonal analysis of chlorophyll concentration in the Arabian Sea and the BoB has been studied by Shah *et. al*, 2017. It was observed that there has been an increase in chlorophyll concentration in both the Arabian Sea and the BoB from 1980 to 2000's with respect to a gradual increase in SST. The chlorophyll values ranged between 0.5 to 1.3 mg m^{-3} in 2000's which was 0.4 to 0.9 mg m^{-3} in 80's. The chlorophyll values in the BoB which were 0.2 to 0.5 mg m^{-3} in 80's have increased to 0.5 to 0.7 mg m^{-3} in 2000's (Shah et. al., 2017). Singh and Chaturvedi (2010) studied the chlorophyll variation in the Arabian Sea and the BoB and concluded that the Arabian Sea was found to be higher in chlorophyll concentration compared to the BoB. Reduced chlorophyll concentrations in the BoB was attributed to the increased SST, a strong stratified layer which could not be easily broken by weaker winds over the BoB, thus leading to reduced nutrient availability (Singh and Chaturvedi, 2010).

The impacts of climate change on fisheries and aquaculture occur as a result of both gradual atmospheric warming along with associated physical and chemical changes in the aquatic environment. Most marine fishes are adapted to a narrow range of temperatures related to their metabolic activities and food availability. An increase in SST of 1^0C will increase the metabolic activity by 10%. These changes in metabolic activity will induce changes in the distribution and abundance of fish stocks (Zacharia et. al., 2016). Changes have been observed in the diet composition of Indian mackerel (*R. kanagurta*) as an impact of climate change, from a diet dominant in zooplankton and copepods in 1960-61 to a diet dominant in phytoplankton consisting of coscinodiscus sp. in 2011-2014.

The SST anomalies greater than the summer maxima seem to impact the spawning of many marine fishes. Fish species tend to shift their spawning seasons to cooler months in order to avoid temperature anomalies. The threadfin breams, which are short-lived, fast-growing and highly fecund species are seen to have a shift in a spawning season when SST exceeds 29^0C. Data on the spawning of *N. japonicus* indicate that during the warm months (April- September) of 1981-1985, there occurred 35.3% spawners, which were reduced to only 5.0% during 2000-2004 for the same months. It was also observed that the percentage of spawners increased to 95% during October-march (coolest months) in 2004 which was only 65% during 1985 for the coolest month (Rao, 2011).

In relation to climate change, marine species either extend their distributional boundary or shows a latitudinal shift. Catfishes that were earlier distributed between 8ºN and 14ºN latitudes (southwest and southeast coasts of India) showed a reduction in catch from 35,000t to 7,800t as the SST in the southern latitudes exceeds 29ºC. In the same way the catch increased from 16,000t to 42,500t in the northwest and northeast coasts of India for the same period as the SST in the northern latitudes ranged between 27ºC and 28.5ºC (Rao, 2011).

False Trevally, a commercially important fish of India, was usually found along the Rameshwaram coast of southeast India and also at depths ranging from 15 to 90 meters. But during the past decade, the catch of this species declined as it moved to other coasts including the east coast of Sri Lanka (Rao & Vivekanandan, 2008).

The tropical coastal and small pelagic fishes such as the oil sardine, *Sardinella longiceps* and the Indian Mackerel, *R. kanagurta*, that form the major share of the Indian marine catch, were found to have a restricted distribution between latitudes 8ºN and 14ºN and longitude 75ºE and 77ºE (Malabar upwelling zone along the southwest coast of India) when the SST ranged between 27ºC and 29ºC. The catch of these two species is found to have increased between 14ºN and 22ºN latitudes but without any reduction in catch from the Malabar upwelling zone, indicating that this is a distributional extension and not a distributional shift (Rao, 2011).

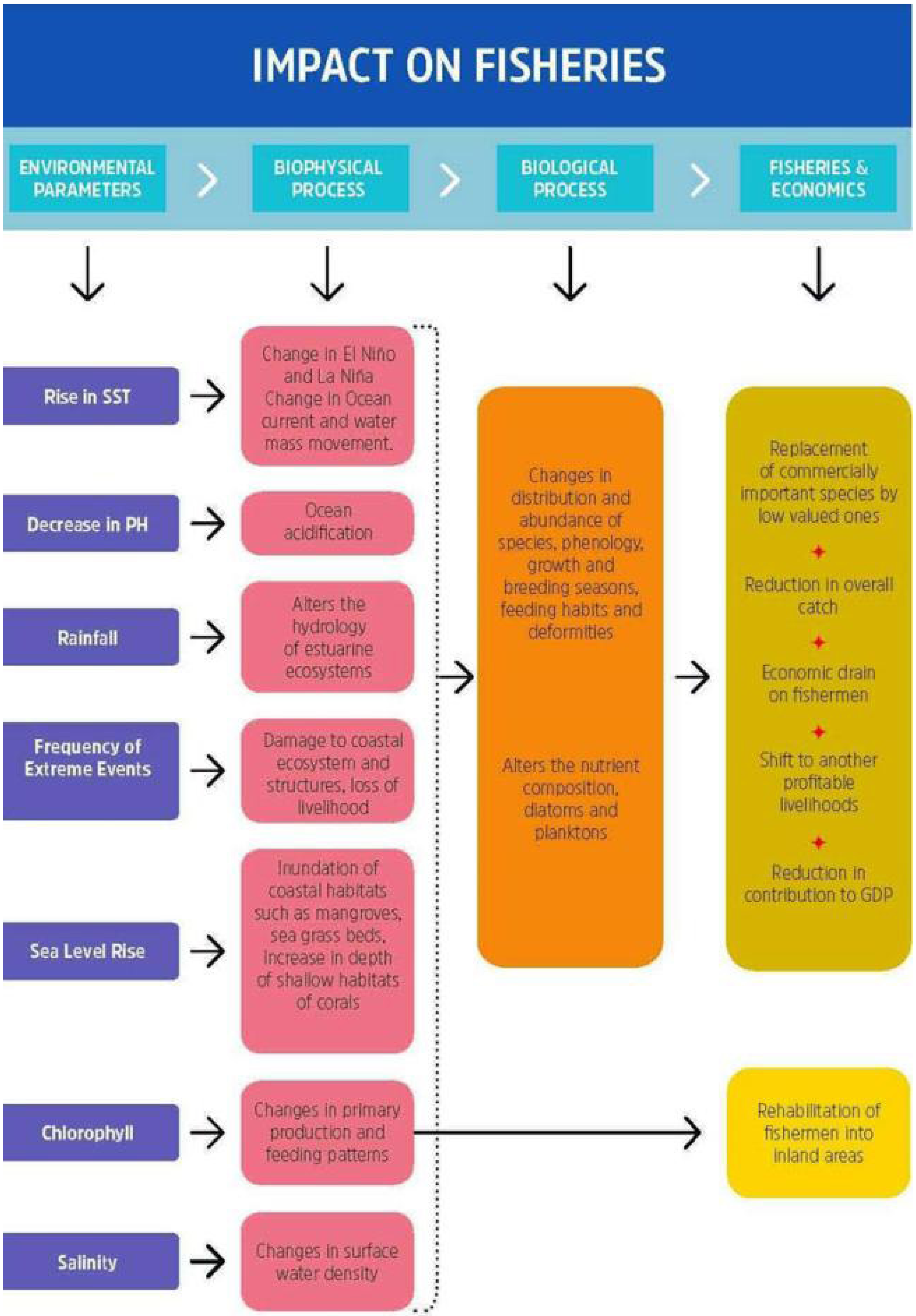


Figure 4.36: Impact of Climate Change on Fisheries

Climate change impact is likely to affect already vulnerable fisheries and ocean-dependent communities through less stable livelihoods, changes in the availability and quality of fish for food, and rising risks to their health, safety and homes. Since marine fishing communities stay close to the seashore or along estuaries, coastal erosion as well as increased extreme events such as storms and storm surges can affect their homes as well as craft and gear which are often stored by the sea. In India, 70% of the catch is by 30% of the mechanized boats; the remaining 70% of the boats are small scale/artisanal catching only a third of the total catch - which translates to a high population dependent on the resources. Thus, small-scale fisheries sector comprising artisanal and subsistence fishers will be the most vulnerable one as low and irregular income from fishing activities lead to poor adaptability to the economic effects.

4.5.4 Adaptation framework

4.5.4.1 Adaptation to coastal flooding/ erosion

There are a number of options for adaptation to rising sea levels that cause coastal flooding. These include natural solutions such as the expansion of the area under mangroves and artificial solutions such as the building of seawalls. This has been the preferred response in the case of the Lakshadweep islands.

For Andhra Pradesh, the cost of building a seawall was estimated for the total coastal stretch of 980 km by assuming the unit cost as a running foot of the wall of height 7 feet (3ft. below the ground & 4ft. above the ground) using Reinforced Cement Concrete (RCC). The capital, maintenance and repair costs were estimated to be about INR 122.1 crores. The benefit-to-cost ratio is presented in the Figure 4.37.

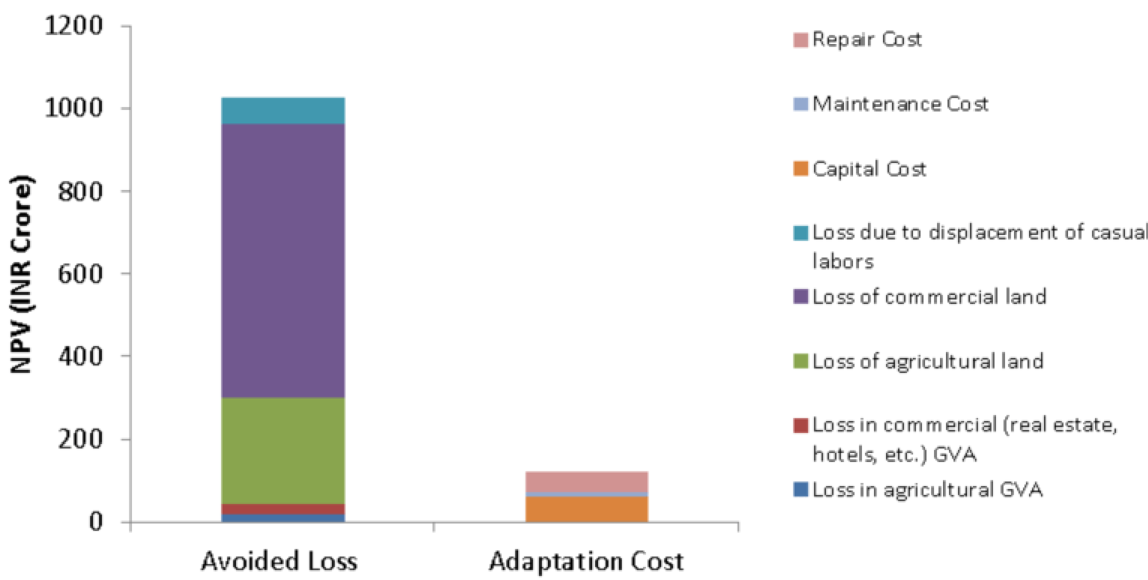


Figure 4.37: Benefit to Cost Ratio

There are limitations to this adaptation methodology as it may not be required for the entire stretch of the coast or be appropriate where there are other options available such as natural ecosystems that act as buffers. Also, engineering approaches can have large-scale environmental consequences. However, this estimate is just indicative of the fact that losses can be high but can be avoided through appropriate adaptation measures.

In the case of the Islands, the adaptation framework to be developed has to be holistic following a cluster approach. In Lakshadweep, each island has its constraints. Certain infrastructure facilities which cannot be established in all islands are to be utilized by other islanders. For instance, due to limited land availability, it is not possible to establish an airport on all the islands, therefore an airport on one strategic island can serve as a common airport for a cluster of islands. Similarly, the management approach of the island has to take into account both the land and the marine areas (lagoon and sea). Some examples of adaptations are given in the Table 4.8 below.

Table 4.8: Adaptation interventions for specific vulnerabilities (Lakshadweep Islands)

Sector	Vulnerabilities	Recommended adaptation interventions
Agriculture	Lack of nutrients in the Island soil	Use of sludge from Sewage Treatment Plants (STPs) as manure, post construction of STP in the islands.
	Inadequate irrigation facilities	Use of recycled waste water for irrigation after construction of STP in the islands.
Fisheries	Overfishing of live bait fishes from the reef area	Restrictions on the use of nets.
		Respect and use local knowledge: Avoiding use of certain species. (*e.g.,* locals of Minicoy Island are against the use of certain bait fish varieties like Gumbala (clupeid) and Phitham (silver sides). They consider that these varieties are harmful to tuna and tend to avoid using them). This must be followed by fishermen from the other Islands of Lakshadweep.
	Lack of storage and processing facilities	Establishment of adequate storage spaces and ensure immediate marketing of fish and fish products.
Sea Level Rise	Erosion	Designed underwater breakwaters/artificial reefs.
Coastal Ecosystems	Reduction in number of coral species	Coral transplantation, coral garden; establish no-fishing zones/closed seasons and limitations on fishing gear.
	Seagrass ecosystem decline	a) encouraging natural recolonization and by transplantation of mature seagrass plants taken from healthy donor beds.; establish no-fishing zones/closed seasons and limitations on fishing gear.

4.5.4.2 Adaptation in Coastal Ecosystems

Studies have shown that different coral species respond differently to rising temperatures. Hence coral transplantation for the recovery of reefs takes into account this aspect by using resistant and resilient species. However, other factors are also found to contribute to a reef's ability to withstand bleaching and need to be studied further.

4.5.4.3 Adaptation in the Fisheries Sector

A number of adaptation actions have been identified and include the following:

- Public awareness to enhance the protection of coastal and marine ecosystems;
- Mangrove mapping, conservation and restoration;
- Habitat mapping and modelling;
- Vulnerability assessment along Indian coastal zones and conservation;

- Monitoring, control and surveillance;
- Promoting aquaculture along with resilient strategies/cage farming;
- Cultivation of halophytes;
- Green fishing protocols for carbon footprint reduction;
- Intensification of seaweed farming along Indian coastal regions;
- Develop knowledge base for climate change and marine fisheries;
- Adopt code of conduct for responsible fisheries;
- Enhancing co-operation and partnerships;
- Evolving common platforms and sharing best practices;
- Protection and conservation of coral reefs, mangroves, sea grass and littoral vegetation

4.5.5 Economic cost

A wide range of estimates exist regarding the economic losses and damages caused by climate impacts to the Indian economy. Isolating the climate component of total losses due to extreme weather events continues to remain a challenge. It is critical for developed countries to fulfil their commitment in providing adaptation finance to minimize further losses, and adequate compensation for unavoidable loss and damage. The potential economic losses of coastal inundation due to SLR, from 2015 to 2050 with mean sea level anomaly with respect to 1970-2010 were calculated with the impact calculation with estimates confined to the agricultural and commercial sectors (in the real estate sector). Evaluation of impacts is based on the assumption that the impact of SLR will affect the different sectors in the same proportion as per the land utilized across different sectors. Permanent losses include loss of agricultural and commercial land. Productivity losses include loss of agricultural productivity, commercial productivity and loss due to migration of casual labour.

Economic losses estimates presented here should be considered at the conservative side, as there are other impacts such as health, infrastructure damage that can be valued to better evaluate the benefits of investments in adaptive measures.

Case studies

Two case studies were commissioned and are presented in the boxes below.

Box-3: Effect of Elevated Sea Surface Temperatures on Giant Clams

- Giant clams act as excellent surrogate for coral reef ecosystem since these are also affected by Elevated Sea Surface Temperatures (ESST). A case study was carried out on the effect of ESST on *Tridacna maxima* (giant clam) populations across three islands *viz*. Agatti, Bangaram - Tinnakara and Kavaratti in the Lakshadweep archipelago along with predictive modelling on the impacts to its population under various scenarios.
- Study found mean summer SST > 30 °C triggered *T. maxima* bleaching. Time-series analysis of SST data (1965–2016) indicated increasing incidence of anomalous temperature (β=0.09 ± 0.04SE); but SST anomalies did not cause immediate clam mortality.
- Population density showed large inter-annual variations that were synchronous between reefs. Population growth models showed a stable density trend after 50 years under past bleaching incidence (20%yr^{-1}), but declining density (R=−0.05 ± 0.02), high risk of quasi-extinction (0.31–0.61 across reefs), and low density (geometric mean: 9–15 individuals ha^{-1} across reefs) under the prevailing high bleaching incidence (40% yr^{-1}).
- Study concluded that climate change-induced frequent SST anomalies are likely to compromise the viability of giant clam populations. Mariculture of clams for reintroduction/restocking should be considered an important intervention to secure the species.

Box-4: Status and Health of Coral Reefs of the Gulf of Mannar and Palk Bay

- The Gulf of Mannar (GoM) and the Palk Bay in South Eastern India are two of the four major reef areas in India and have in the past suffered significant damages from direct human activities such as coral mining and destructive fishing practices as well as indirectly from pollution and land-based sedimentation leading to poor water quality.
- A case study was carried out on the impacts of climatic and non-climatic stressors on the status and health of coral reefs of the GoM and the Palk Bay, which also included modelling elements to predict future reef status.
- After the stoppage of destructive processes, reef recovery in the GoM was documented till 2010 when a minor bleaching event was recorded. A massive bleaching event in 2016 resulted in an average bleaching of 23.9% of the corals, but subsequent recovery was observed.
- Surveys revealed that there were differences in coral response to heat stress (degree of bleaching) and in their ability to recover after bleaching among the islands and the different coral species.
- A predictive model has been prepared regarding future bleaching events in the GoM. For coral reefs, projection layers have been developed for RCP 4.5 and RCP 8.5 in near-time and longer-term time periods to enable coral reef management
- The model identifies priority locations where the reefs are predicted to suffer from severe annual bleaching.
- Under a 'business as usual' emissions scenario (RCP8.5) all islands in the GoM will experience annual severe bleaching (ASB) prior to 2070 and bleaching twice per decade prior to 2060. The onset of ASB showed a clear east to west gradient, with reefs towards the Eastern end of the GoM all predicted to experience ASB before 2045.
- The reduced emissions scenario RCP4.5 has clear ameliorating effects, and it shows that the majority of islands will not experience ASB between now and 2070.
- Coral transplantation for reef rehabilitation can be done with resistant and resilient species to fight the impacts of coral climate change.

4.6 Urban Ecosystem and Infrastructure

The changing climate is posing unprecedented challenges to existing human and economic activities, natural ecosystems, and man-made ecosystems in many ways. Firstly, it is creating new risks for their existence as well as safe and economically viable operations. For instance, infrastructure assets are planned with some visibility of magnitude and type of potential climate induced risks (Hallegatte, 2009). However due to climate change, new dimensions are being added to the risk profile of these assets. Climate is changing the conceptual basis of risks and some specific risks may become more critical for the asset in future, which are either not visible today or do not hold importance in the basket of risks that the asset currently faces (Stern, 2007). Secondly, climate change appears to exacerbate the existing risks faced today. Thirdly, climate change threatens the usable life span of assets, products and even services. Regulatory or product and technology risks could make the asset redundant sooner than the planned lifespan or physical risks could reduce the usable life of the asset. Finally, it creates allied risks that arise out of disruptions in network of infrastructure such as supply chain risks. Risks can only be managed and cannot be eliminated. The palliative financial burden could be huge and economic implications can only be evaluated till the first or the second order and therefore the total indirect palliative impacts may be lower than the actual losses that many sectors and regions may face.

4.6.1 Infrastructure Assets and Climate Change

Infrastructure is generally immobile and made up of large and lumpy physical assets such as flyovers, bridges, buildings, roads, power plants, transmission lines, piped networks, cable lines, towers, etc. It is vulnerable to changes in the incidence and variability of climate-induced natural calamities as it is exposed to natural weather situations (Naswa & Garg, 2011) and has a very locale-specific context in the climate change discussions. Thus, it becomes vital to understand the risks, impacts, vulnerabilities, and adaptation needs for the infrastructure sector.

National Institute of Transforming India (NITI Aayog) has noted that India spent an average 4.7% of its GDP on infrastructure building during 1992-2010 as compared to countries like China, Indonesia and Vietnam which spent 7.3 percent of their GDP as infrastructure investment (NITI Aayog, 2015). Hence, there are large investments being planned for the infrastructure sector in India. Union budget 2017-18 allocated Rs. 3,96,135 crores in creating and upgrading infrastructure for next fiscal year (Bhaskar & Sood, 2017). Actual capacity needs and the investment thereof may be much higher than these planned investments.

Box-5: Case of Domestic Coal Supply Chains on Power Generation in India

The study explores the implications for coal supply chains linked to electricity (power) generation. The study was undertaken to understand the components of the coal supply chain from mine to power plant. On the mine end, inundation has been reported as one of the primary reasons for disruption and disasters in coal mines. Again, there have been evidence of supply chain disruption due to flooding of tracks which has resulted in coal flows to power plants. The least disruption has been noted at the power plant end.

The coal supply chain is more likely to be affected as more frequent and severe natural disasters may damage mine, energy infrastructure and equipment. Heavy rain and erosion affect the slope stability near opencast mines. Hotter and drier conditions tend to increase the risk of coal catching fire. Some of the adaptation strategies may have a comprehensive management system to address climate adaptation: some of the mining companies have set up management processes that facilitate integrated management of climate impacts. Strengthening infrastructure related to coal handling processes, siding and road especially during the monsoons for opencast mines may be suggested. Another adaptation strategy may be having comprehensive pumping systems. As many countries have already adopted the floating pump concept, this will help in the near future when the rainfall exceeds the moderate 40-60 mm daily on a continuous basis.

The supply chain and distribution routes for the coal is mainly dependent on rail transportation. Natural disasters and heavy rainfall are likely to disrupt railway routes, especially the tracks, bridges, rolling stocks and degrade roads. Maintenance of tracks and bridges, especially of dedicated heavy haul corridors may be able to address some of the issues.

In the case of the power plant end (i.e. the end of the supply chain at the coal yard), impacts of increased precipitation affect the unloading of coal and its quality due to higher moisture content. Thermal plants may need to have higher buffer inventory to overcome monsoon demands. In the coal supply chain, the power plant is the least affected due to climatic change. Higher rainfall leads to increased moisture content of the coal and has been historically associated with reducing coal inventories.

Transport infrastructure is a critical sector that faces the challenges posed by the weather and climate. The performance of transport systems deteriorates under adverse and extreme weather conditions.

Ports being located on the coasts face peculiar climate change impacts. Their location makes them one of the most vulnerable infrastructure assets predisposed to sea-level rise, amplified storm activities, and increased flooding if they are situated at the mouth of a river (Becker, et al., 2012). The literature indicates storm surges and increased sea-levels have the most potential direct impacts on the ports and their operations. However, the magnitude of these impacts and other direct, as well as indirect impacts of climate change on a port, depend on its location and topographical nature of the area where the port is located (Wright, 2013). Increased temperature extremes are also expected to impact the port infrastructure and hence its operations. The thermal expansion of metals used in machinery like cranes may impact the operational efficiency of the port. The warehouses and other subsidiary infrastructure may also need to be redesigned to withstand the higher temperatures. More cooling requirements or enhanced cold supply chain needs may come up for storage of goods in transit. Ports need their employees to primarily work outdoors. Thus, higher temperatures may alter their efficiencies as well as the ports operational requirements. Other than these direct impacts, there will be several other indirect impacts of climate change on the ports. It is also important to note here that the impacts not just on the port but also on the entire supply chain have a bearing on the performance of the port. Any disturbance anywhere in the entire supply chain right from the loading port to the landing port and further downstream to client point has an impact on the evacuation of goods from the port.

Box-6: Case of Port Infrastructure

This study identifies the climate change parameters that impact the two ports of Kandla and Vishakhapatnam. Located on the western coast in the state of Gujarat and established in 1955, Kandla is the largest major port in the country by the volume of cargo handled. Located on the eastern coast, facing the Bay of Bengal, Vishakhapatnam (Vizag) in Andhra Pradesh and established in 1933 has been the second largest major port in terms of volumes of cargo handled. Hence, the vulnerability of these 2 ports have been assessed.

A vulnerability index was created to assess the impacts of cyclonic activity and heavy downpour using system condition variables (SCV), sustainable development variables (SDV) and climate change variables (CCV) as described in (Garg, et al., 2007). Vulnerability Index range of both the ports shifts towards the right under various RCP scenarios for the future, indicating the mean value becoming higher.

With appropriate and timely adaptation measures, the impacts of vulnerability of the ports to changing climate may be reduced. Beach nourishment, vegetation management, use of sandbags, seawall/ breakwater is some of the measures that may serve for reducing the impacts of sea-level rise as well as buffer against changing rainfall and cyclonic movement patterns. Costs involved in mangrove plantation along the coast near Vizag and Kandla ports as well as beach nourishment at Vizag have been calculated for this study.

Railways is another crucial transport infrastructure that serves as the backbone of an economy. India has the fifth largest and most densely used rail network in the world. Its network carries 19,000 trains each day (passenger and freight) and connects 8,000 stations. On an average day, Indian Railways traffic comprises 23 million passengers and 3 million tonnes of freight. The infrastructure of the Indian Railways is vulnerable to the effects of a changing climate.

Box-7: Case for Railways Infrastructure

This study analyses the major climate risks and potential for climate adaptation measures for the Indian Railways network for future time periods under different climate scenarios. The study is significant because it provides information about required adaptation measures given the changing nature of climatic threats.

For this project, the Indian Railways infrastructure such as stations, bridges and track, that are potentially vulnerable to extreme climate events, were digitized and mapped using Google Earth data. The mapping includes 565 major bridges and 803 major stations.

Landslides: Landscape susceptibility analysis was conducted specifically for Konkan Railway, Northeastern Frontier Railway and Northern Railway. The entire Konkan Railway is found to be highly susceptible to landslides. In other zones, the railway lines in the Jammu and Kashmir region, and the lines in the Uttarakhand and Himachal Pradesh region are susceptible to landslides.

Temperature: The highest increase in maximum summer and winter temperatures will be seen in Northern Zone. The number of extreme hot days is also projected to increase in future climate scenarios. The frequency of hot days is up to 20 days and 50 days in a year on an average in RCP 2.6 and RCP 8.5 scenarios respectively. Southern Railway zone is the most affected zone.

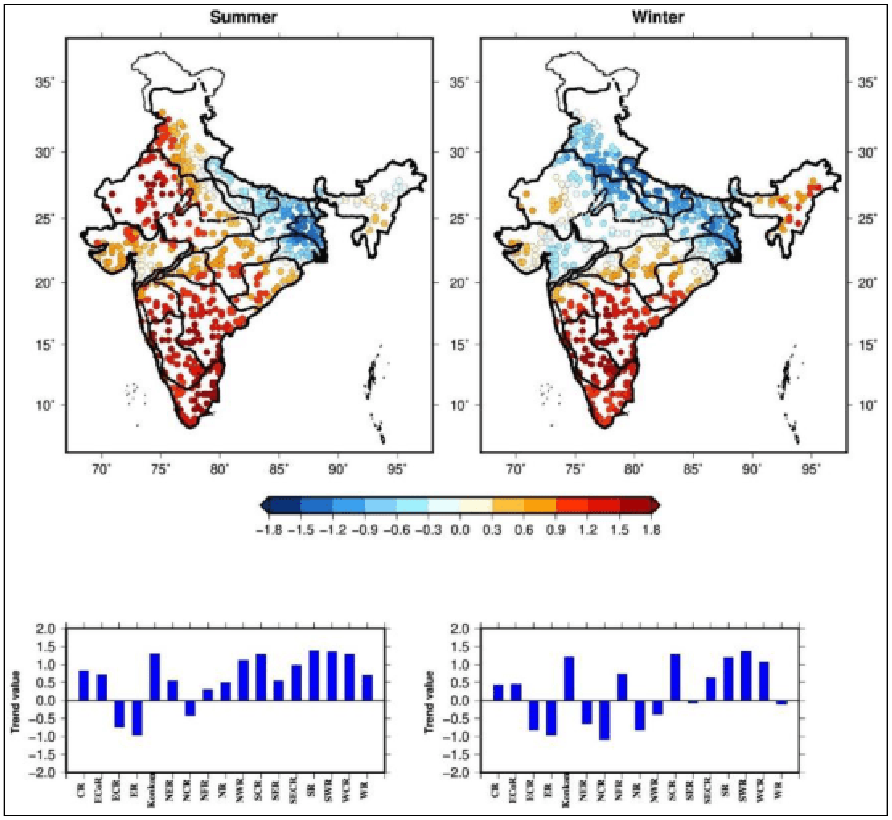


Figure 4.38: Trend of maximum temperature at major railway stations across India

Precipitation: The historical frequency of extreme precipitation days ranges up to 15 days in a year on an average and is highest for Northern Frontier railway zone and East coast railway zone. The change is up to 2 and 4 days in the far future for RCP 2.6 and 8.5 respectively. The difference is significant in the North Frontier railway zone in RCP 2.8 condition. While for RCP 8.5, change is notable for the East Coast, North Frontier, and Southern Railway zones.

Floods and Cyclones: In terms of prevalence, the infrastructure impacted by floods is much higher than the infrastructure impacted by cyclones. Floods cause damage by disrupting operations and causing accidents on railway tracks. Both floods and cyclones can damage railway infrastructure (tracks and bridges) and can cause accidents that lead to loss of life and lead to impacts on regular operations. There is an increase in the hazard index across all scenarios. While the increases in hazard index are modest in the near future (less than 10 points) across all zones, high increases in hazard are seen in Eastern, East Central, North Eastern, North Frontier, South Eastern and Southern zones in far period especially in the RCP 8.5 climate pathway. economic impacts have been estimated using historic accident data, and future projections for traffic and accidents based on the future hazard index at the level of the Railway zone. The projected costs are expected to rise sharply in the future in all zones if Indian Railways does not take appropriate adaptation measures.

Fog: Fog poses risk by disrupting railway operations. Trains have to operate at slower speed during fog and low visibility conditions, causing reduction in line capacity. Many trains are also cancelled each year because of fog issues. In this study, all tracks are classified into whether they are fog impacted or not.

Adaptation: The Indian Railways can take adaptation measures at the zonal level to reduce the impacts of floods and cyclones. Based on assumptions of costs and benefits from improved infrastructure, the study calculates the potential economic impacts of adaptation measures for Indian Railways in near future. Adaptation to fog requires improves signalling and telecommunication equipment in the Indian Railways, especially in the regions impacted by fog. Improved signalling techniques, such as upgrading from LED based navigation (which works well in high visibility) to laser-guided decision-making can improve the efficiency of train movement during low visibility conditions. Modern technological solutions, such as that used by autonomous vehicles, could further help drivers visualise the external environment (through low-light cameras etc.) on screens built into the train, without having to look outside in foggy environments.

The priority of investment is determined based on the magnitude of returns to railways. Four zones (East Central, North Central, North Western, South Western) are high priority zones for flood and cyclone adaptation. Central is a medium priority zone. The Railways may also invest in adaptation for East Coast, Northern and West Central zones if funding is available.

Cities are not just contributors to but also bear the brunt of climate change. Thus, urban infrastructure consisting of local transport network of streets, flyovers, bridges, streetlights and street furniture, bus and train services, water supply and waste water, drainage and solid waste management networks, gas and heat networks, communication and fibre optics networks alongwith the social infrastructure like public health centres, schools, and parks and gardens, also face heightened climate change impact concerns due to their immobile nature.

The cities located on the coasts face the threats of land inundation, saline water intrusion, coastal erosion, degradation of the dunes, flooding, storm surges and degradation of natural barriers and buffers like mangrove swamps. A number of major cities are located in low-lying areas and thus, are vulnerable to flooding. India has a long coastline of over 8,000 km. Almost 130 towns and cities on the coast and a total of around 260 million people living within 50 km of the coast are threatened by sea level rise.

A recent study suggests that the 1 and 3-day concurrent hot day hot night (CHDHN) events have increased significantly in India between 1984-2016 as compared to 1951-1983 (Mukherjee & Mishra, 2018). The number of hot days and frequency of heat waves are expected to increase due to climate change, leading to heat-induced health impacts and mortality. Moreover, cities are heterogeneous in nature with varying microclimates and the land use mix has an impact on heat induced relative mortality risks. A recent study describing the case of Ahmedabad, found impacts of localized temperature variations on mortality risks. The study also infers that with increase in built-up spaces by 1% in the land use mix, the relative risk of heat related mortality increases by 0.59 points at 40°C and by 0.78 points at 45°C (Avashia et al., 2015). Another study has examined the role of land use in experience of thermal comfort for Bengaluru. Their results showed that the average urban green spaces provided local cooling effects till points 347 m beyond its boundary and that an average green space was almost 2.23°C cooler than the point where it ceased to provide cooling effects (Shah, et al., 2021).

Box-8: Case Study on Inclusive Urban Housing

The potential synergies between resilience and sustainability, are important for a large developing country like India. Further, there are also potential synergies between the agendas for reducing poverty and inequalities and increasing climate change resilience in cities of the developing countries. Adequate, affordable and climate resilient housing is one strategy that can help to build resilience of communities. Improved resilience through housing can also have positive links with mitigation efforts in the cities. Thus, this study looks into inclusive urban housing as a strategy to bring in climate change resilience for the case study of Ahmedabad city. This study focusses on housing from the affordable housing programmes and schemes funded by any or all three levels of government and compares and contracts with a control group from the existing self-constructed housing by the urban poor, mainly the slums, *chalis* and pavement dwellings.

Rapid growth and development, increasing urbanization, frequent high heat waves experienced in the city have increased heat hot-spots in cities. The results clearly show that residents of informal housing and pavement dwellers experience significantly higher temperatures indoors compared to their formal counterparts. In some cases, the difference is as high as 8°C. The influence of microclimate variables was more significant on temperatures outside the house (in shade) compared to indoor temperatures. The main reason, in case of informal and pavement dwellers could be the building materials made up largely made of heat trapping corrugated tin sheets. Other factors such as low insulation and congested neighbourhoods were found to exert significant influence on indoor temperature. The vulnerability of these households is further aggravated due to low incomes, lack of legal tenure, poor access to basic infrastructure and absence of cooling devices (fans).

This study informs the following key policy findings. Formal housing is an important intervention to enhance resilience to heat impacts and should be prioritized in urban policy at the national level and in urban development plans. Initiatives undertaken under the Heat Action Plan of Ahmedabad or housing strategies adopted under national programmes should prioritize pavement dwellers and informal housing while dealing with the issues of climate change and heat. Urban heat resilience requires a comprehensive approach – mainstreamed in urban policies, planning and design that collectively influence built form and green cover. Formal housing is a long-term solution requiring co-operative efforts between the public and private sectors. Simultaneously, intermediate and relief measures for residents of informal housing could include financial assistance for incremental improvements for adaptation to heat, as suggested through the retrofitting strategy.

The other set of risks for cities comes in terms of heavy precipitation events leading to flash floods and riverine flooding which may result in property and infrastructure damage, water logging and pollution, disruption of business and livelihood, and escalation in water-borne and water-related diseases. The city anatomy containing the constructed areas such as buildings, roads, infrastructure and other paved areas act as a barrier for rainwater to percolate into the ground leading to increased runoff (Satterthwaite et al., 2007).

Box-9: Case Study on Urban Floods

The changing climate poses threats of various types of extreme precipitation events that can cause flooding in urban areas and hence hinder the daily lives of the citizens. This study here identifies the specific climate change as well as urban development parameters that impact the urban flooding situation for 5 cities in India across size-class and climate zones namely- Indore, Surat, Agartala, Bengaluru, and Shimla.

In order to understand the economic implications, the municipal budgets of these cities were examined. A range of budget shares for preventive and palliative activities related to flooding as part of the total budget can be observed here. For large cities like Bangalore and Surat, the budget is 20 to 25 times higher than that of smaller cities like Agartala and Shimla. Moreover, the share of the budget being spent on preventive measures as well as palliative activities related to flooding concerns is also 3 to 5 times higher.

Further, three future scenarios were generated over and above the business-as-usual in order to capture high, medium and low urban growth. The budget share requirements for selected cities under all growth scenarios as well as RCPs were computed.

The share for preventive and palliative measures in the budgeted expenditure for the selected cities rises under all the RCPs and growth scenarios. For Bangalore, from current 1.56 %, the spending may go up to 2.74 %. However, for Agartala, the spending may increase 2.5 times from 0.04% to 0.10% under certain scenarios. In case of Shimla, the rainfall pattern shows a significant leftwards shift. Thus, the required spending in future on flooding prevention may decrease further in addition to the effect of the topography of the city.

Further, the flood risks increase in the cities since urban development alters the hydrological and hydro-meteorological environments. Climate change-related precipitation changes are an added complexity to the flood risks of cities. Thus, as described for urban heat land use has a significant role to play in urban flooding as well. 47 cities in India were analysed by a research study to assess their land use change over past 3 decades at mapping accuracy ranging from 81 to 93% (Avashia et al., 2020). They find that during 1990, agriculture comprised of the highest share within existing municipal limits at 32.37%, built-up area at an average of 25.46% was the second largest share. The urban built-up area has increased to occupy 46.09% of the land spaces within the municipal boundaries of these 47 cities in 2010 and 47.97% in 2017.

Box-10: Case of Land Use Transitions and Urban Flooding

Flooding is the most frequently occurring disaster globally and is responsible for 43 % of the total events recorded between 1998 and 2017. The intensity and area affected by floods are expected to increase across India because of climate change. Land use change is a pivotal factor of flood risk management. This study examines the relationship between changing land use patterns and flooding events. We restrict the scope of this study to 42 major cities across India based on land use data from 1990, 2000, 2010, and 2017 from remote sensing. The timeline considered here for the future assessment is 2016–2050 (near term) because in urban-level exercises, projections into the long-term future (2100s) may prove unrealistic. Future projections of the occurrence of flooding events for nine models under three climate change-related Representative Concentration Pathways (RCPs)—2.6, 4.5, and 8.5—and three urban development scenarios were carried out. The results suggest that cities should preserve the land uses that act as a sponge—the green, open and blue spaces. As these spaces decrease, the projected flooding events increase. Under the RCP 2.6 scenario, the number of flooding events is significantly lower (95 % confidence) than under RCPs 4.5 and 8.5 (Figure 4.39). The expected flooding occurrences between RCP4.5 and RCP8.5 are not significantly different (95 % confidence) for many scenarios, this study highlights the need for Indian cities to undertake integrated spatial planning measures for a resilient, sustainable urban future.

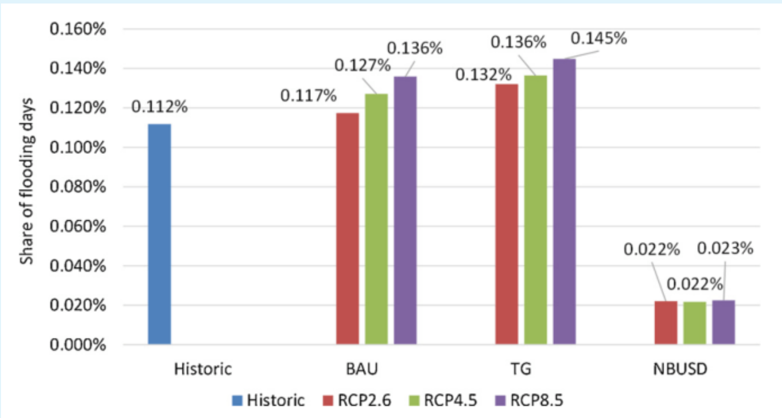


Figure 4.39: Historic and projected flood incidences across scenarios

4.6.2 Understanding and Quantifying the Risks, Impacts and Vulnerability

Vulnerability to climate change is the "degree to which a system is susceptible to, i.e. propensity or predisposition to be adversely affected, adverse effects of climate change including climate variability" (IPCC, 2013).

The rapid expansion of Indian cities, driven by increase in population and urban development has placed increased stress on the demand and supply of necessary infrastructure services, that already face gaps. This developmental pressure on urban systems hinders their ability to adapt to climate change and affects the resilience of the cities to the climate change.

An Urban Vulnerability Index that can help identify and target climate vulnerable regions, sector or populations, raise awareness, and can contribute to a monitoring strategy and would periodically indicate the state of climate vulnerability in urban areas in various states/UT in the country. The urban vulnerability index may serve as a decision support system to the Government of India for devising adaptation and mitigation strategies for urban sector in India.

Box-11: Case of Urban Vulnerability Index for Cities

A study aimed at designing a climate vulnerability Index for 6 Indian cities- Delhi, Mumbai, Chennai, Bangalore, Shillong, and Srinagar was conducted in order to understand and assess the respective vulnerabilities and risks incurred by a city. The cities were shortlisted on the basis of their geographical location, population, ecosystem types (coastal region, hilly region, flat terrain) and recent encounter with hazards/ hazard trends and the severity caused/ impact of the same. The selection of hazards for each city is done in terms of its relation to climate change. For each city two Major hazards are chosen on the basis of the severity. Additionally, methodology was developed and tested for developing the Climate Vulnerability Index framework for each city.

An index is developed using urban vulnerability to capture each indicator. Study identified 7 broad indicators and sub indicators to represent the climate vulnerability of the cities. The indicators were determined taking-Physical, Hazard, Social, Economic, Infrastructure and Administration vulnerabilities into consideration. A framework was designed, and the respective sub indicators were defined under each indicator, with a purpose to assess climate vulnerability of the cities.

The vulnerability ratings or scorings for all the six components (Physical, Hazard, Demographic, Social, Economic, Infrastructure and Administration/governance Vulnerabilities) in the UVI are the averages of the existing vulnerability of their respective sub-indicators.

4.7 Gender: Assessing gender-based vulnerability and risk to climate change

Women make an enormous contribution to society by performing triple functions of reproduction, production and household work. Women, especially in rural and peri-urban areas, have to trudge long distances for fetching fuelwood, freshwater and fodder to keep the household running. In doing so, women have to incur significant losses by way of physical (labour and energy), temporal (time), affective (negative feelings and attitudes) as well as cognitive costs (forego opportunities of education, skill and intellectual development). This leads to time poverty for undertaking economic activities and participating in decision-making roles leading to their poor status in society.

While the climate risks and hazards faced across the country affect all its citizens, the impacts do not affect all groups equally. The impacts of climate change and disasters affect weaker socio-economic groups with much higher intensity. Women, especially those from lower economic backgrounds, face some of the most severe effects of climate change. Globally, it is now accepted that the climate crisis and its impacts are not 'gender-neutral'. This is reinforced by the recently released IPCC AR6 WGII Report on "Impacts, Vulnerability and Adaptation" which states with high confidence that climate-induced changes are not experienced equally across genders, income levels, classes, ethnicities, ages or physical abilities. Climatic extremes and climate change further confound the scenario by magnifying manifold the workload of women and enhancing their vulnerability.

Recurring incidences of erratic rainfall and increasing possibilities of extreme events can result in the loss of agricultural produce. Women are exposed to harvest losses, which are often their sole source of food and income. Climate change may, thus, result in a consequent shrinkage of work opportunities, and would inflict a blow to the socio-economic edifice of the rural womenfolk. Second, climate variability usually impacts sectors that are traditionally associated with women, such as paddy cultivation, cotton and tea plantations, and fishing. In India, about 65 per cent of the total female workers are engaged in one of the most climate sensitive sectors – agriculture, thereby constituting 30 per cent of the total cultivators and about 43 per cent of the total agricultural labourers in the country.

A study based on a review of more than 100 research studies done in Asia and Africa pertaining to the gender-differentiated impacts of climatic variability, stresses, and extremes such as droughts, floods, heat waves, and cyclones on the coping strategies adopted by men and women to tide over the difficult periods has shown far greater negative impacts on women in terms of their Practical and Strategic Gender Needs (Box 12). Another impact of disasters on women is seen in the form of violence against women. A study conducted across 583 districts of the country revealed that standard deviation fluctuation of rainfall below its long-term mean resulted in a 4.4% increase in domestic violence cases (Sekhri & Storeygard, 2014). There is also evidence that in the pandemic such as recent COVID -19, violence against women and girls intensified manifold (UN Women, 2020). A combination of all these factors leads to poor performance of women in productive domains and hence their poor status in society leading to poor ranks in terms of gender-based indicators of development.

When faced with stressful environmental conditions or disasters, families including women have to use several mechanisms or strategies using their human, social, and financial resources to cope with the situation. The gender work program in Lima in COP20 led to the adoption of a path-breaking Gender Action Plan (GAP) to address the issues of increasing gender equity in relation to climate change. The COP25 in 2019 has further called the member nations to enhance the implementation of GAP. Two key activities of GAP include developing tools to strengthen the evidence base of gender-differentiated impacts of climate change as well as to enhance the availability of sex-disaggregated data for making gender-responsive climate policies, strategies and actions. Several such tools/indices have been developed over time such as Gender Equity Index (Social Watch), Gender Gap Index (World Economic Forum), Gender

Inequality Index (UNDP) and the Gender Vulnerability Index (Plan International). However, they either fail to or inadequately capture the gender dimension of the climate-related vulnerability of populations. The Women Resilience Index for South Asia and Japan in 2014 reflects the preparedness of women for different disasters but is not specific to climatic disasters only (Action Aid, 2014). In addition, it does not cover the productive, reproductive, and community roles played by women in the family and society.

Box 12: Key impacts of climate change on Practical and Strategic Gender Needs of women. (adapted from Kher and Aggarwal, 2019).

Climate change impacts	Impacts on Practical Gender Needs	Impact on Strategic Gender Needs
Reduced crop and live-stock production	Food shortage leading to greater malnutrition in women and girls due to prioritised male needs	Less income leads to low prioritisation of education especially of girls
Reduced water and fuel availability	Increased workload for women: more time and energy spent on water and fuel collection, poor hygiene and sanitation directly affecting their health and reproductive roles	Time poverty for income generation, skill development, and other creative activities
Increased occurrence of diseases	Increased care giving load for children, elderly and sick	Loss of income generation opportunities and community participation
Climatic extremes	Loss of housing, assets, and livelihoods; higher domestic violence	Loss of income generation and educational opportunities; higher school dropout rates especially of girls
Male outmigration	Increased workloads on women	Forced to learn skills, greater decision making and control over income
Human security	Increased domestic and external conflicts; violence against women	Reduced mobility

An index called 'Gender based Climate Risk Index' (GCRI) has been developed. GCRI is an innovative and holistic tool to address these gaps and to address the call for innovative tools for capacity strengthening of stakeholders to understand gender equity issues. GCRI index follows the IPCC AR5 Risk Assessment Framework and considers all aspects of productive, reproductive and community roles of women (Figure 4.40). The risk framework of IPCC integrates the twin domains of climate change adaptation and disaster risk reduction and brings attention to the risks associated with climate change and its potential consequences on populations. It also brings more seriousness to the issue of the impacts of climate change and working out solutions for risk reduction (GIZ and EURAC, 2017). 'Risk' to climate change and extremes is an outcome of the interplay between 'Hazards', 'Exposure' and 'Vulnerability'. The latter (vulnerability) further constitutes 'Sensitivity' and 'Lack of Adaptive Capacity' as its sub-components.

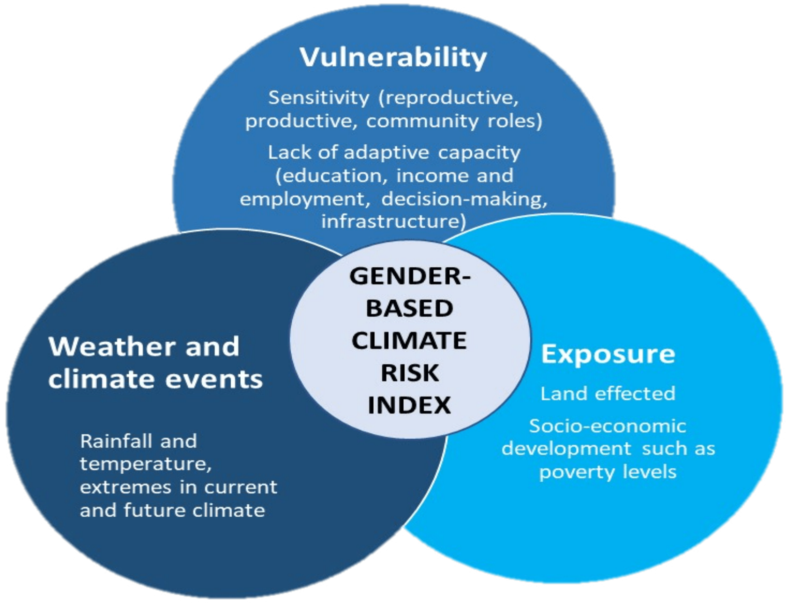


Figure 4.40: Components of the risk index used in the present study based on AR5

In order to make the risk index gender sensitive, the Practical-Gender-Needs (PGNs) and Strategic-Gender-Needs (SGNs) of women are included in the above framework for risk assessment. The PGNs comprise needs identified by men and women in their socially accepted roles in society. They are practical, often concern inadequacies in living conditions (lack of water and sanitation, poor healthcare facilities), need to be fulfilled immediately and are also context specific. The SGNs on the other hand are the needs of women arising out of socially structured, often subordinate position of women to men in society. These needs refer to the needs for education, income earning, legal status and rights, ownership and control over productive resources, participation in decision-making at the household, community or national level (Moser, 1993).

The GCRI had 4 sub-indices namely Hazards, Exposure, Sensitivity and Lack of Adaptive Capacity. A total of 54 indicators were used to capture the index. The validity of GCRI was established by an expert consultation workshop with specialists from the fields of climate change, gender studies, health and nutrition, energy, water and sanitation sectors from national and international organizations. The reliability of the index was established by using the Cronbach alpha test for internal consistency among the indicators of sub-components. The index was calculated using the same methodology as used by UNDP Human Development Index (2009).

Secondary data was collected from a variety of sources such as India Meteorological Department, Census of India, National Family Health Survey, Ministry of Water Resources, Central Ground Water Board, Central Water Commission, Ministry of Women and Child Development, Ministry of Environment Forests and Climate Change, Ministry of Statistics and Programme Implementation, National Sample Survey Organization, Ministry of Human Resource Development and Central Statistical Organization. In order to permit comparison between males and females, the indicators were normalized using maximum and minimum values from the combined data of males and females in different states in

India. The Indian states were classified into six equidistant categories namely no risk, low risk, moderate risk, high risk, very high and finally extreme risk based on their GCRI score. The index values ranged from zero representing least vulnerability/risk to one representing the highest risk.

The analysis showed that despite males and females being exposed to the same climate-related hazards and exposure, there was a huge variation in the overall climate-related risk faced by males and females (Figure 4.41). This was due to the much higher vulnerability of women reflected by their greater sensitivity by way of poor health and reproductive health status, inadequate provision of household facilities including sanitation and very limited access to productive resources and restricted participation in community roles. Women were also limited in their adaptive capacity because of lower literacy levels, poor income, extremely low participation in decision-making at all levels as well poor infrastructure. By contrast, men faced much lower vulnerability as compared to their female counterparts because of lower sensitivity (better health, greater participation in workforce, higher economic participation, and ownership of assets) and greater adaptive capacity (higher literacy, awareness, economic and political participation and decision-making capacity).

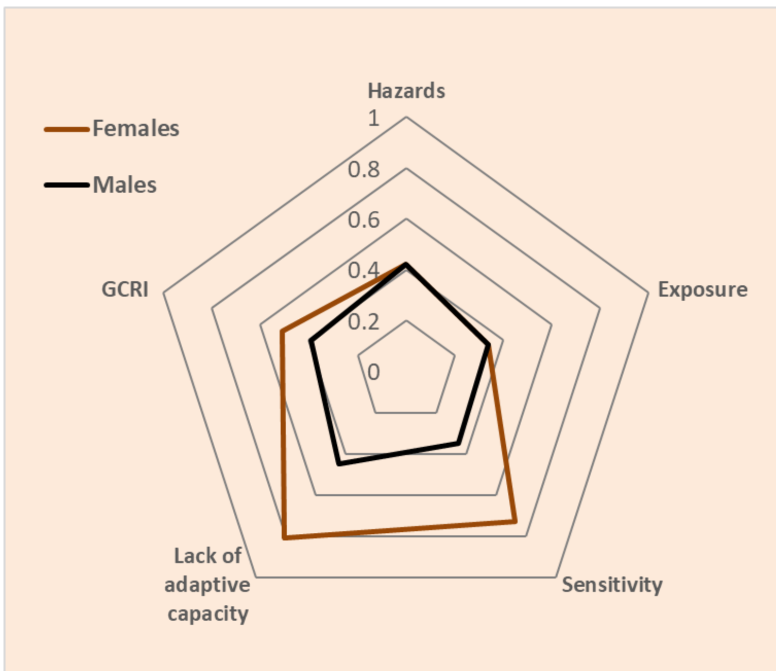


Figure 4.41: GCRI and its sub-indices for males and females (India) showing greater sensitivity and poor adaptive capacity of women.

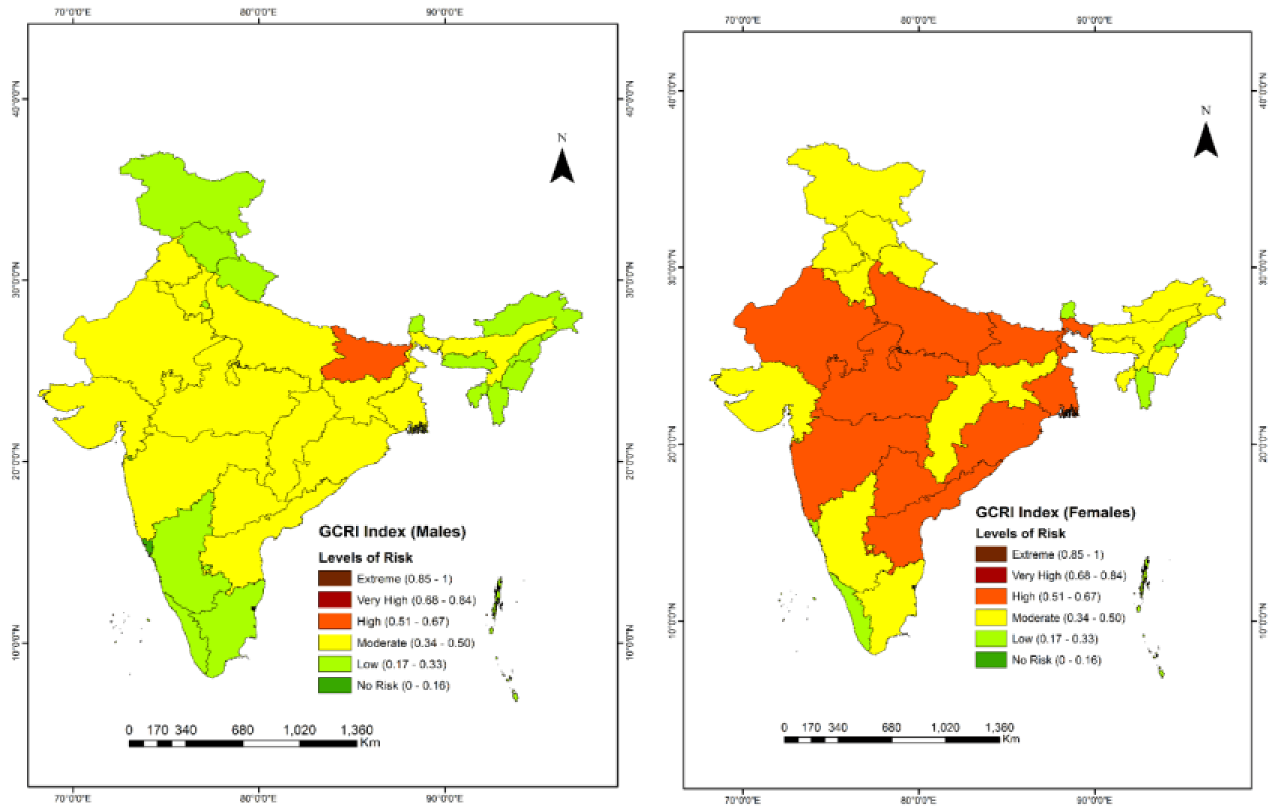


Figure 4.42: Gender based climate risk index for female and male populations in states of India showing higher levels of risk faced by women (Higher the value of GCRI, greater the risk faced).

The study has also shown large gender-based differentials among the states at risk of climate change as the GCRI values of females ranged from 0.25 (low risk) in Goa to as high as 0.62 (high risk) in Bihar (Figure 4.42). By comparison, males faced much lower levels of risk as the GCRI values ranged from as low as 0.16 in Goa to 0.51 in Bihar. A weighted average of GCRI scores reflect a 10%-point difference between the climate-based risk faced by males and females.

Most of the highly populous states such as West Bengal, Maharashtra, Odisha, Rajasthan, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh and Bihar, comprising of 55% of geographical area of the country and home to 64% of the total female population, were in the category of high risk for females (Figure 4.43). These states performed poorly in all four components of GCRI, especially in sensitivity and lack of adaptive capacity which put together comprise the vulnerability component. In the remaining states, women faced moderate levels of risk. By comparison, only 9% of the male population of India faced high risk to climatic extremes and 72% were at moderate risk (Figure 4). The remaining male population faced no or low risk.

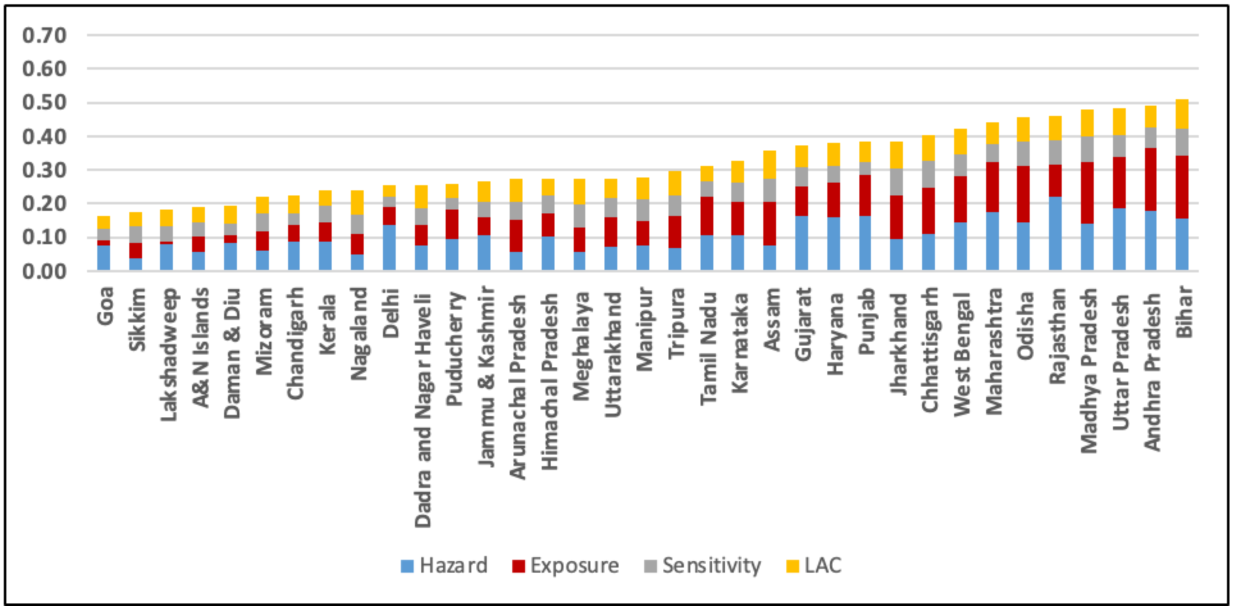


Figure 4.43: Variation in GCRI components among females and males across States and Union Territories in India.

4.7.1 Gender based risk in future climate

In order to assess the risk faced by women in future climate scenarios, GCRI was also computed for future time slices (2030, 2050 and 2080) for RCP 8.5 (Figure 4.44). A total of 42 indicators were used for the computation as some indicators had to be dropped because of the lack of data availability for future scenarios. The climate projections for different time slices were computed by taking an ensemble mean of 11 Global Climate Models. The GCM baseline was corrected using the IMD baseline, the correction was also incorporated into climate data of future climate. The socio-economic data for future scenarios were also required. While population projections and fertility rates were obtained from Registrar General of India (2025) and Population Foundation of India (2050 and 2080), the data for several other indicators were computed using the same rate of change as between 2001 and 2011. For a few indicators, such as the level of violence faced and participation in decision-making, the current values (2015-16) were used in the absence of clear trends.

The results showed, as expected, that the hazards index increased in the future from 0.42 in 2000 to 0.45, 0.48 and 0.54 in 2030, 2050 and 2080 respectively. The increase in the hazard proneness of different states and UTs is expected due to variations in rainfall patterns, temperature trends and occurrence of climatic extremes.

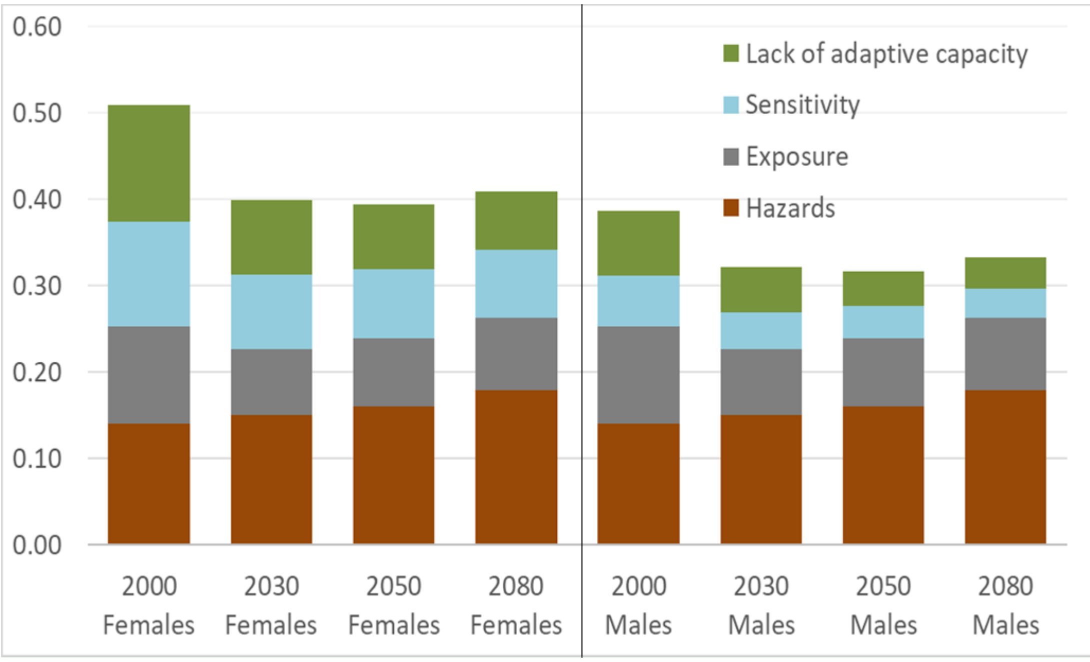


Figure 4.44: GCRI and its components for females and males for different climate change scenarios of RCP 8.5.

The susceptibility of different states in India to 'exposure' to climate change related events is expected to reduce substantially from 0.36 in the year 2000 to 0.25-0.26 from 2030 onwards. The considerable reduction in the levels of susceptibility to exposure to climate change events from 2000 to 2030 is expected due to overall development in the country and consequent improved performance in several indicators such as percentage of people living below poverty line, population living in kutcha house and reduction in the rate of forest degradation. However, the slight increase in the susceptibility to exposure from 2030 to 2080 was due to a higher percent of area affected by floods and droughts, rapid migration and urbanization leading to increased proliferation of slums in some states.

Despite the increase in the hazard component, it is interesting to note that there is likely to be a reduction in the climate-related risk faced by both males and females. The GCRI for females is likely to decline from 0.51 in 2000 to 0.40-0.41 from 2030 onwards. The corresponding male values will reduce from 0.40 in 2000 to 0.32-0.34 in the same period. Thus, it can be inferred that improvements in different sectors such as better health services, nutrition, per capita income and overall development are likely to be partially offset by rising temperatures, variations in rainfall patterns, and a higher proportion of flood and drought-prone area. It is, however, also important to recognize that females will continue to remain moderately vulnerable to climatic risks even in the future.

Considering the greater risk to climate-related extremes and disasters faced by women as compared to men, across all states in India, it is necessary to take effective steps to reduce their vulnerability and risk. This can be done by reducing their sensitivity to climate-related factors and enhancing their human capacity to adapt. It is important to invest in women's education (for increased awareness and knowledge), access to medical facilities and sanitation (better health and nutritional status), economic participation (for income generation and consequent participation in adaptation and mitigation efforts and adoption of sustainable adaptation strategies) as well as the participation of women in the community, political and administrative domains (to enhance gender sensitive and transformative decision making at all levels). These strategies can help women and their families to lead climate-resilient lives.

It is also important to note that in recent times, the Government of India has launched several schemes/ programs that can directly or indirectly reduce the risk of women to climate change. Box 13 shows a few such schemes and how these are strengthening the capacity of women by reducing their exposure and sensitivity and strengthening their adaptive capacity against climatic risks. Widespread and effective implementation of these initiatives coupled with a greater emphasis on meeting the Strategic Gender Needs of women regarding income, employment, and control over financial and other resources can be instrumental in enhancing the adaptive capacity of women to meet the challenges of climate change.

Box 13: Strategies to reduce the vulnerability of women to climate-related risks in India.

Scheme/ Program		Impact on women's climate risk reduction
Pradhan Mantri Ujjawala Yojana Started in 2016 to provide cooking gas in women's name and to develop a smoke free rural India		Increased adaptive capacity by enhanced access to clean fuel which reduces drudgery and the time spent on collecting firewood; improved respiratory and eye health; reduced GHG emissions and pollution.
Nal Se Jal and Jal Jeevan Mission Started in 2019 to enhance water and sanitation security of the households		Reduced sensitivity to climatic risks through enhanced access to safe and adequate drinking water leading to less workload and diseases
Swaccha Bharat Mission Started in 2014 for improved hygiene and sanitation		Reduced sensitivity to climatic change through improved access to sanitation leading to better hygiene and health.
Pradhan Mantri AwasYojana Started in 2015 to provide safe housing to the poor		Climate-proof housing for poor families reduces exposure to climatic extremes leading to increased resilience and improved quality of life

Janani Shishu Suraksha Karyakram, and Mother and Child tracking Systemof National Health Mission Started in 2005 to support reproductive health of women		Reduced infant and maternal morbidity and mortality rates by facilitating pre and post-natal check-up, institutional deliveries and immunization reduces sensitivity to climatic risks
Mahatma Gandhi National Rural Employment Guarantee Act Started in 2005 to provide livelihood security to families with one-third jobs for women		Access to paid employment; reduction in gender gap in labor force and poverty increases adaptive capacity of women to climate change
Beti Bachao Beti Padhao Started in 2015 to encourage growth and development of girls		Enhanced educational level of girls leading to better status and employment opportunities, strengthens adaptive capacity of women to climate change

4.8 Economic cost of impacts

National budgets provide the major part of finance for climate change adaptation and related efforts in India. A large proportion of budgetary expenditure that is allocated to poverty alleviation, development programmes, natural resources management, health and sanitation, education, and disaster management, is critical to reducing socio-economic vulnerabilities.

India's blueprint on climate action, the National Action Plan on Climate Change (NAPCC), encompasses nine national missions, both on adaptation and mitigation, and covers various climate-vulnerable sectors. Of these nine missions, the first three pertain to developing energy sources and improving energy efficiency to mitigate greenhouse gas emissions into the atmosphere, which constitutes mitigation efforts. The remaining five have specific adaptation objectives incorporated into their mission objectives.

In addition, State-level Action Plans on Climate Change (SAPCCs) have been formulated with a higher focus on adaptation and afforestation than on mitigation. Agriculture, water, health, forests, and coasts are the major sectors covered for addressing State-specific climate impacts. Thirty-Four States /Union Territories (UTs) have prepared and their State Action Plan on Climate Change (SAPCC) in line with NAPCC taking into account the State-specific issues relating to climate change.

Expenditure on human capabilities and livelihood, health improvement and disease control, risk management, and poverty alleviation constituted more than 80% of the total spending on adaptation in India.

In addition, the Government of India has set up the National Adaptation Fund with a budget provision of INR 350 crore for 2015–16 and 2016–17. Presently, 27 projects have been approved by NABARD under the National Adaptation Fund.

Multilateral finance for adaptation in India has been provided by Global Environment Facility (GEF), Green Climate Fund (GCF), Adaptation Fund (AF), and Special Climate Change Fund (SCCF). The total multilateral funding received by India for adaptation related projects from GEF since 2017 is USD 69.8 million, USD 9.86 million from Adaptation Fund since 2014 and USD 30.9 million from Green Climate Fund since 2017[4].

Multilateral finance will be useful in addressing a part of the adaptation finance required by India. Domestic resources will be needed in the future as well to address the gap.

4.8.1 Sector-wise cost of climate change impact and adaptation in India

4.8.1.1 Agriculture sector

Agriculture contributes close to 14% of the nation's GDP (ESI, 2018–19). The total central plan outlay for agriculture and allied activities was INR 12,000 crore in 2015–16 and peaked to almost INR 19,000 crores in 2013–14. There have been rapid advances in the diversification of agriculture (ibid). The government's focus has shifted to drylands from irrigated lands, which has given better returns from the 11th Five-Year Plan onwards. In 2015, the kharif food grain production has touched 135 metric tonnes (MT) (ESI, 2016). Oilseed production stood at a high of 23.6 MT, sugarcane production at 305.2 MT, and cotton production at 32.1 MT despite a slowdown in the latter two sub-sectors. From 2014 to 2015, the acreage under crops increased for both Kharif and Rabi (year-on-year) by 3.9 and 5.95% from the previous year. Irrigation has made significant advances. Now more than 90% of wheat fields and 50% of paddy fields are irrigated, as are almost 20% of pulses.

Climate change is a global phenomenon with varied locale specific impacts based on sub-regional and temperature zones. For India, its implications on agriculture will be varied across the various agro-ecological and meteorological zones at the micro level. There is little understanding of the potential loss in production and economic value of different crops due to climate change impacts, more so for India's states.

The estimates here are presented at the macro-level crop production for a No Climate Impact (NCI) scenario and two Climate Impact (CI) scenarios, RCP8.5 and RCP4.5[5]. The macro-level productivity losses and associated economic impacts for the two CI scenarios are also estimated. There are important gaps in the agriculture impact literature for India, leading to important uncertainties in deriving robust impact factors from the literature. These uncertainties are addressed by taking a high and a low range of climate impacts on crop productivity for each of the CI scenarios. Finally, the national level losses are downscaled to the state level to find the key states that will be impacted most due to climate change.

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5 A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory (not emissions) adopted by the IPCC. The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m2, respectively).

Production loss and its economic valuation

We find that wheat, maize, oilseeds, and sugarcane (due to the reduction in sugar content) are more vulnerable to climate change than rice and cotton. Even the achievement of more ambitious nationally determined contribution (NDC) targets proposed by countries (RCP4.5 scenario) means that the impact on crops will be significant, though this will become more pronounced after 2050. The impacts in the RCP8.5 scenario is felt in the near term, by 2030. In the RCP4.5 scenario, the total economic value of crop loss (including both food and non-food crops) due to climate change impacts are projected to be USD 28.6 to 54.8 billion during 2030–2050 (all figures are in 2015 prices, an undiscounted sum of yearly losses), and USD 612 to 1,014 billion during 2050–2100. In the RCP8.5 scenario, total losses for food crops due to climate change impacts would be USD 70.0 to 122.9 billion during 2030–2050 and USD 1,436–2,691 billion during 2050–2100.

In terms of the economic valuation of losses state-wise, Uttar Pradesh would suffer the highest economic loss due to the impacts of climate change on state agriculture. This is because the state is the largest contributor to India's food crop and sugarcane production. Across RCP scenarios, Uttar Pradesh will account for 20–22% of the economic value of cumulative national crop loss between 2030 and 2050 and 25–28% of the economic value of cumulative national crop loss between 2050 and 2100. The estimated economic value of this loss is almost USD 27 billion between 2030 and 2050 (in 2015 prices, undiscounted). After Uttar Pradesh, Maharashtra will face the most significant economic losses due to climate change impacts on agriculture. This is because sugarcane and cotton are grown in abundance in the state, and their economic value is high. The state would share 11–12% of cumulative national economic loss across RCP scenarios during 2030–2100. Apart from Uttar Pradesh and Maharashtra, the other important states (in terms of their contribution to nation's agriculture) that would suffer economic value loss due to the climate change impacts are Madhya Pradesh, Rajasthan, Punjab, Gujarat, and Haryana.

We also find that a reduction in crop production will increase crop prices relative to the business-as-usual (BAU) scenario. The prices of wheat and sugarcane could increase by 30% in the RCP8.5 scenario by 2050 relative to BAU price. Oilseed and maize prices could increase by at least 20% in 2050 relative to BAU. By the end of the century, prices could increase by at least 100% relative to the BAU for most crops; even the price of rice would increase by 70% relative to its price in the BAU scenario by 2100 if the world is not able to limit its emissions below the RCP8.5 level.

Areas of improvement for adaptation

Key areas of improvement for the agriculture sector are related to three aspects: data, adaptive capacity, and adaptive finance.

- First, the availability of data and information is an important limitation in undertaking a detailed adaptation analysis of India's agriculture sector. The constraints and challenges pertaining to climate change adaptation primarily stem from the uncertainties in knowledge and understanding of the impacts of climate change that would unfold at the local levels. In addition, the context-specific nature of adaptation makes it challenging to have a one-size-fits-all solution, especially in a country as diverse as India. The estimates at the state and national level can be made more robust if there is enough literature related to the impact of climate change on the productivity of all the key crops across agro-ecological zones and states. More extensive literaturewill provide a good basis for an even deeper analysis of climate change's economic impacts on India's agriculture and food economy.

- Second, it is critical to enhance the adaptive capacity of crops through better research. While we wait for more literature to be generated on the impact of climate change on crop productivity, it is clear that, by and large, the impact is going to be negative. As crop productivity keeps increasing, in the long run, owing to the current levels of low productivity, it will overcome the reduction in productivity growth due to climate change impacts. Climate-resilient agriculture will ensure that India's agriculture productivity truly achieves its growth potential.

- Finally, international adaptation finance plays a vital role. Adaptation efforts, for example, climate-resilient high productivity crops, need significant finances to undertake the necessary research It is imperative that developed countries financially support India to enhance the adaptive capacity of its agricultural systems. Only through these collective interventions can India reduce the imminent climate risks its agriculture and agriculture-dependent communities face in the near and long-term future.

4.8.1.2 Heat stress on labour productivity in the workspace buildings and transport modes

India's urban population registered a decadal growth of 31.8% during 2001–2011 (S. J. Gupta 2014). India's urbanisation pattern confirms that the trend of the concentration and agglomerations of urban population in large cities is getting stronger. All urban centres in India are growing extensively and at a swift pace. It is imperative to mainstream adaptation strategies in the urban development plans to reduce risks to a large population.

A primary survey across four megacities (Delhi, Mumbai, Chennai, and Kolkata) representing four different climatic zones was conducted to understand the extent of productivity loss due to heat stress in the building and transport sector and the economic valuation of productivity loss. The key findings from the primary survey of four megacities are as follows:

- It makes good sense to invest in various adaptation strategies to prevent the adverse impact of heat stress on labour productivity.

- The monetary value of human labour productivity loss due to heat stress on the human body and workability is more than the adaptation cost needed to maintain a work ambience that facilitates human productivity at a 100% workability level.

- Heat stress is high among drivers and conductors in the public transport system due to long hours of heat exposure (as they carry out their jobs on a moving vehicle throughout their work time) compared to people working within buildings.

- The monetary cost of providing Air Conditioning (AC) in the buildings and transport vehicles could be lower than labour productivity loss due to heat stress. Besides, 50% productivity can be gained by a change in clothing type, which can further reduce the air conditioning costs.

In future, to reduce GDP losses due to reduced labour productivity from heat stresses, all workplaces have to be necessarily air conditioned. Similar to developed countries, AC rooms, residential living and workplaces, and Air-Conditioned modes of transport would ensure 100% workability for users. However, there is a huge scope for implementing multiple strategies in combination with the AC environment to enable the population to cope with current temperature and humidity variations and extremes. These adaptations come with both low-cost and high-cost options. Low-cost options cannot provide 100% workability but could reduce the adaptation cost for remaining management of remaining adverse climatic impacts.

Some key low-cost and high-cost strategies

- Some practical low-cost strategies for the building sector are changing clothing patterns, increasing air circulation by installing different fan types, and installing window blinds and window curtains.

- High-cost coping strategies include different types of roofing and ceiling pattern such as installation of false ceiling, galvanised iron (GI) sheets, and green roofs.

- Installation of AC is found to be the most effective high-cost coping strategy.

- The cost of providing air conditioning in the building sector to reduce heat stress inside the building premises could be comparatively lower in long-term as compared to continued productivity losses caused owing to heat stress.

- In the transport sector, coping strategies include installing mini portable fans, magnetic sunshades, vehicle curtains, grass bed on the top of the vehicle, and air conditioning to provide thermal comfort to passengers, drivers, and conductors.

4.8.1.3 Cost of adaptation for forests in India

The available literature on cost estimation of adaptation is relatively scant. Only few studies are available for the forestry sector as a whole and none exists on India’s forestry sector. In the absence of literature, the following strategy could be followed for assessing the adaptation costs for forests in India:

- *Assessment of the adaptation cost at the national and state level based on the cost incurred in implementing adaptation strategies:* It is estimated based on national and state budgetary allocations for proposed adaptation measures in the forestry sector. It provides an estimate of national cost for adapting to climate change in the forestry sector. A careful examination of expenditure incurred on the adaptation strategies at the national and state levels can be used to assess the cost incurred on adaptation.

- *Cost of adaptation for households in the forested communities:* Vulnerable households, dependent on forests for their livelihood, need to adapt to climate change. There is both monetary and non-monetary cost associated with adaptation because of low availability of forest produce, loss of irrigation facilities, and opportunity cost associated with increased time spent on collection of forest produce. Therefore, a primary survey of vulnerable communities is conducted, which elicited information on their dependence on forests, their perception of climate change, their adaptation options, support from different government agencies for their strategies, the barriers they face, and finally, their willingness or capacity to pay for adaptation to climate change for forests.

4.8.1.4 Impact of climate change on water resources and human well-being

Due to climate change, the demand for water infrastructure is likely to increase and different stakeholders often respond to the climate stimuli to moderate the harm and reduce the risk. For a better understanding, a small study was conducted to synthesise the available information on the adverse effects of climate change on India's quantity, quality, and distribution of water resources. The study also looked at the past and projected future trends on climate change and various hydrological parameters and estimated the likely adaptation costs of climate-induced changes in water resources under different climate scenarios with and without adaptation.

Estimating the cost of adaptation to climate change requires an estimate of adaptive infrastructure investments. However, this is difficult as the outcome is not clearly known, and the expenditures can easily be passed under business-as-usual development projects. For example, the Government of India has undertaken planned or adaptive public investments from time to time, some of which may have been targeted at climate change though they are not explicitly categorised under adaptation expenditures. Some of the schemes, like the employment guarantee programme, sound like a poverty alleviation or development scheme. The data shows that most of the expenditure in these schemes is incurred towards work such as drought proofing, flood control and protection, land irrigation, micro-irrigation works, and water conservation works, which are directly connected with climate adaptation strategies. These expenditures are likely to go up due to climate change as the poor are more impacted.

The study also analysed other adaptation costs on water resources in the form of planned and unplanned expenditures. Agricultural insurance is a significant adaptation expenditure incurred by the states and the farmers. Though the share of gross capital formation as the per cent of total gross capital formation has been on the decline, the absolute value of public and private gross capital formation has increased in India. Therefore, it can be surmised that union budgets are not an exact reflection of climate change adaptation costs incurred in India. Nevertheless, the study does give an idea of the minimal expenditure that the governments have to commit to ensure that the GDP does not fall due to fluctuations in water levels.

The marginal costs are estimated to assess the adaptation costs for providing additional storage capacity. The marginal cost of providing one additional unit of water services is calculated using the cost of storage capacity of various major, medium, and minor irrigation projects in different states, along with their irrigation potential, hydropower potential, flood protection services, and drinking water provision. The results indicate that for every 1 million cubic metres (mcum) of storage capacity, the marginal costs increase by 0.20 per cent. The marginal cost of irrigating an additional 1,000 hectares increases by 0.67 per cent of the mean value and providing additional flood protection increases by 0.095 per cent of the baseline value.

Despite various actions and strategies, the residual impacts of climate change are still persistent. The economic cost of climate change on agricultural and non-agricultural sectors is also estimated. The climate-induced water resources availability has been proxied through variability in monsoon. The output of both agricultural and non-agricultural sectors is determined by the state's hydrological conditions (proxied by total rainfall and the shocks to this variable through the deviations in monsoon), the state-level infrastructure (included in GDP via the capital formation), and the spillover impacts of other sectors along with the lagged output reflect the level effect. Monsoon variability has both direct and indirect impacts on GDP—directly impacting the non-agricultural sector and indirectly through changes in agricultural GDP and the farm investments. Each state is unique and the panel data captures these state-level effects along with temporal changes in GDP. The use of GDP as an outcome indicator captures all the direct and indirect impacts.

It is too simplistic to generalise the impact of climate change on water resources at sub-regional and national levels over time as different regions will be impacted differently within India. Higher water stress areas would experience acute adverse effects due to declining water resources than areas with higher water availability. Regions with higher monsoon rainfall variability and limited irrigation and those with more agro-based industries show variation in their contribution to GDP. The state-level analysis shows that the impact of climate change would be highly varied.

Impacts of climate change on coastal areas in India

Coastal regions harbour some of the most diverse and productive ecosystems as a functional interface between land and water. However, they are currently reeling under immense pressure from a medley of stressors such as extreme weather events such as cyclones (whose frequency and intensities are enhancing). Of coure, exposure would depend upon population growth, settlements and urbanisation, and development activities that alter the structure and function of these ecosystems. Climate change poses an additional threat that varies both in the severity of temporal and spatial impact. Scientific predictions suggest that due to climate change, most coastal regions will also be subject to increased flooding levels, leading to loss of land due to inundation, accelerated erosion, saltwater intrusion, and loss of wetlands and mangrove ecosystems.

India has a low-lying, densely populated coastline of over 8,000 km. The most densely populated regions are the delta regions around the east coast. Most coastal regions are agriculturally fertile, with paddy fields occupying them. But these regions are highly vulnerable to inundation and salinisation. Moreover, tourist activities on beaches and onshore oil exploration activities are also at risk. Flooding and erosion associated with changes in coastal sea level have an impact on coastal ecology and infrastructure. The

Delft Hydraulics Study for UNEP (1989) identified India among the 27 countries most vulnerable to sea-level rise (SLR). In the wake of climate change, a mean SLR of 15–38 cm is expected along India's coast by the middle of the twenty-first century and 46–59 cm by the end of the century. In addition, a projected increase in the intensity of tropical cyclones by 15 per cent poses a high threat to populations living in cyclone-prone coastal regions of India. The frequency of formation of cyclones is five to six times higher in the Bay of Bengal than in the Arabian Sea. Therefore, India's east coast is more vulnerable than the west coast, with natural disasters likely to cause massive damage to life and property. A large share of the coastal population in India is also dependent on coastal and marine resources. Any impact on the coastal ecosystem has a direct impact on coastal livelihoods. However, the extent of their vulnerability depends on several factors, including socio-economic profile, infrastructure development, land-use patterns.

In this context, an assessment was undertaken to understand the impacts on India's coastal regions to sea-level rise, cyclones, and storm surges to assess their economic costs.

The study presents a tropical cyclone assessment over the Bay of Bengal and Arabian Sea for observations from the Indian Meteorological Department (IMD) and baseline, future projections using the PRECIS RCM[6] results. An empirical approach adopted to analyse tropical cyclone activity has been able to successfully track tropical cyclone tracks over the Bay of Bengal and the Arabian Sea. The frequency of cyclonic storms is likely to increase in future compared to the baseline over the Bay of Bengal and the Arabian Sea regions. The number of cyclonic storms occurring over baseline and RCP 4.5 scenarios is almost the same; however, there is a probability of more intense cyclones over the Bay of Bengal.

The study also analyses the surge height and inundation, mapping vulnerable regions along the east coast by generating fine resolution flexible mesh through the ADCIRC[7] model, in addition to analysing the trends of cyclonic events for 116 years (1900–2016). The prepared vulnerability map shows the vulnerable areas with the extent of affected regions along the coastline of Odisha and Andhra Pradesh due to storm surge. There might be certain factors responsible for extreme storm surge height and flooding. Still, the vulnerability map analysis reveals that the presence of water bodies or inlets near the coastline along the regions leads to more inundation. On the other hand, areas covered with more vegetation (forest), ghats (mountains or hills), and of undulating topography have a minimised risk of inundation. The continental shelf of Odisha is wider with a gentle slope than Andhra Pradesh, which could also be a factor because Odisha experienced high surge height and more inundation than Andhra Pradesh.

4.8.1.5 Cost of impact and adaptation

The relative rise in sea levels generates numerous biogeophysical impacts that directly or indirectly result in economic losses. Such impacts may be categorised into primary and secondary impacts as described below. It is imperative to understand and illustrate the potential adverse effects of coastal flooding, which can negatively affect infrastructure, agriculture, and other economic sectors.

6 PRECIS RCM - Providing REgional Climates for Impacts Studiesl

7 ADCIRC - The ADvanced CIRCulation model

- ***Primary impacts*** are physical impacts caused by sea-level rise. These impacts can include crop loss, loss of land, and damages to residential building, commercial building, facilities (oil, gas, electricity, wastewater treatment and communication systems), roads, and bridges in addition to loss of life. Sea-level rise threatens to wipe off large areas of land, leading to a decline in agricultural and commercial productivity and also contributing to coastal habitat degradation.
- ***Secondary impacts*** are either short-term or long-term impacts that result from the cascading effect of the primary impact. These manifest in several ways as loss due to business interruption, mass migration, loss due to discontinuance of tourism activities, cost of dislocation, and conditions that lead to disability-adjusted life years (DALYs) (due to diseases like malaria or diarrhoea).

The biggest impact would be the loss in agricultural productivity, loss of income from major commercial activities, and income loss of casual labour.

In order to moderate these economic losses, the following adaptation strategies to cope with sea-level rise have been identified:

- ***Engineered protection***: These types of intervention are aimed at preventing inundation to a certain amount of increase in water level, such as building a seawall, levees, and dikes or sand dunes. Although they are reliable in withstanding sea-level rise, they cause damage to the environment, are also economically expensive to build, and need continuous maintenance once they are built.
- ***Planned measures***: These measures require modification in development standards so as to decrease the vulnerability of the exposed infrastructure. These strategies reduce the damage caused by flooding and include the development of resilient infrastructure, drainage system, and introduction of building codes and resilient land-use policy.
- ***Ecosystem-based protection***: Ecosystem-based strategies include the development of green infrastructure that will reduce of overall water level increase by absorbing the water or reducing the wave power. These solutions consist of the development of wetlands, mangroves, oyster, coral reefs, and vegetable dunes.

4.9 Human Health: Impacts, Vulnerability, Climate Change Projections, and Adaptation

Climate change programme in India has visualized the importance of health sector, therefore, health has been added as an additional Mission (in addition to 8 missions) to develop National Action Plan on Climate Change and Health (NAPCCH). There are various adverse impacts on health including eye diseases, skin diseases, mortality due to heatwave, disasters, loss of health infrastructure, respiratory diseases, waterborne and vector-borne diseases and malnutrition etc. of which mortality due to heatwave and alteration in the spatio-temporal distribution of vector-borne diseases are the main areas (Bush et al., 2011; Dhiman et al., 2010).

4.9.1 Vulnerability Assessment

4.9.1.1 Vulnerability to heat waves

Extreme temperatures can influence normal functioning of the human body leading to pathological states such as exacerbation of cardiovascular and respiratory disease and ultimately death (Kovats and Hajat, 2008). Adverse health effects of temperature extremes are shown by heatwaves in Europe (Fouillet et al., 2006; Barriopedro et al., 2011), the United States (NOAA, 2012), and Russia (Barriopedro et al., 2011). Here, the study focuses on vulnerability of Indian population to heat waves. However, studies that assess future heat-related health impacts are largely absent in India (Huang et al., 2011).

Impact projection

The heterogeneity in average annual temperatures, daily deaths, topography, and pollution was analysed across the five cities (Table 4.9. Ahmedabad, located in the hot and dry climate zone, had the highest average temperatures, whereas Shimla (in the cold climate zone) had the lowest. Mumbai, which has the highest population among the five cities, had the highest values of average daily deaths as well as PM_{10}. Using the non-parametric Mann-Kendall trend and Sen's slope method, we estimated changes in Tmax for the period of 1951-2015 using gridded observations from IMD. We find significant increases in temperatures for the period of 1951 to 2015 across four of the five cities. Bangalore and Hyderabad witnessed a warming of more than 1ºC ($p<0.05$) in Tmax between 1951-2015 while in Mumbai and Ahmedabad Tmax has increased by 0.82 ($p<0.05$) and 0.46ºC($p<0.05$) respectively. Of the five cities, Shimla experienced a decline in Tmax, however, the change was not statistically significant.

Table 4.9: Summary statistics of Temperature and Humidity across different cities*

City	Population (in millions)	Climate zone	Topography	Annual Avg. Temperatures (ºC) (summer season)		Annual Avg. Humidity (%)	Avg. daily deaths	Annual AvgPM10
				Max	Min			
Ahmedabad	6.35	Hot & dry	Plains	34.3 ± 4.6	21.5 ± 5.6	56.7 ± 17.8	100 ± 18	93.9 ± 58.7
Bangalore	8.49	Temperate	Plateau	29.4 ± 2.7	18.7 ± 2.3	66.6 ± 15.5	120.7 ± 17	108.3 ± 69.8
Hyderabad	2.17	Composite	Plains	33.6 ± 3.8	20.7 ± 3.6	53.1 ± 17.6	74.7 ± 16.2	80.4 ± 21.9
Mumbai	17.30	Warm & humid	Coastal area	32.3 ± 2.4	22.7 ± 4.0	69.2 ± 13.8	225.6 ± 30.7	174.4 ± 86.6
Shimla	0.17	Cold	Hilly region	20 ± 5.1	11.2 ± 5.3	NA	4.2 ± 2.7	54.4 ± 25.2

*Annual average and standard deviations computed based on observed data for years 2005 – 2012

An increase in the magnitude, frequency, and duration of heatwaves during the observed period in four cities i.e. Ahmedabad, Bangalore, Hyderabad, and Mumbai while there was no consistent rise in the magnitude or the frequency of heatwaves in Shimla, which is consistent with the observed changes in Tmax. For most of the selected cities, the summer season (April-May) period is dominated by the occurrence of heatwaves.

Projected changes in temperature and heat waves

Bias-corrected Tmax data from 23 CMIP5 models were used to estimate multi-model ensemble mean change in Tmax for the projected future climate. An average projected increase (from baseline Tmax) of 2ºC and 3.7ºC in 2080s under RCP 4.5 and RCP 8.5, respectively (Table 4.10). The results show the highest multi-model ensemble mean a projected increase in Tmax for Shimla and the lowest for Ahmedabad. These findings are consistent with Chaturvedi et al. (2012) who reported a projected increase by 3.3°C to 4.8°C by 2080 in India.

Table 4.10: Current and future estimates of maximum temperatures (°C) across different cities**

		RCP 4.5			RCP 8.5		
City	**Baseline**	**2020**	**2050**	**2080**	**2020**	**2050**	**2080**
Ahmedabad	38.1±3.7	38.7 ± 3.8	39.7 ± 3.7	40.1 ± 3.8	38.8 ± 3.8	40.4 ± 3.8	41.8 ± 4
Bangalore	33.1±2.7	33.6 ± 2.8	34.5 ± 2.8	34.6 ± 2.9	33.7 ± 2.8	35.2 ± 2.9	36.3 ± 2
Hyderabad	36.3±3.7	36.9 ± 3.7	37.9 ± 3.8	38.2 ± 4	36.9 ± 3.8	38.7 ± 4	39.9 ±4.2
Mumbai	33.9±2.8	34.4 ± 2.7	35.2 ± 2.8	35.5 ± 2.9	34.4 ± 2.7	35.9 ± 2.8	37.0 ±2.9
Shimla	24.5±4.3	25.2 ± 4.5	26.4 ± 4.4	27.2 ± 4.3	25.3 ± 4.3	27.4 ± 4.5	29.5 ±4.5

**Averages and standard deviations computed across 23 models for baseline (2000 – 2009) and future climate scenarios (2020s: 2020 to 2029; 2050s: 2050 to 2059; 2080s: 2080 to 2089). These are for the summer season only.

It is estimated Heat Wave Magnitude Index daily (HUMId) for the projected future climate using the bias-corrected Tmax data from the 23 CMIP GCMs. In addition to the increase in Tmax across five cities, a significant projected rise in the heatwave severity was observed under the future climate scenarios. All five cities are projected to experience a non-linear increase in the severity of heatwaves in the future under the RCP 4.5 and 8.5 (Figure 4.45). For instance, the magnitude of heatwaves is projected to increase 8-10 times from the mid to end of the 21st century. The frequency of severe heatwaves with a magnitude above 16 was also estimated for the projected future climate (Mishra et al., 2017). Similar to the severity, it is found that heatwaves will become more frequent in these urban areas under the projected future climate. The frequency of heatwaves is projected to increase more than 20 and 10 times the baseline by the end of 21st century under the RCP8.5 and RCP4.5, respectively. It is found that significant difference between the projected magnitude and severity of heatwaves under the RCP 4.5 and 8.5, which highlights the importance of climate change mitigation and limiting the global mean temperature under the COP21 Paris Agreement.

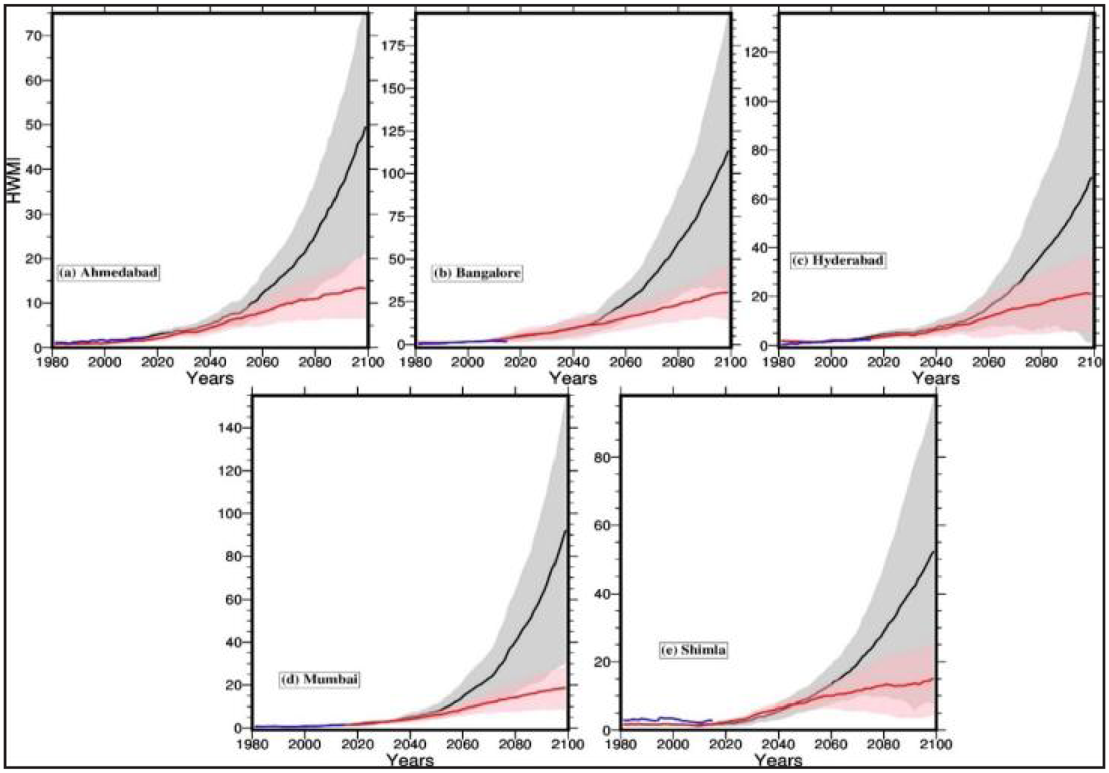


Figure 4.45: Projected changes in the frequency of heatwaves in 30-year window based on HWMId under RCP4.5 (Red) and RCP8.5 (black) scenarios for five cities. HWMId>16 were chosen. Grey color and pink color shaded area show the spread of frequency estimated based on 23 CMIP5 models. The frequency estimated for a 30-year moving window is shown at the end of the 30-year window.

4.9.1.2 Vulnerability Impact Assessment and Adaptation Measures to Combat Adverse Impacts of Climate Change on Vector Borne Diseases

Vulnerability Assessment of the Impacts of climate change

Malaria

Transmission Windows (TWs) of malaria based on T°C were generated for the baseline years (1976-2005) and for the 2030s, 2050s, and 2080s under RCP 2.6, 4.5 and 8.5. The threshold of T and RH were taken as 18-32°C and 50% to 90% RH respectively.

Dengue and Chikungunya

Review of literature revealed that the favorable temperature ranges for Dengue (DENV) and Chikungunya (CHIKV) virus transmission are 13-35°C (McLean et al., 1974; McLean et al., 1975; Watts et al., 1987) and 13-34ºC (Araujo-Ruiz et al., 2010; Carbajo & Vezzani, 2015; Mordecai et al., 2017), respectively. Accordingly, TWs were generated for baseline (for the year 1976-2005) and for different projection scenarios under RCP 2.6, 4.5 and 8.5 for the years 2030s, 2050s, 2080s.

Japanese encephalitis (JE)

Based on the occurrence of JE cases in Gorakhpur (Uttar Pradesh) which reports the highest cases in the country, the threshold of 20-30°C temperature and >50 % RH were used for determining the TWs under baseline and projected scenarios by the year 2030s, 2050s and 2080s under three RCPs.

Development of Vulnerability map and indices for susceptible areas and the population at the State/District level:

Determination of relationship between climate variables and VBDs (Vector Borne Diseases)

In view of available epidemiological data of VBDs, relationship of VBDs with climatic variables (Temperature, Rainfall and Relative Humidity) have been analyzed for some representative districts (Table 4.11). Further, correlation coefficients were calculated to quantify the strength of relationship for month-to-month and the effect of lag period.

Table 4.11: List of districts for which relationship between climate variability and VBDs has been analyzed

State	District	Malaria	Chikungunya	Dengue	Japanese Encephalitis	Ka-la-Azar
Gujarat	Ahmedabad	√	√	√		
Himachal Pradesh	Kangra	√				
Rajasthan	Bikaner	√				
Andhra Pradesh	Vishakhapatnam	√	√			
	East Godavari			√		
Tripura	West Tripura			√		
Delhi	Delhi	√		√		
Uttar Pradesh	Gorakhpur				√	
	Deoria				√	
Assam	Dibrugarh				√	
	Kamrup				√	
	Jorhat				√	
	Golaghat				√	
Bihar	Saran					√

It was found that there was 0 to 5 months of lag period for a significant correlation between malaria and climatic factors which varied from area to area. The correlation coefficient between Rainfall and dengue cases in Ahmedabad showed a significant correlation at the lag of 2 months. In the case of JE the vector of which prefers to breed in stagnant water, the significant correlation between temperature, rainfall and relative humidity was from 1-3 months lag.

Malaria vulnerability based on temperature and relative humidity in India

A baseline map of climate suitability for malaria based on temperature and relative humidity was prepared, which shows that in the Eastern part i.e. Uttar Pradesh and Bihar state, Transmission Windows (TWs) are open for 4-6 months and 7-9 months in Jharkhand, Orissa, West Bengal, Chhattisgarh state. North Eastern part shows the opening of TWs for 7-9 months in almost all states except Tripura and a few districts of Assam state (TWs open for 10-12 months). Arunachal Pradesh being a colder region shows no transmission suitability in some districts while in some, TWs are open for 1-3 months. In the Himalayan region particularly Jammu & Kashmir, Himachal Pradesh and Uttarakhand, there is diversity in the opening of TWs from no transmission to 4-6 months of suitability. Similarly, Rajasthan state also shows the opening of TWs from 0 to 4-6 months. Interestingly, in Madhya Pradesh, TWs remain open for 4-6 months in every part of the state. In the south, the states of Kerala, Karnataka and Tamil Nadu show TW of 10-12 months.

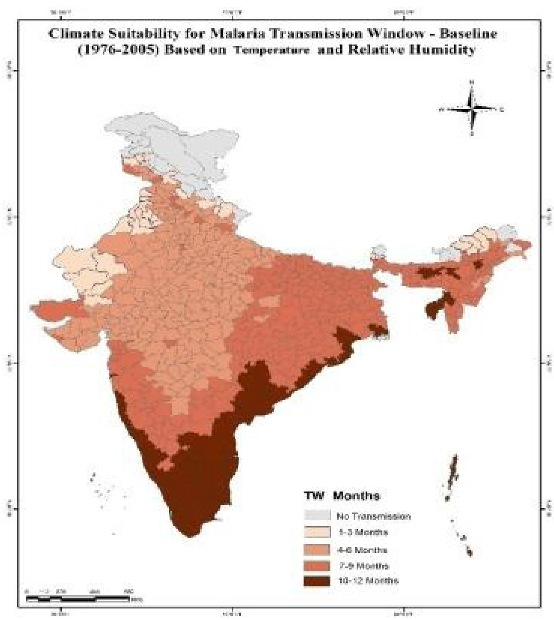
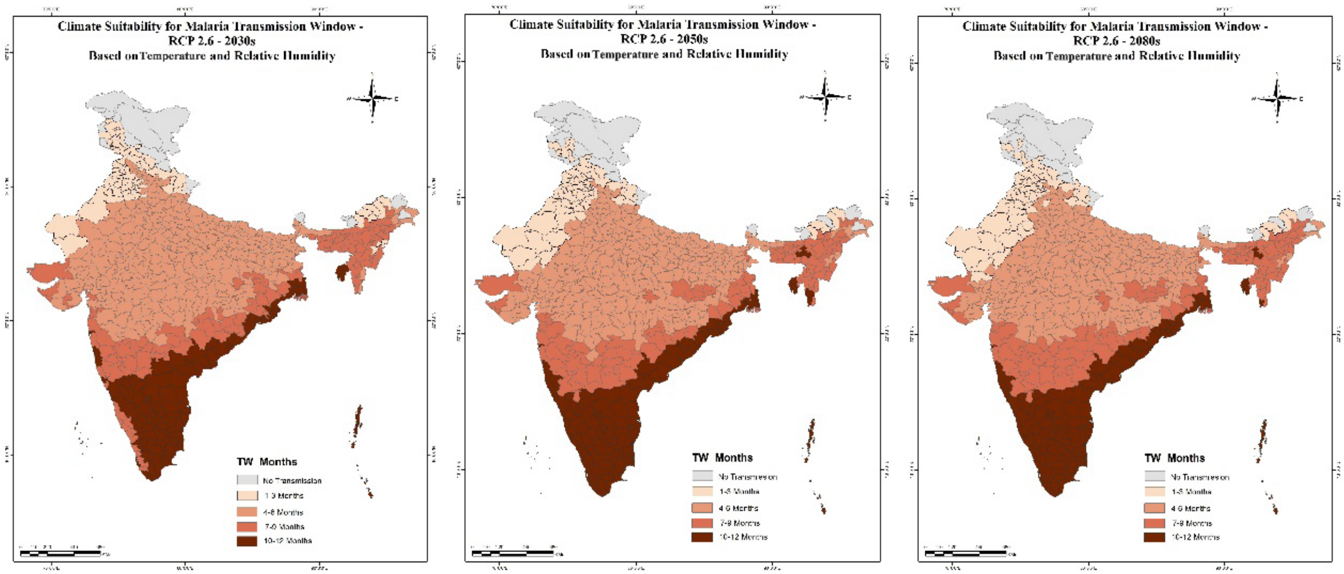
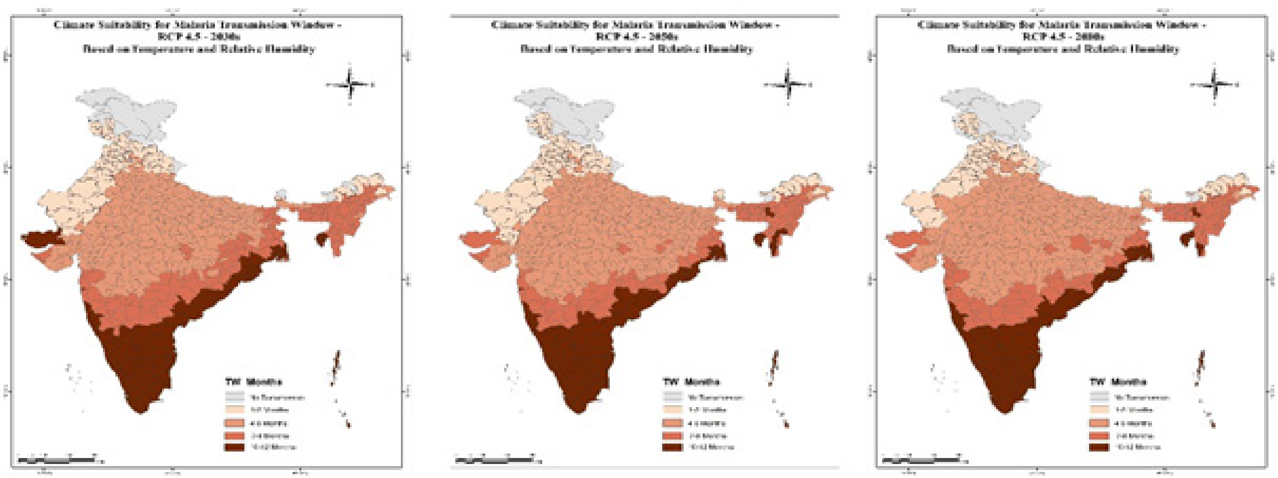


Figure 4.46: Baseline year (1976-2005) TWs of Malaria transmission based on temperature and relative humidity.



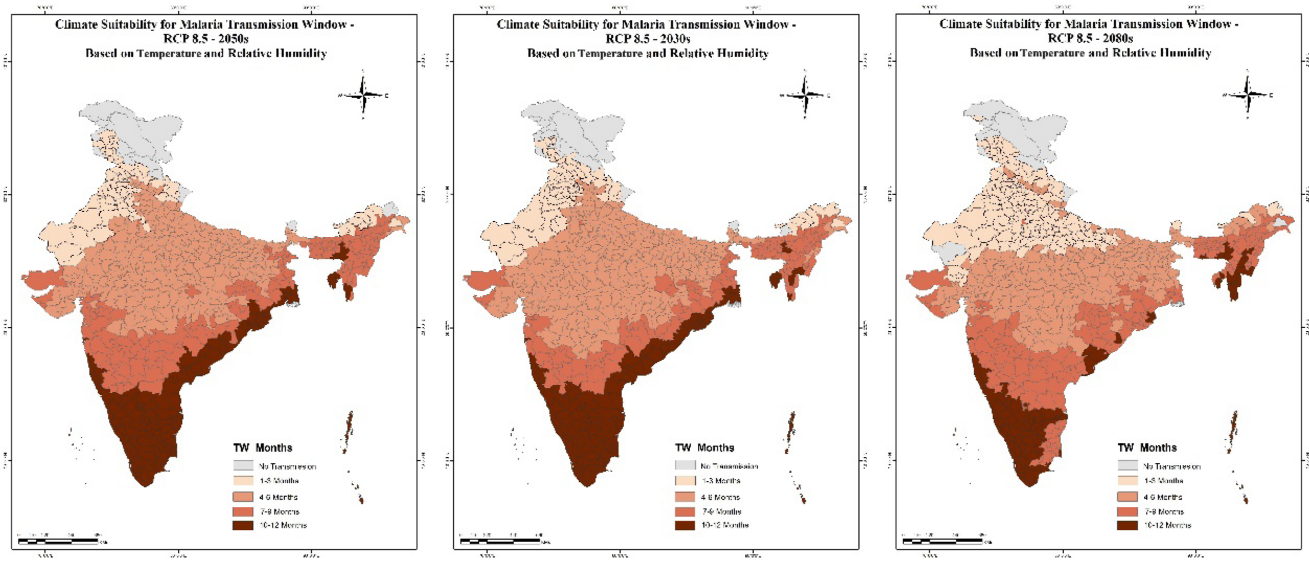
(2030s) (2050s) (2080s)

Figure 4.47: Projected TWs of malaria transmission for the year 2030s, 2050s and 2080s for RCP-2.6, based on temperature and relative humidity.



(2030s) (2050s) (2080s)

Figure 4.48: Projected TWs of malaria transmission for the year 2030s, 2050s and 2080s for RCP-4.5, based on temperature and relative humidity



(2030s) (2050s) (2080s)

Figure 4.49: Projected TWs of malaria transmission for the year 2030s, 2050s and 2080s for RCP-8.5, based on temperature and relative humidity

A comparison was made between climate suitability in the baseline years i.e. 1976-2005 (Figure 4.46) and future projections for the years 2030s, 2050s & 2080s using RCPs 2.6, 4.5 & 8.5 (Figure 4.47-4.49). All three projected scenarios RCP 2.6, 4.5 & 8.5 reveal the introduction of new foci in Jammu and Kashmir (Baramula, Jammu, Kupwara, Doda, Kulgam, Anantnag), Arunachal Pradesh (Tawang, East Kameng, Lower Subansir, Upper and lower Siang and Lohit), Himachal Pradesh (Kinnaur, Chamba, Kullu, Mandi), Uttarakhand (Uttarkashi, Rudraprayag, Pauri, Almora and Bageshwar) in the 2030s.

Similarly, there is a visible decrease in TWs from 4-6 to 1-3 months in the districts of Rajasthan, Punjab and Haryana. In projected scenarios, eastern states particularly Bihar, Orissa, Jharkhand, Chhattisgarh and some districts of West Bengal show a decrease in TWs from 7-9 to 4-6months for all the years. In the North-east, like Assam and Tripura shows a decrease in TWs from 10-12 to 7-9 months. On the other hand, the southern part of the country shows decreases from 10-12 months to 9-10 months suitability. Comparison between the years shows that there is reduction in suitability by the year 2080s, particularly in the RCP 4.5. In projected scenarios for the years 2030s, 2050s and 2080s states like Madhya Pradesh, Karnataka, Kerala, and Maharashtra do not show any major change.

Fuzzy-Based Climate Suitability of Malaria Transmission (FCSMT): For *P. vivax,* new foci of transmission are visible in parts of Jammu & Kashmir, Uttarakhand and Himachal Pradesh. An increase in the number of months of TWs in North Eastern states and a reduction in parts of Orissa and Gujarat states are also seen. In the case of *P. falciparum,* few foci in Jammu & Kashmir and Uttarakhand; an increase in transmission months in northeastern states and a reduction in parts of Orissa and Gujarat states are visible (Figure 4.50).

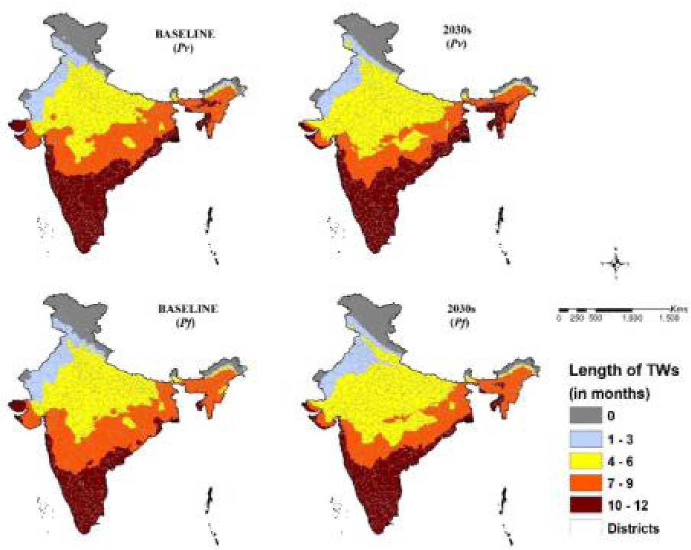


Figure 4.50: Composite climate suitability map for malaria transmission for the baseline and projected the 2030s.

Changes in Climate Suitability between Baseline and Projected 2030s

The climate suitability change map (Figure 4.51) depicts the changes in a number of months of TWs (new foci/extension/reduction) projected to occur by the 2030s as compared to the baseline year. The major changes are:

1. Some areas in a few districts of the western Himalayan states like Jammu and Kashmir, Himachal Pradesh and Uttarakhand, are likely to have new foci of transmission;
2. In other Himalayan states like the northern parts of West Bengal, Bihar and Sikkim, a spatial extension of TWs by two months within the districts is more likely;
3. All of the foothill blocks/circles of the Arunachal Pradesh districts are projected to gain up to three months of *Pv* and *Pf* malaria TWs, the highest being the Wakro, Chowkham and Tezu circles of the Lohit district with seven months.
4. Few districts in Rajasthan, Punjab, Gujarat, Maharashtra and West Bengal are also likely to experience nearly two months gain in P*v* malaria TWs,
5. Maharashtra, Madhya Pradesh, Telangana, Odisha, Karnataka and West Bengal are also likely to experience an increase in nearly two TW's months for *Pf* malaria transmission;
6. Coastal districts of Maharashtra, Odisha, Goa and West Bengal are also likely to become suitable for *Pf* malaria transmission; and,
7. Rest of the districts in the states of Haryana, Bihar, Uttar Pradesh, Andhra Pradesh and Tamil Nadu are projected to experience a reduction in the number of months of TWs.

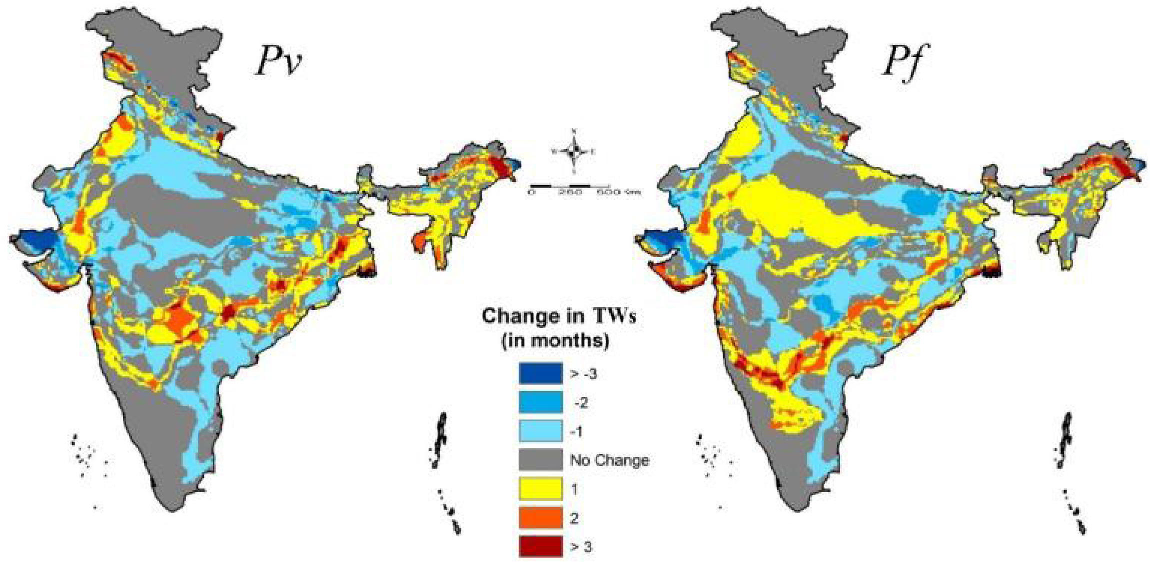


Figure 4.51: Projected changes in the number of months in the Transmission Window (TW) for malaria (Pv and Pf) transmission by the 2030s as compared to baseline years.

Box-14: Shift in malaria transmission windows based on climatic factors in India.

The future implications of climate change on malaria transmission at the global level have already been reported, however such evidences are scarce and limited in India. Here the study assessed, identifies and maps the potential effects of climate change on Plasmodium vivax (Pv) and Plasmodium falciparum (Pf) malaria transmission in India. A Fuzzy-based Climate Suitability Malaria Transmission (FCSMT) model under the GIS environment was generated using Temperature and Relative Humidity data, extracted from CORDEX South Asia for Baseline (1976–2005) and RCP 4.5 scenario for future projection by the 2030s (2021–2040). National malaria data were used at the model analysis stage. Model outcomes suggest that climate change may significantly increase the spatial spread of Pv and Pf malaria with a numerical increase in the transmission window's (TW) months, and a shift in the months of transmission. Some areas of the western Himalayan states are likely to have new foci of Pv malaria transmission. Interior parts of some southern and eastern states are likely to become more suitable for Pf malaria transmission. Study has also identified the regions with a reduction in transmission months by the 2030s, leading to unstable malaria, and having the potential for malaria outbreaks.

Dengue vulnerability based on temperature and relative humidity in India

As per the baseline map of climate suitability for dengue transmission based on temperature and relative humidity (Figure 4.52), almost all the parts of the country have climate suitability for dengue transmission except the upper part of Jammu and Kashmir, Uttarakhand, Sikkim and Arunachal Pradesh. Entire Tamil Nadu, parts of Karnataka, Orissa, Andhra Pradesh, West Bengal, and North East and Bihar states, TWs are open for 10-12 months.

The comparison between baseline (1976-2005) and future scenarios years i.e. 2030s, 2050s & 2080s using RCPs 2.6, 4.5 & 8.5 (Figure 4.53 – 4.55) indicate future potential districts with new foci under all three projected scenarios RCP2.6, 4.5 & 8.5. The districts with new foci are in Jammu and Kashmir

(Baramula, Chilas, Mirpur, Jammu), Arunachal Pradesh (Dibang Valley, Lohit, Tawang), Himachal Pradesh (Kinnaur), Sikkim (Mangan).

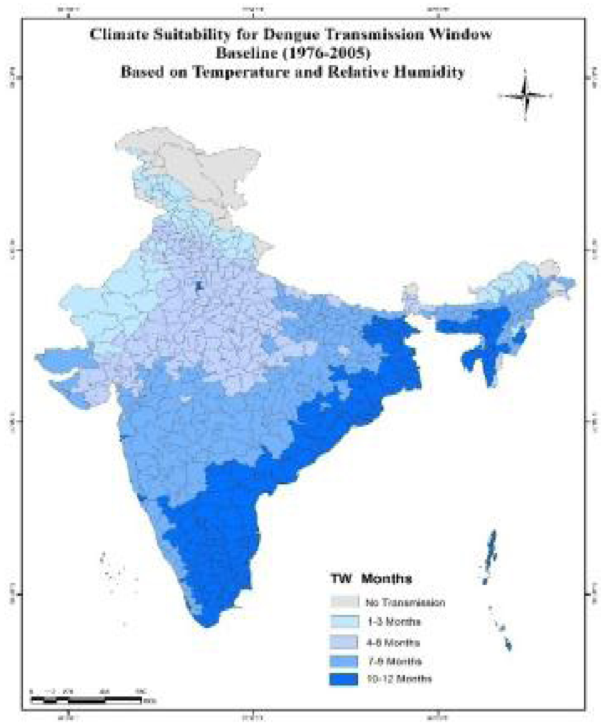
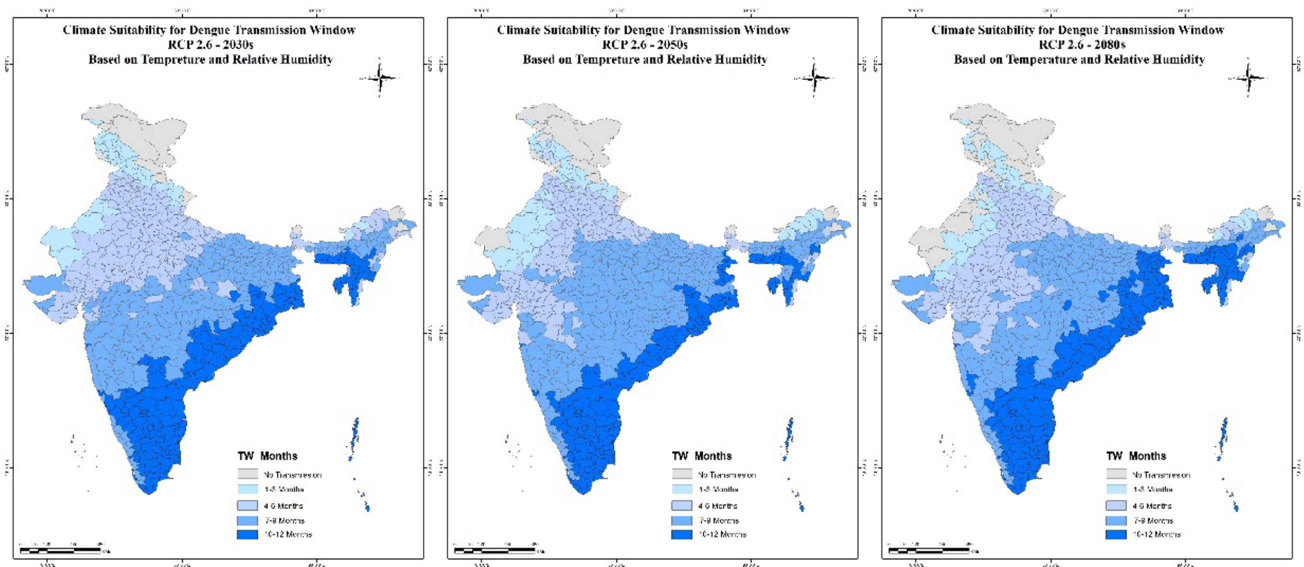
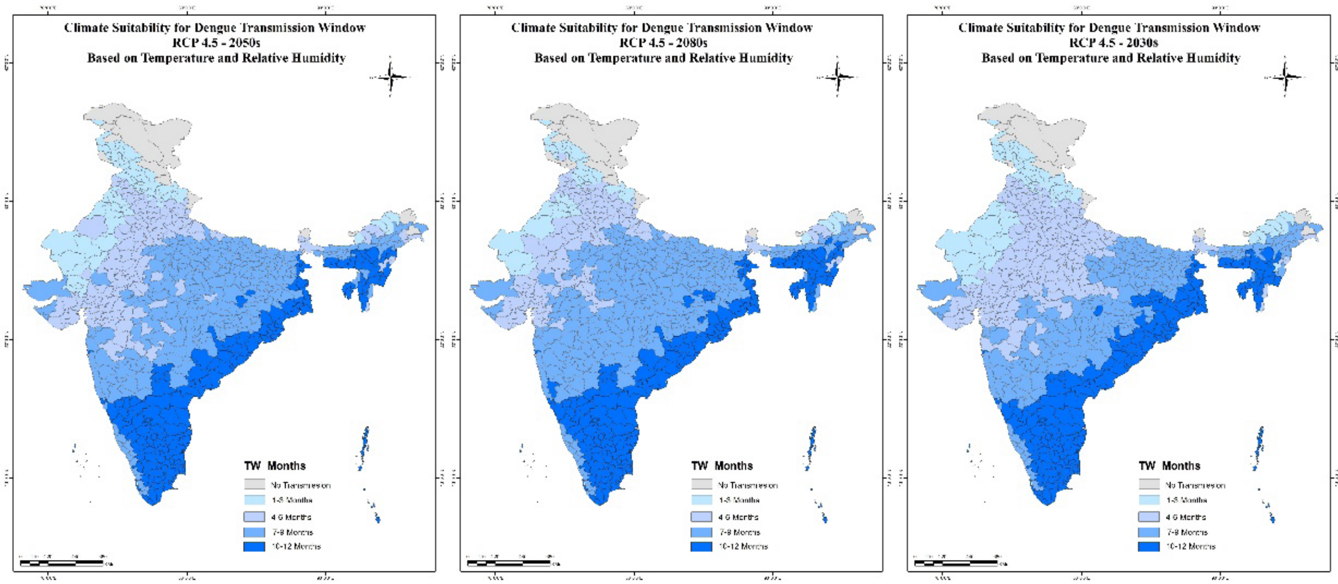


Figure 4.52: Baseline year (1976-2005) TWs of Dengue transmission based on temperature and relative humidity.



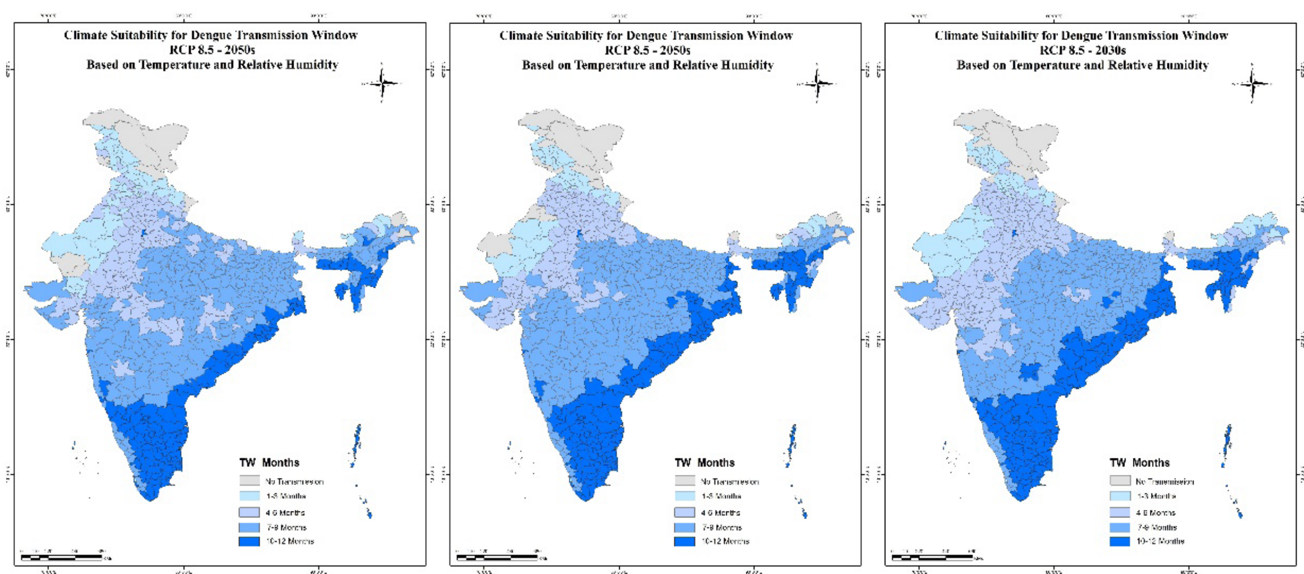
(2030s) (2050s) (2080s)

Figure 4.53: Projected TWs of dengue transmission for the year 2030s, 2050s and 2080s for RCP-2.6, based on temperature and relative humidity.



(2030s) (2050s) (2080s)

Figure 4.54: Projected TWs of dengue transmission for the year 2030s, 2050s and 2080s for RCP-4.5, based on temperature and relative humidity



(2030s) (2050s) (2080s)

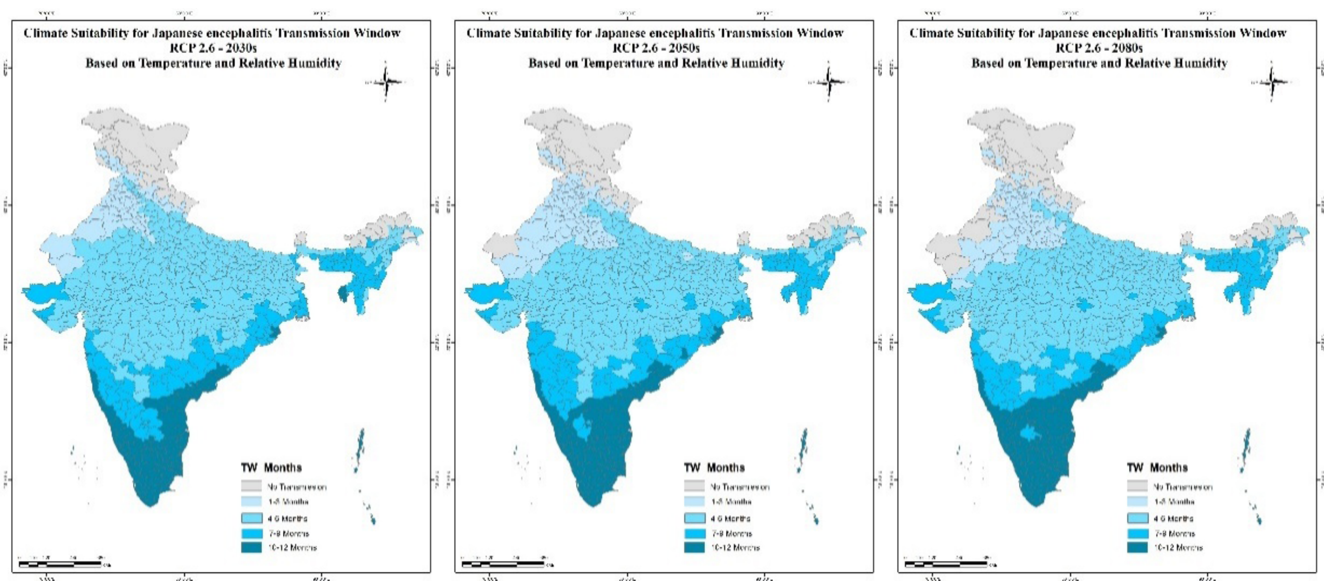
Figure 4.55: Projected TWs of dengue transmission for the year 2030s, 2050s and 2080s for RCP-8.5, based on temperature and relative humidity.

Districts of Rajasthan show a decrease in TWs and potential for no transmission by the 2050s and 2080s in RCPs 2.6 and RCP8.5 due to a reduction in relative humidity. In projected scenarios the states particularly Madhya Pradesh, Uttar Pradesh, Jharkhand, and some districts of West Bengal show changes in intensity in TWs from 4-6 to 7-9 months by the year 2050s, 2080s in all three RCPs. On the other hand, the Southern part of the country i.e. Tamil Nadu state remains the same for climatic suitability of dengue transmission for all the years under the projected scenario.

Japanese encephalitis (JE) vulnerability based on temperature and relative humidity in India

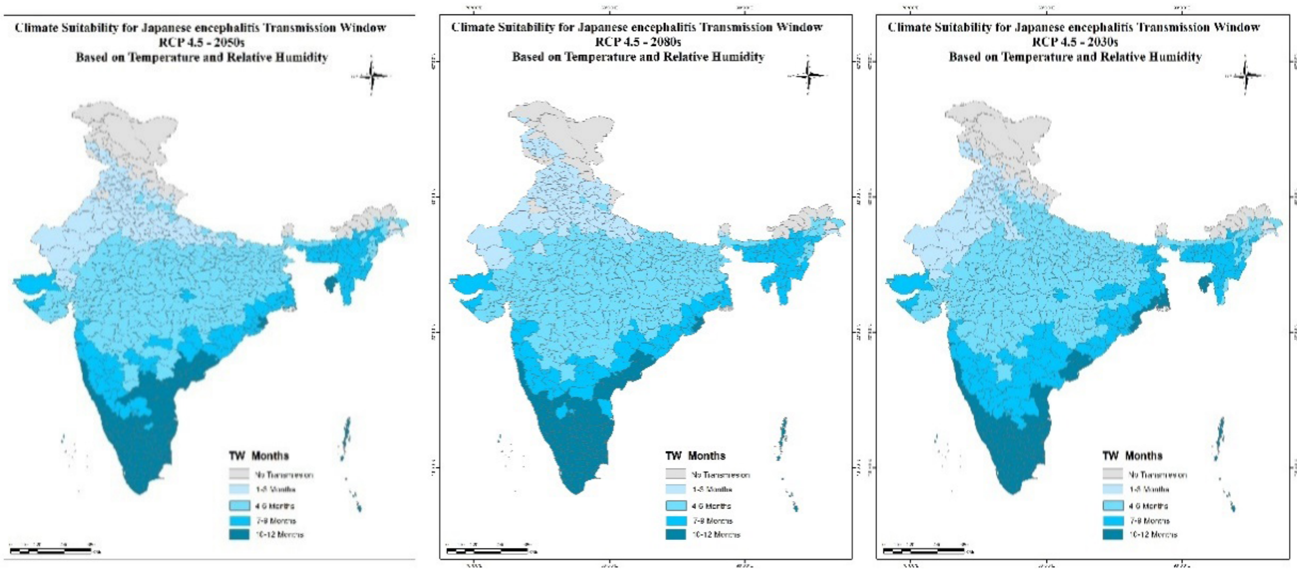
Analysis reveals (Figure 4.56-4.58) the introduction of new foci in Jammu and Kashmir (Srinagar, Jammu, Bedgam, Ramban, Kulgam, Pulwama, Supiyan, Anantnag), Arunachal Pradesh (Tawang, East Kameng, Lower Subansiri, Upper and West Siang, Changlang, Kurung Kumey), Himachal Pradesh (Kullu, Mandi), Uttarakhand (Uttarkashi, Rudraprayag, Chamoli), Sikkim (East, west and South Sikkim) by the year 2030s, 2050s, 2080s under the RCPs 2.6, 4.5 and 8.5 respectively, in the months of July to October (Figure 4.63-4.65).

Similarly, there is a visible increase in intensity in TWs from 4-6 to 7-9 and 7-9 to 10-12 months in the districts of West Bengal, Andhra Pradesh, Karnataka, Tripura, Assam, Gujarat, Manipur, Nagaland. In projected scenarios Eastern states particularly Bihar, Odisha, Jharkhand, Chhattisgarh and some districts of Madhya Pradesh, and Uttar Pradesh do not show any major change.



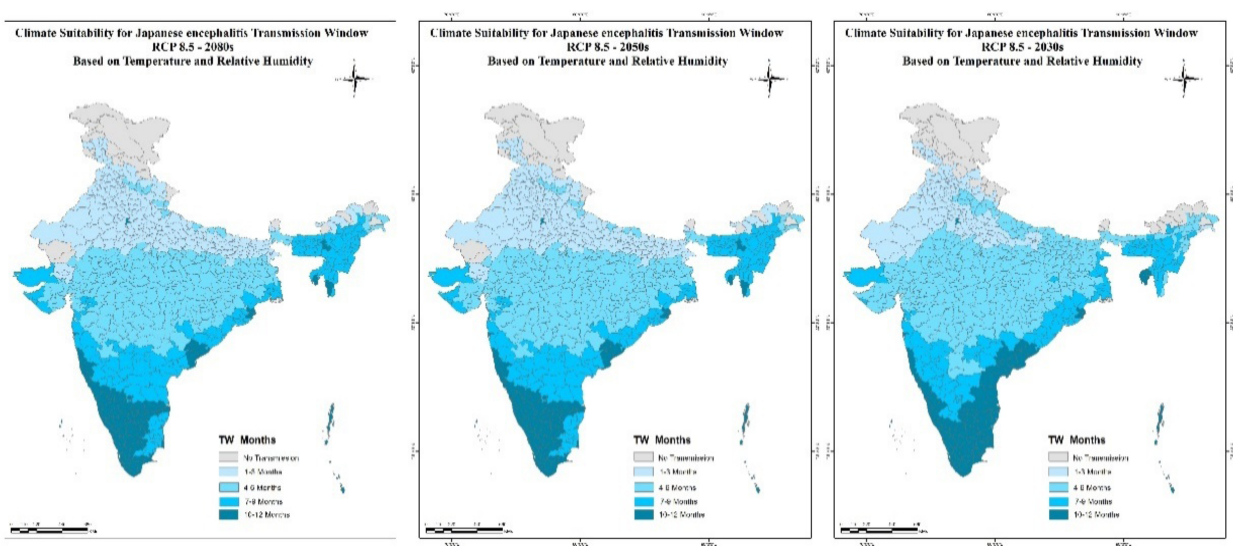
(2030s) **(2050s)** **(2080s)**

Figure 4.56: Projected TWs of JE transmission for the year 2030s, 2050s and 2080s for RCP-2.6, based on temperature and relative humidity.



(2030s) (2050s) (2080s)

Figure 4.57: Projected TWs of JE transmission for the year 2030s, 2050s and 2080s for RCP-4.5, based on temperature and relative humidity



(2030s) (2050s) (2080s)

Figure 4.58: Projected TWs of JE transmission for the year 2030s, 2050s and 2080s for RCP-8.5 based on temperature and relative humidity.

4.9.1.3 Additional Population at risk

Figure 4.59-4.60 reveal the additional population at risk and additional transmission intensity of malaria, dengue, chikungunya, Japanese Encephalitis (JE) and Kala azar. The population of nearly 0.0079 to 10.08 million people are at the risk due to malaria transmission by 2030s. In absolute terms the number of people with an increased growth rate by 2030s will face the potential risk of malaria transmission in the projected districts. Simultaneously for the potential transmission of dengue & chikungunya (0.045

– 4.77 million), JE (0.015–10.08) million and Kala azar (0.001–9.58) million are the additional risk due to climate change and exposed to disease transmission by the 2030s. It is possible that districts with year-round suitability for transmission may have less number of cases than the districts with <6 months of transmission which may be due to and occurrence of outbreaks and socio-economic conditions. Therefore, the additional population at risk may be taken with uncertainty.

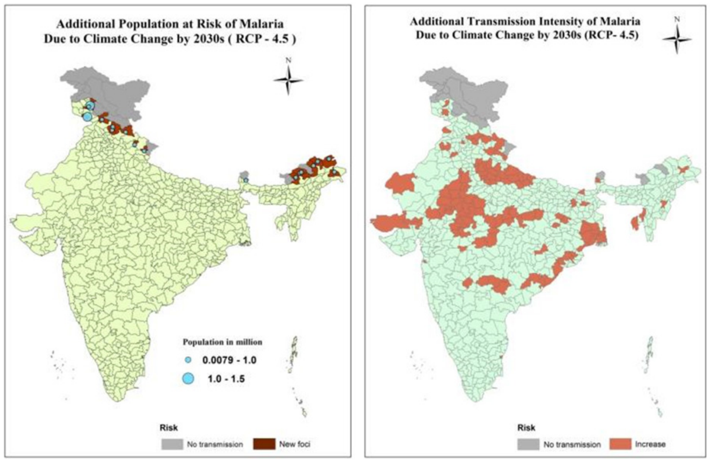


Figure 4.59: Additional population at risk and transmission intensity of malaria due to climate change

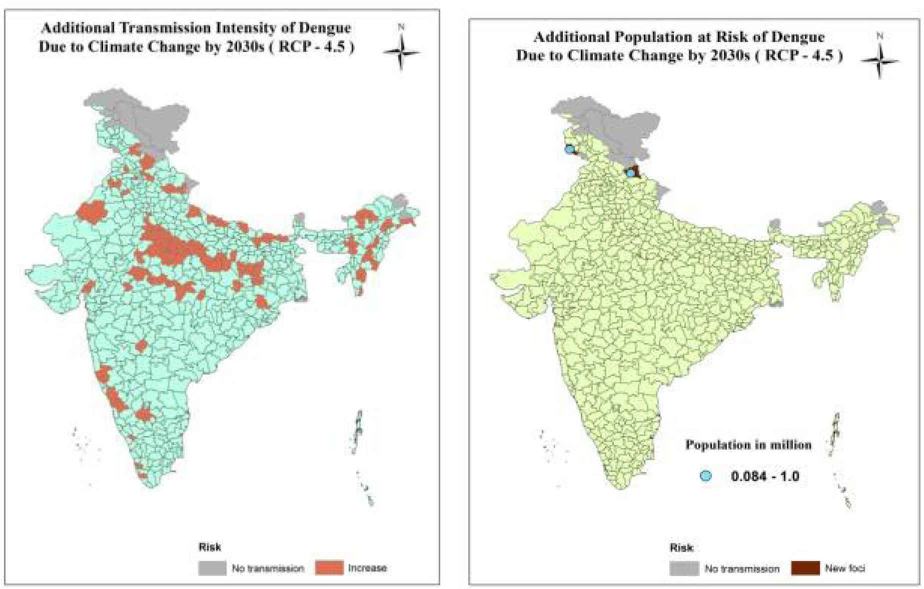


Figure 4.60: Additional population at risk and transmission intensity of dengue due to climate change

4.9.1.4 Vulnerability maps

Due to high sensitivity and low adaptive capacity, vulnerability is highest in North-east India and the states of Orissa, Chhattisgarh, Jharkhand, Bihar, Uttar Pradesh and Madhya Pradesh (Figure 4.61). On the other hand, Gujarat along with the Southern states of Tamil Nadu and Kerala exhibit the least vulnerability to malaria. Moderate Vulnerability is observed in Himachal Pradesh, Uttarakhand, Punjab and Rajasthan.

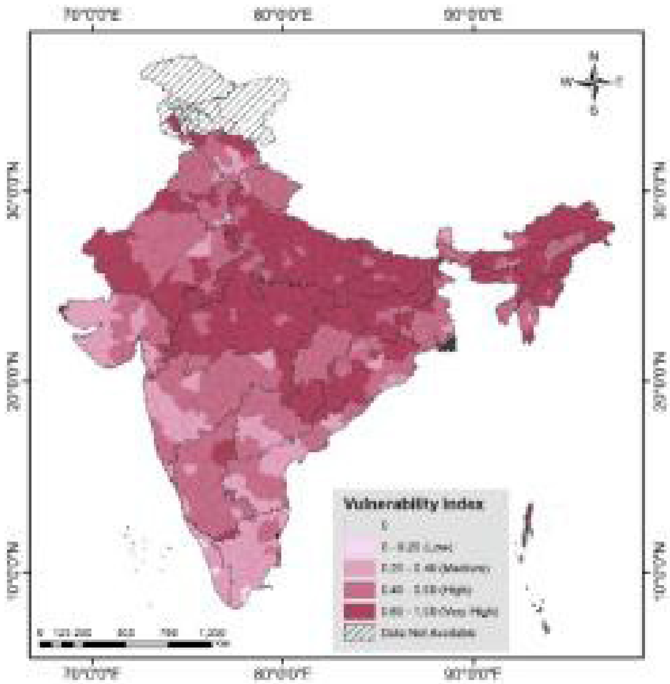


Figure 4.61: District-wise vulnerability of exposure to malaria climate change hazard Risk

Figure 4.62 presents the district-wise malaria risk profile of the country with respect to climate change. As evident from the map, the highest risk of malaria due to climate change is concentrated in North-east and Central-India including the states of Orissa, Chhattisgarh, Jharkhand and Gujarat. Despite a high risk of hazard, Southern India exhibits a very low risk of malaria due to climate change owing to a high adaptive capacity. The northern most states – Rajasthan, Punjab, Haryana, Himachal Pradesh and Uttarakhand – also exhibit low risk of malaria.

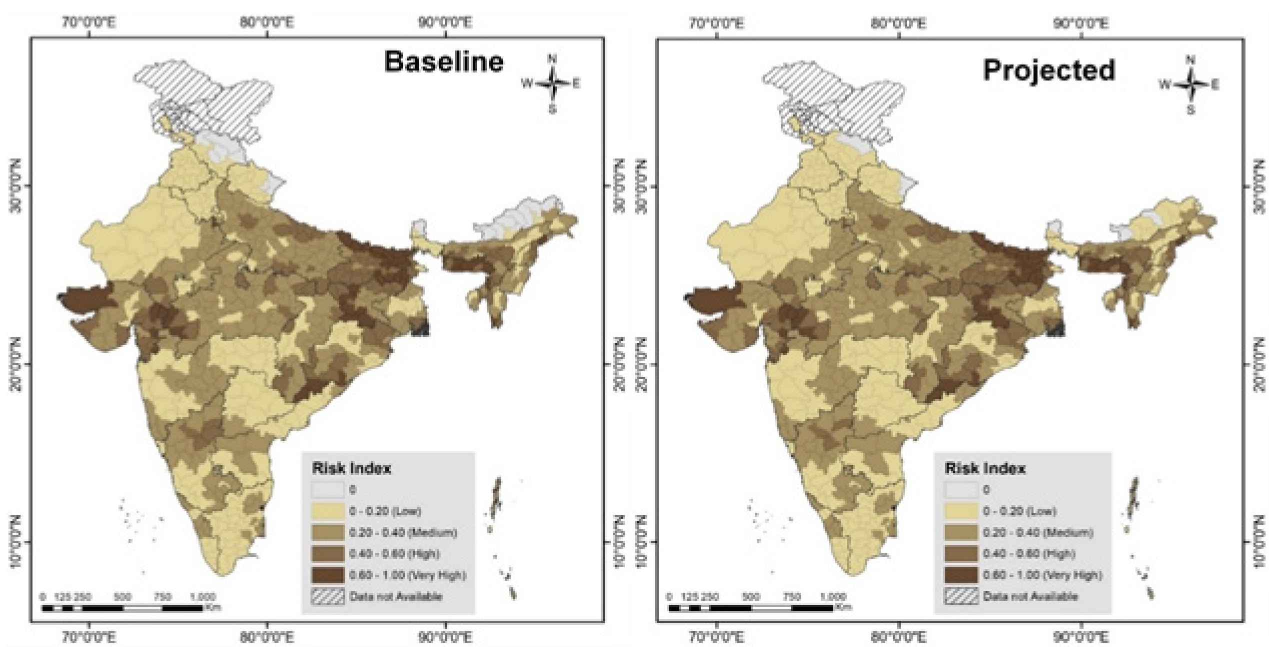


Figure 4.62: Risk due to climate change impacts on malaria

The baseline and projected risks to malaria due to climate change show marked differences in the Himalayan states of Himachal Pradesh, Uttarakhand and Arunachal Pradesh. Several districts in these states are projected to be at low to moderate risk of malaria due to climate change by 2030 despite showing no risk of malaria in the baseline map. This corresponds to an opening of new foci of transmission in these districts which introduces the risk of malaria in regions that were malaria free. In Gujarat, the vulnerability index is low. An increase in transmission windows does not lead to any change in the overall risk as it is offset by low vulnerability.

Limitations: It has been observed that mosquitoes find micro-niche within a house to get the most suitable climatic conditions, therefore, wherever the transmission windows are cut or reduced due to relative humidity, mosquitoes may obviate such conditions and the projected reduction in TWs due to relative humidity may not happen. For example, the projection of no transmission of Dengue by 2050s and 2080s due to the reduction in relative humidity may not hold true.

4.9.2 Adaptation framework

Current adaptations: India, National Vector Borne Disease Control Programme (NVBDCP) exists which provide guidelines and supervise implementation of VBD control programme in the country. The strategies of diagnosis, treatment of cases and control of vectors already exists. Even for health education, Information Education and Communication material and strategies exist. The efforts will be made to introduce the same in new foci of disease transmission. National Institute of Malaria Research (NIMR) has submitted a draft Health Adaptation Plan to National Programme on Climate Change and Human Health.

Proposed Short and long-term Adaptation and prevention measures are as follows:

Short Term Adaptation Measures:

- In areas where Vector Borne Diseases (VBDs) are already prevalent, the transmission window for each district needs to be analyzed, which can be used to plan and direct timing of IRS schedule (one-two months before peak transmission).

- In areas where VBDs are projected to emerge, information regarding vectors and VBD transmission must be imparted to the communities. This requires an understanding of the present knowledge gaps in the community and the most preferred modes of imparting information.

- Keeping this in mind, a Knowledge, Attitude, Practices and Behavior study was carried out to determine the present knowledge gaps in the community and their ability to cope with future impacts of climate change. The community was less aware of the symptoms of malaria and its treatment methods which is logical as they had little to no prior experience of malaria. While many people rightly cited high fever with chills as the major symptom of malaria, however a quarter of the respondents were unable to name any symptom and several even attributed headaches and body aches to the disease.

- Mass media has been found to be the major source of information of people living in villages, which indicates that audio/visual-based IEC and BCC material should be developed for airing on different television and radio channels. Furthermore, doctors and health professionals were found to play a minimal role in imparting information, which shows that they must be trained to play a more important role in improving the knowledge of the communities.
- Good knowledge of VBD did not necessarily improve the preventive practices of the community, which highlights the need for increasing the focus on behavioural change in communication-based intervention strategies by promoting vector control activities through group participation.

Long-Term Adaptation Measures

Long-term adaptation measures involve strengthening the health systems to enable them to cope with the projected rise in transmission. The adaptive capacity assessment study of selected districts in Himachal Pradesh and Uttarakhand highlighted the inadequacies of the Government Health Centres in these locations, in meeting with the demands of increased risk for vector-borne diseases. Most of the Health Centres lacked Rapid Diagnostic Kits (RDKs) (83.3%) for VBD detection, spray pumps and insecticides for vector control (66.7%, 83.3%) and anti-malarials for treatment (58.3%) owing to the negligible number of malaria cases in the district. High rate of vacancies (21%) as well as lower than recommended bed capacity in several Health Centres, adds to the inability of the Health Centres to cope with future risks of VBDs. The major cause for this inadequacy was that current vector control programme focuses only on the present risks of the disease and do not account for future projections and risks. This makes such regions extremely vulnerable to future epidemics. It is, therefore, advised to include projected risks to vector-borne diseases within the major disease control programme and equip vulnerable Public Health Centers (PHCs) with the necessary tools to combat the projected increase in VBD.

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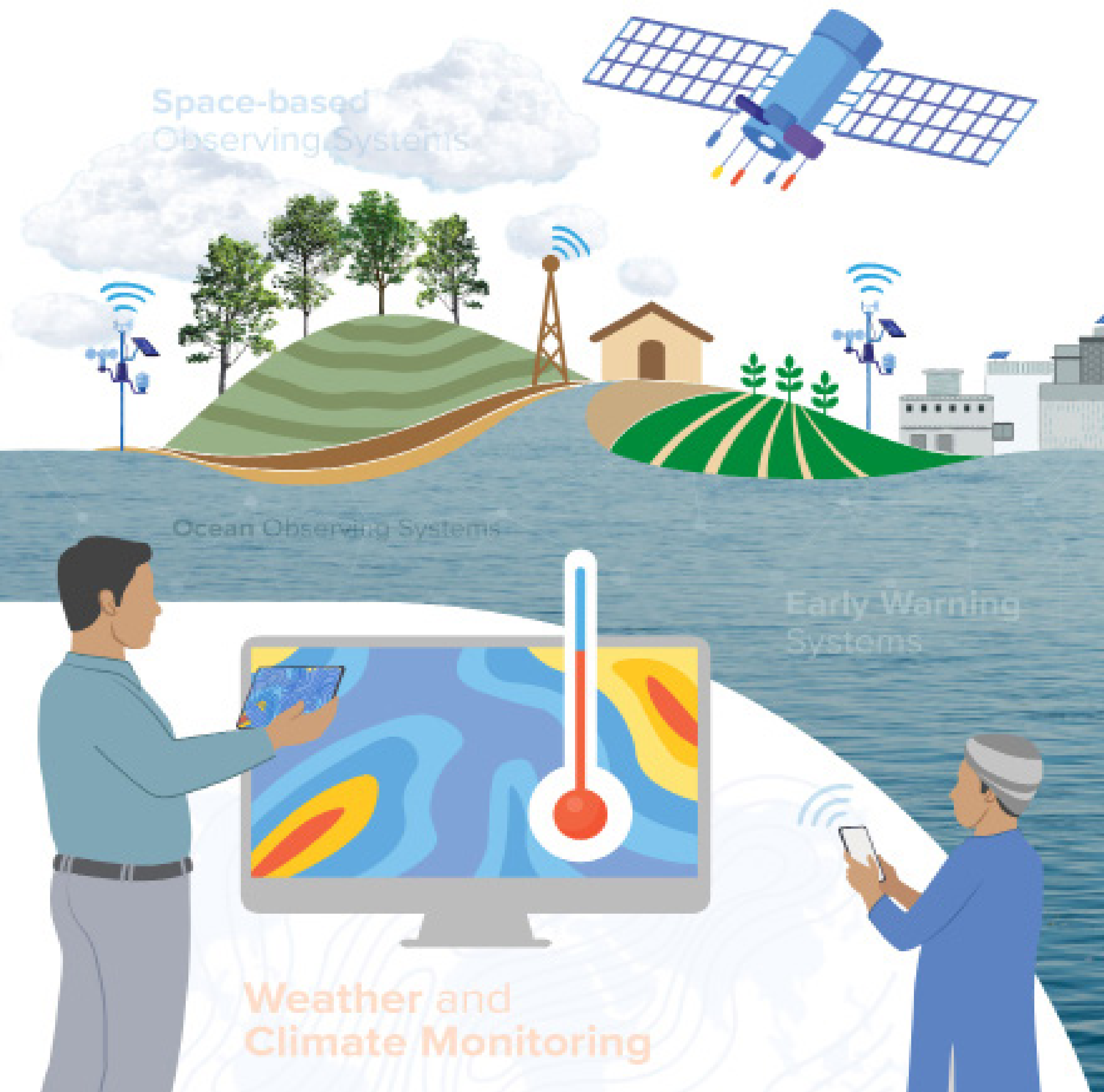
Research and Systematic Observation



RESEARCH AND SYSTEMATIC OBSERVATION

Chapter 05

5.1 Introduction

Climate research has become a major focus of scientific query since the latter half of the 20th century, especially after the identification of the impact of Greenhouse Gases (GHGs) and global warming on the Earth's climate system. Many countries, both the developed and developing, are spending a considerable amount of resources on climate research that will help governments and society to take appropriate steps. This chapter details the vast institutional setup at the backdrop of India's climate change research, supported by systematic observation networks – atmosphere, weather and climate forecasting, satellite-based observation networks and oceanic observations. It also describes India's effort in monitoring the terrestrial surface – cryosphere, mountain meteorology, ecosystems and hydrology. The chapter also includes descriptions on India's participation in international research and measurements programmes, thereby endorsing India's commitment towards a concerted effort in enhancing knowledge about the understanding of climate change.

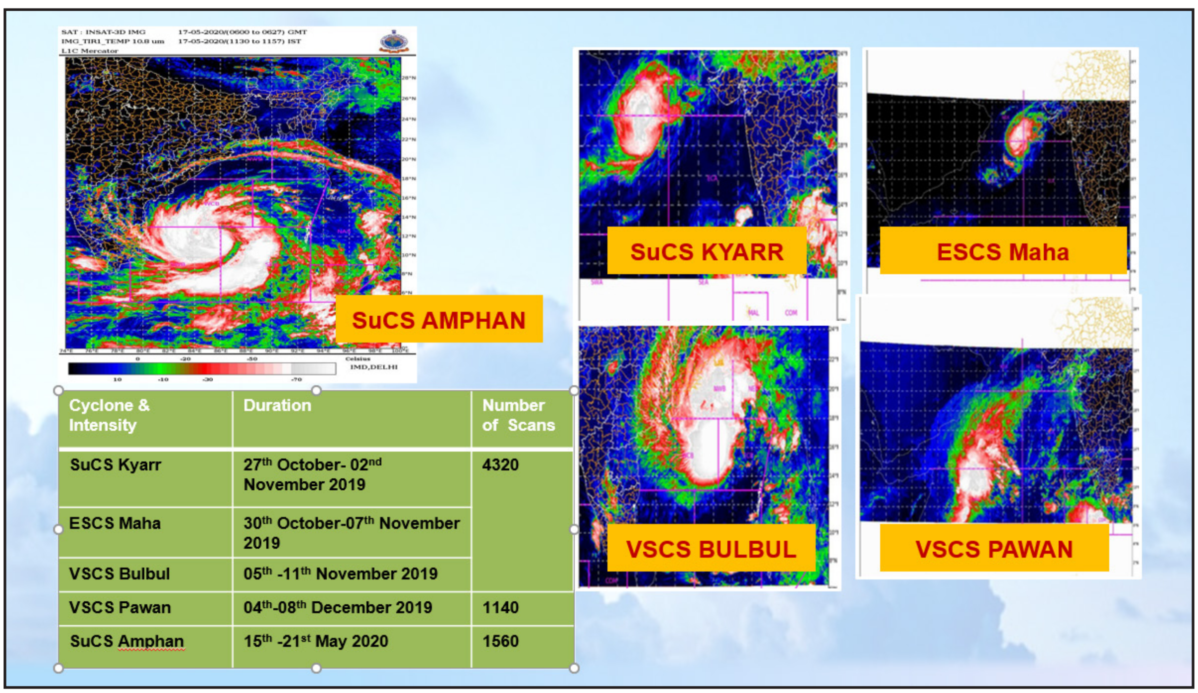
Climate change is being recognized as a major threat to present day society on a global and regional scale, because of its likely adverse impacts on ecosystem, agricultural productivity, water resources, socio-economic systems and sustainability. It has been recognized that there are important science and technology related issues that need to be addressed and also that the present efforts in India to deal with the climate change issue need to be upscaled.

5.2 Weather and Climate Observation System in India

India Meteorological Department (IMD) operates weather and climate monitoring, detection, and warning services for various sectors of economy. The weather and climate observation system consist of a multitude of individual surface- and space-based observation systems. Long-term objectives of the observation system are to improve and optimize systems for observing the state of the atmosphere to meet the requirements, in the most effective and efficient manner, for the preparation of increasingly accurate weather analyses, forecasts and warnings, and for climate and environmental monitoring. The meteorological services have significant societal impact. Public/private/government sectors demand for accurate prediction of weather and climate at various temporal and spatial scales is increasing due to possible impacts of global climate variability and change. Improved and reliable forecast of weather and climate requires high resolution dynamical models backed by comprehensive data assimilation systems. Thus, intensive monitoring of various weather systems through different platform-based observation systems provides not only the necessary information about current weather systems, but their effective assimilation in numerical models also provide important guidance for skillful forecasts generation. The main space and surface-based observing systems are further discussed in the chapter.

5.2.1 Satellite Meteorology

The conventional observation networks have limitations when observing global weather and climate system with observations limited largely to the land areas of Earth, and the Oceanic areas being mostly under-sampled. Satellites and complementary in-situ networks provide the global coverage needed to observe and document global weather. The meteorological satellites play a significant role in operational weather forecasting. IMD has established Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS satellites. Dedicated Earth stations have been setup with capabilities to receive the data from INSAT-3D, INSAT-3DR and upcoming INSAT-3DS satellite. MMDRPS systems consist of advance state of the art servers to process the complete set of data within 7 minutes after completion of scanning along with the storage capacity of order 2.0/2.0 PB (Main/ Mirror) and 324 TB SSD. The meteorological satellite data of INSAT is processed and disseminated by INSAT Meteorological Data Processing System (IMDPS). INSAT-3D and INSAT-3DR are dedicated meteorological geostationary satellites and located at 82-degree and 74-degree East longitude respectively. These satellites carry a multi spectral six channel Imager, 19 channels Sounder, Data Relay Transponder and Search & Rescue Transponder.



Cyclone & Intensity	Duration	Number of Scans
SuCS Kyarr	27th October- 02nd November 2019	4320
ESCS Maha	30th October-07th November 2019	
VSCS Bulbul	05th -11th November 2019	
VSCS Pawan	04th-08th December 2019	1140
SuCS Amphan	15th -21st May 2020	1560

Figure 5.1: RAPID SCAN during cyclone events

From MMDRPS system, products such as Net Radiation, Potential Evapotranspiration, Actual Evapotranspiration, Land Surface Albedo, Shortwave Radiation over Ocean, Cloud Particle Effective Radius, Cloud Optical Thickness, Improved IMSRA, Total Precipitable Water, High density visible winds over Ocean, INSAT 3D/3DR Merged winds and 5-day composite winds from Imager and Cloud Top Temperature and Cloud Top Pressure from Sounder are also being generated on an operational basis and being disseminated through a dedicated webpage. As shown in Figure 5.1, IMD is using weather data explorer application - Real Time Analysis of Products and Information Dissemination (RAPID) which is hosted in IMD website. This software acts as a gateway to Indian Weather Satellite Data providing quick interactive visualization and 4-Dimensional analysis capabilities to various users like application scientists, forecasters, and the public.

5.2.2 IMD Global Navigation Satellite System (GNSS) Network

IMD established Global Navigation Satellite System (GNSS) Network Pilot Phase project for measuring the total Integrated Precipitable Water Vapour (IPWV) in 2005 at five stations (New Delhi, Guwahati, Kolkata, Mumbai, and Chennai) as shown in Figure 5.2. The Network was further extended in 2017 with additional 25 stations covering most of the important areas which are responsible for weather monitoring for continuous monitoring of troposphere total IPWV at every 15 min interval with the primary purpose of assimilation of IPWV data into the Numerical Weather Prediction models and to act as an additional tool for nowcasting of thunderstorms, dust storms, monsoon studies and for climate research.

Figure 5.2: India Meteorological Department Global Navigation Satellite System (GNSS) receiver network

5.2.3 Weather Radar Network of India Meteorological Department

Radars are used for detection of various weather systems like thunderstorms, hailstorm and tracking of cyclonic storms as shown in Figure 5.3. They are also used in rainfall estimation and hail warning. Various meteorological, hydrological and aviation products generated from Doppler weather radar data is extremely useful to the weather forecasters. Radars help to estimate the storm's intensity, location, and in forecasting its future path for safe navigation of aircrafts and ships. IMD has upgraded the conventional radars in the observational network with Doppler radars using digital technology. IMD now has 33 radars in the country. Eight Doppler Weather Radars (DWR) are in operation along the east coast of India including DWR at Kolkata, Paradip, Gopalpur, Visakhapatnam, Machhilipatnam, Sriharikota, Chennai and Karaikal and five along the west coast at Thiruvananthapuram, Kochi, Goa, Mumbai and Bhuj.

There are various ongoing projects pertaining to the installation of Doppler Weather RADARs (DWRs) across the country. Details of the same follow:

- Under Integrated Himalayan Meteorological Programme (IHMP), 10 X-Band DWRs are being installed in the Himalayan and Sub-Himalayan region Leh, Banihal Top, Kufri, Surkanda Devi, Murari Devi, Jot, Lansdowne, Mukteshwar, Jammu and Ayanagar (Delhi).
- 03 C-Band DWRs are proposed to be installed in Bangalore, Sambalpur and Raipur.
- Existing 04 S-Band coastal region DWRs at Visakhapatnam, Chennai, Machilipatnam and Kolkata are being upgraded to dual polarized S-Band DWRs.
- 08 C-Band DWRs are proposed to be installed in Aurangabad, Port Blair, Ranchi, Ahmedabad, Mangalore, Balasore, Malda and Agatti (Lakshadweep).
- 08 X-Band DWRs are planned to be installed in the North Eastern region in Guwahati, Jorhat, Tezpur, Silchar, Imphal, Aizawl, Dimapur and Dhubri.
- 05 X-Band DWRs are proposed to be installed in various cities under 'Urban Meteorology' scheme in Pune, Varanasi, Kolkata, Bhubaneswar and Kozhikode.

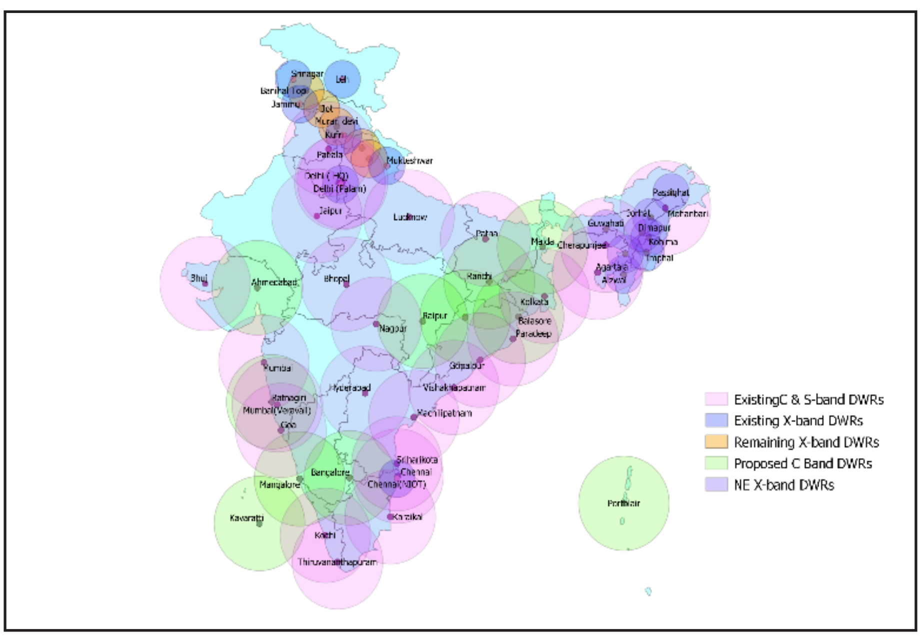


Figure 5.3: Weather Radar Network of India

5.2.4 Upper Air Observation Network

As a part of Global Observing System (GOS) network, IMD has a network of upper air observatories comprising 56 Radiosonde/Radiowind (RS/RW) stations as shown in Figure 5.4 and 62 pilot balloon observatories (PBO) to measure vertical profile of atmosphere. RS/RW network serves as the main observation system for determination of vertical structure of the atmosphere viz., temperature, wind, atmospheric pressure and humidity essential in Numerical Weather Prediction (NWP) analysis and model assessment. Observations for measurement of wind speed and direction alone are made two to four times a day at PBO as shown in Figure 5.5. In the upper air domain of Global Climate Observing system (GCOS), IMD, aiming on further improvement of upper air data quality, established Global Climate Observation System Upper Air Network (GUAN) standard radiosounding observations at its six Regional Meteorological Centres (RMCs) namely New Delhi, Mumbai, Kolkata, Chennai, Nagpur and Guwahati.

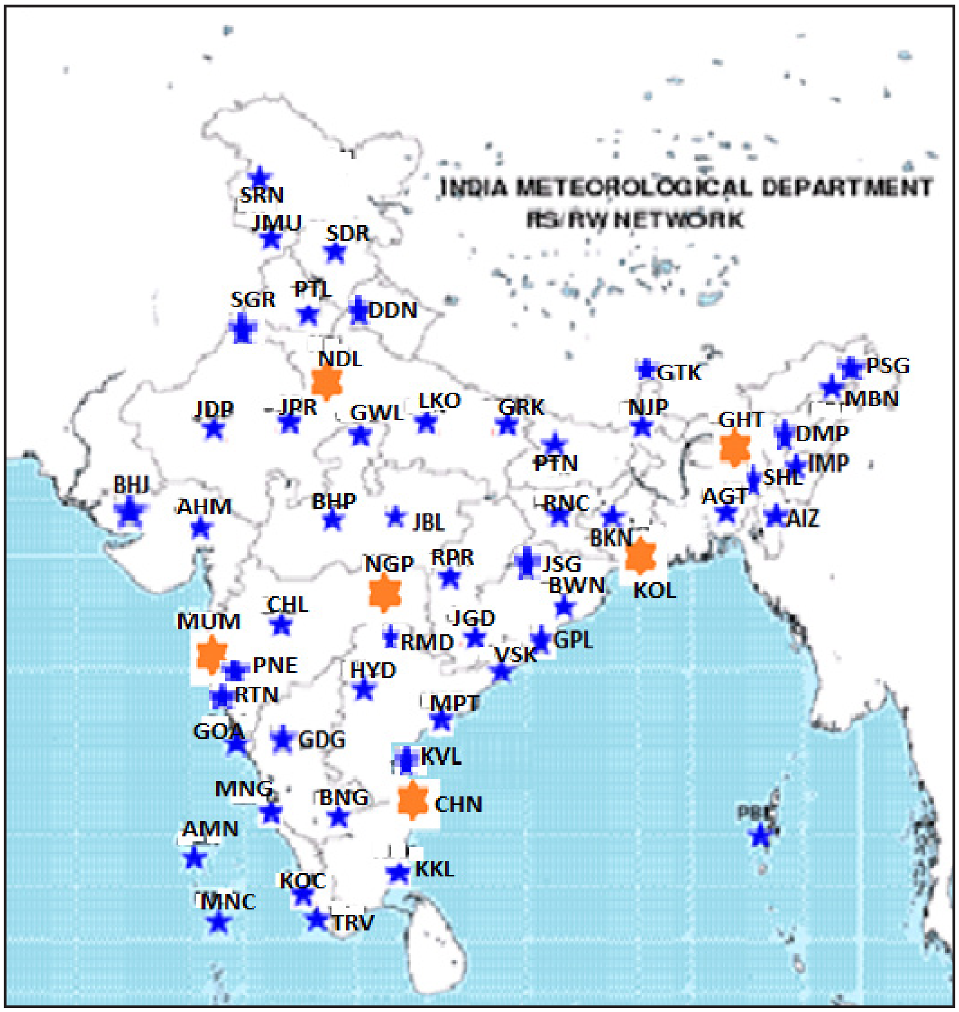


Figure 5.4: Radiosonde/Radiowind Observatories in India (GUAN standard stations in orange and other Sounding stations are shown in blue)

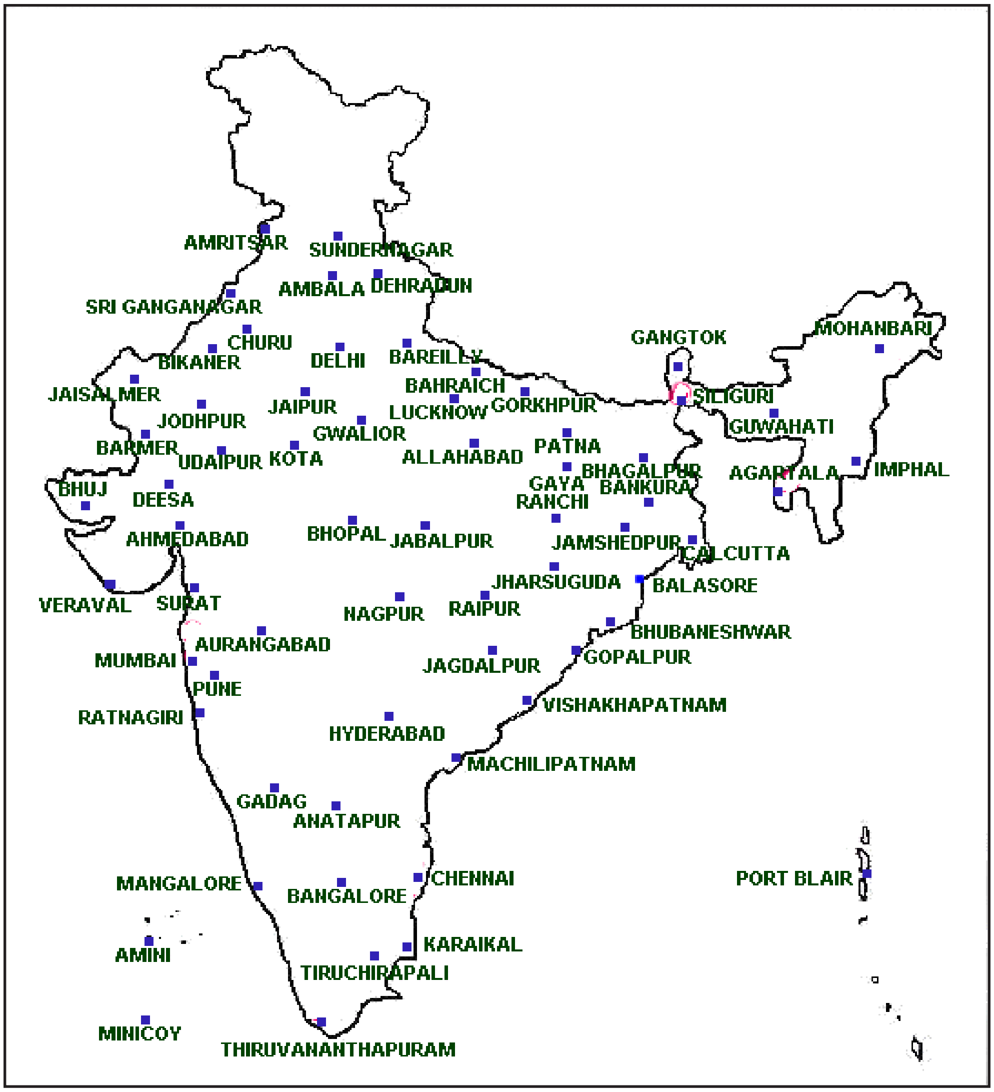


Figure 5.5: Pilot Balloon Observatories in India

5.3 Surface Observation Networks

Reliable weather forecast and climate prediction is vital for responding to the risks posed by climate change and extreme weather events. Surface weather observations are an important aspect of meteorology and the basis for all weather safety messages, weather forecasts, and weather warnings worldwide. IMD was formally established in 1875 with a network of about 90 weather observatories for systematic observation and research. At present, IMD maintains 206 surface observatories as shown in Figure 5.6, 735 Automatic Weather Stations (AWS) as shown in Figure 5.7, and 1350 Automatic Rain Gauge Network (ARGN). A network of 27 High Wind Speed Recording systems is established along east and west coast of India. It is capable of providing uninterrupted data in cyclone prone coastal areas during severe weather conditions including high winds and heavy rains. Surface weather observations include several elements such as temperature, pressure, precipitation, wind, visibility, relative humidity etc.

Figure 5.6: IMD Network of Surface Meteorological Observatories

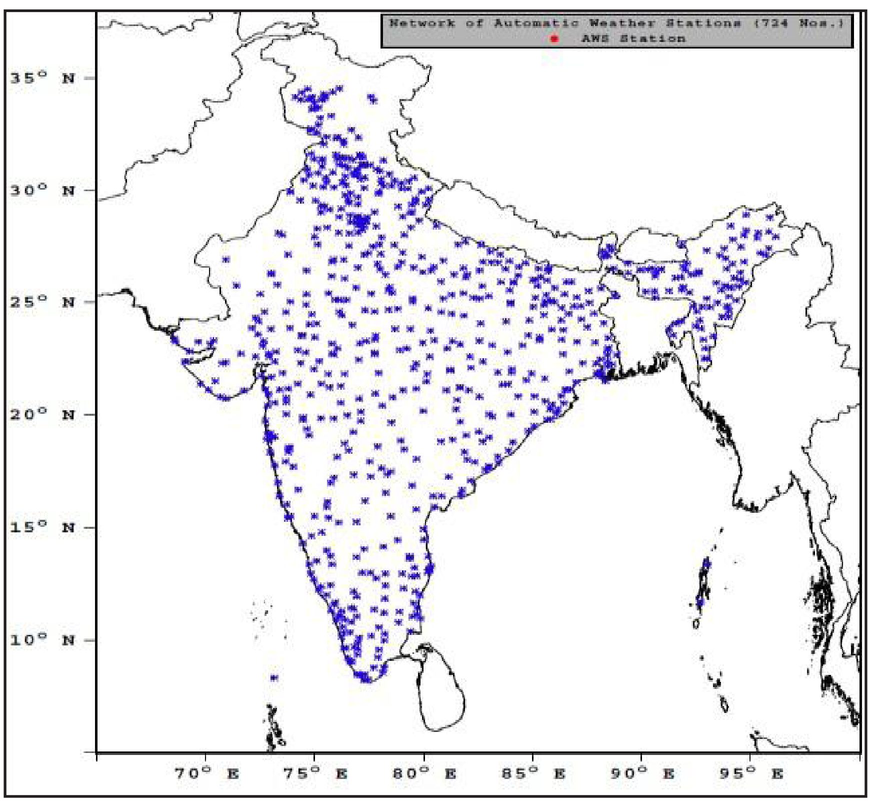


Figure 5.7: IMD Network of Automatic Weather Stations in India

5.4 Environment Monitoring

IMD conducts monitoring and research related to atmospheric constituents that are capable of forcing change in Earth's climate, may cause depletion of the global ozone layer, and play key roles in air quality from local to global scales. IMD contributes to the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) programme as shown in Figure 5.8. The main objective of GAW is to provide data and other information on the chemical composition and related physical characteristics of the atmosphere and their trends, required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere. IMD maintains a network of ozone, aerosol, precipitation chemistry and solar radiation monitoring stations.

Figure 5.8: Environment Monitoring Network of IMD

5.5 Agrometeorology Observation Network

Weather and climate information plays a vital role in agriculture management and production. Under the network of observatories related to agrometeorology, at present there are 224 Agromet observatories, 3 Evapotranspiration Stations, 9 Soil Moisture Stations and 17 Dew gauge stations in the country. Weather forecast based agromet advisory is provided to the farmers at district level through a network of existing 130 Agro-Met Field Units (AMFUs) located in each Agro Climatic Zone. After operationalisation of district level Agromet Advisory Services successfully from 2008, India Meteorological Department is venturing into providing Agromet Advisory Services at the block level across the country in collaboration with

Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), State Agriculture Department, Indian Institute of Technology (IITs) and other organizations under the Gramin Krishi Mausam Sewa (Rural Agrometeorological Services) project. The pilot study is in progress in approximately 500 blocks and the goal is to cover 6,500 blocks in 660 districts. In order to improve the quality of the agromet advisory services, regular direct interactions are being made by the Agrometeorological Field Units (AMFUs) with the farmers, State Agromet Advisory Services (AAS) units and Agrimet Division are regularly participating in farmers' gathering to personally interact with the farmers and collect feedback. Keeping the need for AAS to be more crop and location-specific and considering the extension to all farming households in the country, the network of Gramin Krishi Mausam Seva (GKMS) scheme as shown in Figure 5.9 is being extended to district level by establishing 530 District Agromet Units (DAMUs) in the premises of Krishi Vigyan Kendras (KVK; Agriculture Science Centres) in collaboration with Indian Council of Agricultural Research (ICAR). District Agromet Units (DAMUs) are being established in KVKs under ICAR network in a phased manner for rendering block level AAS.

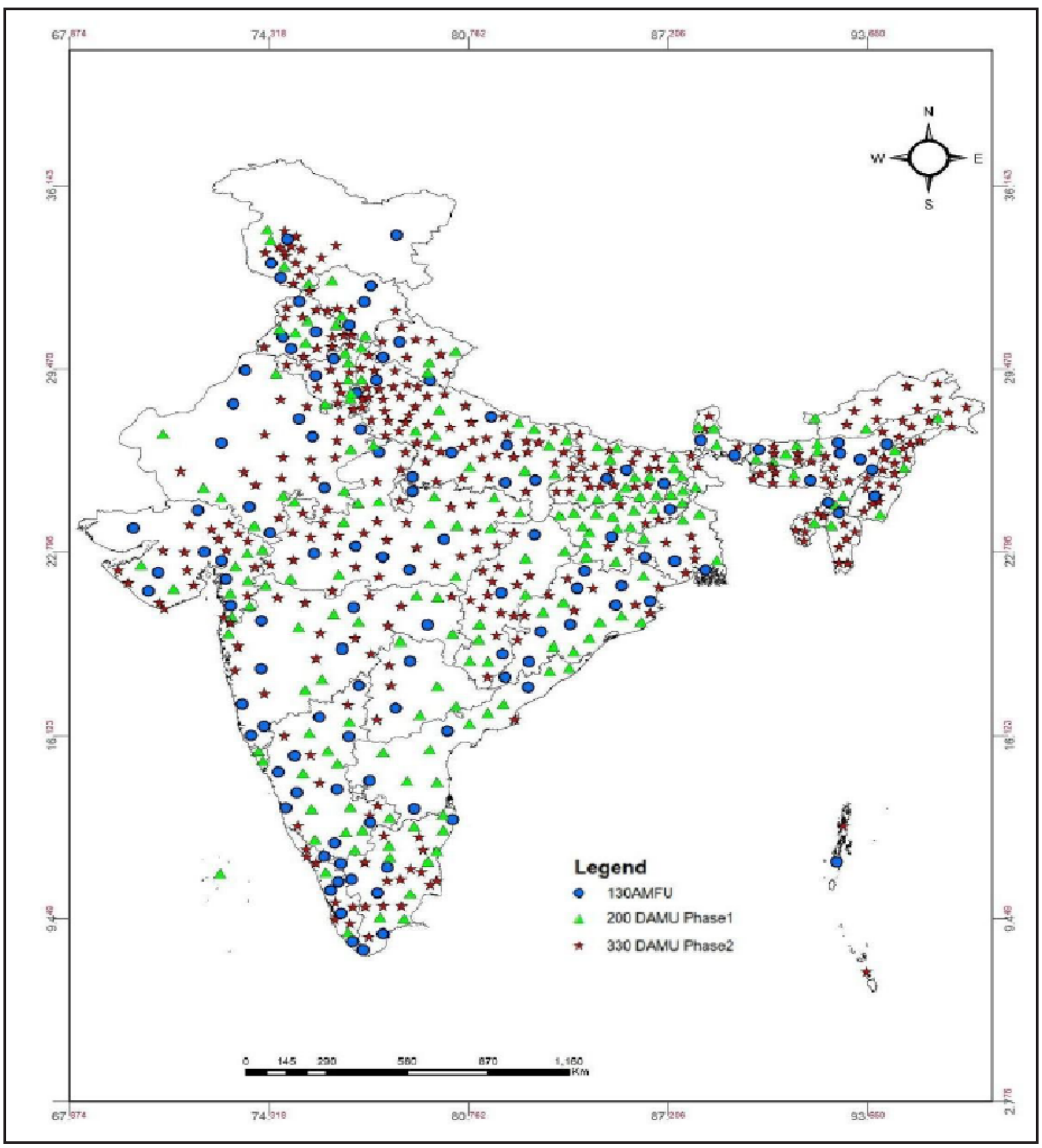


Figure 5.9: Present and Proposed Network Under GKMS

5.6 Ocean Observation

Sustained ocean observation is crucial to understand complex oceanic processes, their variability, their interaction with the atmosphere and the development of operational ocean services for the benefit of society. The Ministry of Earth Sciences (MoES), Government of India leads the national ocean observation programs along the Indian coast and in the Indian Ocean through its autonomous institutions, the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and the National Institute of Ocean Technology (NIOT), Chennai. Data from these observing networks are efficiently and effectively utilised for the generation of ocean information and advisory services viz., potential fishing zone advisories, harmful algal bloom information, coral bleaching alerts, ocean state forecast, tsunami, cyclone and storm surge early warning services, etc. that support blue economy initiatives and enhance the safety of life. The scientific rationale of all these observation programmes is to support the greater goal of sustainable development and ecosystem restoration, expanding biological observation networks and marine biodiversity observations, innovation and using advanced technologies for low-cost, multidisciplinary observations, and to improve global ocean observation networks.

Several of India's ocean observing networks form integral parts of the Global Ocean Observing System (GOOS) programme of the Intergovernmental Oceanographic Commission (IOC/UNESCO). INCOIS contributes significantly to the largest multi-national ocean observation programme, the Argo network, by deploying floats in the Indian Ocean. So far, INCOIS has deployed 494 floats in the Indian ocean to collect ocean hydrographic and biogeochemical observations from the top 2000 m of the ocean. As part of the Global Drifter Program (GDP) under GOOS, INCOIS participates and deploys lagrangian drifting floats in the Indian Ocean. As part of this program, INCOIS plans to deploy 30 drifters per year in the North Indian Ocean (1 drifter in 5°x5° box) at a measurement frequency of 1 hour. INCOIS is also part of the 19 institutions joint XBT program and maintains eXpendable BathyThermographs (XBT) lines along select sea routes around India. This is one of the longest ongoing observational programs jointly executed by INCOIS and the National Institute of Oceanography (NIO, Goa, India). Under the XBT (XCTD) program temperature (temperature and salinity) profiles of the upper ~800 m of the ocean along regular commercial shipping routes is collected and processed for analysis. These long-term measurements are critical to improve our understanding of the interannual to decadal-scale volume transport in the oceans.

National Institute of Ocean Technology (NIOT, Chennai) established the Moored Ocean Observation Network comprising of Met-Ocean, CAL-VAL and Tsunami buoys for data collection and to disseminate real time data. The present buoy network comprises of twelve Ocean Moored buoy Network for northern Indian Ocean (OMNI) buoys, four coastal buoy systems, one CAL-VAL buoy system and two tsunami buoys. Besides, one IndARC mooring at Kongsfjorden, Norway, one ADCP mooring and a Directional Wave Rider buoy off Chennai is also being maintained by NIOT. The met-ocean data from OMNI Buoy is received at NIOT and disseminated to INCOIS for further transmission on Global Telecommunications System (GTS) in real-time for its utilisation by operational agencies globally. The OMNI programme contributes to the Global Ocean Observing System (GOOS). In addition, MoES supports Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) programme of National Oceanic and

Atmospheric Administration/Pacific Marine Environmental Laboratory (NOAA/PMEL) under the INDO-US collaboration. NIOT and INCOIS are extending operational support to NOAA/PMEL for RAMA buoys in the Indian Ocean since 2008. A Joint OMNI-RAMA Indian Ocean Data Portal was developed by INCOIS jointly with NIOT and NOAA/PMEL. The joint data portal showcases the large inventory of meteorological and oceanographic data sets with direct access for data display and delivery.

INCOIS maintains a network of 34 ship-based Autonomous Weather Stations (AWS) that collects marine meteorological data and reports in real-time to the data reception centre at INCOIS. The primary objective of the AWS programme is to measure the surface met-ocean parameters to validate and refine the forcing parameters (obtained from different met agencies) for the Indian Ocean Forecasting System (INDOFOS) which is being operated at INCOIS. The network of 16 Wave Rider Buoys (WRB) installed along India's coasts continuously monitor the ocean state and helps in accurate forecasting of the nearshore wave conditions, including high swell events, surges, cyclone induced waves etc. and plays a very crucial part of the coastal zone management.

There is a network of 36 real-time tide gauge stations around the Indian coastal regions and island stations, maintained by INCOIS, to monitor the sea level variations around the coasts. This network forms a major component of the Indian Ocean Tsunami Warning System (IOTWS) located at INCOIS besides the Tsunami detecting buoys. Long-term sea level observations are critical for understanding the decadal climate variability at local and regional scale in the context of sea level rise due to global warming and its impact on the coasts.

INCOIS maintains a network of five Tsunami Buoys with surface buoys (three in the Bay of Bengal and two in the northern Arabian Sea). NIOT maintain two Tsunami Buoy Systems in the north Indian Ocean and data being transmitted to INCOIS in real-time. These open ocean tsunami buoy systems equipped with bottom pressure sensors can provide warnings to coastal areas that will be first impacted by a tsunami, before the waves reach them and nearby tide gages.

As a part of 'Coastal Monitoring' programme, INCOIS will soon establish buoy based autonomous water quality observatories at six locations in Indian Coastal waters along West (Veraval, Goa, Kochi) and East (Chennai, Visakhapatnam and Digha) coast of India. The first phase deployment is at Visakhapatnam and Kochi which will be subsequently scaled up at other locations. The data recorded by the observatories is aimed at monitoring water quality parameters, developing an understanding of coastal processes, assessing the health of the coastal waters, model validation, assimilation, and forecasting of water quality parameters.

The Indian Coastal Ocean Radar Network (ICORN) comprising 10 High Frequency (HF) radars along mainland coastal locations and Andaman Islands was established by NIOT. Out of 10 sites, 6 are located along the east coast of India, a pair covering the Gulf of Khambhat, Gujarat in the west coast of India, and the remaining two are in the Andaman Islands. These HF radar systems map surface currents, wave characteristics, and spectra in wide swaths of coastal waters up to 200 km offshore, 24 hours a day, and in all weather conditions. These surface observations are then reported to the data reception centers at NIOT and INCOIS. Main users of these high-quality data include academia, research institutes, and ocean information service providers.

INCOIS, in collaboration with National Institute of Oceanography (NIO, Goa), maintains a network of three equatorial subsurface current meter moorings and eighteen Acoustic Doppler Current Profilers (ADCP) around India's coasts. The long records of subsurface current data help in model simulation validation, basic research on Indian Ocean coastal currents etc.

INCOIS conducts regular cruises in the ocean to collect physical, biological, chemical, and meteorological data from Indian Ocean. These observation campaigns are aimed at collecting in-situ observations to study specific processes that are important to improve in the ocean forecast models for better forecasts. INCOIS utilises state of the art observation tools like ocean gliders, lagrangian floats, Air-Sea Interaction Meteorology (ASIMET) system, eddy covariance flux system, underway Conductivity, Temperature, Depth (CTD) systems, conventional and lowered Acoustic Doppler Current Profiler (ADCP) systems, etc. to collect data.

A real-time network of thirty-five collocated Strong Motion Accelerometers (SMA) and Global Navigation Satellite System (GNSS) receivers are established in the Andaman & Nicobar Islands with real-time satellite connectivity. This real-time GNSS and SMA data will be used for the estimation of moment magnitude which is a critical indicator of the tsunamigenic potential of an earthquake. These observations together with the tsunami monitoring buoys and coastal tide gauge stations form the observation component of the Indian Ocean Tsunami Warning System.

Under the ambitious "Deep Ocean Mission" programme (as shown in Figure 5.10), INCOIS proposed to deploy eight deep ocean gliders with the intent to maintain two continuous transects: one in Bay of Bengal and another in Arabian Sea which measures ocean physical and biogeochemical parameters up to 1000 m depth. Moreover, it is planned to deploy 48 deep Argo floats in the Arabian Sea, Bay of Bengal, and Equatorial Indian Ocean that can measure vertical profile of temperature, salinity, and Dissolved Oxygen (DO) up to the ocean bottom (~ 5000 m depth). Additionally, 150 wave drifters are to be deployed to study and observe surface waves and swells characteristics in the Indian ocean. In its first phase, two Slocum Gliders transects of approximately 5300 kms was successfully completed (17.5 ^{o}N to 4.5 ^{o}N along 89 ^{o}E) in the waters of Bay of Bengal during 05 March to 20 May 2021 (~76 days).

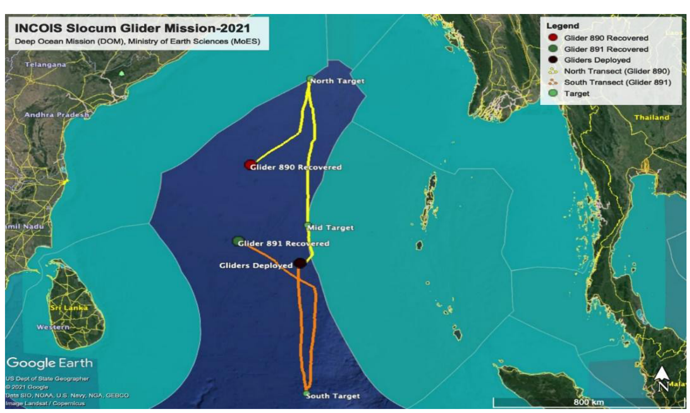


Figure 5.10: Glider transacts in the Bay of Bengal under the Deep Ocean Mission.

5.7 Climate and Global Change

INCOIS is actively involved in numerical ocean modelling activities to provide operational oceanographic services. Taking responsibility for providing ocean analysis, reanalysis, and forecasts, INCOIS has been spearheading the research in numerical ocean modeling and ocean data assimilation in India for the past several years. Currently, it uses a suite of configurations based on Regional Ocean Modeling Systems (ROMS) integrated with the data assimilation scheme, known as the Localized Ensemble Kalman Filter (LETKF) for the forecast of ocean general circulation features. The LETKF system assimilates in-situ temperature/salinity profiles and satellite SST using an 80-member ensemble. INCOIS also uses the Global Ocean Data Assimilation System (INCOIS-GODAS), in which ocean observations are assimilated to the global configuration of Modular Ocean Model (MOM4p0d) using 3DVAR method to generate global ocean analysis, which is extensively used for providing initial conditions for the Monsoon Mission models. Another ocean analysis and forecast system being run at INCOIS is based on HYCOM model and data assimilation using Central Statistical Interpolation Scheme. HYCOM configuration for the global ocean at a lower resolution provides boundary conditions for the Indian Ocean configuration of HYCOM. This HYCOM analysis provides initial conditions for the coupled HYCOM-WRF model used in IMD's cyclone predictions.

To optimise the model simulations and computer resources for operational ocean forecast, INCOIS is implementing a mission mode programme, "Modeling Mission", to build a seamless prediction system from global to regional domain. Under this mission, Modular Ocean Model version 6 (MOM6) with LETKF assimilation system is being developed, which will replace the existing operational systems. Further, for forecasts along the coastal regions and estuaries, FVCOM- a finite volume, unstructured grid ocean circulation model will be used.

5.8 Deep Ocean Mission

The Government of India launched an ambitious "Deep Ocean Mission" programme to grow marine and maritime economy, tackle climate change and pollution, and improve sustainable use of resources. This mission is led by the Ministry of Earth Science, Government of India. This mission has six verticals including a specific vertical related to the "Development of Ocean Climate Change Advisory Services (OCCAS)" that will be coordinated by the Indian National Centre for Ocean Information Services (INCOIS). This vertical aims to provide quantitative indicators of the possible changes under the future climate change scenarios for helping the planning of future marine system driven economy and offshore/coastal installations/ constructions. Under this vertical, a suite of dynamical/statistical models and techniques will be developed to understand and provide future projections of important ocean climate change indicators, such as sea level change, cyclone intensity and frequency, storm surges and wind waves, and biogeochemistry and ecosystem, on decadal to longer time scales and associated impact on the coastal regions. Each of these indicators will be handled as separate modules supported by well-designed observing and monitoring networks.

To downscale the sea level projection for the coastal waters of India, the high-resolution ocean models will be forced by reconstructed projected atmospheric forcing based on 6th phase of the Coupled Model

Inter-comparison (CMIP6) project projections as shown in Figure 5.11. For this purpose, only the 7 best performing CMIP6 models for the Indian Ocean are selected from the 27 coupled CMIP6 simulations. The selected models show the least dynamic sea level bias and relatively better atmospheric conditions over the Indian Ocean during the hindcast period. This study finds that the ensemble mean of the Dynamic Sea Level (DSL; driven by winds and density of the water column) change is projected to be more in the Arabian Sea and along the western Bay of Bengal. Relative to 1994-2014, the projected rise in the Dynamic Sea Level by the end of 21st century (2080-2100) in the north Indian Ocean and around the coast of India is estimated to be ~20-25 cm under the SSP2-4.5 scenario and ~30-35 cm under the SSP5-8.5 (Sajidh et al., 2021).

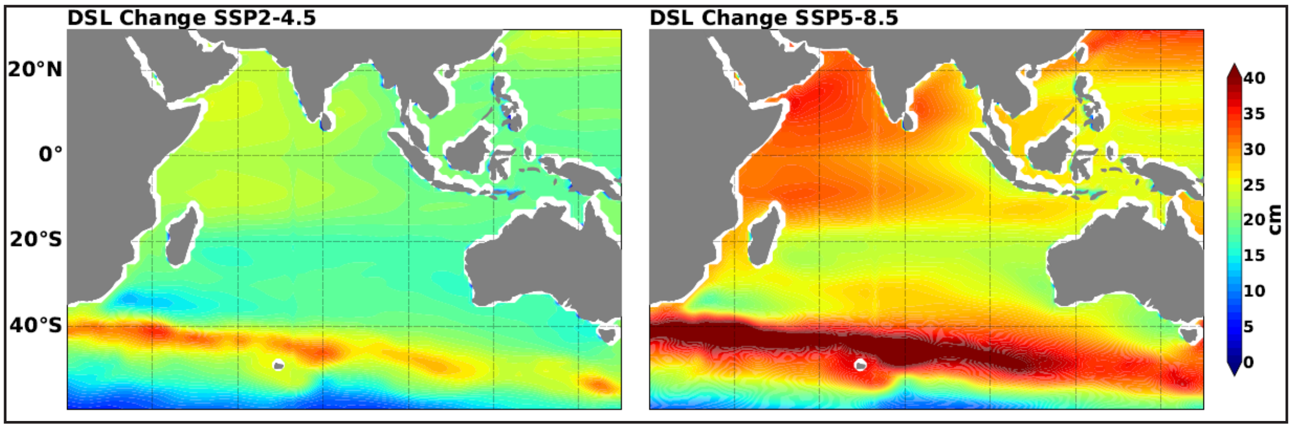


Figure 5.11: CMIP6 model projected change in the dynamic sea level during 2080-2100 relative to the 1994-2014.

5.9 Indian Ocean Warming and Marine Heat Waves

The tropical Indian Ocean has experienced a rapid increase in ocean warming with an average rise in SST of about 1°C over the period of 1951-2015. It is also found that the warming is spatially non-uniform with the strongest warming seen in the Arabian Sea (Climate Change Assessment Report- 2020 by the Ministry of Earth Sciences). Owing to the mean warming of the sea surface temperature, the Indian Ocean is increasingly experiencing marine heatwaves. Marine heatwaves are prolonged warm sea condition events that can cause a destructive impact on marine ecosystems and overlying atmospheric conditions. Recent studies shows that the duration and frequency of marine heatwave events exhibit a rapidly increasing trend in the western Arabian Sea along the coast of Somalia, northern and southeastern Arabian Sea close to the west coast of India and in the northern Bay of Bengal (Saranya et al., 2021; Chatterjee et al., 2020).

5.10 Applications and Tools to aid in Mitigation and Management of Climate Change Impacts on Coastal Areas

5.10.1 Background

Global climate change and the threat of accelerated sea-level rise exacerbate the already existing high risks due to cyclones, coastal floods, storm surge, tsunami, sea level rise, climate change induced extreme weather in coastal areas. The coastal areas with high population density, critical infrastructure and ecosystems, economic growth is becoming highly vulnerable which necessitates the need for proper information, data and strategies to proactively develop a more systematic approach to managing the risk associated with living in coastal areas. In light of these existing hazards and increasing risks in coastal regions, there is a great need to gain much insight into the exact nature of vulnerability (physical, ecological, socio-economic) and extent of risk in the coastal areas of country. India is a signatory to the Sendai Framework for Disaster Risk Reduction (2015-2030) and is committed to work towards developing a disaster resilient country and therefore it is very imperative to have access to information and knowledge which can be used to mitigate and manage the disaster-prone coastal areas of the country.

5.10.2 Mapping and Modelling the vulnerability and risk of coastal areas

The National Centre for Coastal Research (NCCR) has carried out extensive work in understanding the vulnerability of the coastal areas to Tsunami, coastal erosion, coastal pollution, flooding, sea level rise etc. as shown in Figure 5.12 and has actively collaborated with the state government.

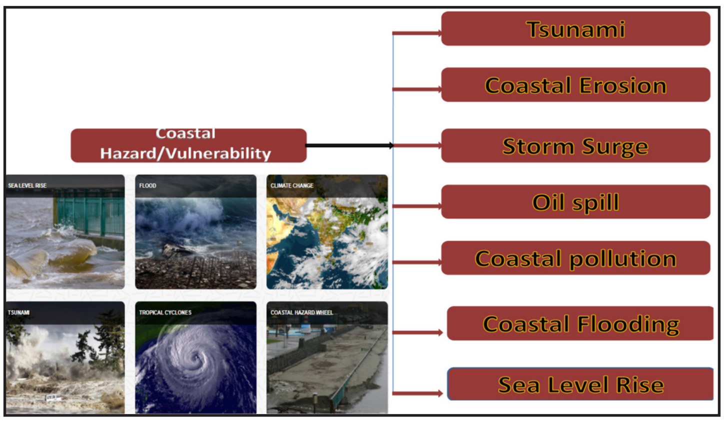


Figure 5.12: Mapping and modeling of Coastal hazards and vulnerability by NCCR

5.10.3 Flood warning systems

Floods have been a recurrent phenomenon in India from time immemorial and are almost becoming an annual phenomenon now as floods of varying magnitude affect different parts of the country. In the past decades extreme rainfall events have increased resulting in floods of unprecedented nature with large scale damage to lives, livelihood, infrastructure and property. These include the 2018 - Kerala Floods, 2017 - Mumbai Flood and West Bengal Floods. 2016 - Brahmaputra Floods, 2015 - Chennai Floods, 2014 - Kashmir Floods and 2013 - North India Floods and the 2005 flood in Mumbai which brought the financial capital of India to a standstill.

NCCR has worked in developing operational state-of-art early flood warning system for two metropolitan cities namely Chennai and Mumbai as shown in Figure 5.13. Integrated flood warning systems referred to as (i-flows) are WebGIS based flood warning decision support system incorporating weather, hydrologic, hydraulic, and hydro dynamic models along with thematic data pertaining to local administration, landuse, socio-economics and infrastructure to serve as operational decision support system for flood mitigation operations by the state administration. Subsequent to the 2015 deluge in Chennai, the office of the Principal Scientific Adviser (PSA) to the Govt. of India initiated a multi-institutional project with active involvement of Indian Institute of Technology (IIT) Bombay as the lead, Indian Institute of Sciences (IISc), Bangalore, IIT- Madras, Institute of Remote Sensing (IRS), Anna University, along with the partnership of institutes of Ministry of Earth Sciences (IMD, NCMRWF, INCOIS and NCCR) and the Government of Tamil Nadu developed the Chennai flood warning system.

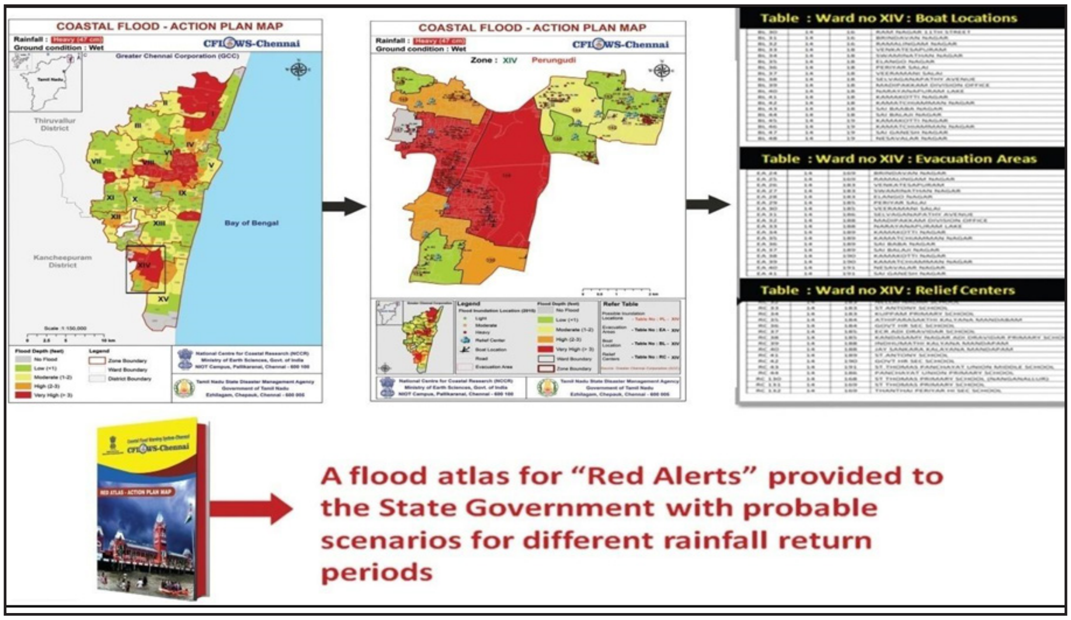


Figure 5.13: Flood Atlas for Red Alerts – for mitigation operations

Subsequently, the system was upgraded as real time Integrated Flood Warning system (IFLOWS-Chennai), to serve as an operational tool for IMD and the state government incorporating high resolution weather models and forecast are being issued two days in advance.

Ministry of Earth Sciences in collaboration with Disaster Management Department, Municipal Corporation of Greater Mumbai (MCGM), Govt of Maharashtra developed the 'Integrated Flood Warning System' for Mumbai referred to as iFLOWS-MUMBAI and was launched on 12th June 2020 as shown in Figure 5.14.

Figure 5.14: Infographic on iFLOWS-Mumbai

I-FLOWS comprises seven modules, namely Data Assimilation Module, Flood Module, Inundation Module, Vulnerability Module, Risk Module, Dissemination Module, Decision Support System. Since the river bathymetry is an essential dataset for accurately capturing the terrain conditions, extensive bathymetry data collection was undertaken in all rivers namely Mithi, Dahisar, Oshiwara, Poisar, Ulhas, lakes and creeks by NCCR in association with MCGM and IMD, Mumbai. The system incorporates weather models from NCMRWF, IMD, field data from the rain gauge network stations setup by IITM, thematic layers on landuse, infrastructure etc. provided by MCGM. Based on inputs from weather models, Hydrologic models are used to transform rainfall into runoff and provides inflow inputs into the river systems. Hydraulic models are used to solve equations of fluid motion to replicate the movement of water to assess flooding in the study area. The hydro dynamic models and storm surge model are used to calculate the tide and storm surge impacts into the model domain. The system will use forecasted rainfall from the numerical weather models and flood inundation will be estimated for Mumbai three days in advance. The system will also work in now cast mode using precipitation data available from the dense network of rain gauges and radars established by Ministry through IIT Madras. A web GIS based decision support system is built to calculate the vulnerability and risk of elements exposed to flood.

5.10.4 Climate Change Risk Information System (CCRIS) – NCCR Initiative

This project Climate Change Risk Information System (CCRIS) is aimed to aid and build capacity of coastal India by generating usable information and operational tools related to coastal hazards such as cyclones, coastal floods, storm surge, tsunami, sea level rise, extreme weather due to climate change, their impacts, vulnerability and risk for effective disaster risk reduction and mitigation activities as shown in Figure 5.15. The main objective of this project is to aid and build capacity of coastal India by generating usable information and operational tools related to coastal hazards such as cyclones, coastal floods, storm surge, tsunami, sea level rise, extreme weather due to climate change, their impacts, vulnerability and risk for effective disaster risk reduction and mitigation activities. The sub-objectives are:

- To develop a spatial database on hazards and exposure elements collated from various sources integrate this data in generating information for risk reduction and planning.
- To develop tools / framework / methodologies for coastal hazards, vulnerabilities, and risk assessment at different scales for practical and operational purposes.
- To extend scientific and technical expertise to assist the coastal stakeholders in their disaster risk reduction, mitigation and adaptation activities through capacity building and training courses made available to coastal India through web-based platform.

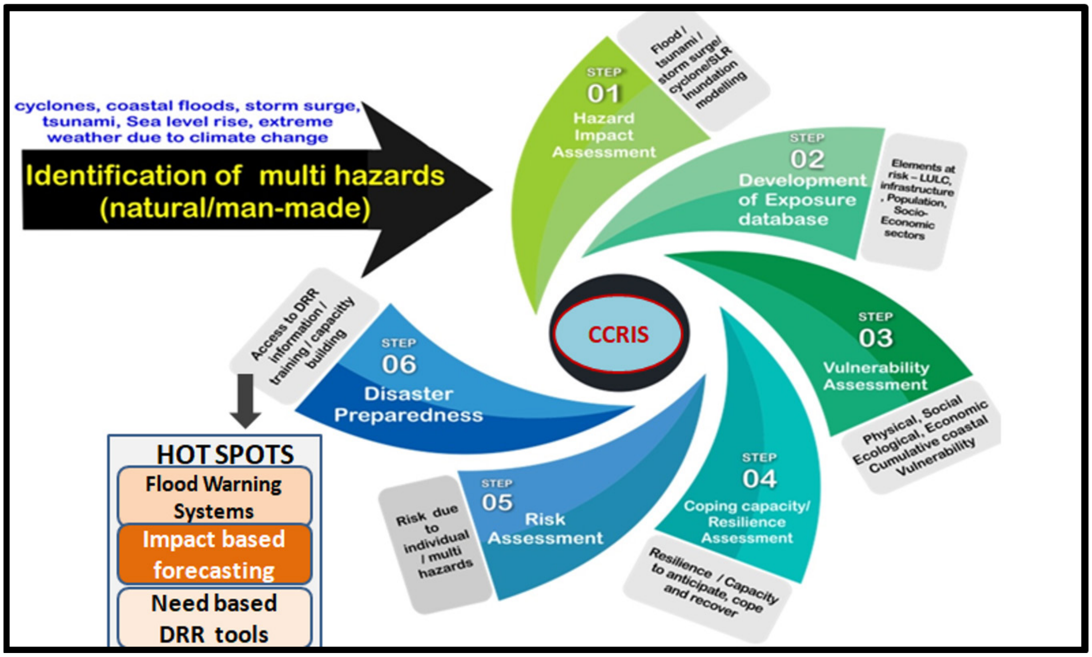


Figure 5.15: Modules in Climate Change Risk Information System

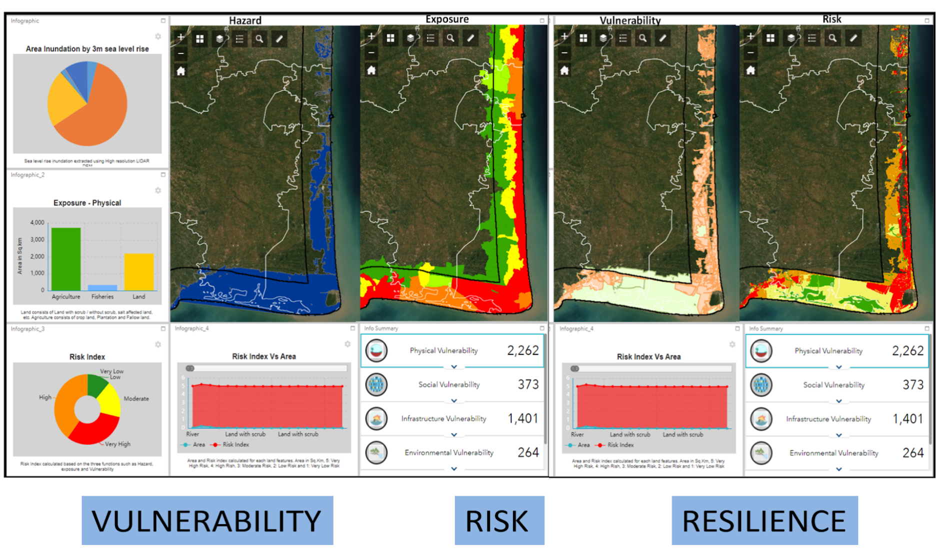


Figure 5.16: Coastal Risk dashboard for multi hazards developed for Tamil Nadu

Climate Change Risk Information System is being developed for the state of Tamil Nadu as shown in Figure 5.16 to help administrators and coastal stakeholders respond to coastal hazards and climate-related risks by providing usable, user-centric information to support decisions for disaster risk reduction and improving resilience of the state.

5.11 Estimation of CH_4 Fluxes During 2011-2017 Using Top-down Modeling and Observations

A top-down modeling study (inversion) is being carried out for the estimation of country-wise methane (CH_4) fluxes during 2011-2017 (Janardanan et al., 2020). It uses GOSAT satellite and surface observations (including surface observations from four different sites in India as Sinhagad by Indian Institue of Tropical Meteorology (IITM) Pune, Cape Rama Goa, Port Blair, and Pondicherry), a high-resolution inverse model NIES-TM-FLEXPART-VAR (NTFVAR) that couples a Lagrangian Particle Dispersion Model FLEXPART, with a global Eulerian model NIES-TM. Optimization was applied to natural (wetland) and anthropogenic emissions on a bi-weekly time step and the results were analyzed on a country scale. For the base scenario, the study used EDGAR anthropogenic CH_4 emission inventory scaled to match the national reports to the UNFCCC. The application of an inversion system, based on high-resolution transport with the combination of surface and satellite observations, enabled to study the natural and anthropogenic methane emissions over a spatial scale and to evaluate the national methane emission reports. The top-down study estimates India's CH4 emission as 24.2±5.3 Tg yr^{-1}, which is 19.2% higher than India's CH_4 emission estimated by the BUR-3 (19.55 Tg yr^{-1}) (this report). However, India's CH_4 emission estimated by EDGAR (v4.3.2-2012) (32.6 Tg yr^{-1}) is approximately 39% higher than the emissions reported by India's BUR-1 (19.8 Tg yr^{-1}), BUR-2 (20.05 Tg yr^{-1}), and BUR-3 (19.55 Tg yr^{-1}) (Figure 5.17).

The inversion result for India validated against the CH_4 profiles observed by the aircraft over two north Indian urban regions. The posterior fit to the observations showed a clear improvement, especially in the boundary layer (Figure 1b). The aircraft observations were conducted under the CAIPEEX project 2014, 2015, by the Indian Institute of Tropical Meteorology (IITM), Ministry of Earth Sciences, Govt. of India. Overall, the validation with the surface stations used in the inversion and the aircraft observations used for validation only, the posterior simulations showed a better fit to the observations than the prior forward model.

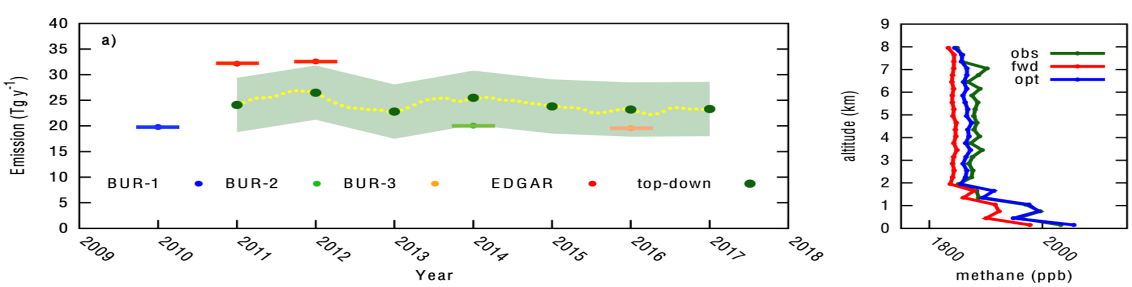


Figure 5.17: The average anthropogenic methane emission (2011-2017) for India (top-down) along with the emissions reported in BUR-1, BUR-2, BUR-3, and EDGAR. (b) The vertical profiles of forward simulations using prior fluxes and optimized fluxes compared with the aircraft methane observations over India averaged over 300m altitudes.

5.12 Systematic Observation Networks

5.12.1 TERRAIn: NCESS network of Critical Zone Observatories

National Centre for Earth Science Studies (NCESS), under the Ministry of Earth Sciences (MoES) has established a network of Critical Zone Observatories (CZOs) – TERRAIn (Tropical Ecosystem Research ObservatoRies in PeninsulAr India) – with an aim to understand the relative influence of natural perturbations (climate variability) and anthropogenic interferences on the hydrological and biogeochemical cycles in different agroclimatic regions of peninsular India and act as global test bed for furthering high end Critical Zone studies. These CZOs aim at the integration of Earth surface processes (such as landscape evolution, weathering, hydrology, geochemistry, and ecology) at multiple spatial and temporal scales and across climatic, lithological and anthropogenic gradients to understand the Critical Zone processes and also to predict the response of the Critical Zone to climate change. Under the TERRAIn network, a total of three CZOs have been already established in southern peninsular India (Figure 5.18) – (i) Attappadi CZO (Bhavani River), (ii) Munnar CZO (Periyar & Amaravati Rivers) and (3) Aduthurai CZO (Cauvery Delta) representing Sub-humid-semi-arid transition zone, humid and tropical wet and dry climatic regimes respectively (Figure 5.19). Each of the three CZOs has been instrumented (Figure 5.20) for systematic and long-term monitoring of key Critical Zone variables and processes. These CZOs are expected to generate long-term data set of terrestrial and atmospheric variables (including streamflow, groundwater, soil moisture, evapotranspiration, hydrogeochemistry of surface, ground and pore waters, meteorological variables, canopy features such as leaf area index, vegetation water content, biomass) which will lead to a detailed understanding of the effect of climate change on the Critical Zone processes (including changes in the rates of weathering, soil erosion, exchange of fluxes between the terrestrial environment and atmosphere, biogeochemical cycle etc.). Further the three CZOs are being developed as sites for calibrating and validating remote sensing products on land surface, hydrology and atmospheric variables.

With a dense network of observations, CZOs will provide a database to understand the relative effect of climate change in the functioning and resilience of the Critical Zone. In the context of climate change assessments, the NCESS CZOs aim to understand the (i) changes in the hydrological partitioning due to changes in the rainfall pattern, (ii) changes in the surface-ground water connectivity – changes in baseflow, (iii) changes in the soil moisture regimes of different landscapes and (iv) changes in the rates of fluxes (energy, gas, and water fluxes) between terrestrial environment and atmosphere. Further, the CZOs will act as experimental sites for studying the adaptation of agriculture to climate change and contribute to the concept of 'Per Drop More Crop'.

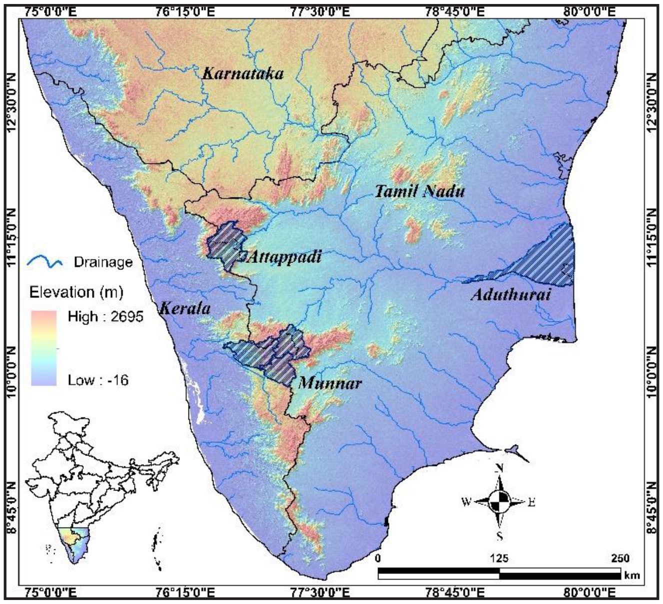


Figure 5.18: Locations of Attappadi, Munnar and Aduthurai CZOs belonging to the TERRAIn network.

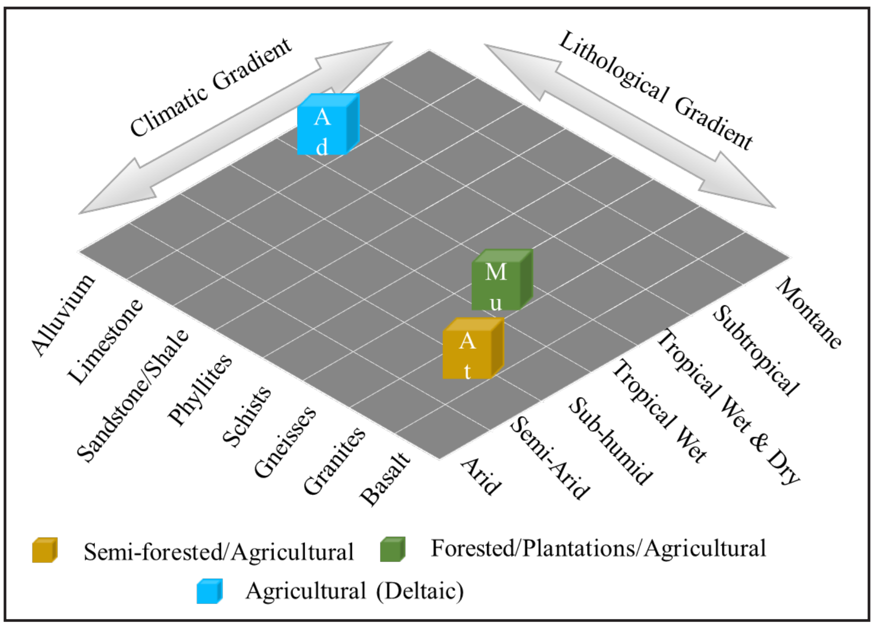


Figure 5.19: NCESS CZOs – (At- Attappadi; Mu – Munnar; Ad – Aduthurai) at different climatic, lithological and land-use gradients.

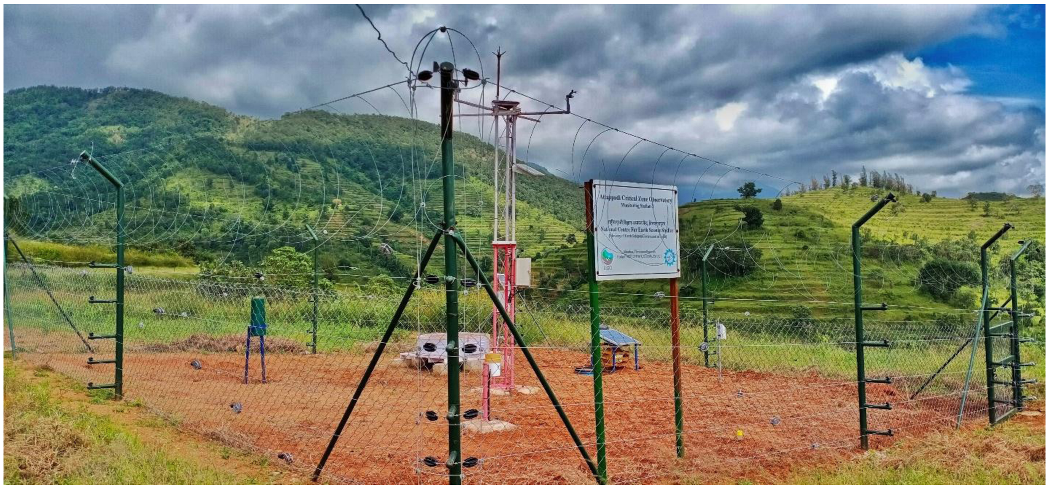


Figure 5.20: Agro-meteorological monitoring station in Attappadi CZO

The spatiotemporal studies of surface and groundwater sources CZO revealed that the solute loading in streams and shallow aquifers of Attappadi CZO is dependent largely on the incongruent dissolution of aluminosilicate minerals in the host rocks under the climatic gradients prevailing in the region with humid climate in the west to semi-arid climate in the east. Hydrochemical studies of the surface water reveals that the interplay of climatic factors over the geologic characteristics of the terrain assume a significant role in determining the solute transfer and hydrochemical composition of the river waters. The mass balance model calculations show that the silicate weathering rate is to the tune of 8.86 t/km^2/year with a carbon dioxide consumption rate (CCR) of 2.18 x10^5 mol.km^{-2}y^{-1}. Long-term monitoring of the hydrochemical characteristics of the waters in the Attappadi CZO could unravel the source contribution and future trends in hydrochemical characteristics of the surface and groundwater systems of the region.

5.12.2 Paleomonsoon reconstruction during the Holocene from south western India

The global climate has substantially altered since the post-industrial (1850 AD) era resulting in spatial and temporal precipitation changes. The instrumental data that seldom extends beyond the last two centuries could hardly pave a background for future climate predictions. Thus, the limited extend of instrumental data invoked the need to produce a continuous climate reconstruction especially for the Holocene epoch to project a reliable future climate trend. The Holocene epoch has been broadly divided in to three viz. the Greenlandian Stage (11.8−8.2 ka), Northgrippian Stage (8.2−4.2 ka) and Meghalayan Stage (4.2 ka−1950 AD). The temperature and precipitation variabilities in the last two millennia have been recognised as Roman Warm Period (RWP: 2500−1450 yr BP), Dark Ages Cold Period (DACP: 1450−1050 yr BP), Medieval Warm Period (MWP: 1050−650 yr BP), Little Ice Age (LIA: 650−100 yr BP) and Modern Warming (MW: 100 yr BP−Present). The Indian climate is significantly controlled by the Indian Summer Monsoon (ISM) which enters from the southwest India and gradually progresses along the western coast and the Western Ghats resulting in extensive rain throughout the country. The ISM variability over the Indian landmass is basically a manifestation of lateral migration of the Intertropical Convergence Zone (ITCZ). The ISM has shown a teleconnection with the global climate variables such as the El Nino Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Indian Ocean Dipole (IOD), natural forcing (solar, volcanic and orbital). However, the limited instrumental data availability restricted in establishing the appropriate linkage of ISM with other climate variables.

As the southwestern Indian coast acts as the gateway of ISM over the Indian subcontinent, the National Centre for Earth Science Studies (NCESS) has taken up studies to reconstruct high-resolution past monsoon variability using sedimentary archives of coastal regions and inland lake systems. It also aims to delineate the association of the ISM with global climate variables with specific focus on the last few millennia.

NCESS studies demonstrated that 4.2 ka dry climate was more pronounced event over Indian landmass and northern Indian ocean. While the 8.2 ka was significantly observed over northern Indian Ocean but less recorded in Indian landmass. During the last two millennia, the LIA has been a dramatic period that witnessed reduced solar forcing and increased volcanic events leading to frequent El Nino events and negative NAO phase causing winter precipitation in the region. The migration of ITCZ plays a major role in controlling the progress of the ISM over Indian subcontinent. A recent multiproxy study on the sediments of Vellayani lake, Southern India revealed that strengthened ISM during 6.4 ka followed by its gradual weakening. A strengthened monsoon spell during 4.3−2.6 ka and MWP has been elucidated from the study. The comparison with global records revealed that a frequent occurrence of ENSO events resulted in weakening of ISM during last 4 ka.

The signatures of global climatic events in the southwest Indian sedimentary archives were deliniated with the aim to reconstruct the past climate and monsoonal variability on higher resolution through the study of sedimentary archive at different latitudinal scales as shown in Figure 5.21. The latitudinal scale reconstruction of monsoon variability will provide the signatures of monsoon progression over the Indian landmass and its linkage with other global climate variables can be distinctly decoded. The engrossed and decoded climate variability and monsoonal changes will further be implemented in the established climate models that will yield reliable future climate predictions.

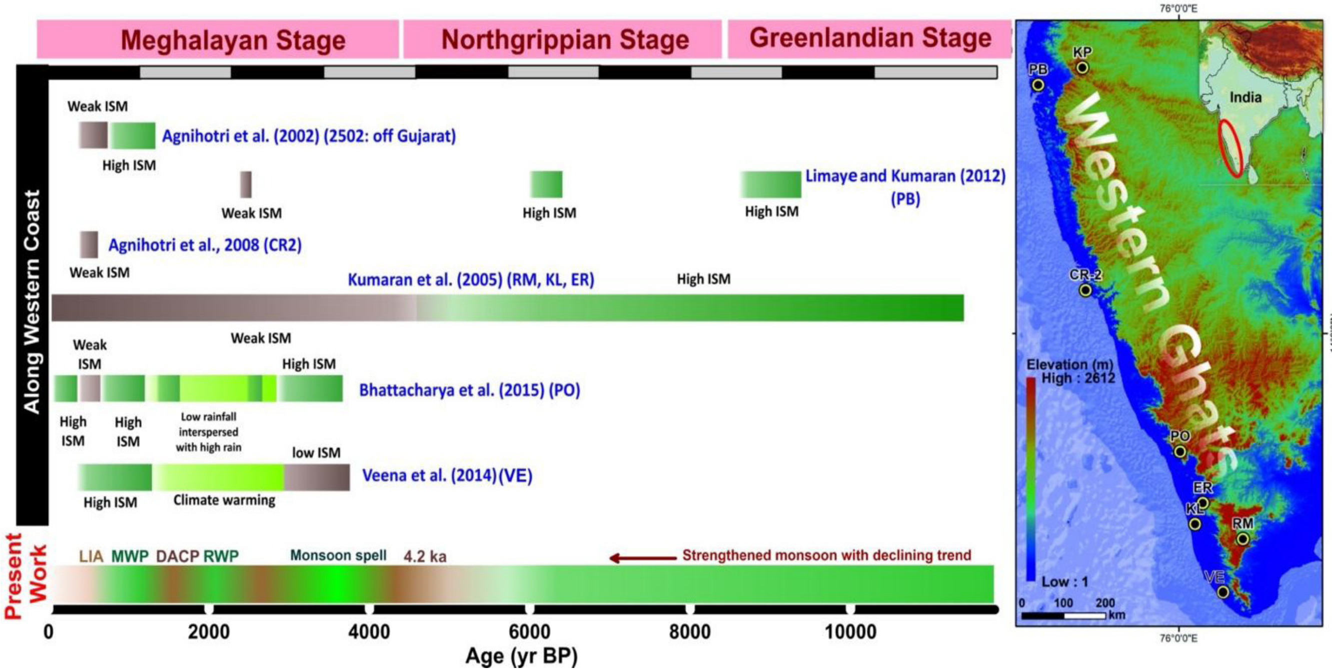


Figure 5.21: Figure depicting the available studies along the western Indian coast revealing the past monsoon variability. The present study is the collation of the studies discussed above which in turn provided the complete climate reconstruction of the Holocene epoch. The green and brown colour shows strengthening and weakening of monsoon.

5.12.3 Spring monitoring stations

The west coast of India hosts many clustered natural springs, many of them with high drinking water potential. Climate, land-use change and anthropogenic interventions have placed considerable stress on the quality and quantity of the spring waters in the recent decades. Spring monitoring stations has been set-up in Varkala as shown in Figure 5.22 South Kerala (Cold water Spring Clusters) and Belthangadi, Dakshina Kannada (warm water spring) to systematically monitor the hydrology (discharge) and hydrochemistry of the natural springs and study the response of the springs to climate changes and associated environmental changes and plan for their wise use, management, conservation and sustainability. The study mainly focusses on the natural springs in the west coast of India. In southern Kerala, 13 selected springs are lying around in Ayiroor and Ittikkara river basins. A total of 15 springs are selected from the southern Karnataka region, out of which, two of them are thermal springs.

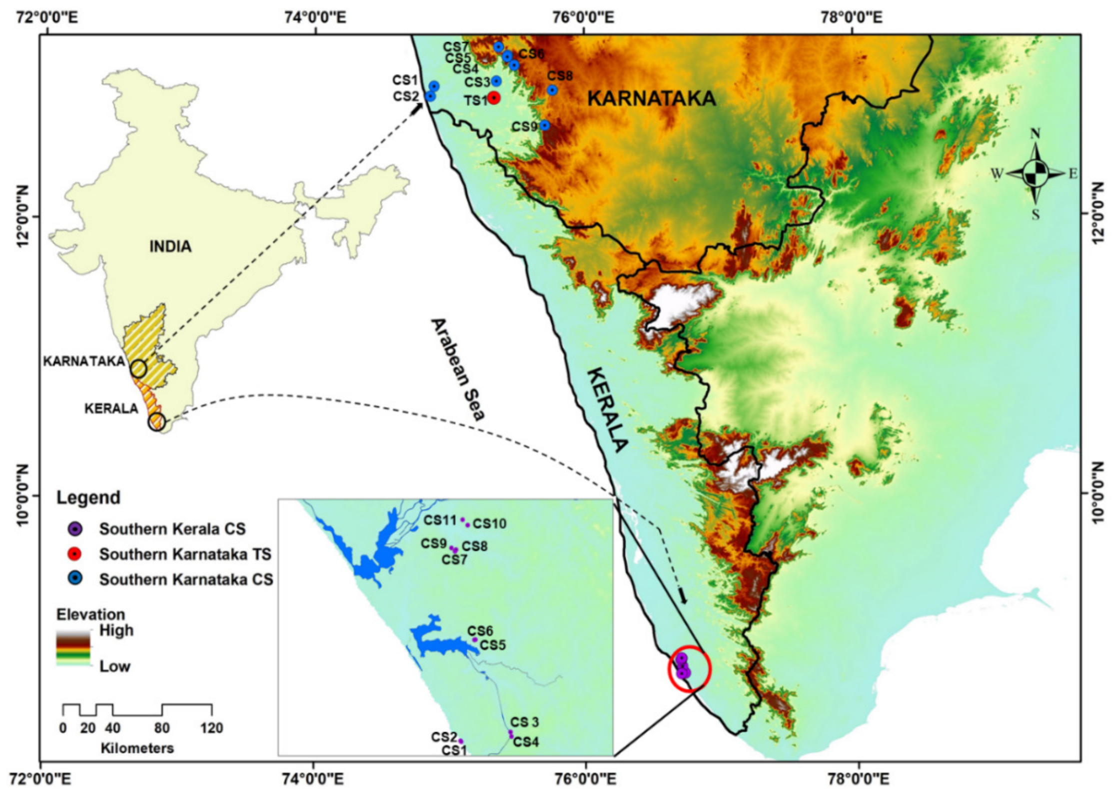


Figure 5.22: Geographical representation of spring locations and nearby watersheds of Varkala (Southern Kerala and Southern Karnataka).

The continuous monitoring of discharge patterns of springs revealed a marked reduction in average water potential of the cold-water springs as show in Figure 5.23. The effects of climate change on precipitation patterns such as increased rainfall intensity, reduced temporal spread, and other anthropogenic factors are mainly behind these fluctuations. Long-term observations on the hydrology and hydrochemistry of springs can aid in understanding the response and resilience of spring waters to climate change.

Figure 5.23: Snapshot of the natural springs in the Varkala region, South Kerala.

5.13 Atmospheric Observations

5.13.1 High-Altitude Cloud Physics Observatory at Rajamallay (Munnar - Kerala), Southern Western Ghats

The National Centre for Earth Science Studies (NCESS), under the Ministry of Earth Science Studies (MoES), Government of India has set up a High-Altitude Cloud Physics Observatory (HACPO) at Rajamallay (1,820 m above MSL), near Munnar (Kerala) in Western Ghats. The station is located about 5 km west of the Anamudi (2695 m) peak - the highest peak in Western Ghats. The major objectives of the establishment are "Observational and modelling studies of cloud processes, tropical rainfall, vertical thermodynamic structure of monsoon clouds in improving the cloudiness parameterizations and precipitation regimes over the complex terrain of Western Ghats region". A combination of incessant ground based and satellite measurements will be used to improve the precipitation forecast in this complex terrain of the Western Ghats. The long-term observations and database will be useful for addressing the climate change issues in the ecologically sensitive Western Ghats which is believed to be a treasure trove of biological richness and diversity. As India is located in the centre of the monsoon domain and southwest India (where the HACPO is located as shown in Figure 5.24) is the Gateway of ISM, the continuous, long term data base generated from the station will be of very much useful to understand the regional climate changes and linking it with the data generated on national and global levels.

Figure 5.24: A view of the HACPO at Rajamallay, Munnar.

Since 2017, the Atmospheric Science Group of NCESS has been continuously monitoring various meteorological parameters for understanding the characteristics of clouds and rainfall variability. We are fortunate to collect and analyse atmospheric variables during the extreme climate events to which the region is subjected, recently. The observatory is equipped with state-of-the-art instruments like Micro Rain Radar (Metek, Gmbh), Disdrometer (Parsivel, OTT Hydromet GmbH), Ceilometer (CHM15k Nimbus) and Automatic weather station used for the measurements of rain drop size distribution up to 6 km, cloud base height (m) and ambient weather conditions respectively. Later observatory was upgraded with rain gauges (TB4 Siphon), profile soil moisture sensor (Sentek drill and drop) and flux tower (10 m; Campbell Scientific) for an integrated study for critical zone analysis and boundary layer flux transport. To enhance the understanding of orographic precipitation in mountain terrain, high resolution rain gauges and automatic weather stations are also installed at two more locations – one at Silent at 1786 m above MSL and the other at Mattupetty at 1629 m above MSL), around the Rajamallay site. Efforts are on to upgrade the station to international standards for carrying out frontline studies in atmospheric processes and to maintain the high-resolution atmospheric measurements. In view of the complexities of the elevated terrain the use of local and large-scale atmospheric observation is essential for planning the mitigation strategies effectively related with climate change.

5.14 Concluding Thoughts

A community that is more informed and prepared will have a greater opportunity to rebound quickly from weather and climate-related events, including adapting to sea level rise. The ability to rebound more quickly can reduce negative human health, environmental, and economic impacts. The resilience of the coastal areas is measured by the information it possesses in helping coastal communities and decision makers make informed choices to assess risk, minimize losses, and protect their livelihood and property. Decision makers in coastal communities around the country need actionable information to make informed choices to enable thriving communities, ecosystems, and economies. Early warning systems and decision support systems help communities identify risks and vulnerabilities to apply sustainable solutions that increase resilience to the impacts of climate change, extreme weather, coastal inundation, and other hazards and environmental stressors. Investments in improved response to coastal environmental hazards is the need of the hour and will ensure that coastal citizens, planners, emergency managers, and other decision makers have the reliable information they need when they need it.

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Finance, Technology and Capacity Building Needs and Support Received

FINANCE, TECHNOLOGY AND CAPACITY BUILDING NEEDS, AND SUPPORT RECEIVED

Chapter 06

6.1 Introduction

This chapter provides a snapshot of India's financial and technological needs for low-carbon development and for adapting to the impact of climate change. It also notes the context of international/multilateral climate finance as relevant to India and the barriers to the flow and adequacy in meeting India's financial needs. It is important to note that the coverage in this chapter is not a complete or final statement of India's finance and technology needs and requirements for low-carbon transition both in the short and long term.

Since 2004, India has been regularly reporting on its constraints and gaps, along with its financial, technical, and capacity-building needs, through various submissions to the UNFCCC. These include the Initial National Communication in 2004, the Second National Communication in 2012, the First Biennial Update Report (BUR-1) in 2016 and the Second Biennial Update Report (BUR-2) in 2018. The country's constraints and gaps were also emphasized in the International Consultation and Analysis conducted by the UNFCCC for BUR-1 in 2017, BUR-2 in 2019, which were documented in the respective Summary Reports by the Team of Technical Experts.

Despite being clearly expressed and documented, these financial, technical, and capacity-building needs have largely remained unmet. Hence this chapter should be read in conjunction with the information provided by the Government of India to the UNFCCC since 2004.

6.2 International Context

Finance to reduce GHG emissions and to adapt to the impacts of climate change is a critical enabler of low carbon transition in developing countries. Climate change adaptation and mitigation are imposing an additional financial burden on developing countries including India, especially considering the inadequate financial support from developed countries.

It is a matter of deep concern that developed countries have neither taken the lead in combating climate change nor fulfilled their promise of providing new and additional financial resources and technology transfer to developing countries, under the provisions of United Nations Framework Convention on Climate Change (UNFCCC). Indeed, the developed countries have been lagging so much on providing finance, that the 26th session of Conference of Parties (COP26) to the UNFCCC passed an unprecedented resolution of “regret” at the failure to achieve this objective. This “regret” has been recorded in the cover decision of COP26, the “Glasgow Climate Pact”. In any case, the figure of USD 100 billion annually, that was promised at Copenhagen in 2009, is now highly insufficient. Further, in this context, the Sharm El-Sheikh Implementation Plan agreed upon at the 27th Conference of Parties (COP27) to the UNFCCC, expressed “deep concern” regarding the significant financial costs associated with loss and damage for developing countries, which are resulting in a growing debt burden and impairing the realization of the Sustainable Development Goals (UNFCCC, 2022). Further, it noted with concern the growing gap between the needs of developing countries, in particular those due to the increasing impacts of climate change and their increased indebtedness, and the support provided and mobilized for their efforts to implement their nationally determined contributions, highlighting that such needs are currently estimated at USD 5.8–5.9 trillion for the pre-2030 period (UNFCCC-SCF, 2021a).

The Sharm El-Sheikh Implementation Plan is also the first cover decision of the COP to provide explicit cost estimates for the transition to a low-carbon economy, though such figures need to be taken as indicative and not comprehensive or complete. It highlighted that about USD 4 trillion per year needs to be invested in renewable energy up until 2030 to be able to reach net zero emissions by 2050, and that, a global transition to a low-carbon economy is expected to require an investment of at least USD 4–6 trillion per year (IEA, 2022).

Given the huge costs involved, it is deeply concerning that developed countries have still not met the goal of providing 100 billion USD in climate finance per year to developing countries. The UNFCCC Standing Committee on Finance (UNFCCC-SCF) has released a report on the progress made by developed countries towards achieving the goal of mobilizing USD 100 billion per year (UNFCCC-SCF, 2022). The report makes it quite clear that while estimates vary, it is widely accepted that the goal has not been achieved. Under the UNFCCC and the Paris Agreement, developed countries are required to provide finance to developing countries for meeting the cost of adaptation and incremental cost of mitigation. At COP26, where India’s National Statement announced its ***Panchamrit*** of climate action including net zero by 2070, India emphasized the need to increase ambition in the transfer of climate finance and low-cost climate technologies. India also asserted that it is necessary that as we track the progress made in climate mitigation, we should also track climate finance insisting that climate justice entails that countries who do not live up to their promises made on climate finance must be pressured too.

India considers that the current climate finance is lacking in scale, scope, and speed, contrary to the letter and spirit of the Convention, is hugely dominated by loans and not grants or loans on adequately concessional terms, with an overwhelming emphasis on mitigation to the neglect of adaptation. These have also been borne out by various reports from multilateral institutions as well as academic literature. Preliminary estimate suggests that trillions of dollars will be required for meeting India’s climate change actions; however, climate finance needs of developing countries are yet to be adequately addressed by developed nations.

Despite repeated calls for maintaining a balance between adaptation and mitigation finance, and such a provision being enshrined in the Paris Agreement (Article 9.4) as well as in the governing instrument of the Green Climate Fund, global climate finance is heavily focused on mitigation (more than 90% on average between 2017–2020) (Kreibiehl et al., 2022). Although global tracked climate finance for adaptation has shown an upward trend, current global financial flows for adaptation, including from public and private finance sources, are insufficient for and constrain the implementation of adaptation options, especially in developing countries (IPCC, 2022a). Knowledge of climate change and its sectoral impact is limited among key institutions and stakeholders in the adaptation space. This is primarily driven by limited awareness and lack of knowledge resources such as technical skills, quality data, and research studies, especially at the regional and sectoral levels. The key constraints for implementation of adaptation options in addition to knowledge, are technology, capacity, finance and lack of adequate participation from the private sector. The UNEP Adaptation Gap Report 2022 states that international adaptation finance flows to developing countries are 5-10 times below the estimated needs and the gap is widening. The estimated annual adaptation needs are USD 160-340 billion by 2030 and USD 315-565 billion by 2050 (UNEP, 2022).

UNFCCC-SCF has also noted that the continued rise in public climate finance flows that conflate both adaptation and mitigation requirements complicate the assessment of the balance between mitigation and adaptation (UNFCCC-SCF, 2021b). The rise in such finance, it notes, is most obvious in flows from multilateral climate funds and through bilateral channels. While certain multilateral climate funds such as GCF allocate climate finance for projects in this cross-cutting category to adaptation or mitigation, not all institutions do so in their programming or reporting. According to the SCF, "this makes it more difficult to track progress in scaling up adaptation finance and ultimately achieving a balance between finance for adaptation and mitigation objectives" (Ibid.).

Another impediment to meeting financial needs of developing countries is the rise of non-concessional loans (Carty & Kowalzig, 2022). While international public climate finance is critical in the face of the current economic challenges in developing countries due to extreme weather, food and energy crises, the majority of mitigation climate finance and a part of adaptation finance flows to developing countries are in the form of concessional and non-concessional loans. The share of non-concessional loans for climate action in the portfolio of multilateral development banks is rising. Currently, developed countries cannot report non-concessional loans as Official Development Assistance (ODA), as such loans do not have conditions (grace periods, maturities, or interest rates) favorable enough to the recipients. However, the lack of an agreed-upon definition of climate finance means that they can still be reported as climate-related finance (Carty & Kowalzig, 2022; Kreibiehl et al., 2022). This means that climate finance can be lent at rates that profit the providers and includes funding due for repayment by the developing countries. Developing countries are thus being saddled with debt to deal with climate change.

The Sharm El-Sheikh Implementation Plan acknowledged the debt crisis facing many low-income countries and encouraged multilateral development banks to define a new vision and commensurate operational model, channels and instruments that are fit for adequately addressing the global climate emergency, including deploying a full suite of instruments, from grants to guarantees and non-debt instruments, taking into account debt burdens, and to address risk appetite, to substantially increase climate finance. Further IPCC AR6 WG III chapter on investment and finance notes that "shifting to a grant equivalent net flows definition of climate finance, which is now universally accepted for all other aid flows by all parties since 2014 and which took effect since 2019 on every other public international good finance provision (under the SDGs), with the sole exception of climate finance, would resolve many uncertainties: the disbursement of climate finance flows on a grant equivalent basis that is comparable across institutions, instruments and countries, and measurement with greater accuracy about the effective transfer of resources" (Kreibiehl et al., 2022).

While the developed countries are yet to meet their already confirmed commitments in climate finance, currently negotiations in climate finance are on New Collective Quantified Goal (NCQG). Developing countries, including India, are engaged in these negotiations in good faith, but it remains to be ensured that developed countries do not engage in the changing of goal posts yet again in climate finance, even in the absence of substantial progress on the ground.

It is in this overall context, India looks forward to climate specific grants and/or concessional loans, predominantly from public sources of funding, with appropriate balance between mitigation and adaptation and based on India's articulation of its needs and development aspirations.

6.3 India's Mitigation and Adaptation needs

Despite its low contribution to the world's cumulative carbon dioxide emissions and current annual per capita emissions, India has committed (conditional to the availability of finance, technology and capacity building support) to follow a low-carbon path of development by adopting various ambitious climate goals in the short and long-term, including the aspiration of net zero by 2070 within India's fair share of the global carbon budget. India's updated NDC sets the target to achieve about 50 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the transfer of technology and low-cost international finance including from the Green Climate Fund (GCF). Other financial needs are associated with India's transport fuel and electric mobility targets, energy efficiency in industry, battery storage, and cooling demands for thermal comfort in buildings.

India also announced the National Hydrogen Mission in 2023 with the primary goal to make India a hub for producing, using and exporting green hydrogen and its byproducts (MNRE, 2023a). It is expected that the Mission will result in a substantial reduction of carbon emissions in the economy, decreased reliance on imported fossil fuels, and allow India to take the lead in technology and the market of Green Hydrogen. The plan envisages that the financing of the Green Hydrogen Mission in India would require both public and private investment, with government support serving to de-risk private investment from various sources. These investments would be primarily directed towards developing new projects and assets for hydrogen production, supporting retrofits to enable greater use of green hydrogen and ammonia, and related activities such as software, testing, and maintenance. To accelerate the Mission, strategic partnerships with global stakeholders in technology, financing, regulations, trade, and policy are considered essential. India will explore joint investments, collaborative projects, long-term trade agreements, and active engagement in international collaborative efforts for hydrogen and fuel cell development.

By many measures and indices, India may be ranked high among countries affected by climate change and is significantly vulnerable to extreme weather events such as cyclones, floods, and droughts. These events result in the loss of lives, damage to infrastructure, and hinder economic and social progress. While India has established an extensive knowledge network of national and international institutions on climate adaptation, there remains a considerable gap in adaptation technologies available to India. The adaptation priorities for the country stem from three sources – one, from an understanding of potentially high consequences and highly likely climate risks facing the country; two, from the socio-economic context and the development needs of the country; and three, from addressing the constraints to adaptation. For detailed information on India's adaptation priorities, please refer to India's Adaptation Communication at Annexure-A of this report. Challenges around technology transfer, technology co-creation and intellectual property rights reflect the larger debate on the responsibility of developed nations to support climate action in developing nations. The other pertinent issue for India is the need to assess technological requirements across sectors and sub-national levels to understand the scale of deployment, levels of risk (present and future) that adaptation options can address, temporal dimensions for implementation (short, medium and long term), and associated costs and benefits. Therefore, India requires significant technological support and has significant needs to adapt to current and future climate risks in its most vulnerable sectors, including agriculture, water, natural ecosystems and biodiversity, and health. In addition, managing infrastructure is also a crucial aspect that requires consideration, given the likely increase in the frequency of extreme weather events in the country. Technologies for climate-resilient infrastructure and disaster risk management are also needed.

The cumulative expenditure needed for adaptation in a Business as Usual (BAU) scenario, without any additionality, is estimated to be ₹56.68 trillion till 2030, assuming 2023-24 as the base year of analysis. Climate induced damages could lead to an incremental cost of ₹15.5 trillion by 2030, and the requirements for building adaptation capital stock could be as high as ₹72 trillion after accounting for the country's developmental needs and climate-induced pressures. Urgently increasing adaptation finance flows to India is a crucial requirement for India to be able to meet its long-term sustainable development and economic growth objectives.

Many developing countries have also identified climate technology needs in their nationally determined contributions (NDCs). The agriculture and water sectors were the top priority for most developing countries, followed by infrastructure and health in developing countries. For India as well, improving agricultural productivity and building climate resilience in agriculture remains one of the top priorities.

6.4 Finance Received from various sources

6.4.1 Issues with tracking climate finance

Tracking climate finance poses several challenges, including the lack of a common definition of climate finance, the lack of additionality of the funds, and the lack of transparency and consistency in reporting. There is also the issue of double counting, where the same finance is counted twice, as well as the challenge of tracking adaptation finance, which is often more difficult to measure than mitigation finance. Developing countries have also stressed the need for grant-based finance and counting the grant-equivalent public financing, whereas many organizations continue to count and report concessional and non-concessional loans at face value (Weikmans & Roberts, 2019). Additionally, some developing countries may lack the capacity to track and report climate finance, and there is a need for better coordination and harmonization of reporting standards across different organizations (Carty & Kowalzig, 2022). All of these factors can make it challenging to accurately track climate finance and assess progress towards meeting climate finance goals. Therefore, the amount of climate finance committed reported in this section, especially from multilateral development banks, should be considered only in the light of these unresolved issues.

6.4.1.1 Green Climate Fund (GCF)

According to the GCF India dashboard, there are nine GCF projects in India with a total GCF financing of USD 542.3 million (GCF, 2023). While the information on the total amount of co-financing for the projects is not available on the dashboard, from the individual project documents it is evident that these projects involve substantial co-financing from either Government of India, state governments or government institutions.

For example, the cost of implementing the project titled "FP084: Enhancing Climate Resilience of India's Coastal Communities", is estimated at USD 130.27 million over the period 2019 to 2024. The GCF input of USD 43.42 million will cover 33 percent of the costs, with the remaining 67 percent coming from leveraged co-financing of USD 86.85 million from the governments of the three states of Andhra Pradesh (USD 20 million), Maharashtra (USD 26.85 million) and Odisha (USD 20 million), as well as contributions by the Government of India at the national level through the MoEFCC (USD 20 million).

6.4.1.2 Global Environment Facility (GEF)

As of March 2023, India has received a total financing commitment (including co-financing) of USD 500.49 million from GEF Trust Fund (GET) spread over 51 national projects with a co-financing ratio of 11.55 (GEF, 2023). This means that for USD 1 of GEF financing, USD 11.55 is financed by either government, private or multilateral entities. India has also received a commitment of USD 17.36 million spread over 3 regional projects from GEF with a co-financing ratio of 4.17. From the Special Climate Change Fund (SCCF), India has received a commitment of USD 10.8 million spread over 2 projects, with a co-financing ratio of 10.85.

India's average co-financing ratio as of February 2023 of 1 (GEF) to 11.55 (co-financing) across national projects funded by GEF Trust Fund is much higher than the average for GEF projects.

GEF's updated co-financing policy had set out a level of ambition for "the overall GEF portfolio to reach a ratio of co-financing to GEF project financing of at least 7:1, and for the portfolio of projects and programs approved in upper-middle-income countries and high-income countries that are not small island developing states or least developed countries to reach a ratio of investment mobilized to GEF financing of at least 5:1" (GEF, 2018). According to a GEF report on the progress of the updated co-financing policy the "level of indicative co-financing across the GEF-7 portfolio has reached some USD 7.8 in co-financing for each dollar of GEF project financing. The indicative level of investment mobilized is at USD 5.6:1." (GEF, 2020)

Table 6.1 provides information on climate finance from GCF and GEF committed towards India from 2016 onwards and as reported in the OECD (2022) database.

Table 6.1 GEF and GCF reported Climate Finance towards India from 2016 as reported in the OECD database (OECD, 2022).1

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2017	GROUND WATER RECHARGE AND SOLAR MICRO IRRIGATION TO ENSURE FOOD SECURITY AND ENHANCE RESILIENCE IN VULNERABLE TRIBAL AREAS OF ODISHA	GCF	FP045	Concessional and developmental	34357	0	0	Grant	Public corporations	14015	I.4. Water Supply & Sanitation	Water resources conservation (including data collection)
2018	ENHANCING CLIMATE RESILIENCE OF INDIA'S COASTAL COMMUNITIES	GCF	FP084	Concessional and developmental	0	0	43419	Grant	United Nations Development Programme	43071	IV.2. Other Multi-sector	Food security policy and administrative management

1 Notes: 1. Table below reports climate finance committed 2016 onwards 2. The database verified is not verified by the GoI. 3. Several projects appear more than one time in the table because of various reasons such as different channel of delivery, different financial instrument, different OECD purpose code and corresponding sector and sub-sector. This is reproduced here as reported in the database. 4.The classification of purpose code and sector/sub-sector for each project is as designated and claimed by the agency and may not reflect accurately the nature of the project on the ground or the relative weight of different sectors in the project. 5. Several projects are classified and claimed as fully or partially climate-specific by the entities. These may not meet the criteria for climate finance as provided by the Convention and articulated by India to the global community for consideration as part of climate support and climate finance

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2018	LINE OF CREDIT FOR SOLAR ROOFTOP SEGMENT FOR COMMERCIAL, INDUSTRIAL AND RESIDENTIAL HOUSING SECTORS	GCF	FP081	Not concessional or not primarily developmental	0	100000	0	Debt instrument	Public corporations	23230	II.3. Energy	Solar energy for centralised grids
2018	ENHANCING CLIMATE RESILIENCE OF INDIA'S COASTAL COMMUNITIES	GCF	FP084	Concessional and developmental	0	13025.7	0	Grant	United Nations Development Programme	43071	IV.2. Other Multisector	Food security policy and administrative management
2018	ENHANCING CLIMATE RESILIENCE OF INDIA'S COASTAL COMMUNITIES	GCF	FP084	Concessional and developmental	30393.3	0	0	Grant	United Nations Development Programme	43071	IV.2. Other Multisector	Food security policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2018	LINE OF CREDIT FOR SOLAR ROOFTOP SEGMENT FOR COMMERCIAL, INDUSTRIAL AND RESIDENTIAL HOUSING SECTORS	GCF	FP081	Not concessional or not primarily developmental	0	100000	0	Debt instrument	Public corporations	23230	II.3. Energy	Solar energy for centralised grids
2016	GREEN-AG: TRANSFORMING INDIAN AGRICULTURE FOR GLOBAL ENVIRONMENTAL BENEFITS AND THE CONSERVATION OF CRITICAL BIODIVERSITY AND FOREST LANDSCAPES	GEF	9243	Concessional and developmental	0	33558.716	0	Grant	Food and Agricultural Organisation	31110	III.1. Agriculture, Forestry, Fishing	Agricultural policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2016	GRID-CONNECTED ROOFTOP SOLAR PROGRAM	GEF	9249	Concessional and developmental	0	22935.78	0	Grant	International Bank for Reconstruction and Development	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2017	SECURING LIVELIHOODS, CONSERVATION, SUSTAINABLE USE AND RESTORATION OF HIGH RANGE HIMALAYAN ECOSYSTEMS (SECURE) HIMALAYAS	GEF	9148	Concessional and developmental	0	1126.851	0	Grant	United Nations Development Programme	31110	III.1. Agriculture, Forestry, Fishing	Agricultural policy and administrative management
2017	CITIES-IAP: SUSTAINABLE CITIES, INTEGRATED APPROACH PILOT IN INDIA	GEF	9323	Concessional and developmental	0	0	9777.778	Grant	United Nations Industrial Development Organisation	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2017	CITIES-IAP: SUSTAINABLE CITIES, INTEGRATED APPROACH PILOT IN INDIA	GEF	9323	Concessional and developmental	0	0	3422.222	Grant	United Nations Industrial Development Organisation	43030	IV.2. Other Multisector	Urban development and management
2017	SECURING LIVELIHOODS, CONSERVATION, SUSTAINABLE USE AND RESTORATION OF HIGH RANGE HIMALAYAN ECOSYSTEMS (SECURE)HIMALAYAS	GEF	9148	Concessional and developmental	0	4194.389		Grant	United Nations Development Programme	31220	III.1. Agriculture, Forestry, Fishing	Forestry development
2017	SECURING LIVELIHOODS, CONSERVATION, SUSTAINABLE USE AND RESTORATION OF HIGH RANGE HIMALAYAN ECOSYSTEMS (SECURE) HIMALAYAS	GEF	9148	Concessional and developmental	0	7261.929		Grant	United Nations Development Programme	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	493.33325		Grant	Economic Commission for Latin America and the Caribbean	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	493.33325		Grant	Economic Commission for Latin America and the Caribbean	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	493.33325		Grant	Economic Commission for Latin America and the Caribbean	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	493.33325		Grant	Economic Commission for Latin America and the Caribbean	43071	IV.2. Other Multisector	Food security policy and administrative management
2019	CAPACITY-BUILDING FOR ESTABLISHING AN INTEGRATED AND ENHANCED TRANSPARENCY FRAMEWORK FOR CLIMATE ACTIONS AND SUPPORT MEASURES	GEF	10194	Concessional and developmental	0	0	4161	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41010	IV.1. General Environment Protection	Environmental policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	STRENGTHENING CONSERVATION AND RESILIENCE OF GLOBALLY-SIGNIFICANT WILD CAT LANDSCAPES THROUGH A FOCUS ON SMALL CAT AND LEOPARD CONSERVATION	GEF	10235	Concessional and developmental	0	0	81.75	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity
2019	STRENGTHENING CONSERVATION AND RESILIENCE OF GLOBALLY-SIGNIFICANT WILD CAT LANDSCAPES THROUGH A FOCUS ON SMALL CAT AND LEOPARD CONSERVATION	GEF	10235	Concessional and developmental	0	0	81.75	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41040	IV.1. General Environment Protection	Site preservation

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	GLOBAL PROGRAMME TO SUPPORT COUNTRIES WITH THE SHIFT TO ELECTRIC MOBILITY.	GEF	10114	Concessional and developmental	0	3510.002		Grant	Asian Development Bank	23642	II.3. Energy	Electric mobility infrastructures
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	1213.012	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	1213.012	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	295.279	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	295.279	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	250	Grant	International Partnership on Microbicides	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	33	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	3514.721	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	3514.721	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	196.8535	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	196.8535	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	104.025	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	31220	III.1. Agriculture, Forestry, Fishing	Forestry development

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	38.325	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	41030	IV.1. General Environment Protection	Biodiversity
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	1711.675	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	750	Grant	International Partnership on Microbicides	31220	III.1. Agriculture, Forestry, Fishing	Forestry development
2019	ELECTRIFYING MOBILITY IN CITIES: INVESTING IN THE TRANSFORMATION TO ELECTRIC MOBILITY IN CITIES	GEF	10276	Concessional and developmental	0	74.998		Grant	United Nations Entity for Gender Equality and the Empowerment of Women	41010	IV.1. General Environment Protection	Environmental policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	ELECTRIFYING MOBILITY IN CITIES: INVESTING IN THE TRANSFORMATION TO ELECTRIC MOBILITY IN CITIES	GEF	10276	Concessional and developmental	0	74.998		Grant	Asian Development Bank	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2019	GLOBAL WILDLIFE PROGRAM	GEF	10200	Concessional and developmental	0	0	2152.75	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	CAPACITY-BUILDING FOR ESTABLISHING AN INTEGRATED AND ENHANCED TRANSPARENCY FRAMEWORK FOR CLIMATE ACTIONS AND SUPPORT MEASURES	GEF	10194	Concessional and developmental	0	0	109.5	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	9.5	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	31220	III.1. Agriculture, Forestry, Fishing	Forestry development

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	9.5	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	465.5	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	31220	III.1. Agriculture, Forestry, Fishing	Forestry development

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	465.5	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	2352	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	2466.6668		Grant	Economic Commission for Latin America and the Caribbean	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	2466.6668		Grant	Economic Commission for Latin America and the Caribbean	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	2466.6668		Grant	Economic Commission for Latin America and the Caribbean	41030	IV.1. General Environment Protection	Biodiversity
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	2466.6668		Grant	Economic Commission for Latin America and the Caribbean	43071	IV.2. Other Multisector	Food security policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	740		Grant	Economic Commission for Latin America and the Caribbean	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	740		Grant	Economic Commission for Latin America and the Caribbean	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	740		Grant	Economic Commission for Latin America and the Caribbean	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	740		Grant	Economic Commission for Latin America and the Caribbean	43071	IV.2. Other Multisector	Food security policy and administrative management
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	2072.9875	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	31220	III.1. Agriculture, Forestry, Fishing	Forestry development

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	TRANSFORMING AGRICULTURAL SYSTEMS AND STRENGTHENING LOCAL ECONOMIES IN HIGH BIODIVERSITY AREAS OF INDIA THROUGH SUSTAINABLE LANDSCAPE MANAGEMENT AND P	GEF	10204	Concessional and developmental	0	0	2072.9875	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	41030	IV.1. General Environment Protection	Biodiversity
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	1819.5185	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	1819.5185	Grant	United Nations Entity for Gender Equality and the Empowerment of Women	43030	IV.2. Other Multisector	Urban development and management
2019	GLOBAL PROGRAMME TO SUPPORT COUNTRIES WITH THE SHIFT TO ELECTRIC MOBILITY.	GEF	10114	Concessional and developmental	0	2340.002		Grant	United Nations Entity for Gender Equality and the Empowerment of Women	23642	II.3. Energy	Electric mobility infrastructures
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	1850		Grant	Economic Commission for Latin America and the Caribbean	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	1850		Grant	Economic Commission for Latin America and the Caribbean	31161	III.1. Agriculture, Forestry, Fishing	Food crop production

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	1850		Grant	Economic Commission for Latin America and the Caribbean	41030	IV.1. General Environment Protection	Biodiversity
2019	FOOD SYSTEMS, LAND USE AND RESTORATION (FOLUR) IMPACT PROGRAM	GEF	10201	Concessional and developmental	0	1850		Grant	Economic Commission for Latin America and the Caribbean	43071	IV.2. Other Multisector	Food security policy and administrative management
2019	GLOBAL WILDLIFE PROGRAM	GEF	10200	Concessional and developmental	0	0	2752.25	Grant	International NGO	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	2343.1465	Grant	Asian Development Bank	43030	IV.2. Other Multi-sector	Urban development and management
2019	SUSTAINABLE CITIES IMPACT PROGRAM	GEF	10391	Concessional and developmental	0	0	2343.1465	Grant	Asian Development Bank	43030	IV.2. Other Multi-sector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	1617	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41010	IV.1. General Environment Protection	Environmental policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2019	SEVENTH OPERATIONAL PHASE OF THE GEF SMALL GRANTS PROGRAMME IN INDIA	GEF	10125	Concessional and developmental	0	0	48	Grant	United Nations Department of Political and Peacebuilding Affairs, Trust Fund in Support of Political Affairs	41030	IV.1. General Environment Protection	Biodiversity
2020	ACCELERATING ADOPTION OF SUPER-EFFICIENT TECHNOLOGIES FOR SUSTAINABLE THERMAL COMFORT IN BUILDINGS IN INDIA	GEF	10370	Concessional and developmental	0	5000		Grant	United Nations Development Programme	41010	IV.1. General Environment Protection	Environmental policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	MAINSTREAMING NATURAL CAPITAL VALUES INTO PLANNING AND IMPLEMENTATION FOR SUSTAINABLE BLUE ECONOMIC GROWTH IN INDIAN COASTAL DISTRICTS	GEF	10385	Concessional and developmental	1750			Grant	United Nations Environment Programme	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2020	MAINSTREAMING NATURAL CAPITAL VALUES INTO PLANNING AND IMPLEMENTATION FOR SUSTAINABLE BLUE ECONOMIC GROWTH IN INDIAN COASTAL DISTRICTS	GEF	10385	Concessional and developmental	1750			Grant	United Nations Environment Programme	41030	IV.1. General Environment Protection	Biodiversity
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	26.6666	26.6666	Grant	Food and Agricultural Organisation	31120	III.1. Agriculture, Forestry, Fishing	Agricultural development

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	26.6666	26.6666	Grant	Food and Agricultural Organisation	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	26.6666	26.6666	Grant	Food and Agricultural Organisation	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	26.6666	26.6666	Grant	Food and Agricultural Organisation	41030	IV.1. General Environment Protection	Biodiversity
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	26.6666	26.6666	Grant	Food and Agricultural Organisation	43071	IV.2. Other Multisector	Food security policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	8	8	Grant	Food and Agricultural Organisation	31120	III.1. Agriculture, Forestry, Fishing	Agricultural development
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	8	8	Grant	Food and Agricultural Organisation	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	8	8	Grant	Food and Agricultural Organisation	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	8	8	Grant	Food and Agricultural Organisation	41030	IV.1. General Environment Protection	Biodiversity

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	8	8	Grant	Food and Agricultural Organisation	43071	IV.2. Other Multisector	Food security policy and administrative management
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	20	20	Grant	Food and Agricultural Organisation	31120	III.1. Agriculture, Forestry, Fishing	Agricultural development
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	20	20	Grant	Food and Agricultural Organisation	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	20	20	Grant	Food and Agricultural Organisation	31161	III.1. Agriculture, Forestry, Fishing	Food crop production

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	20	20	Grant	Food and Agricultural Organisation	41030	IV.1. General Environment Protection	Biodiversity
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	20	20	Grant	Food and Agricultural Organisation	43071	IV.2. Other Multisector	Food security policy and administrative management
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	5.3334	5.3334	Grant	Food and Agricultural Organisation	31120	III.1. Agriculture, Forestry, Fishing	Agricultural development
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	5.3334	5.3334	Grant	Food and Agricultural Organisation	31130	III.1. Agriculture, Forestry, Fishing	Agricultural land resources

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	5.3334	5.3334	Grant	Food and Agricultural Organisation	31161	III.1. Agriculture, Forestry, Fishing	Food crop production
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	5.3334	5.3334	Grant	Food and Agricultural Organisation	41030	IV.1. General Environment Protection	Biodiversity
2020	TRANSFORMING RICE-WHEAT FOOD SYSTEMS IN INDIA	GEF	10480	Concessional and developmental	0	5.3334	5.3334	Grant	Food and Agricultural Organisation	43071	IV.2. Other Multisector	Food security policy and administrative management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	2.07669	2.07669	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	2.13962	2.13962	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	2.07669	2.07669	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	37.52331	37.52331	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	38.66038	38.66038	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	37.52331	37.52331	Grant	Asian Development Bank	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	3.11586	3.11586	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	3.21028	3.21028	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	3.11586	3.11586	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	56.28414	56.28414	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	57.98972	57.98972	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management
2020	LIVABLE CITIES IN INDIA: DEMONSTRATING SUSTAINABLE URBAN PLANNING AND DEVELOPMENT THROUGH INTEGRATED APPROACHES	GEF	10484	Concessional and developmental	0	56.28414	56.28414	Grant	United Nations Environment Programme	43030	IV.2. Other Multisector	Urban development and management

Year	Project Title	Provider	Donor project No.	Concessionality	Adaptation-finance - Commitment - Current USD thousand	Mitigation-related - Commitment - Current USD thousand	Overlap - Commitment - Current USD thousand	Financial Instrument	Channel of Delivery	OECD Purpose Code	Sector (detailed)	Sub-sector
2020	PREPARATION OF INDIA'S FOURTH NATIONAL COMMUNICATION (4NC) AND FOURTH BIENNIAL UPDATE REPORT (BUR4) TO THE UNFCCC AND STRENGTHENING INSTITUTIONAL AND	GEF	10493	Concessional and developmental	0	932.94	932.94	Grant	United Nations Development Programme	41010	IV.1. General Environment Protection	Environmental policy and administrative management
2020	PREPARE INDIA'S FOURTH NATIONAL COMMUNICATION AND FOURTH BIENNIAL UPDATE REPORT (BUR4) TO THE UNFCCC AND STRENGTHENING CAPACITIES ON CLIMATE CHANGE.	GEF	10493	Concessional and developmental	0	4066.83	4066.83	Grant	United Nations Development Programme	41010	IV.1. General Environment Protection	Environmental policy and administrative management

6.4.1.3 Climate Investment Funds (CIF)

Climate Investment Funds (CIF) through its Clean Technology Fund (CTF) has invested in India to foster low-carbon development. As the Indian government's ambitious solar energy plan, aimed at reducing coal dependence, is currently leading the way towards this objective, the CTF has allocated a major proportion of its USD 793 million investment plan in India to the development of over 3 GW of installed solar power capacity, as well as transmission infrastructure to support it. This investment seeks to offset the high initial costs of large-scale solar park projects and de-risk rooftop solar photovoltaic investments, thereby promoting market potential.

Additionally, through Clean Technology Fund - Technical Assistance Facility, USD 800,000 in funding was allocated for technical assistance activities in 2020 and 2021, aimed at facilitating climate finance for financial institutions. Moreover, India has been selected as one of the first four pilot countries for the recently launched Accelerating Coal Transition (ACT) program, which offers up to USD 500 million in financing for program implementation.

Of the USD 794.41 million of CIF-approved funding, the approved co-financing is USD 9.54 billion out of which 15 percent is from the Indian government sources, 20 percent from multilateral development banks, 65 percent from the private sector (CIF, 2021).

6.4.1.4 Multilateral Development Banks

The 2022 Joint Report on Multilateral Development Banks' Climate Finance, reported USD 3.737 billion in MDB climate finance for India for 2022, almost equivalent to the previous reported year (USD 3.735 billion in 2021) (MDBs, 2023). MDB climate finance refers to the amounts committed by the multilateral development banks including the World Bank Group, Asian Development Bank and others to finance climate change mitigation and adaptation activities in the projects they undertake. MDB climate finance includes commitments from the multilateral development banks' own accounts, and from external resources channeled through and managed by the banks.

Between 2016 and 2020, India received USD 16.97 billion (at USD 2020) in climate related finance from MDBs as reported in the OECD Development Assistance Committee's (DAC) database (OECD, 2022). Out of USD 16.97 billion, an overwhelming 94 percent was classified as not concessional or not primarily developmental finance, meaning these loans are without any favourable interest rates or payback terms. Due to the lack of definition of what counts as climate finance, non-concessional loans can be reported as climate finance. Of the reported climate finance, 63 percent were for mitigation, 32 percent for adaptation and 5 percent were cross-cutting across mitigation and adaptation.

6.5 Climate Finance Mobilization from Domestic Resources

In relation to the size of India's economy and given the vulnerability to climate change and variability, India's financing needs are enormous. However, India's climate action is largely financed by domestic resources as climate finance flows from developed countries are falling far short of what is needed to mitigate and adapt to climate change. This is putting a considerable burden on India's domestic resources. Some instances of mobilization and provision of domestic resources are outlined below:

6.5.1 Sovereign Green Bonds

India submitted its ambitious updated NDCs in which it committed to achieving about 50 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources and reducing Emissions Intensity of GDP by 45 per cent from the 2005 level by 2030. In line with the ambitious commitment, in the Government of India, in its Union Budget 2022-23 made an announcement to issue Sovereign Green Bonds. As the country's climate actions have so far been largely financed from domestic resources, it is now trying to target the generation of additional global financial resources through this measure. After the Budget announcement, the Department of Economic Affairs, Ministry of Finance issued the Green Bond Framework (Framework) that set forth the obligations of the Government of India as a green bond issuer (GoI, 2022). The framework was approved by the Ministry of Finance in November 2022 (PIB, 2022b). According to the framework, the government will use the proceeds raised from the sovereign green bonds to finance or refinance expenditure (in parts or whole) for various green projects, including renewable energy, clean transportation, energy efficiency, climate change adaptation, sustainable water and waste management, pollution and prevention control and green buildings. In renewable energy, investments will be made in solar, wind, biomass and hydropower energy projects. The eligible category of projects for climate change adaptation financing are projects aimed at making infrastructure more resilient to the impacts of climate change, as well as investments in information support systems, such as climate observation and early warning systems.

Sovereign Green bonds amounting to Rs 16000 crore were issued in two tranches of Rs. 8000 crore each on 25th January, 2023 and 9th February, 2023 respectively through five and ten-year bonds of an equal denomination in both tranches. It was reported that the bulk of the issue was picked up by local banks and insurance companies, with some participation from foreign banks as well.

6.5.2 Production Linked Incentives

6.5.2.1 High-Efficiency Solar PV Modules

The Indian government has approved a Production Linked Incentive (PLI) scheme for the National Programme on High-Efficiency Solar PV Modules, aimed at achieving gigawatt-scale manufacturing capacity in high-efficiency solar PV modules. The initial outlay for the scheme was Rs. 4,500 crores and the Ministry of New and Renewable Energy (MNRE) issued the scheme guidelines in April 2021. Indian Renewable Energy Development Agency Limited (IREDA), the implementing agency on behalf of MNRE for the PLI Scheme issued bid documents for selecting manufacturers to set up manufacturing capacities, and 18 bids were received. Letters of Award were issued to three successful bidders for setting up 8,737 MW capacity of fully integrated solar PV module manufacturing units within the PLI scheme outlay (MNRE, 2021). An additional allocation of Rs. 19,500 crore was announced in the Budget 2022-23 to establish a larger manufacturing base for solar PV modules with priority given to fully integrated manufacturing units (PIB, 2022a).

6.5.2.2 Electric mobility

The government of India has cleared Rs 25,938 crore (approximately USD 3.1 billion) worth of new PLI scheme for the auto sector to primarily to boost the production of electric vehicles and hydrogen fuel cell vehicles (PTI, 2021).

The Government of India has also announced the PLI for Advanced Chemistry Cell (ACC) batteries with an outlay of Rs. 18,100 crores (approximately USD 2.5 billion) aimed at inviting investments for manufacturing advanced energy storage technology batteries, as a first step towards creating a robust infrastructure for electric mobility in India.

6.5.2.3 National Green Hydrogen Mission

The total outlay for the National Green Hydrogen Mission announced by India in Jan 2023 is Rs. 19,744 crores (USD 2.38 billion), out of which the government has allocated Rs. 17,490 crores (USD 2.11 billion) for the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme, Rs. 1,466 crores (USD 0.17 billion) for the upcoming pilot projects, Rs. 400 crores (USD 0.04 billion) for R&D, and Rs. 388 crores (USD 0.04 billion USD) towards other mission components (MNRE, 2023a).

6.5.3 Financial sector measures for climate action

1. The Security & Exchange Board of India (SEBI) has been one of the early adopters of sustainability reporting for listed entities and requires mandatory ESG-related disclosures for the top 100 listed entities (by market capitalisation) since 2012. Over the years, the requirement was strengthened to cover the top 500 and then the top 1000 entities. SEBI has issued new sustainability reporting requirements under the Business Responsibility and Sustainability Report (BRSR), which are more granular with quantifiable metrics in line with the principles ensconced in the 'National Guidelines on Responsible Business Conduct'. The BRSR was made mandatory for the top 1000 listed entities (by market capitalisation) from 2022–23.

2. Priority Sector Lending (PSL) rules, as notified by RBI, include mitigation projects such as those in renewable energy (e.g. bank loans up to a limit of ₹30 crore to borrowers for purposes like solar-based power generators, biomass-based power generators, wind mills, micro-hydel plants and for non-conventional energy based public utilities, viz., street lighting systems and remote village electrification etc., are eligible for Priority Sector classification.). Further, with a view to foster and develop a green finance ecosystem in the country, RBI has put in place the Framework for Acceptance of Green Deposits for the Regulated Entities and mandates that funds raised through this must be utilized for activities promoting energy efficiency, reduction in carbon emission and fostering climate resilience and adaptation and preserving and enhancing natural ecosystems and biodiversity.

3. SEBI had earlier introduced the regulatory framework for issuance of green debt securities as a mode of sustainable finance vide circular dated May 30, 2017. SEBI has in 2022 allowed an issuer under the SEBI (Issue and Listing of Municipal Debt Securities) Regulations, 2015 ('ILMDS

Regulations') to issue a green debt security if it falls within the definition of "green debt security" as per Regulation 2(1)(q) of the Non-Convertible Securities (NCS) Regulations.

6.6 Technology Needs and Requirements

Technology and innovation play a crucial role in mitigating and adapting to climate change. India recognizes the need to improve the R&D base for green technologies and climate change mitigation and adaptation, while also focusing on its developmental vision for mid-century, including self-reliance and reduced dependence on imports. Data, and its modelling and interpretation, have been identified as an important constraint in planning and implementation of adaptation interventions. It has been observed that there is a lack of uniformity and synchronization of available data within sectors. It was identified that similar indicators and data points could not be homogenized across sectors. Methodologies for the integration of numerical predictions of climate change impacts with socio-economic vulnerability are missing. In the context of adaptation measures, IPCC AR6 WGII Summary for Policymakers notes that "implementing actions can require large upfront investments of human, financial and technological resources, whilst some benefits could only become visible in the next decade or beyond" (IPCC, 2022a). Further, in context of mitigation technologies, IPCC AR6 WGIII Summary for Policymakers notes that "adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity". Further it suggests that "developing countries' abilities to deploy low-emission technologies, seize socio-economic benefits and manage trade-offs would be enhanced with increased financial resources and capacity for innovation which are currently concentrated in developed countries, alongside technology transfer" (IPCC, 2022b).

Under the UNFCCC, developed countries are mandated to promote, facilitate, and finance the transfer of, or access to, environmentally sound technologies and know-how to developing countries, to enable them to implement the provisions of the Convention. Further, the provision of such technologies should be on favorable terms, enabling their effective use, including their widespread diffusion and deployment. The transfer of technology can take place through various means, such as joint ventures, licensing, and other forms of partnerships between the public and private sectors. Yet, developed countries have made very little progress in fulfilling these commitments.

Domestically, India has initiated steps for establishing a National Research Foundation (NRF). The NRF aims to catalyze, facilitate, coordinate, seed, grow, and mentor research in academic institutions around the country, particularly at universities and colleges where research capacity is currently in a nascent stage. This will be the first of its kind foundation to promote research and development across the country. For the creation of the National Research Foundation, a total expenditure of INR 50,000 crores over a period of 5 years beginning from 2021-22 has been approved. There is a need to build capacity at all levels, and particularly at the local level. There is a lack of trained personnel on the ground to operate technical tools and devices. Capacity building and skill development of all stakeholders, across sectors and levels is imperative to enable the effective implementation of adaptation strategies on the ground and the collection of relevant data through appropriate processes.

This section provides a non-exhaustive list of India's technology needs in short, medium and long term. More details are available in India's Third Biennial Update Report (BUR-3) and in India's LT-LEDS submission to the UNFCCC.

6.6.1 Energy Sector technology needs

The energy sector is in need of innovative technologies that can address the challenges posed by climate change and the transition to a low-carbon economy. In this regard, India is making significant strides in developing new technologies and investing in clean energy solutions. One key area where innovation is needed is in the development of smart grid technologies. The use of smart grids can help create a more resilient and flexible energy grid that can better incorporate clean energy sources. Another important area of innovation in the energy sector is the development of bio-based clean energy fuels and carbon dioxide removal technologies. Biotechnology has a critical role to play in converting domestic carbon sources such as agricultural and forest residues, municipal wastes, and gases feedstock from industries, into bio-based fuels and chemicals to replace fossil-derived fuels and chemicals. India is already working on developing such technologies through the Department of Biotechnology, which aims to make sustainable and cost-effective biotechnology-based fuels and chemicals available. Additionally, India is also part of the Mission Innovation initiative, which supports the development of carbon dioxide removal technologies.

Energy storage is another crucial area where innovation is needed in the energy sector. As renewable energy sources such as wind and solar become more prevalent, electricity storage will be necessary to accommodate their intermittent generation. While pumped hydro storage is currently the dominant form of energy storage, lithium batteries are also considered significant. Research is focused on new cell chemistries emerging from the lithium-ion family such as lithium-air, lithium-sulphur, and other metals such as sodium and magnesium. In addition to improving power and charge density, these new technologies could also decrease the cost per unit of energy stored. However, as lithium is not readily available in India, research and innovation into other battery technologies is a strategic requirement. India is also keen on innovation and research and development in green hydrogen, developing biomass-to-liquids fuel production from thermo-chemical processes, commercialization of cellulosic ethanol, and Integrated Gasification Combined Cycle (IGCC) technology and waste heat recovery systems for utilizing the flue gas.

6.6.2 Technology needs in the industrial sector

The low carbon development of the industrial sector is particularly challenging now owing to competitiveness issues, and its inherent heterogeneity, especially in view of the large presence of the Micro, Small, and Medium Enterprises (MSME) sector. Except for biomass usage in certain applications, most options for reducing industrial emissions are still in the concept phase and there is an urgent need for the development of breakthrough processes (e.g., steel production based on hydrogen or electrolysis), which can result in a step-change in emissions reductions.

Technology Information Forecasting and Assessment Council (TIFAC) has taken up assessment of Indian industries for identifying potential technologies and imparting requisite capacity building towards low carbon development. The sectors taken up include steel, cement, transport, MSMEs. TIFAC has also initiated a major study for designing of an innovative cooperative based model for enhancing utilization of biogas and demonstration of biogas grid in Punjab.

In the Indian steel industry low carbon development is a big challenge as opposed to developed economies. It needs R&D intervention for seamless transition to non-coal-based technologies with alternate fuels like hydrogen. This transition needs to be over a period considering the high capital expenditure and readiness of befitting technology. During this transition period innovative R&D technology may be there to reduce the carbon footprint of existing technologies.

Development of alternative building materials to steel and cement is an important research priority, which can reduce emissions from both industry and the built environment. Alternative cement chemistries (i.e., not based on limestone) could provide a low-carbon solution for cement; however, extensive testing is required to provide the construction industry with the necessary confidence for wide-scale acceptance.

Table 6.2 List of mitigation technology needs[2]

S. No.	Area of Implementation	Technology/Remarks
1	Solar Photovoltaics	● Currently, crystalline Silicon (c-Si) technology contributes 95% of global solar PV installations, and thin films contribute to the remainder. Thus, c-Si is likely to contribute 400 GW by 2050 and is essential for India's future clean energy trajectory. ● India lacks technology and manufacturing for the upstream segment of the supply chain, i.e., polysilicon/ingot/wafer. Indian cell manufacturers import wafers, and similarly, cells are imported for module manufacturing. ● c-Si technology has made vast advancements, and the Indian manufacturers have not been able to keep pace with technology changes. ● Existing module manufacturing plants lack economies of scale, which prevents cost reduction. ● India lacks the crucial technologies needed to process/manufacture the raw materials for cell and module manufacturing. ● Equipment (assembly line) used for cell, module, and BoM (Bill of Materials) component manufacturing is not available in India and is imported. ● India needs next-generation PV technologies, including Perovskites, Multi-Junction Solar Cells, Dye induction photovoltaics and organic/inorganic composites. ● China, UK, USA are some of the key countries for technology sourcing.
2	Offshore Wind	● Technology limitation exists in the survey space (oceanographic and geotechnical) ● Heavily dependent on imports for rare earth metals ● Potential to increase the capacity factor of domestic manufacturing units ● Need for modelling and simulation tools, including HPC to improve generation forecasting and performance analysis. ● Denmark, the UK, and Germany are the major technology providers

2 Source: India-LED LTS submitted to the UNFCCC, https://unfccc.int/sites/default/files/resource/India_LTLEDS.pdf ; Report

S. No.	Area of Implementation	Technology/Remarks
3	Energy Storage	• Compressed-air Energy Storage (CAES), Energy Storage Downstream, Grid-Scale Battery Storage System (BESS), Flywheel, Gravity Storage, Hybrid Energy Storage System (HESS), Liquid Air Energy Storage, Super-conducting Magnetic Energy Storage (SMES) • Thermal Energy Storage, Pumped Storage
4	Transport	Key technological requirements in battery storage for advancing electric mobility are: • Lithium Ion (Li-Ion) Batteries, Nickel-Cadmium (NI-CD), Sodium Sulphur (NaS) • Electrochemical Capacitors/Supercapacitors, Iron-Chromium(ICB)Flow Batteries • Zinc-Bromine (ZNBR) Flow Batteries, Vanadium Redox (VRB) Flow Batteries • Redox Flow Batteries, Lead Batteries, Carbon Oxygen Batteries • Fuel Cells, Graphene-based Batteries, Liquid Metal Batteries • Metal-Hydrogen Batteries, Mg-ion Batteries, Niobium-based Batteries, Sodium-based Batteries, Solid State Batteries, Vanadium-ion Batteries, Zinc-based Batteries
5	Advanced Ultra Supercritical Coal Technology (AUSC)	• Materials having characteristics of high creep rupture strength and corrosion resistance at elevated temperature and pressures are not available • Japan and South Korea are potential collaborators for technology transfer (welding technologies)
6	Light Emitting Diode bulb	• LED chip (Wafer Fabrication) is imported
7	Room Air Conditioners	• Rotary compressors - a key component in room air conditioners is largely imported • The local availability of propane and isobutane-based refrigerants that have low Global Warming Potential footprints is a constraint
8	Iron & Steel Manufacturing	• Currently, about 60% of the Indian steel making industry depends on the Blast Furnace-Basic Oxygen Furnace route, which primarily depends on coal. The rest relies on Direct Reduced Iron/Scrap – Electric Arc Furnace/Induction Furnace route. By integrating energy & carbon efficient processes and by transitioning to renewable energy, steel industries can save emissions significantly. Further reduction in emissions can be achieved through adoption of Green Hydrogen in steel making as well as CCUS technologies. 100% Green Hydrogen based iron reduction process along with the use of Renewable Energy can substantially reduce the emissions in steel making. Disruptive alternative steel making technologies also holds promises for future. However, to achieve the speed and the scale of transition required, international collaboration and cooperation in R&D. Knowledge sharing and technology diffusion and co-development is much needed.

S. No.	Area of Implementation	Technology/Remarks
9	Biofuels	● Scaling up issues exist for large scale enzyme production ● Feedstock sourcing has been a perennial problem ● Commercial production of Bio-methanol is cost-prohibitive ● Higher Ethanol Compatible Vehicles and Flex Fuel Vehicle to be introduced ● CBG based vehicles is needed ● Technology development for SAF Production in the country
10	Hydrogen	● Technologies for type III and type IV cylinders, as well as hydride and carbon materials for hydrogen storage ● Catalysts, membranes, and fuel cell manufacturing assemblies ● Hydrogen supply chain infrastructure and dispensing stations ● Green hydrogen utilization in the industry, including ammonia for fertilizers and iron and steel production. ● Petroleum sector is planning for utilisation of green hydrogen in the refineries as well as for blending with CNG/CBG in gas pipelines.
11	Cement	● Proliferation of technology for waste heat recovery from preheater exhaust and cooler vent for co-generation of power ● Wider adoption of grate cooler technology ● Wider adoption of low-NOx multi-channel burners for combustion

6.6.3 Technology options for climate adaptation

Table 6.3: A list of technology options is provided in the table below along with patent information (adaptation technologies) if available.

Sector	Technology Section	Technology Class	Technology Name	Key Characteristics	Origin Country	TRL[3]	Patent Information
Water	Maintaining of sustainable water supply	Water treatment	Delta BW and Delta UF	Water treatment device: low cost and decentralized thanks to the grid or solar panels monitored by telemetry. The machine is equipped with Reverse Osmosis membranes (RO) and produces up to 4000 liters per day of drinking water from brackish water or polluted water from wells (<7gr. of salt per liter), fluorinated or charged with arsenic, cyanide, or mercury due to mining industry.	Switzerland	9	Owner - Swiss Fresh Water Registration -648920 Application – EP 11170597.6 Application - EP 09150934.9 Application - EP 08171132.7
	Water quality assurance	Quality check	WADI The Indicator for Solar Water Disinfection	It is a solar powered UV measurement device that visualizes the process of solar water disinfection in PET bottles.	Austria	9	AT509363
Public Health	Prevention and control of infectious diseases	Rapid Diagnostic Tools	Heat Mapping, Air Quality Control, and Disinfection System	A visualization of the health risk levels is generated and presented on a user interface. Health risk levels for building spaces are determined using occupancy data and health risk data relating to a risk of contracting or spreading an infectious disease.	USA	9	PCT/ US2020/041 792

3 Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

Sector	Technology Section	Technology Class	Technology Name	Key Characteristics	Origin Country	TRL[3]	Patent Information
	Prevention and control of other disease	Pollution Detection, Monitoring, Control, and Management	Air Handling System for Specialized Facility	The air handling system includes an air recirculation system having a blower for drawing air from the specialized environment for recirculation; a recirculation diffuser operatively connected to the specialized environment for recirculating air back to the specialized environment by action of the blower, and recirculation ductwork providing a pathway for air traveling from the blower to the recirculation diffuser.	USA	9	PCT/ US2004/001 828
			System for Capturing and Monitoring Atmospheric Pollutants	The technology comprises a protective frame that surrounds and protects the entire system. This includes; a supply module, a gas bioremediation system that serves to capture and bioremediate the polluted gas streams that pass through same, a control and monitoring module that lists and modifies operating parameters in real-time, and at least one particle capturing unit	Mexico	9	PCT/ MX2017/0 00134

Sector	Technology Section	Technology Class	Technology Name	Key Characteristics	Origin Country	TRL[3]	Patent Information
			Portable Fluid Sensory Device with Learning Capabilities	E-sensing, miniature devices with communication capabilities to analyze the composition of fluids and concentrations of harmful substances. The system comprising autonomous fluid sensory devices, intermediary devices, and database servers can operate in a learning mode or a user mode. Measurements can be filtered, and normalized to statistically eliminate the differences in measurements due to bad operational conditions, differences of device configurations or differences of local parameters	France	9	PCT/ EP2016/05 3783
			Development of a nano-C-based biocatalyst for remediation of atrazine and other environmental pollutants	The current invention developed by researchers at the University of Missouri is a nanostructured carbon-based biocatalyst for remediation of pesticides such as atrazine and other environmental pollutants	USA		AUTM10016

Sector	Technology Section	Technology Class	Technology Name	Key Characteristics	Origin Country	TRL[3]	Patent Information
			Hybrid Control System for eliminating Dust Mites and Airborne Microbes	A climate controller for controlling both temperature and humidity comprises an ultrasonic transducer placed in a water container, a heater, a compressor a condenser, a capillary tube, an evaporator, a control system, an inverter, a temperature sensor, and a humidity sensor. The climate controller can be operated in full control mode or stand-by mode.	Thailand	9	PCT/TH2015/000039
		Pollution Detection, Monitoring, Control and Management (Water)	Fishing, trapping, and killing of E-coli	Removing pathogens from water sources, treating Escherichia coli (E. coli) in water samples. A water treatment system uses a process of 'fishing, trapping, and killing' to treat Escherichia coli (E. coli).	Canada	9	PCT/CA2017/000200

Sector	Technology Section	Technology Class	Technology Name	Key Characteristics	Origin Country	TRL[3]	Patent Information
			Identifying Sources of Microbial Contamination in Environmental Samples WIB-3205	It has been designed to kill the anthrax spore, the most difficult biological to kill.	USA	9	PCT/ US2019/02 5292
				Due to its effectiveness towards the anthrax spore, the system and methods of the disclosure can remediate airborne pathogens such as Clostridium difficile, MRSA, aspergillus, streptococcus, etc., each representing a significant source and causality of hospital-acquired infections (HAIs) and a consistent threat to both the residential and clinical environments.			

Table 6.4: Sector-wise adaptation technology needs

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
Agricul-ture	Climate-resil-ient farming measures	Infrastructure &Technology	Parka TM Crop Cuticle Supplement	Using a cuticle spray to protect crops against environmental stress, improve fruit quality, yield at harvest, and extend the shelf life.	USA	9
			Precision Agriculture Technologies coupled with Hyperspectral Imaging	It uses multispectral and hyperspectral images captured by high-speed cameras to generate maps of agricultural fields and to keep track of plant health.	Mexico Australia USA	NA
	Climate-resil-ient livestock management	Feedstock Im-provement	Compositions and Combinations for Use as Food Supplements for Animals	The OmniGen portfolio developed by Phibro Animal Health Corporation com-prises products that lead to optimized productivity, longevity, and reproduction of animals.	USA	NA
		Livestock man-agement	Cattle Barn	Invented by Huazhong Agricultural Uni-versity to increase the design efficiency of the cattle house and therefore lower the cost of upkeep, better hygiene of the rearing area.	China	NA
	Agricultural water man-agement	Drip irrigation	Télé-Irrigation	Invented by Tech-Innov SARL uses clean energy sources along with mobile ap-plications to make the irrigation system smart and sustainable.	Niger	9
	Agricultural soil manage-ment	Soil management	Soil Analysis Using Near-Infrared Spectros-copy (NIR)	The equipment SpecSolo-Scan sensors detect vibrations of the soil sample and perform multivariate data calibrations using a database of 1 million repre-sentative soil samples from all over the country.	Brazil	7
	Agricultural environment monitoring	Agricultural environment monitoring and modelling	Use of Drones in Preci-sion Agriculture	Drones provide raw data for analytical modeling, and can also do soil health scans, monitor crop health, assist in planning irrigation schedules, apply fer-tilizers, estimate yield data and provide valuable data for weather analysis.	China,USA	NA

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
	Agricultural environment monitoring		Auravant precision Agriculture Digital Platform	It is a digital agriculture platform that improves agronomic knowledge which allows for maximization of yield, minimized costs, optimum scheduling time, and reduced environmental impacts.	Argentina	9a
			Smart Agriculture Xtreme: Smart agriculture PRO	Developed by Libelium uses IoT technology to provide smart agricultural solutions. It allows for daily monitoring through real-time information even in remote locations. Agriculture PRO is designed for vineyards monitoring for enhancing wine quality, selective irrigation and conditions control in greenhouses.	NA	NA
		Early warning system, Monitoring, modelling	Frost control/Heat stress System	ANAGEA Consultores S.p.A has developed a software forecast and gives a 12-hour prior alert on frost/heat stress at each monitoring point.	NA	7
		Early warning system, Monitoring and modelling, and Agriculture & Livestock disease management	Precision Crop Management Platform	Semios, is a precision crop management platform that uses site-specific crop data for temperature and humidity monitoring, Bee active hours tracking, pest and disease modeling & forecasting, risk index, and frost monitoring.	Canada	NA
		Sustainable intensification of Agriculture	Technologies for SIA	The Sustainable Intensification Lab in Kansas State University is developing approaches and technologies for sustainable intensification of agriculture.	USA	NA
	Agriculture & Livestock disease management	Agriculture & Livestock disease management	Integrated Tools for Pest and Disease Monitoring	This technology by Agranimo provides a real-time simple user interface and alerts to the users to help make application decisions. The Agranimo platform uses sensors, weather forecasts, satellite, and drone images with machine learning algorithms to detect all changes in the soil and microclimate	NA	9
	Post-harvest/ processing/ distribution	Food Conservation	Irradiation Technology for Food Preservation	Irradiation technology is used for preserving horticulture products; disinfection of insects and pests in stored food, delay in ripening, inhibition of sprouting in tubers, destruction of parasites, microbes, etc.	Switzerland	NA
			Purdue Improved Crops Storage (PICS) bags	The department of Entomology at Purdue University has developed multilayer plastic crop storage bags called PICS bags which are easy to use, locally made, and chemical-free bags to protect stored crops from pests. Thereby, reducing the use of insecticide and ultimately alleviating the need for farmers to sell their harvest immediately	USA	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
			Wax-Coated Jute Bags (WCJBs) for reducing post-harvest storage losses	Jute bags have high a water-absorbing quality which leads to moisture build-up in stored seeds, leading to fungal growth. This issue can be addressed by modifying the micro-texture and chemical make-up of jute fabric with alkali and wax treatments to develop the WCJBs.	NA	4-Mar
		Food Conservation	Our Food	Our Food is a Hyderabad based start-up that has established a 'network of "Farmer Franchises" that deploy new age, low-cost micro- processing units with the help of rural entrepreneurs to process the raw material at the farm gate		
		Food Conservation	Sabjikothi	Sabjikothi is an IoT-enabled tent-like self-assembled storage device that extends the shelf life of farm produce without any artificial cooling. Developed by Saptkrishi, this storage device only needs 10 watts of electricity either on or off-grid, and a litre of water per day to function.		
Water	Maintaining of sustainable water supply	Desalination of water	fastRO® C series CONTAINERIZE D seawater reverse osmosis system	FastRO C seawater reverse osmosis system is a containerized desalination solution, with most parts installed into 1 or 2 containers, and a freshwater capacity of 50 to 2,000 m3 /day. The technology has 3 steps filtering process including sand filter, pre-filter, and the main filter to ensure better protection for the high-pressure pump, energy recovery device, and RO membrane.	China	9
			Oneka Desalination	Wave-powered desalination for autonomous drinking water production targeting small island communities and includes pumping offshore through reverse osmosis filters and membranes to obtain high-quality drinking water	Canada	9
			High Recovery seawater desalination system	An advanced designed seawater RO desalination system is developed by Hitachi as a solution for membrane fouling. A less fouling system makes enables the operation of water recovery in the RO process much higher.	Singapore	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readiness Level
		Extraction of Groundwater	ASR-Coastal (Aquifer Storage and Recovery using multiple partially penetrating wells)	ASR-Coastal was developed to overcome such coastal water shortages by improving the underground storage of freshwater in brackish and saline aquifers. The concept is to inject fresh water in times of surplus to create a reserve for times of need.	Netherland s	9
		Water catchment and harvesting	Fog harvesting	Fog harvesting provides an alternative source of fresh water through a technique used to capture water from wind-driven fog. They are typically installed in areas where the presence of fog is naturally high, typically coastal and mountainous regions. The systems are usually constructed in the form of a mesh net, stabilized between two posts that are spread out at an angle perpendicular to the prevailing wind carrying the fog.	NA	9
			SOURCE Hydropanel	SOURCE Hydropanels make drinking water from only sunlight and air Using solar PV, SOURCE takes ambient air via fans and absorbs water vapor from that air onto a hygroscopic material.	NA	9
			WaterSeer	Vici labs in collaboration with UC Berkeley and the Peace Corps Association have developed WaterSeer, a wind-powered device that can be installed anywhere. It can produce 11 gallons of clean drinking water per day using air.	NA	2-Jan
		Water saving technologies	Floating Covers (BARRIER BALL)	Barrier Ball® is a floating cover for liquid bodies composed of plastic spheres loaded with water (ballast). The spheres cover 91 percent of the surface and form a barrier that reduces the liquid-gas interface, the entry of sunlight, and eliminates the water mirror	Chile	9
		Water treatment	Delta BW and Delta UF	Water treatment device: low cost and decentralized thanks to the grid or solar panels monitored by telemetry. The machine is equipped with Reverse Osmosis membranes (RO) and produces up to 4000 liters per day of drinking water from brackish water or polluted water from wells (<7gr. of salt per liter), fluorinated or charged with arsenic, cyanide, or mercury due to mining industry.	Switzerland	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
	Water quality assurance	Wastewater treatment and recycling	Struvia	Struvia technology has been developed by Veolia Water Technologies to facilitate the recovery, valorization, and reuse of phosphorus contained in wastewater and concentrated industrial water.	NA	9
			DEWATS	Decentralized Wastewater System (DEWATS) refers to a decentralized, community-level wastewater treatment technology. DEWATS is a technical approach to decentralized wastewater treatment in developing communities. DEWATS is designed to be affordable, low maintenance, use local materials, and meet environmental laws and regulations.	Germany	9
			Mizuchi Aerobic without sludge Biofilter(ABWS)	The Mizuchi Aerobic Biofilter Without Sludge (ABWS) is a low-cost, highly efficient wastewater solution. The highly innovative system uses 70 percent less energy compared to conventional activated sludge systems, requires no chemicals, and does not generate sludge.	Singapore	9
			Direct nano filtration(d-NF) membranes	It is based on dNF technology which enables direct treatment of wastewater without intensive pre-treatment and can lead to 95 percent recycling.	Netherland s	9
		Quality Check	WADI The Indicator for Solar Water Disinfection	It is a solar-powered UV measurement device that visualizes the process of solar water disinfection in PET bottles.	Austria	9
	Water-related disaster risk management	Resilient infra-structure	Bioswales	Bioswales work on the same principle as rain gardens but are planted with the same hardy, water tolerant species suitable for storm control on a larger level.	NA	9
		River protection	HoTRiverS project	It aims to understand stream temperature patterns, controls, and responses to climate change using drones and river temperature modelling.	UK	1
		Risk management and disaster prevention	Artificial lowering of glacial lakes	It is the process of draining water from vulnerable to overflowing by digging a canal from the lake to a nearby river. It will reduce the risk of burst events.	NA	Commercial Maturity
			Underground Taming of Floods for Irrigation (UTFI)	It targets to recharge excess wet season flows to aquifers to enhance water security during dry spells and droughts.	NA	9
	Service management of water ecosystem	Smart solutions	Cloud to street	It allows professionals to make better decisions in complex situations by delivering critical insights about the extent and impact of flood events.	USA	9
			Maia Analytica WILMA	It provides real-time analytical tools to assist wastewater treatment operators with proactive decision-making.	Canada	4

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
Forest-ry			Scattered Fodder Trees on Pasteur / Fodder Orchard	An integrated farming system that helps in the cultivation of fodder and fuelwood in widely spaced, regularly harvested land that lost its nutrients. It addresses the concerns of input availability and labor shortage while leading to increased productivity and additional income.	NA	9
		Forest management	Green Bots	An intelligent and interoperable network of devices interconnected through a dynamic, global infrastructure network can be created to connect and exchange data across locations at any time. These technology-driven smart sensors (called 'green bots') can be key to preserving India's forests, while also providing data that can catalyze more sustainable forest management.	China	9
			Technologies to Reduce Deforestation UAV System	The Unmannered Aerial Vehicle (UAV) system is fully automated and offers the benefit of being less expensive yet can work faster to combat the impacts of deforestation. The machine can plant ten seeds per UAV per minute. The drone fires pods into the ground, which enables the planting of many trees in less time. Every pod is loaded with a pre-germinated seed in a nutritious hydrogel that gives the most favorable mineral environment and all the moisture needed to sprout it out.	United Kingdom	9
			Methods for Rehabilitating Degraded Forests and Mined Sites	CSIR-Forestry Research Institute of Ghana has established a suitable time-tested methodology for rehabilitating degraded forests and mined sites that cater to the diverse goals of forest management. The methodology provides guidance on land preparation and site-species matching and selection based on measured indicators; stand management as well as fire and tree health monitoring.	Ghana	9
			Techniques for the Production of Improved Seeds and Seedlings	CSIR-FORIG has successfully developed technologies to produce superior planting materials for major native species.	NA	9
			Laser Measurement-based Precision Forestry	Using airborne laser scanning (ALS) data, a planned harvesting area is matched to previous harvests of similar forests, and existing harvester data is then used to create a very detailed representation of the forest plan for cutting.	USA	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readiness Level
			Eddy Covariance Flux towers	Eddy Covariance is the standard method utilized by biometeorologists and ecologists to estimate and analyze trace gas fluxes between the ecosystem and the atmosphere. The eddy covariance sensors are usually non-invasive, that can measure ecosystem fluxes at spatial scales of a few hundred meters.	USA	9
		Forest conser-vation	Forest Stand Target Attribute Prediction	Stereo-SAR can produce 3D metrics that can be used in the mapping of forest stand attributes. Stereo-SAR is especially suitable for mapping forest height-relat-ed variables.	Finland	9
			System and Method for Forest Fire Control	A system for forest fire control com-prising a plurality of forest fire control nodes. Each node is comprised of one or more detection means of an environmental condition, at least one communication transceiver for sending and receiving data indicative of a sensed environmental condition, and of at least one hanging unit configured for hanging the node on a tree.	USA	9
			Molecular markers	Molecular markers are essential in stud-ying forest species concerning quality control. Molecular markers reduce the rotation time and increase disease and pest resistance in trees.	Nigeria	7
			Artificial Neural Network	The application of Artificial Neural Networks (ANN) to predict the behaviors of nonlinear systems has become an attractive alternative to traditional statis-tical methods.	USA	
				The most widespread application of ANN is spatial data analysis from multi-ple sources.		
			Mechanized harvesting in Forestry	Mechanized harvesting involves fully mechanized systems to improve safety, productivity, and process control. The mass-removal machines operate by applying an external force, shaking the limb or tree trunk mechanically by holding it or applying force in the form of a jet of water or air to vibrate limbs, foliage, and twigs.	USA	9
		Reforestation	Plantation Technology	Forest crops are raised artificially either by sowing or planting in general in which naturally occurring tree species have been replaced by planted trees.	NA	

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
			Next-Generation Sequencing (NGS) Technologies for Tree Breeding	NGS technologies fetch popularity in next-generation tree breeding programs to assess species divergence in natural populations and gain substantial momentum and attention among the scientific community, tree breeders, and policymakers.	Italy	
		Early warning system	USDA forest service warning system for forest health	Understanding the potential threats such as identifying potential invasive organisms, identifying potential pathways of invasive organisms, identifying other environmental threats, identifying vulnerable ecosystems.	USA	9
			Forest Disturbance Early warning system	The Forest Disturbance Early Warning System (FDEWS) provides regularly updated information about likely forest disturbances, even when skies are cloudy. Maps show disturbances that have occurred since baseline, with the date of the first detection.	UK	
		Risk management and disaster prevention	Spatial technology for forest fire management	A wildfire risk model can serve as an early warning system to predict the level of severity of fire risks, which is significant for wildfire prevention and fighting strategies. Developing a GIS-based wildfire hazard model which aims to identify geographic locations with the highest wildfire hazards and risks would be beneficial.	Malaysia	
			Pest and disease monitoring	Pest and disease monitoring encompasses digital monitoring of potential outbreaks, for instance, with UAVs, and coordinated response management to minimize damage to the forest. UAVs can achieve a detection accuracy of 80 to 95 percent for pest and disease outbreaks, over very large areas of forest.	America	
			Fire monitoring	Fire monitoring entails the digital monitoring of fires, with UAV or satellite, for example, to provide early warnings and coordinate firefighting efforts.	America	
	Forest carbon sink management	Monitoring of carbon sink	Smart Sensor Node	The sensor node needs to gather the parameters of carbon sinks, carbon flux, carbon emissions monitoring which is based on a variety of different sensing devices for accessing environmental information, carbon flux of fixed observation tower, and the communication between the sensor node and the center uses the way of wireless networks. The basic principle of carbon budget monitoring is calculated by using the model, which integrates gradient changes of regional concentrationofCO2.	China	

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
			LiDAR (Light Detection and Ranging) system	LiDAR (Light Detection and Ranging) system that can measure how much carbon is stored in forests and where human activities including deforestation are releasing it.		
	Forestry & Land ecosystem restoration	Conservation and restoration	Genetically engineered (GE)	Genetically engineered (GE) trees potentially formulate breeding values noticeably and reduce the life cycle, resulting in increasing yield and plummeting off the exploitation load on natural forests.	Italy	
			Genomic selection (GS)	Genomic selection (GS) was a milestone discovery based on high-throughput sequencing technology offering an innovative tool for understanding quantitative trait variation in forest trees.	Italy	
		Improved management	Scanning Technology; Wood Technology	In scanning technology lasers, optical scanners, and X-ray scanners are used to measure logs and detect flaws that may be superficial and interior Scanners allow for increased energy efficiency and optimal utilization of logs.	Nigeria	
			Engineered wood products	To increase wood utilization, a great deal of the waste left from the sawing process is incorporated into products that can be substituted for solid wood products or products made from other materials.	Nigeria	
	Forest & Land ecosystem change detection and prediction	Monitoring and modelling	Tree Monitoring (GIS Base)	The technology seeks to monitor the tree planting program to account for species type, growth, and health, and the contribution towards carbon sequestration made by each tree planted.	South Africa	9
			Forest Modelling	Forest modeling is very essential in guiding the management activities by using data on the tree or animal characteristics, environmental conditions or variables, and management techniques to predict how forests will react to different management strategies or regimes over time.	Nigeria	
			Satellite technology for forest monitoring	It helps to assess the vast territories with significant ease, compared to other methods. Using satellite imagery and AI, many companies work on early forest fire detection, climate change impacts analysis, and even harvesting.		

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
			Unmanned Aerial Vehicle (UAV) for Forests	UAVs have been utilized for capturing RGB or VNIR images for studying forests or agricultural systems. It allows integration of active sensors such as LiDAR as well as passive hyperspectral sensors that can provide crucial information regarding the canopy structure and health of the target ecosystem.	Panama	
			Airborne Laser Scanning (LiDAR)	Airborne Laser Scanning (LiDAR) provides precise measurements of forest structure from which forest carbon can be monitored, providing wall-to-wall mapping at a higher resolution than any other remote sensing product.	USA	9
			Terrestrial laser scanners	Terrestrial laser scanners utilize light detection and ranging (LiDAR) technology to capture the 3-D structure of their surroundings as a collection of returns resulting from emitted pulses of energy reflecting from objects.	USA	9
			Phenocams	Phenocams are digital cameras (RGB or VNIR) that are set up to capture time-lapse images of plant leaves/canopy; these time-series images can be used for derivation and quantitative analysis of plant phenology	USA	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
Public Health	Prevention and control of infectious diseases	Rapid Diagnostic Tools	CRISPER-Based Viral Diagnostics - SHERLOCKv2	SHERLOCKv2 can detect viruses such as DNY and ZKV with 2 attomolar sensitivity in bodily fluids using a paper-based, field-deployable format [10]. Highly adaptable for other agents by employing virus-specific guide CNAs.	India	7
			Heat Mapping, Air Quality Control, and Disinfection System	A visualization of the health risk levels is generated and presented on a user interface. Health risk levels for building spaces are determined using occupancy data and health risk data relating to a risk of contracting or spreading an infectious disease.	USA	9
	Prevention and control of other disease	Vector Borne Disease Detection, Control, and Prevention	Gazelle	Hemedex has developed this 'Gazelle' platform that claims to differentially diagnose both Plasmodium falciparum (Pf) and Plasmodium vivax (Pv) in a single blood	USA/ India	7
				sample.		
		Pollution Detection, Monitoring, Control, and Management	Air Handling System for Specialized Facility	The air handling system includes an air recirculation system having a blower for drawing air from the specialized environment for recirculation; a recirculation diffuser operatively connected to the specialized environment for recirculating air back to the specialized environment by action of the blower, and recirculation ductwork providing a pathway for air traveling from the blower to the recirculation diffuser	USA	9
			System for Capturing and Monitoring Atmospheric Pollutants	The technology comprises a protective frame that surrounds and protects the entire system. This includes; a supply module, a gas bioremediation system that serves to capture and bioremediate the polluted gas streams that pass through same, a control and monitoring module that lists and modifies operating parameters in real-time, and - at least one particle capturing unit.	Mexico	9
			Portable Fluid Sensory Device with Learning Capabilities	E-sensing, miniature devices with communication capabilities to analyze the composition of fluids and concentrations of harmful substances. The system comprises autonomous fluid sensory devices, intermediary devices, and database servers can operate in a learning mode or a user mode. Measurements can be filtered, and normalized to statistically eliminate the differences in measurements due to bad operational conditions, differences of device configurations or differences of local parameters,	France	9

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readineness Level
			Development of a nano-C-based biocatalyst for remediation of atrazine and other environmental pollutants	The current invention developed by researchers at the University of Missouri is a nanostructured carbon-based biocatalyst for remediation of pesticides such as atrazine and other environmental pollutants	USA	
			Breeze Low-Cost Air Quality Sensors and Environmental Intelligence Cloud	The sensor starts gathering climate data and data on all major air pollutants with a measurement interval of 30 seconds. Based on the algorithms of the proprietary Adaptive Cloud Calibration Engine (ACC), the sensors are continuously recalibrated to ensure the highest possible data quality and accuracy.	Germany	9
			Hybrid Control System for eliminating Dust Mites and Airborne Microbes	A climate controller for controlling both temperature and humidity comprises an ultrasonic transducer placed in a water container, a heater, a compressor a condenser, a capillary tube, an evaporator, a control system, an inverter, a temperature sensor, and a humidity sensor. The climate controller can be operated in full control mode or standby mode.	Thailand	9
			Low-Cost Air Quality Sensors Networks	The system is currently equipped to measure levels of Ozone, CO, NOx, VOC, dust, noise, relative humidity, and temperatures. The highly compact sensors are stored in a home router-like box that is simply powered-in and hooked to the LAN plugs (or Wi-Fi) of the internet router -just plug and play Immediately after it is connected, the sensors are operative, sending a pulse of information every 20 seconds.	Israel	9
			Membrane Separation Technology 6: BTX Vapor Separation	Disposal of hazardous chemical substances, removal of benzene from the air.	Israel	9
				A filter that blocks is commonly developed to separate benzene from the atmosphere		

Sector	Technology Section	Technology Class	Technology Name	Key characteristics	Origin country	Technology Readiness Level
		Pollution Detection, Monitoring, Control and Management (Water)	Fishing, trapping, and killing of E-coli	Removing pathogens from water sources, treating Escherichia coli (E. coli) in water samples.	Canada	9
				A water treatment system uses a process of 'fishing, trapping, and killing' to treat Escherichia coli (E. coli).		
			Identifying Sources of Microbial Contamination in Environmental Samples WIB-3205	It has been designed to kill the anthrax spore, the most difficult biological to kill.	USA	9
				Because of its effectiveness towards the anthrax spore, the system and methods of the disclosure can remediate airborne pathogens such as Clostridium difficile, MRSA, aspergillus, streptococcus, etc., each representing a significant source and causality of hospital-acquired infections (HAIs) and a consistent threat to both the residential and clinical environments.		

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Units and Quantities

BCM	Billion Cubic Meter (equals 1 km^3)
C	Celsius
Gg	Giga gram
GW	Gigawatt
GWh	Giga Watt hour
ha	Hectare
km	kilometre
km^2	Square kilometre
km^3	Cubic kilometre
ktoe	kilo tonne of oil equivalent
kW	kilowatt
kWh	kilowatt hour
kWp	kilowatts peak
m	Million
m^3	Cubic meter
Ma-1	Water equivalent per unit area per year Mha Million hectare
MJ	Mega Joule
Mt	Million tonne
$MtCO_2$	Million tonne of Carbon dioxide
$MtCO_2e$	Million tonne of Carbon dioxide equivalent
$MtCO_2eq$	Million tonne of Carbon dioxide equivalent
MW	Megawatt
$m.w.e.a^{-1}$	Mean water equivalent per annum
t	tonne
Tg	Teragram
TJ	Terajoule
toe	tonne of oil equivalent

Conversion Table

1 Gigagram (Gg)	=	1000 tonne		
	=	10^9 g		
1 Teragram (Tg)	=	1 Million tonne		
	=	1000 Gg		
	=	10^6 tonne	=	10^{12} g
1 Terajoule (TJ)	=	10^3 GJ		
	=	10^{12} Joules		
1 Calorie	=	4.18 J		
1 Lakh	=	100,000	=	10^5
1 Crore	=	10,000,000	=	10^7
1 Million	=	1,000,000	=	10^6
1 Billion	=	1,000,000,000	=	10^9
1 Trillion	=	1,000,000,000,000	=	10^{12}

ANNEXURE II - Institutional Arrangements

Composition of the National Steering Committee (NSC) for India's Third National Communication (TNC) and Biennial Update Reports (BUR) to the United Nations Framework Convention on Climate Change (UNFCCC)

Chairman

i. Secretary, MoEFCC

Members

ii. Special/ Additional Secretary (In-charge: Climate Change matters), MoEFCC

iii. CEO, NITI Aayog or his representative

iv. Secretary, Department of Agricultural Research and Education, Ministry of Agriculture and Farmers Welfare or his representative

v. Secretary, Department of Agriculture Co-operation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare or his representative

vi. Secretary, Department of Economic Affairs, Ministry of Finance or his representative

vii. Secretary, Ministry of New and Renewable Energy or his representative

viii. Secretary, Department of Science & Technology or his representative

ix. Secretary, Ministry of Coal or his representative

x. Secretary, Ministry of Power or his representative

xi. Chairman, Railway Board or his representative

xii. Secretary, Ministry of Road Transport & Highways or his representative

xiii. Secretary, Ministry of Shipping or his representative

xiv. Secretary, Ministry of Petroleum & Natural Gas or his representative

xv. Secretary, Department of Water Resources, River Development and Ganga Rejuvenation or his representative

xvi. Secretary, Ministry of Health & Family Welfare or his representative

xvii. Secretary, Ministry of Earth Sciences or his representative

xviii. Secretary, Department of Rural Development or his representative

xix. Secretary, Ministry of Housing and Urban Affairs or his representative

xx. Secretary, Department of Industrial Policy & Promotion, Ministry of Commerce and Industry or his representative

xxi. Secretary, Ministry of Steel or his representative

xxii. Secretary, Ministry of Civil Aviation or his representative

xxiii. Secretary, Ministry of Statistics and Programme Implementation or his representative

xxiv. Director General, India Meteorological Department or his representative

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xxvi. Representative, United Nations Development Programme, India-Office, New Delhi

xxvii. Joint Secretary (Climate Change), MoEFCC

Member Secretary

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Composition of the Technical Advisory Committee for India's Third National Communication and Biennial Update Reports to the United Nations Framework Convention on Climate Change

Chairman

i. Additional Secretary / Special Secretary (In-charge: Climate Change matters), MoEFCC

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i. Representative, Indian Space Research Organization

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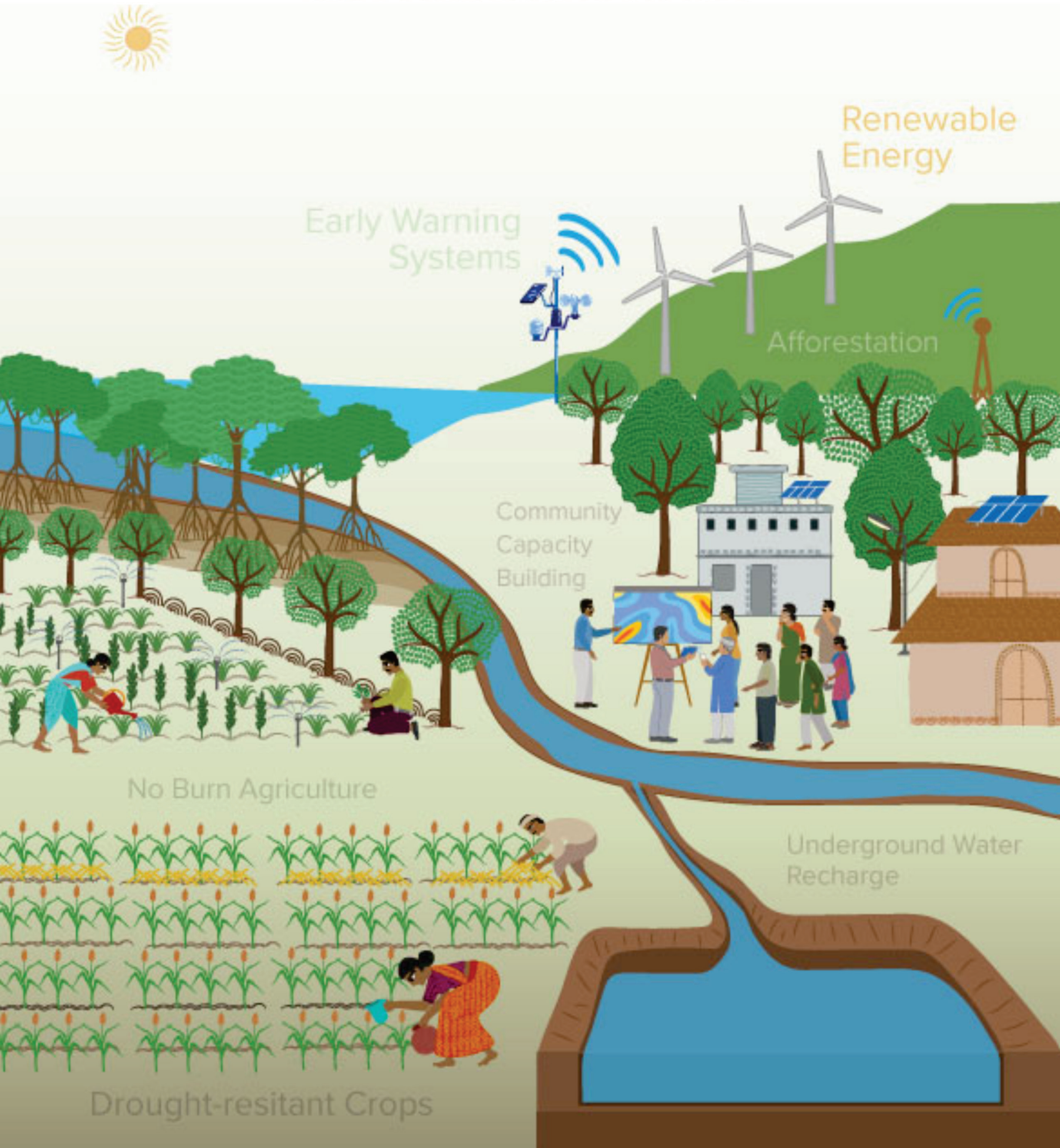
List of events /consultative meetings

- Series of Meeting of the Inventory Experts on TNC from 20 February 2023 to 24 February 2023 at MoEFCC, Indira Paryavaran Bhawan, New Delhi.
- Meeting of the Technical Advisory Committee to India's Third National Communication to the UNFCCC on 29 March 2023 at Indira Paryavaran Bhawan, New Delhi.
- Meeting to the National Steering Committee to India's Third National Communication to the UNFCCC on 02 May 2023.

Initial Adaptation Communication



सत्यमेव जयते

India’s Initial Adaptation Communication to the United Nations Framework Convention on Climate Change

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Executive Summary

India, as a Party to the United Nations Framework Convention on Climate Change (UNFCCC) has taken ambitious and visionary efforts to address climate change induced challenges at national and local levels to provide global benefits and remains committed to implement the Paris Agreement. As per the Article 7, paragraphs 10 and 11 of the Paris Agreement, India intends to submit its first Adaptation Communication to UNFCCC.

With the highest mountain range in the world, the Himalayas to its North, the Thar desert to its West, the Gangetic delta to its East and the Deccan Plateau in the South, India is home to vast agro-ecological and physiographic diversity. More than 50 per cent of its population depends on climate-sensitive sectors of agriculture, fisheries, natural ecosystems, and forestry for their livelihoods. This makes India and its population vulnerable to all possible manifestations of climate change, such as increased summer and winter temperatures, erratic and uncertain precipitation across space and time leading to floods and droughts, increased frequency and intensity of wind and storm events, sea level rise and an increase in sea surface temperature.

As per Census of India, 2011, 31 per cent of the country's population lived in urban areas. India's urban population is estimated to reach 37 per cent by 2030, and 70 per cent of India's GDP in 2030 is expected to be generated from urban regions. Due to the concentration of economic activities in urban agglomerations, energy consumption, and consequently emissions are higher in cities making these important regions for climate action. Therefore, given the extent of vulnerable population in cities, climate adaptation and climate resilience are also key requirements for urban India.

India's Nominal Gross Domestic Product (GDP) in the year 2022-23 is estimated to attain a level of INR 272.4 trillion.[1] The growth in real GDP during 2022-23 is estimated at 7.2 percent as compared to that of 9.1 per cent in 2021-22. As of 2022-23, the Gross Value Added (GVA) composition of India for the agriculture, forestry and fishing was at 18.4 per cent, the industry sector at 28.2 per cent and the services sector at 53.4 per cent.

India, despite its pressing development imperatives, has accorded a prominent focus to the sustainability aspects in its accelerated economic growth. Hence, with the twin actions of balancing the NDC targets along with becoming a US$ 5 trillion economy by 2025- 26, India has the potential to grow at 6.5 to 7 per cent and will become US$ 7 trillion by 2030. International experience, especially from high-growth East Asian economies, suggests that such growth can only be sustained by a "virtuous cycle" of savings, investment and exports catalyzed and supported by a favorable demographic phase. Hence, heeding to the infrastructure deficit represented by different indicators, the pressures of urbanization and industrialization with the imperative of sustainable growth through implementation of NDC targets, India faces a formidable and complex challenge in working towards economic progress.

1 (2023). Ministry of Statistics and Programme Implementation (MoSPI). Press Note on Provisional Estimates of National Income 2022-23 and Quarterly Estimates of Gross Domestic Product for the Fourth Quarter (Q4) of 2022-23

The climatic parameters of temperature, precipitation and Indian ocean warming have been increasing along with carbon dioxide content in water since the middle of the twentieth century and are projected to be increasing in the future. Extreme events like droughts, floods, storm surges and sea level rise are also observed and projected to be increasing. A mixed trend has been observed for extreme storm events, though it has been projected to increase.

The rising temperature will have detrimental effects on the agriculture, fisheries, forestry and biodiversity sectors, besides increasing the intensity of thunderstorms, tropical cyclones and marine heat waves. Extreme precipitation events are likely to cause flash floods, destruction of standing crops, landslides and increased instances of urban floods and water logging, which would have severe implications for infrastructure in the climate sensitive coastal and Himalayan regions. The frequency of heat waves is observed to be increasing over the central and north- western parts of India and is projected to be 3 to 4 times higher, compared to the 1976–2005 baseline period, by the end of the twenty-first century under the RCP 8.5 scenario.

India recognizes adaptation is inevitable and imperative for its development process and has been undertaking several efforts to increasingly mainstream adaptation efforts while furthering developmental requirements through a range of schemes/ projects/ programmes of several Ministries, like the Ministry of Jal Shakti (Water), Ministry of Environment, Forest and Climate Change, Ministry of Agriculture and Farmers' Welfare, Ministry of Fisheries, Animal Husbandry and Dairying, Ministry of Science and Technology, Ministry of Rural Development, Ministry of Earth Sciences etc., to improve adaptive capacities and reducing socioeconomic vulnerabilities of the people.

Climate change is a major threat to the humanity but with local consequences. India has adopted a more proactive, ambitious and forward looking development approach through its commitment to Nationally Determined Contribution (NDC). It links India's commitment to ecologically sustainable economic development with its age old civilizational values of respecting nature, incorporating a sense of inter- generational and intra-generational equity. Thus, a co-benefit approach underlies India's Climate change strategy.

Many of the schemes/programs of the Government of India, find synergies with several multilateral frameworks - the UNFCCC, the United Nations Convention to Combat Desertification (UNCCD), the Sendai Framework for Disaster Risk Reduction, the RAMSAR Convention, the Convention on Biological Diversity (CBD) and contribute significantly to different Sustainable Development Goals (SDGs) while addressing climate concerns. Traditional and local knowledge systems are a way of life in India. The immense potential of traditional knowledge systems that have supported local societies in organizing lifestyles successfully in remote and fragile areas of the country has been acknowledged and appreciated by integrating them into the formal sector policies and practices.

National Action Plan on Climate Change (NAPCC) outlines a national strategy that aims to enable the country to adapt to climate change and enhance the ecological sustainability of India 's development path. Out of the various focused National Missions under the NAPCC, few Missions focus on adaptation and/or adaptation co-benefits. Besides NAPCC, State Action Plans on Climate Change (SAPCC) are being implemented in all the States and Union Territories (UTs). SAPCCs are designed to be context- specific, considering the different ecological, social, and economic conditions of each state. By incorporating climate change considerations into state-level policies and programs, SAPCCs help India to adapt to the impacts of climate change, protecting its local communities and ensuring sustainable development. All the States and UTs have prepared and submitted their respective SAPCCs using a common framework prepared by the Ministry of Environment, Forest and Climate Change, Government of India. Some of the states in India have also revised their respective SAPCCs as per the revised framework.

As a part of the updated NDC, India has introduced the concept of Mission 'LiFE' (Lifestyle for Environment) to promote responsible consumption by focusing on behaviours and attitudes of individuals and communities. Hon'ble Prime Minister of India introduced Mission LiFE to the World at the 26th session to the Conference of Parties to the UNFCCC.

The Mission LiFE recognises that Indian culture and living traditions are inherently sustainable. Our approach is based on the philosophy, "*What is needed today is mindful and deliberate utilization instead of mindless and destructive consumption*". The Government of India, through its initiatives and policies, has reiterated the importance of 'living cultures and traditions' that evolve over time while maintaining the strength of their original essence – that of sustainability. Nudge policies gently steer people towards desirable behaviour even while preserving their liberty to choose. Drawing on the psychology of human behaviour, behavioural economics provides insights to 'nudge' people towards desirable behaviour.

Planning, implementation and monitoring of adaptation actions for a large and diverse country like India poses a formidable challenge due to certain constraints. Limited knowledge and resources such as technical skills, quality data, and research studies, especially at regional and sectoral levels are key constraints to adaptation planning. The constraints for the implementation of adaptation actions are technology, capacity, finance and lack of adequate participation from the private sector. Based on the above challenges and constraints, three broad categories of adaptation priorities for India have been identified as –

i. Priorities related to knowledge systems on climate change risks and adaptation,
ii. Priorities related to a reduction of exposure to climate risk; and
iii. Priorities related to building resilience and adaptive capacity.

Women play an active role in the process of adaptation. They are the ones who have a major role in decisions at the household levels on the types of *chulla* (cookstove) used for cooking, as also deciding the sanitation norms. In India, about 65 per cent of the total female workers are engaged in one of the most climate sensitive sectors – agriculture, thereby constituting 30 per cent of the total cultivators and about 43 per cent of the total agricultural labourers in the country. Considering the contribution and importance of women in the micro level adaptation planning, India formally adopted Gender Responsive Budgeting (GRB) in 2005-2006. Government of India has introduced several schemes to benefit the women as a part of developmental actions and minimize the vulnerabilities caused due to climate change.

India will continue to endeavour its best in terms of meaningful climate actions. The national circumstances demand high priority being accorded to adaptation, being a country that is highly vulnerable to extreme weather events. Climate change impacts are expected to worsen with the passage of time because of the momentum due to the present carbon stock continuing to raise the temperature. Hence, India's adaptation needs intensify leading to an increase in adaptation costs. India is doing adaptation in mission mode. However, means of implementation still remains the critical issue due to the absence of an adequate flow of international climate finance. India is stepping up its targets largely by relying on its domestic budgetary resources. The developing countries must get their fair share in the atmospheric resource, respecting the principles of equity and common but differentiated responsibilities.

MoEFCC is the nodal Ministry under the Government of India for coordinating and managing climate change related policies, programmes, actions, and reporting information under Article 4.1 of the Convention and has constituted an Apex Committee for Implementation of Paris Agreement (AIPA). Under the supervision of AIPA, a Steering Committee has been formed for drafting 'India's first Adaptation Communication to UNFCCC'. The Steering Committee set up seven Sectoral Working Groups (SWGs) to cover priority sectors, themes and regions: Agriculture, Water, Coastal and Island, Himalayan Ecosystem, Disaster Management and Infrastructure Resilience, Forestry and Biodiversity and Adaptation Resources.

The SWGs consists of line Ministries, research organisations, think- tanks and academic institutions, thus making the preparation process of the Adaptation Communication iterative and consultative, involving all important stakeholders. The SWGs were provided with a broad framework and template to provide inputs for Adaptation Communication. The seven SWG reports were compiled and sent to an expert committee which comprised national experts in each sector for their views and comments. As States and UTs play an important role in the implementation of climate actions, inputs and feedback were invited from the States and UTs for finalisation.

The total adaptation relevant expenditure was 5.60 per cent of the GDP in 2021-2022, growing from a share of 3.7 per cent in 2015-16 (Figure 1), which shows that India has been making consistent efforts to integrate climate resilience and adaptation into development plans and spending a significant amount of resources for adaptation, despite the competing demands especially from the social sector for resources.

The cumulative expenditure needed for adaptation in a Business as Usual (BAU) scenario, without any additionality, is estimated to be INR 56.68 trillion till 2030, assuming 2023-24 as the base year of analysis. Climate induced damages could lead to an incremental cost of INR 15.5 trillion by 2030, and the requirements for building adaptation capital stock could be as high as INR 72 trillion after accounting for the country's developmental needs and climate-induced pressures.

Besides, India's adaptation finance needs are challenging to quantify and too large to be resolved with its already stressed domestic resources. While individual estimates are subject to uncertainty, it is clear that the adaptation finance required is significantly higher than current adaptation finance estimation.

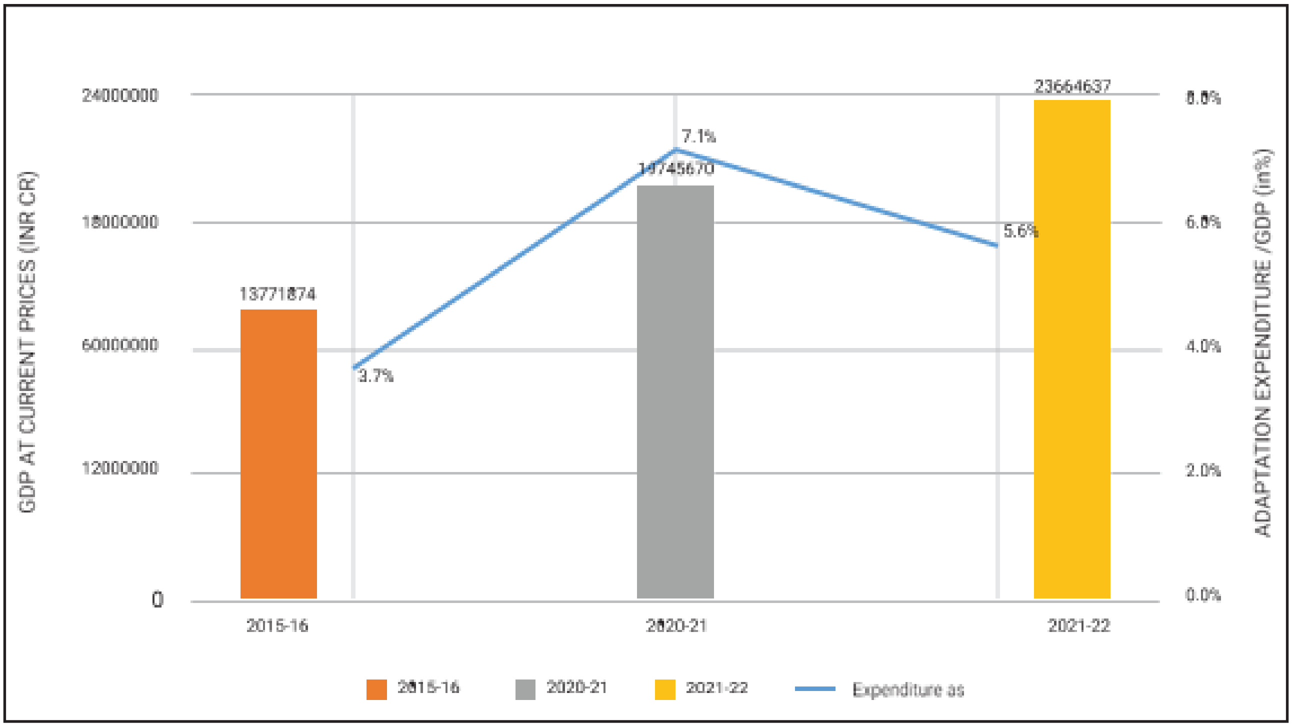


Figure 1 : Adaptation Relevant Expenditure as a per cent of GDP

The 2022 UN Adaptation Gap Report found that estimated adaptation costs in developing countries were 5-10 times greater than the international adaptation finance flows, and that the adaptation gap was widening. Urgently increasing adaptation finance flows to India is a crucial requirement for India to be able to meet its long term sustainable development and economic growth objectives.

Hence, international climate finance holds the key to the effective implementation of adaptation plans in India.

India's first Adaptation Communication to the UNFCCC also comprises chapters on National Circumstances and Impacts, Vulnerability Assessment of India's Third National Communication. This Annexure contains additional information to communicate upon India's Adaptation Efforts, and future needs of India for Adaptation.

The **first chapter** highlights the adaptation efforts of India in climate sensitive sectors such as water, agriculture, disaster management, coast and islands, forestry and biodiversity, and the Himalayan ecosystem, the institutional arrangements for adaptation in the country, monitoring and evaluation related to adaptation, the co-benefits of mitigation and synergies with international and multilateral frameworks.

The **second chapter** emphasizes the future needs for adaptation, identifying key gaps and barriers to adaptation, adaptation priorities for the country, implementation constraints and resource needs.

These adaptation efforts align with the long-term vision outlined by the Government of India in the NAPCC and NDC. The exercise of putting together the AdCom report is part of a broader process of climate change action conducted in line with UNFCCC guidelines.

List of Abbreviations

AdCom	Adaptation Communication
AIPA	Apex Committee for Implementation of Paris Agreement
AIBP	Accelerated Irrigation Benefit Programme
AR5	IPCC's Fifth Assessment Report
AF	Adaptation Fund
ATMA	Agriculture Technology Management Agency
BCM	Billion Cubic Meters
CAD &MM	Command Area Development & Water Management
CBD	Convention on Biological Diversity
CCA-RA	Climate Change Adaptation in Rural Areas of India
CSD	Climate Sensitive Diseases
CSR	Corporate Social Responsibility
CSDRM	Climate Smart Disaster Risk Management
CVI	Coastal Vulnerability Index
CWWG	Crop Weather Watch Group
DEST	Department of Environment, Science & Technology
DoWR	Department of Water Resources
DoA & FW	Department of Agriculture and Farmers Welfare
DRR	Disaster Risk Reduction
DW&S	Department of Drinking Water and Sanitation
DSR	Direct Seeded Rice
FSG	Food Security Groups
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIM	Green India Mission
GIS	Geographic Information System
GIZ	Deutsche Gesellschaftfür Internationale Zusammenarbeit
GoI	Government of India
GEF	Global Environment Facility
GCF	Green Climate Fund
GRB	Gender Responsive Budgeting

GSDP	Green Skill Development Programme
HKKP	Har Khet Ko Pani
HRVA	Hazard Risk Vulnerability Assessment
ICRIER	Indian Council for Research on International Economic Relations
ICZM	Integrated Coastal Zone Management Plan
IUCN	International Union for Conservation of Nature
INCOIS	Indian National Centre for Ocean Information Services
IIT-D	Indian Institute of Technology-Delhi
IMD	India Meteorological Department
IHR	Indian Himalayan Region
IPCC	Intergovernmental Panel on Climate Change
LiFE	Lifestyle for Environment
M&E	Monitoring and Evaluation
MoSPI	Ministry of Statistics and Programme Implementation
MoJS	Ministry of Jal Shakti
MoEFCC	Ministry of Environment, Forest and Climate Change
NAQUIM	National Aquifer Mapping Programme
NCIWRD	National Commission on Integrated Water Resources Development
NADMP	National Agriculture Disaster Management Plan
NAFCC	National Adaptation Fund for Climate Change
NAPCC	National Action Plan on Climate Change
NCRMP	National Cyclone Risk Management Project
NDC	Nationally Determined Contribution
NFHS	National Family Health Survey
NDMA	National Disaster Management Authoirty
NDMP	National Disaster Management Plan
NICRA	National Innovations in Climate Resilient Agriculture
NIPFP	National Institute of Public Finance and Policy
NMSA	National Mission for Sustainable Agriculture
NMSHE	National Mission for Sustaining the Himalayan Ecosystem
PM-STIAC	Prime Minister's Science, Technology and Innovation Advisory Council
PMCCC	Prime Minister's Council on Climate Change
PMFBY	Pradhan Mantri Fasal Bima Yojana
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana

PMP	Probable Maximum Precipitation
PAU	Punjab Agriculture University
PMSS	Probable Maximum Storm Surge
PDMC	Per Drop More Crop
RBSK	Rashtriya Bal Swasthya Karyakram
RD&GR	River Development and Ganga Rejuvenation
RRR	Repair, Renovation and Restoration
SAPCC	State Action Plans on Climate Change
SDGs	Sustainable Development Goals
SDMP	State Disaster Management Plans
SDRF	State Disaster Management Force
SRI	System of Rice Intensification
SMI	Surface Minor Irrigation
STEP	Support to Training and Employment Programmme
SWG	Sectoral Working Groups
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UTs	Union Territories
VSS	Vana Samraksha Samities
WDC	Watershed Development Component

NATIONAL ADAPTATION STRATEGIES, POLICIES AND PROGRAMMES

Chapter 01

1.1 Introduction

The adverse impacts of climate change on the developmental prospects and differential vulnerabilities among States, regions and different groups of people within the same region due to substantial variations in topography, climatic conditions, ecosystems as well as diversity in its social structures, economic conditions and needs of different communities are amplified enormously. Hence, India recognizes adaptation is inevitable and imperative for its development process. A range of actions have been proactively introduced to minimize the impacts and vulnerabilities. Besides targeted programmes like the NAPCC and SAPCCs, India has been implementing a series of schemes to maintain a high economic growth rate to improve the living standards of its people, to strengthen the adaptive capacities of the vulnerable communities and to reduce their vulnerability to the impacts of climate change. Thus, India has been pursuing a two-pronged policy approach by mainstreaming adaptation into its developmental planning through a qualitative shift in its growth trajectory and by drawing adaptation benefits from the ongoing schemes. India believes people can live in harmony with nature by harnessing its potential for the benefit of mankind without undue exploitation leading to irreversible damage and consequences that block the developmental progress.

The Human Development Index Report 2021-2022, which measures a nation's health, education and standard of living puts India in the medium human development category with a value of 0.633. The average literacy rate in India stands at 74.04 per cent with a remarkable increase in female literacy rates in recent years. India has put in commendable efforts to provide electricity to its population, while keeping its commitment to sustainability. The total installed capacity of grid interactive renewable power, which was 95,803 MW in 2021 increased to 1,09,885 MW (a growth of 14.70 per cent) during a year (2022).[2] Over the years, it has also made significant strides and improved its gender ratios according to the latest National Family Health Survey (NFHS-5).[3] For every 1000 men, India has 1020 women. It has a fertility rate of 2.0, falling below the replacement level fertility, and a rising median age of 29 years. This along with a falling dependency ratio, leaves India at the cusp of a demographic transition, giving India its most valuable asset in an ageing world- a large youth population that can drive its development.

1.2 Current Adaptation Strategies, Policies and Plans

The Government of India has been undertaking several initiatives to mainstream adaptation efforts while furthering developmental requirements. Table 1 highlights some of the significant schemes/ projects and programmes pursued by the Government of India (GoI), either designed as climate change adaptation strategies or to help improve adaptive capacities. These plans, schemes, policies, programmes and projects have been mapped as per the adaptation typology presented in IPCC's fifth assessment report (WG II AR5) to provide an outline of the different kinds of adaptation actions being undertaken in the country. The mapping indicates the climate risks and vulnerabilities at the national

2 Ministry of Statistics and Programme Implementation, National Statistical Office 2023, https: //www. mospi.gov.in/sites/default/files/ publication_reports/Energy_Statistics_2023/EnergyStatisticsIndia2023.pdf

3 Ministry of Health & Family Welfare. (2021). National Family Health Survey—5 (2019-2021). Government of India. https: //main.mohfw.gov.in/ sites/default/files/NFHS-5_Phase-II_0.pdf

level that have emerged from an assessment of climate impacts, risks and vulnerabilities facing the country. The categorization of adaptation action in the AR5 typology is as follows:

Structural and Physical Options: This category highlights discrete adaptation options, with clear outputs and outcomes that are well defined in scope, space, and time. They include structural and engineering options (e.g. seawalls, dykes, slope revetments and other coastal protection structures); the application of discrete technologies (e.g. water-saving technologies); the use of ecosystems and their services to serve adaptation needs (e.g. mangrove conservation and replanting); and the delivery of specific services at the national, regional, and local levels (e.g. social safety nets and social protection).

Social Options: This category includes various adaptation options that target the specific vulnerability of disadvantaged groups, including targeted vulnerability reduction and social inequities. Included in this category are Education (e.g. awareness raising, extension, outreach, community meetings, and other educational programs); Informational strategies (e.g. early warning systems, climate services); and Behavioural measures (e.g. Household preparation and evacuation planning).

Institutional Options: Numerous institutional measures can be used to foster adaptation. These range from Economic instruments (e.g. taxes, subsidies, and insurance arrangements) to Policies, Plans and Regulations (e.g. Land zoning laws; Building standards and practices; Laws to support disaster risk reduction).

Even before NAPCC came into being, the Government of India had several individual programmes and schemes which contributed to developing adaptive capacities. **Table 1** provides an overview of the missions, plans, programs and schemes.

Table 1: Mapping of adaptation relevant plans, schemes, programs and projects of the Government of India

Sectors	*National Government plans, programs and missions*	*Sub-programmes, Schemes, and projects*	*Structural*				*Social*			*Institutional*	
			Engineering	*Technological*	*Ecosystem*	*Services*	*Educational interventions*	*Informational strategies*	*Behavioral measures*	*Economic instruments*	*Policies and Plans*
Water	National Water Mission	*Jal Shakti Abhiyan*	✓								
		Sahi Fasal		✓						✓	
		R&D Projects						✓			
		Baseline studies						✓			
		Training and Capacity Development Workshop					✓				
		State Specific Action Plan	✓	✓			✓	✓			
	The Dam Rehabilitation and Improvement Programme		✓								
	The *Jal Jeevan* Mission		✓	✓		✓	✓				
	Namami Gange/ National Mission for Clean Ganga				✓						
	National River Conservation Programme				✓						
	National Plan for Conservation of Aquatic Ecosystem				✓						
	Atal Bhujal Yojna	Institutional Strengthening & Capacity Building									✓
		Incentive Component								✓	
	National Aquifer Mapping and Management Programme				✓			✓			

Sectors	National Government plans, programs and missions	Sub-programmes, Schemes, and projects	Structural				Social			Institutional	
			Engineering	Technological	Ecosystem	Services	Educational interventions	Informational strategies	Behavioral measures	Economic instruments	Policies and Plans
Agriculture	National Mission for Sustainable Agriculture (NMSA)	Rainfed Area Development (RAD)			✓					✓	
		Sub-Mission on Agroforestry (SMAF)			✓					✓	
		National Bamboo Mission (NBM)			✓					✓	
		Soil Health Management (SHM). This includes *Paramparagat Krishi Vikas Yojana* (PKVY).			✓	✓					
		Monitoring, Modeling and Networking (CCSAMMN)			✓			✓			
	National Innovations in Climate Resilient Agriculture (NICRA)		✓	✓	✓		✓	✓			
	Rashtriya Krishi VikasYojana (RKVY)- RAFTAAR			✓							
	National Rural Livelihood Mission – *Deendayal Antyodaya Yojana*–This includes *Mahila Kisan Sashaktikaran Pariyojna.*					✓					
		Agriculture Technology Management Scheme		✓							
	National Mission on Agricultural Extension and Technology (NMAET)	SMAE: Sub-Mission on Agricultural Extension		✓							
		SMSP: Sub-Mission on Seed and Planting Material		✓							
		SMAM: Sub-Mission on Agricultural Mechanization		✓							
		SMPP: Sub-Mission on Plant Protection and Plant Quarantine		✓							
	Pradhan Mantri Fasal Bima Yojana or the Prime Minister Crop Insurance Scheme									✓	
	Pradhan Mantri Kisan Samman Nidhi(PM-Kisan)									✓	
	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	Accelerated Irrigation Benefit Programme (AIBP)	✓								
		Command Area Development and Water Management (CAD&WM)	✓								
		Her Khet ko Pani Per Drop More Crop (Micro Irrigation)	✓	✓							

Sectors	***National Government plans, programs and missions***	***Sub-programmes, Schemes, and projects***	***Structural***				***Social***			***Institutional***	
			Engineering	***Technological***	***Ecosystem***	***Services***	***Educational interventions***	***Informational strategies***	***Behavioral measures***	***Economic instruments***	***Policies and Plans***
Horticulture	Mission for Integrated Development of Horticulture (MIDH)	National Horticultural Mission (NHM)		✓						✓	
		Horticulture Mission for North East and Himalayan States (HMNEHS)		✓						✓	
Livestock		*Rastriya Gokul* Mission (RGM)		✓						✓	
	National Livestock Mission (NLM)	Breed Development of Livestock & Poultry		✓						✓	
		Feed and Fodder development		✓						✓	
		Extension and Innovation		✓			✓				
		Livestock Health and Disease Control	✓								
		National Programme for Dairy Development								✓	
		Livestock Census and Integrated sample Survey						✓			
		National Animal Disease Control Programme		✓							
		Dairy Infrastructure Development Fund	✓								
		Animal Husbandry Infrastructure Development Fund	✓								
Fisheries	*Pradhan Mantri Matsya Sampada Yojana* (PMMSY)									✓	✓

Sectors	***National Government plans, programs and missions***	***Sub-programmes, Schemes, and projects***	***Structural***				***Social***			***Institutional***	
			Engineering	***Technological***	***Ecosystem***	***Services***	***Educational interventions***	***Informational strategies***	***Behavioral measures***	***Economic instruments***	***Policies and Plans***
Forestry	Compensatory Afforestation Act (CAMPA) 2016					✓					
Forestry	Green India Mission (GIM)				✓						
Forestry	*Nagar Van UdyanYojana*				✓						
Forestry	Intensification of Forest Management Scheme (IFMS)				✓						
Forestry	*Pradhan Mantri Van Dhan Yojana*									✓	
Forestry	Green Skill Development Programme (GSDP)						✓				
Coastal Zones	National Coastal Mission	Integrated Coastal Zone Management Project (Phase I)		✓	✓			✓	✓	✓	
Coastal Zones	National Coastal Mission	Beach Environment and Aesthetics Management System (BEAMS)			✓	✓	✓				
Coastal Zones	National Coastal Mission	Blue Economy: Integrated Development and Management of Fisheries	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coastal Zones	Coastal and Marine Protected Areas							✓			✓
Himalayan Ecosystems	National Mission for Sustaining the Himalayan Ecosystem(NMSHE)		✓	✓	✓	✓	✓	✓	✓		
Himalayan Ecosystems	Hill Area Development Plan		✓	✓			✓				
Himalayan Ecosystems	National Mission on Himalayan Studies (NMHS) MoEFCC						✓	✓			
Himalayan Ecosystems		Mid-Himalayan Watershed Development project*	✓	✓							
Himalayan Ecosystems		Assam Agricultural Competitiveness Project *								✓	
Himalayan Ecosystems		Securing Livelihoods in Himalayas *								✓	
Himalayan Ecosystems		The Meghalaya Community Led Landscape Management Project *			✓		✓	✓			

Sectors	***National Government plans, programs and missions***	***Sub-programmes, Schemes, and projects***	***Structural***				***Social***			***Institutional***	
			Engineering	***Technological***	***Ecosystem***	***Services***	***Educational interventions***	***Informational strategies***	***Behavioral measures***	***Economic instruments***	***Policies and Plans***
Disaster risk reduction and resilient infrastructure	*Aapda Mitra* (Friends in Emergency)						✓				
	Coalition for Disaster Resilient Infrastructure (CDRI)		✓				✓	✓		✓	
	National Disaster Management Policy 2009 & DM Act 2005 & NDMP-2019		✓	✓	✓	✓				✓	✓
	National Health Mission	National Vector Disease Control Programme				✓		✓			
	Village Disaster Management Plans					✓					✓
	National Cyclone Risk Mitigation Project[1]	Early Warning Dissemination Systems	✓	✓		✓	✓				
		Cyclone risk mitigation infrastructure	✓				✓	✓			
		Technical Assistance for Multi-hazard Risk Management		✓			✓				
	National Mission for Sustainable Habitat(NMSH)	Atal Mission on Rejuvenation and Urban Transformation (AMRUT)		✓							
		Swachh Bharat Mission (Rural and Urban)			✓	✓					
National Health Mission	National Programme on climate Change and Human Health (added) National Vector Disease Control Programme					✓		✓			

** Refers to projects funded by multi-lateral agencies like World Bank and GEF but coordinated by Central Ministries of Government of India*

1.3 Flagship Adaptation Programmes in Climate Sensitive Sectors in India

Various Ministries of the Government of India have been consistently developing and implementing relevant climate adaptation programmes to protect the natural environment and also to reduce social and economic vulnerabilities and build adaptive capacities to withstand both current and future climate change impacts. The following sections provide a brief description of the nature of adaptation actions undertaken in the priority sectors.

1.3.1 Agriculture and Allied Sectors

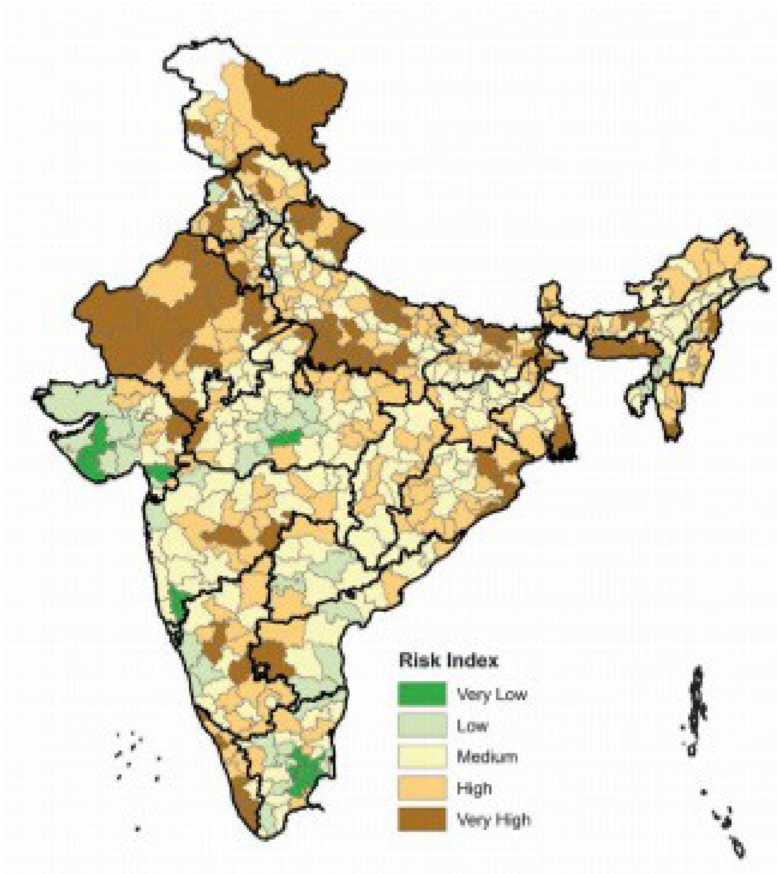
Agriculture is one of the most vulnerable sectors to climate change in India and correspondingly, it is the most significant sector for adaptation. Of the total workforce, 54.6 per cent was engaged in agricultural and allied sector activities.[4]

Risk and Vulnerability of Indian Agriculture to Climate Change[5] (assessed for district level)

- A district level study categorized 109 districts into 'very high' and 201 districts into 'high' climate change risk categories. Small farm size, associated with lack of economies of scale, weak bargaining power, difficulties in accessing information and capital was found to be are a cause of risk particularly in 52 of 310 districts, identified to have 'very high' or 'high' risk.
- The presence of high value capital assets in places of occurrence of a hazard also poses high risk.
- Low access to irrigation is the most prominent vulnerability-related driver of risk in 116 districts
- High frequency of droughts in 156 districts, cyclone in 93 districts and flood in 61 districts have been major factors contributing to risk.
- Rise in minimum temperature is the most significant factor in determining risk in 271 districts

4 National Cyclone Risk Mitigation Project-II. Retrieved from The World Bank.

5 TERI, Climate Resilient infrastructure services Case study brief: Visakhapatnam; https: /www.teriin. org/eventdocs/files/Case-Study-Vishakhapatnam.pdf



Estimated Losses Due to Climatic Change: Past studies indicate that at the aggregate national level, climate change impacts on agriculture are likely to be adverse. Studies have estimated total agricultural net revenue losses to the tune of 8 – 12 per cent for India, for a 2 °C rise in temperature and 7 per cent increase in precipitation (Kumar and Parikh, 2001; Sanghi and Mendelsohn, 2008).

Agriculture in India is dominated by marginal, small and medium farmers. These vulnerable sections will bear the brunt of climate change impacts while contributing little to the problem of global warming. The Government of India pays special attention to the needs of these section of the population in the schemes for agriculture through appropriate considerations.

The details of the flagship schemes and programmes, including the National Mission for Sustainable Agriculture (NMSA), are available in the National Communication and Biennial Update Report to UNFCCC. Considering significant risks of climate extreme and disasters in agriculture sector, the Ministry of Agriculture and Farmers Welfare has also come up with a comprehensive National Agriculture Disaster Management Plan (NADMP).

1.3.2 Water Sector

Water is recognized as vital to India's economic growth, the well-being of its people and the sustainability of its ecosystems. India witnessed major droughts (Bundelkhand 2017-2018, Gujarat 2016, and Maharashtra 2013) and floods (Kerala 2018, Gujarat 2017, and Madras 2015) during the recent years.

With our population expected to cross 1.7 billion by 2050, the demand for water resources in India will leapfrog in the future. Along with food security needs, demand for water resources from rapid urbanisation and industrialisation will further exacerbate pressure on water resources. As per National Commission on Integrated Water Resources Development (NCIWRD) Report -1999, water requirement of the country for high demand scenario is 843 billion cubic meters (BCM) and 1180 BCM for the year 2025 and 2050 respectively.

Temperature and precipitation are projected to increase in the warming climate in the Indian river basins. For the projected increase in the precipitation to reflect in water resources, it needs to translate into groundwater or surface water resources. We have inadequate storage to take care of the increase in precipitation under climate change. On the other hand, there are multiple evidences of rapid groundwater depletion in Northern India, which is related to extensive groundwater abstraction for irrigation.

Higher water demands during the dry season can only be met if this increased waster availability during the monsoon season can be stored in surface and/or groundwater reservoirs.

Over the last few years, the Government of India as well as State Governments have been implementing a range of projects and programmes focused on groundwater recharge, and efficient use of water for agriculture, through the use of specialized technologies.

The risk of an increased number of extreme events, intense rainfall events leading to flooding and landslides, changes in rainfall pattern, temperature extremes and heatwaves, storms, cyclone, and extended dry spell and increased variability in hydrological components has increased in the observed climate and projected to increase in the future (Singh et al., 2020; Aadhar and Mishra, 2020; Mishra et al., 2017). India, being an agrarian economy, agriculture is the primary consumer of its total water resources (about 84 per cent). However, flood irrigation is a prominent practice in most parts of the country, which plays a significant role in groundwater depletion. By adopting advanced irrigation techniques (like sprinkler and drip irrigation to eliminate flood irrigation), we can reduce the irrigation water usage per crop.

Moreover, national-level drought monitoring, early warning system, rainwater harvesting, application of water-saving technologies, efficient irrigation systems, optimal reservoir operations, and change in crop pattern are required to reduce the severe impact of drought.

Water quality is an essential aspect of water resources. 80 per cent of total municipal and industrial discharge are dumped into rivers without undergoing adequate treatment (Wastewater report, 2018; Schellenberg et al., 2020). Major rivers are polluted due to industrial waste and other sources of pollutants.

The government schemes like Grey Water Recycle and Reuse scheme, Namami Ganga Programme, and Ganga Rejuvenation are few worthy efforts in this direction. However, we need to improve the coverage and efficiency of the aforementioned programmes to improve water quality.

To deal with water issues in an integrated manner under a single umbrella, the Ministry of Jal Shakti (MoJS) was created in May 2019, which includes: The Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD & GR) and the Department of Drinking Water and Sanitation (DW&S). Programmes have been taken up to increase storage, both in large and local reservoirs, as well as under the ground.

The National Water Mission assesses the impacts of climate change on the hydrological cycle by-compiling and maintaining a comprehensive water database in the public domain and assessing the impacts of climate change on water resources.

- Under the National Aquifer Mapping and Management Programme, out of the nearly 3.3 million sq. km of geographical area of the country, a mappable area of around 2.5 million sq. km has been identified by the Central Ground Water Board. Acquifers in the entire mappable area have been mapped.
- The first ever Water Bodies – First Census Report, has been released by the Ministry of Jal Shakti (MoJS) on April 25th, 2023. MoJS had commissioned the first census of water bodies in 2018-19, along with the sixth Minor Irrigation (MI) Census. The objective of the Census of the Water Bodies was to develop a national data base for all water bodies for informed decision making and availability of authentic water data in the public domain. As per the Report, there are 24,24,540 water bodies in India of which Ponds are 14,42,993 (59.5%).
- Ground Water Resources Assessment is carried out annually jointly by State Ground Water Departments and Central Ground Water Board under the guidance of the respective State Level Committee on Ground Water Assessment at State Levels under the overall supervision of the Central Level Expert Group. As per the latest compilation of the Dynamic Ground Water Assessment Report 2022 , 1006 units in various States (14%) have been categorised as Over Exploited , 260 (4%) as Critical , 885 (12%) as Semi Critical and 4780 (67%) as Safe .
- In addition, the Central Water Commission (CWC) has a network of 1543 hydrological observation stations in all river basins for water resource planning and flood forecasting.
- Other measures to mitigate the adverse impact of climate change is through promoting community led action for water conservation, augmentation and preservation of water resources through the Jal Shakti Abhiyan which calls for community action prioritising vulnerable and over-exploited areas in partnership with other flagship like the Jal Jeevan Mission for strengthening sources for drinking water in 150 Water Stressed Districts. The National River Conservation Plans (NRCP) covering 36 rivers (other than Ganga) seeks to abate pollution and rejuvenate the rivers. Under the National Plan for Conservation of Aquatic Ecosystems, proposals for the conservation of 164 wetlands across the country are under consideration for sanction.

1.3.3 Forestry and Biodiversity

India is among a few countries in the world where, despite ongoing developmental efforts, forest and tree cover are increasing considerably. This has been made possible through the introduction of various schemes to enable continuous economic growth, keeping in mind the imperatives of sustainable development.

India is one of the top ten biodiverse countries in the world, which can be attributed to the fact that forests are worshipped in India by several communities and serve as an important source of sustenance and livelihood in the country. India's biodiversity boasts of about 55,048[6] species of plants and around 1,03,528[7] some of which have been designated as 'biodiversity hotspots' of the country. India hosts 4 out of 35 biodiversity hotspots in the world.[8] Given that the climate is a governing factor that affects the structure, distribution and ecology of forests, changes in the climate are most likely to alter the dynamics of forest ecosystems and have been observed to be affecting the forests and the related ecosystems significantly through changes in their physiology, structure and species composition.

According to a study by Ravindranath et al. (2019), the percentage of forested grids that will be impacted by climate change lies in the range of 18 per cent to 25 per cent under RCP 4.5 scenario (short and long-term), which increases to 20 per cent to 28 per cent under RCP 8.5 short and long-term scenarios, respectively. The major forested and biodiversity rich regions of Western Ghats and the North-eastern regions are likely to be less impacted by climate change, particularly in the short-term.

However, the impact is relatively higher in the long-term under both RCP 4.5 and RCP 8.5 scenarios. Temperate and sub-tropical forests in the Himalayan region and the tropical deciduous forests in the North-eastern region are more likely to be impacted by climate change, particularly in the long term. The impact of climate change seems to be highest in the arid regions of Rajasthan, and semi-arid regions of Maharashtra and Gujarat (Ravindranath et al., 2019).

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6 Plant Discoveries Sourced from: https://bsi.gov.in/uploads/documents/Plant%20Discoveries/Plant%20 Discoveries%202021.pdf

7 Number of Animal species known from India (updated December 2021).

8 MoEFCC. (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.

Vulnerability of the Forestry Sector to Climate Change[9]

Approximately 40 per cent of forested grids in the country have been assessed to have 'high' and 'very high' vulnerability towards climate change and its impacts. Since these grid points are widely distributed across the peninsular States of Tamil Nadu, Andhra Pradesh and Karnataka, central Indian States of Maharashtra, Madhya Pradesh and Jharkhand, West Bengal and the north eastern States of Assam, Nagaland, Mizoram, Manipur and Tripura.[10] Therefore, it can be observed that the due emphasis has been given to the conservation and restoration of forests. The loss of the forests and related biodiversity is expectedly going to be accelerated due to climate change.[11] At the national level, studies have shown that wildlife ecosystems are being adversely impacted especially in fragile ecosystems such as the Himalayas where the increase in temperature is nearly double to that of the changes taking place in the plains.[12]

The links between biodiversity and climate change run both ways: biodiversity is threatened by climate change, but proper management of biodiversity can reduce the impacts of climate change.

Consequences of climate change on the species component of biodiversity include:

i. Changes in distribution,

ii. Increased extinction rates,

iii. Changes in reproduction timings,

iv. Changes in length of growing seasons for plants.

Some of the specific impacts related to India are as follows:

i. The body of research[13] suggests a substantial impact of climate change on fisheries, with increasing temperatures being associated with reductions in spawning, altered distribution and ecology of commercially important fish species in inland and coastal ecosystems.

ii. From a study conducted by Borges et al. (2020), the vulnerability of pollinators and pollination services in India, in the context of climate change was examined. It is clear that above thermal limits for the species, the pollinator foraging activity declines. Consequences of such results in terms of fruit yield and food availability for primary consumers under climate change scenarios are thus, extremely important.

9 The IPCC 2014 framework on Risk-Impact was adopted to assess the vulnerability of forests of India.

10 Ibid

11 MoEF. (2012). Second National Communication to UNFCCC. New Delhi: Ministry of Environment and Forest, Government of India.

12 DST. (2010). Mission Document of National Mission for Sustaining The Himalayan Ecosystem. New Delhi: Ministry of Science and Technology, Government of India.

13 Based on a review of 102 studies during 2000-18 on the state of current knowledge on the effects of climate change on ecosystem services in India.(Osuri et al., 2018).

iii. Changes in abiotic conditions (reviewed in Bhatnagar et al., 2019) and projected habitats such as forest vegetation cover (Ravindranath et al., 2006), due to climate change are bound to exacerbate the challenges animals face and force them to change their habitat use patterns or disperse to suitable regions to meet their requirements.

The Government of India has taken several steps for the conservation of country's biodiversity which include survey, inventorization, taxonomic validation and threat assessment of floral and faunal resources; assessment to develop an accurate database for planning and monitoring as well as conservation and protection of forests; establishment of a protected area network of national parks, wildlife sanctuaries, conservation and community reserves; designating biosphere reserves for conservation of representative ecosystems; undertaking of species oriented programmes, such as Project Tiger and Project Elephant; complemented with ex-situ conservation efforts. India is committed to ambitious afforestation programmes, a flagship program being the National Mission for a Green India (GIM), besides providing opportunities to the forest dependent communities through various schemes, such as the Pradhan Mantri Van DhanYojna, and Green Skill Development Programme (GSDP).

The Ministry of Environment, Forest and Climate Change has established a network of Long-Term Ecological Observatories as part of the Climate Change Action Programme of India to understand the various anthropogenic and biophysical drives that result in ecosystem change, while considering social and ecological perspective. The Prime Minister's Science, Technology and Innovation Advisory Council (PM- STIAC) following a consultative process has set up a 'National Mission on Biodiversity and Human Well-Being' with the aim of comprehensive documentation of India's biodiversity with the potential for cataloguing and mapping all lifeforms in India. The mission's program on "Biodiversity, Climate Change and Disaster Risk Reduction" will work to assess vulnerability of ecosystems and different biomes in India to climate change and climate disasters by evaluating both historic trends in responses and future projections for different climatic stressors, including extreme events, and develop strategies for integrating ecosystem and nature-based solutions for enhancing resilience to climate change (Bawa et al., 2020).

1.3.4 Coasts and Islands

With a view towards conserving and protecting India's unique coasts and marine environments and promoting development in a sustainable manner, the Government of India places a strong emphasis on adaptation to the impacts of climate change on coastal communities and the fragile and vulnerable coastal ecosystems. Accordingly, several programmes are being initiated to sustainably conserve and manage coasts and marine ecosystems, enhance ecosystem resilience and improve the adaptive capacity of coastal communities to a changing climate.

Government of India has formulated plans to rehabilitate people from low- lying coastal areas who may be adversely impacted due to rising sea levels in the coming decade. A policy document is being formulated on "Mitigation and Rehabilitation measures for people displaced by Coastal and River Erosion" to deal with the extensive displacement of people caused by coastal and river erosion. Indian National Centre for Ocean Information Services (INCOIS) has carried out Coastal Vulnerability

Index (CVI) mapping to assess the probable implications of sea-level rise along the Indian coast. The exercise has generated maps using seven input parameters: shoreline change rate, sea-level change rate, coastal elevation, coastal slope, coastal geomorphology, significant wave height and tidal range. India Meteorological Department (IMD) has prepared a map of the cyclone hazard proneness of the coastal districts of India based on the frequency of cyclones, their intensity, actual/estimated maximum wind strength, Probable Maximum Storm Surge (PMSS) associated with the cyclones and Probable Maximum Precipitation (PMP) for all the districts along the coastline. The IMD has developed a well defined mechanisms/technology for early warning on cyclones so as to enable disaster managers to minimise loss of life and damage to property. The National Disaster Management Plan (NDMP) inter-alia, addresses mitigation, risk reduction, preparedness and response aspects for various disasters including Cyclones under six thematic areas as mentioned below:

i. Understanding Risk,

ii. Inter-Agency Coordination,

iii. Investing in Disaster Risk Reduction (DRR) – Structural Measures,

iv. Investing in DRR – Non-Structural Measures,

v. Capacity Development and

vi. Climate Change Risk Management.

Also to inform, educate and to make the people aware about preparedness, precautions and safeguards during a disaster and post disaster scenarios, the NDMA runs awareness generation campaigns on various disasters including on flood and cyclones from time to time throughout the country, including in coastal states through print and electronic media, including social media. These campaigns aim at saving lives, livestock and livelihood to the maximum extent.

1.3.5 The Himalayan Ecosystem

Climate change concerns in the Himalayas are multifaceted, encompassing floods, droughts, landslides, human health, biodiversity, endangered species, agriculture, livelihoods and food security. The Government of India recognises the fragility of this ecosystem and the subsequent climate risks faced by the communities in the region as well as those living downstream. In this regard, several efforts have been made to secure the Himalayan ecosystem and the communities therein. The National Mission for Sustaining the Himalayan Ecosystem (NMSHE), one of the missions under the NAPCC, is a multi-pronged, cross-cutting mission across various sectors. It contributes to the sustainable development of the country by enhancing the understanding of climate change, its likely impacts and adaptation actions required for the Himalayas- a region on which a significant proportion of India's population depends for sustenance. The mission seeks to facilitate formulation of appropriate policy measures and time-bound action programmes to sustain ecological resilience and ensure the continued provisions of key ecosystem services in the Himalayas. The mission intends to evolve suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem along with developing capacities at the national level to continuously assess its health status.

1.3.6 Disaster Management

India has been able to establish a holistic disaster risk reduction and response mechanism at the National, State and District levels with the aim of reducing existing levels of vulnerability, prevention, and mitigation of disasters and providing appropriate response, rehabilitation and reconstruction measures. The programmes and schemes include early warning system and communications, the construction and sustainable maintenance of multi-purpose cyclone shelters, improved access and evacuation, enhanced capacity, and capability of local communities to respond to disaster and strengthening disaster risk mitigation capacity at the Central, State and local levels. Development and Disasters are two sides of a coin. While a planned development can reduce the risks of disasters, the absence of proper planning can aggravate them. Disaster risk reduction is considered as cross-cutting and common to all sector's plans and activities towards reducing losses and damages due to climate change, and hence, an implicit but imperative adaptation objective. Development should focus on reducing disaster risks and not creating them. One among the Ten Point of Agenda for DRR is that all development sectors must imbibe the principles of disaster risk management. This will ensure that all development projects - airports, roads, canals, hospitals, schools, bridges – are built to appropriate standards and contribute to the resilience of communities they seek to serve. This points to the need for ensuring that all the infrastructure development conforms to the best available standards of disaster safety. Such an approach is a smart strategy, which will pay off in the long term. It is necessary that all the public investments must incorporate disaster risk considerations.

1.3.7 Health

India's Health sector, in preparedness for climate change, has put in place the National Plan on Climate Change and Human Health (NAPCHH); as one of the Missions under NAPCC. The objective is to strengthen health care services against the adverse impact of climate change on health. The NAPCHH is being implemented through planned short-term, medium-term and long-term activities with a view: :

i. To create awareness among general and vulnerable population, health-care providers and policy makers regarding impacts of climate change on human health;

ii. To strengthen capacity of existing and future healthcare workforce to combat health conditions/ diseases due to variability in climate;

iii. To strengthen health preparedness and response by performing situational analysis, developing health adaptation plans, setting up surveillance and early warning systems, building low carbon, sustainable, and climate resilient healthcare infrastructure at national, state and district levels;

iv. To develop partnerships and create synergy with other missions, sectors and organisations to ensure that health is adequately represented in the climate change agenda in the country; and

v. To strengthen research and technology capacity to fill the evidence gap on climate change impact on human health and its solutions.

The Ministry of Health and Family Welfare (MoHFW) has developed a national level Health Mission document and worked together with States to develop individual State Action Plans on Climate Change and Human Health. Necessary steps have been taken to increase public awareness on the subject of health impacts of climate change on climate sensitive conditions including that of heat waves. Indian Meteorological Department (IMD) issues colour coded impact based heat wave warning for interdepartmental sharing and also through mass media for public benefit. IMD in collaboration with local health departments have developed heat action plans in many parts of the country to forewarn about heat waves and also advise action to be taken. The National Disaster Management Authority (NDMA) and IMD are working with 23 States prone to high temperature leading to heat-wave conditions for supporting heat action plans. NPCCHH through Integrated Health Information Platform is implementing a digital surveillance on heat related illnesses and deaths in all public health facilities of all States and Union Territories during each summer season. NPCCHH is implementing a surveillance on air pollution related illnesses in emergencies of about 90 sentinel hospitals in 18 States/UTs, develops training content and undertakes trainings of entire health workforce NPCCHH is also developing guidelines and providing technical and financial support to build low carbon, sustainable, energy and water efficient healthcare infrastructure, and also those resilient to climatic impacts such as of heat and floods etc

In addition, the Government is implementing various other programs and schemes that contribute, inter-alia to India climate action in the Health Sector. Some of the flagship programs are Pradhan Mantri Ayushman Bharat Health infrastructure Mission, Pradhan Mantri Jan Aarogya Yojna, National Digital Health Mission, Pradhan Mantri Swasthya Suraksha Yojna, Pradhan Mantri Swasthya Suraksha Nidhi, different National Programmes addressing Communicable Diseases (such as National Vector Borne Diseases Control Programme (NVBDCP) and Integrated Disease Surveillance Programme (IDSP) and Non Communicable Diseases (such as National NCD Programme and National Mental Health Programme (NMHP), and programmes related to maternal and child health such as Intensified Mission Indradhanush 3.0, Janani Suraksha Yojana, Janani Shishu Suraksha Karyakram. Rashtriya Bal Swasthya Karyakram (RBSK), etc. Finally, Healthcare infrastructure has been acknowledged as an important indicator for understanding the healthcare delivery provisions and welfare mechanisms in the country.

1.4 Institutional Framework for Action on Climate Change in India

As a country vulnerable to natural climate variability, development planning in India has been marked with various climate friendly actions. India, in its development process, formulated a number of policies that have the potential to enhance the adaptive capacities of people. Planning, implementing and monitoring of adaptation actions in a large and diverse country like India pose a formidable challenge. India is mainstreaming climate change adaptation through a dynamic institutional arrangement of Ministries of Government of India at the Central level for planning and policy formulation to address the impacts of climate change by bringing a directional shift in the country's developmental pathways. Research institutions and think tanks at the national and sub-national levels support informed policy making through generating knowledge on vulnerability assessment and adaptation needs at the macro level and identifying challenges in prioritizing and implementing adaptation options at the local levels.

The National Environment Policy (2006) envisaged identifying key vulnerabilities of India to climate change and assessing the need for adaptation to future climate change and the scope for incorporating these in relevant programmes. The formal framework for guiding action on climate change was established in 2007, with the setting up of the Prime Minister's Council on Climate Change (PMCCC).

In 2008, India launched its National Action Plan on Climate Change (NAPCC) with a focus on low carbon pathways and climate resilient development and identified a number of measures that simultaneously advance the country's development and climate change related objectives through focused national missions. A six out of nine missions under NAPCC focus on adaptation and/or adaptation co-benefits, such as the sectors of agriculture, water, forestry, health and the Himalayan ecosystem. NAPCC outlines the following principles in this regard:

iv. Protecting the poor and vulnerable sections of society through an inclusive and sustainable development strategy sensitive to climate change.

v. Achieving national growth objectives through a qualitative change in direction that enhances ecological sustainability, leading to further mitigation of greenhouse gas (GHGs) emissions

vi. Devising efficient and cost-effective strategies for end use demand side management.

vii. Deploying appropriate technologies for both adaptation and mitigation of GHGs emissions extensively as well as at an accelerated pace.

viii. Engineering new and innovative forms of market, regulatory and voluntary mechanisms to promote sustainable development.

ix. Effecting implementation of programmes through unique linkages, including with civil society and local Government institutions and through public-private-partnership.

x. Welcoming international cooperation for research, development, sharing and transfer of technologies enabled by additional funding and a global Intellectual Property Rights regime that facilitates technology transfer to developing countries under the UNFCCC.

To decentralise the NAPCC, the Government of India advised all States/ UTs to submit their respective State Action Plan on Climate Change (SAPCC) in 2010. All the thirty four States and UTs have prepared and submitted their respective SAPCCs using a common framework prepared by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. Some of the States in India have further revised their respective SAPCCs as per the revised framework.

A few key strategies and State-level interventions are highlighted in Box 1. The sectoral missions under the NAPCC are under the jurisdiction of various Ministries of the Government of India. Similarly, SAPCCs are operated by the respective State Governments. The district administrative authorities ensure that the national missions under NAPCC and SAPCCs are implemented on the ground.

The plans and policies thus formulated are implemented at the sub- national level through the State Government's line departments and district authorities to achieve the desired goal of enhancing resilience and improving the adaptive capacities of the communities and ecosystems.

Further, localised climate actions facilitate community engagement by enabling the participation of local stakeholders in adaptation process. The approach enhances the effectiveness and sustainability of climate action by ensuring that local needs, priorities, and knowledge are integrated. Civil society and private sector organisations also support these implementation efforts at the local level. NGOs, corporates and research organizations work with both State Governments and different line Ministries of the Government of India on carrying out climate adaptation research and assessments.

Further, the Central Government constituted the 'Apex Committee for Implementation of the Paris Agreement' (AIPA) in 2020 with the aim to ensure a coordinated national response to climate change. This intricate network of Ministries at the Central level, State Governments, research institutes, think tanks and NGOs and corporates, institutionalizes the directional shift of the India's developmental pathway towards an operational mechanism which enhances resilience and improves the country's adaptive capacity. India has also submitted its third Biennial Update Report to the UNFCCC, along with sharing an ambitious set of objectives for the country under the Nationally Determined Contribution (NDC), in which adaptation is a crucial component[14]. India's NDC categorically stated - "To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change."

One of the key recent initiatives undertaken by the Government of India has been the LiFE or Lifestyle for Environment campaign launched by the Hon'ble Prime Minister that calls for embracing a sustainable lifestyle at the individual level by replacing mindless consumption patterns with mindful utilization. It aims at creating a network of individuals at the global level who can work towards the improved health of the planet.

Box 1: State Action Plans on Climate Change: Key Interventions

SAPCCs are an important vehicle for planning, designing, and mobilizing adaptation actions in India. Adaptation is essentially a local phenomenon as different regions have different vulnerabilities and capacities to adapt to a changing climate and requires an understanding of the local/ regional context. The SAPCCs play a crucial role in identifying and addressing local climate-related challenges. In doing so, they enhance local-level adaptive capabilities, helping communities to be better prepared to tackle the impacts of climate change. SAPCCs are designed to be context-specific, considering the different ecological, social, and economic conditions of each State. By incorporating climate change considerations into State- level policies and programs, SAPCCs help India to adapt to the impacts of climate change, protecting its local communities and ensuring sustainable development. Here select adaptation actions are illustrated from a basket of a much wider array of adaptation actions and strategies being pursued and planned by various States under their respective SAPCCs in sectors and regions vulnerable to climate change.

14 Government of India. (2015). India's Intended Nationally Determined Contributions to UNFCCC. Ministry of Environment, Forest & Climate Change, Government of India.

Agriculture

In the agriculture sector, States have introduced several effective adaptation strategies best suited to their local experiences. Strategies include focus on establishment of networks of seed banks for sustainable seed production by Tamil Nadu; focus on adaptation of inter-cultivation practice and promotion of System of Rice Intensification (SRI) by the State of Telangana; issuance of agro-advisory under the Uttar Pradesh State government initiative- the Crop Weather Watch Group (CWWG); preservation, conservation and monitoring of surface and ground water in Punjab under the Accelerated Irrigation Benefit Programme, Participatory Irrigation Management Programme, Command Area Development and Water Management Programme; Karnataka, Maharashtra and Haryana have implemented major projects on animal husbandry and the veterinary sector to sustain the income of small and marginal farmers, dairymen, and sheep-rearers by adopting a climate-resilient path through conserving and revitalising the State's indigenous livestock (cattle and sheep) varieties.

Water

States in India are taking individual actions alongside strategies proposed by the Central Government. The State of Gujarat implemented a comprehensive plan for the development of a state-wide water supply grid. The grid is a far-sighted, comprehensive, and ambitious water strategy to sustainably supply adequate and safe drinking water to rural and urban populations. Karnataka State has implemented Sujala Agriculture and Horticulture project in 2531 micro watersheds in 11 project districts. The State of Sikkim has introduced a new Spring-shed development programme initiated jointly with WWF-India and People's Science Institute, Dehradun under the banner of "Dhara Vikas". Outcomes include the preparation of a "Village Spring Atlas" and an increase in the discharge of water springs. Maharashtra and West Bengal implemented groundwater management programmes. Rajasthan focuses on improving surface irrigation systems performance, efficiency and strengthening agricultural support services in selected schemes through increased involvement of users and is achieved specifically through Water Sector Restructuring Project. The UT of Chandigarh has enacted a short-term legal framework that mandates rainwater harvesting for all plots larger than 500 square metres.

Disaster Management and Infrastructure Resilience

All SAPCCs call for mitigating disaster risk due to changes in extreme weather patterns which include the development of Hazard Risk Vulnerability Assessment reports (HRVA), State Disaster Management Plans (SDMPs) and State Disaster Management Force (SDRF). Flood- prone States have promoted various initiatives at the local and State level, for instance, Surat city in the state of Gujarat has implemented an elaborate monsoon preparation process to mitigate flood risks. Since 2007, the efforts were on mainstreaming integration of climate change adaptation and disaster risk reduction into developmental planning process as well as in disaster management planning at district and state levels. Gorakhpur district's disaster management plan, disseminated in 2014, was the first as model of climate concerned plan developed taking into consideration of departmental planning. Disaster risk mitigation and preparedness parts of the plan facilitates for adaptation interventions, whereas efforts to integrate adaptation and climate resilience of infrastructure and people's resources during relief and recovery actions are also *being considered. In Rajasthan, flood management plans are being made at the local level (ward-wise). Sikkim is preparing a glacial lake management plan that focuses on deployment of early warning sensors in the potentially vulnerable glacial lakes to minimise the threat of Glacial Lake Outburst Flood (GLOF). Heat stress is another hazard that has garnered a lot of attention in SAPCCs. For example, Heat Wave Action Plan is a priority for all major states especially Uttar Pradesh, Odisha, Telangana and Gujarat. An important aspect of Disaster Risk Reduction (DRR) is the early warning systems. For cyclones, India has successfully established a well functioning cyclone early warning system. As part of the National Cyclone Risk Management Project (NCRMP), eight Indian coastal states which are exposed to cyclones were part of this project during 2011-2018.*

The United Nations appreciated the Government of Odisha for its handling of a very severe category cyclone Phailin, which struck the State in October 2013. Many structural measures are being undertaken to reduce risk of disasters, such as the erection of two thousand shelter homes in districts vulnerable to cyclones and Assam has riverbank stabilisation to address floods. States such as Tamil Nadu, Andhra Pradesh, Odisha, Gujarat, West Bengal are focusing on ecosystem based approaches for DRR, for instance, mangroves being conserved and regenerated as a bio-shield in the coastal villages. The promotion of the use of drought and flood-tolerant varieties in States such as Tamil Nadu, Telangana, Uttar Pradesh and Madhya Pradesh aim to enhance the resilience of agriculture to climate change.

A significant aspect of DRR is capacity development and various States are focusing on it such as Himachal Pradesh with the formulation of State Training Policy, (2009) and the development of standard training modules for various target groups. Additionally, Jammu and Kashmir developed the concept of Climate Smart Disaster Risk Management (CSDRM) which includes hazard risk mapping using Geographic Information System (GIS) and remote sensing. Since the efforts aim at mainstreaming all the sectors of development at all levels in their planning frameworks are considering disaster risk reduction as a cross-cutting requirement. On adaptation, India's Disaster Management Act, 2005 is one of the legal tools and policies available at central and state level that have evolved manifold over past half the century, and in parallel offer a policy environment for the ongoing 2nd paradigm shift in disaster management, i.e. to 'risk management' – addressing hazards and reducing vulnerability, in the background environmental contexts.

More frequent and severe natural disasters may damage energy infrastructure and equipment, which is important for livelihood and resilience. Further, given the projected increase in temperature, energy demand is likely to increase in the areas, which have a large population, growing development needs, and expanding residential and commercial spaces. The State Action Plan of Maharashtra has focused on promotion of cleaner forms of energy, shift to energy efficient systems to conserve energy and climate proofing of new public infrastructure. Their action plan specifically focused on solar rooftop power generation in the urban areas which have large potential in commercial, industrial and residential buildings, use of biomass based power generation, which will use biomass in efficient way. Further, climate proofing of new public infrastructure (like bridges, roads, ports, etc) by incorporating additional ranges of temperature, rainfall, and sea level rise into design specifications was also included.

Forestry and Biodiversity

Various Indian States, through their SAPCCs, have implemented initiatives to improve the quality and quantity of forest cover. States such as Himachal Pradesh, Jammu & Kashmir, and Nagaland have taken proactive steps towards forest conservation, eco-restoration, and biodiversity. enhancement. Andhra Pradesh, Meghalaya, and Maharashtra have established Vana Samraksha Samities (VSS). Jharkhand has undertaken social and farm forestry initiatives. Additionally, the development of agro-forestry projects has been in focus to promote sustainable land- use practices and provide livelihood opportunities to forest-dependent communities, for example, Seraikela-Kharswan district in the State of Jharkhand. Madhya Pradesh has launched the Project Tiger Scheme and the Development of National Parks and Sanctuaries Scheme to promote the eco-development of villages. The State of Gujarat has focused on planting and reviving mangrove forests.

Coasts and Islands

Integrated Coastal Zone Management Plan (ICZMP) has been implemented to improve coastal habitat restoration, sustainable livelihood development, coastal infrastructure planning, disaster risk reduction, and research and monitoring of coastal ecosystems in the States of West Bengal, Gujarat and Odisha. Gujarat has initiated the 'Sagar Khedu Sarvannni Vikas Yojana,' a multidimensional development package for coastal communities aimed at meeting their needs for climate resilience and sustainable livelihood promotion. Kerala has implemented group insurance schemes for active fishermen and habitat improvement activities in the Agasthyamala Biosphere Reserve. Lakshadweep has initiated the Integrated Perspective Plan for the development of Fisheries, aimed at increasing fish landings and improving shore-based infrastructure facilities. Mangrove conservation and restoration is one of the key areas of focus for Andhra Pradesh, Gujarat, Kerala, Maharashtra, Odisha, and Tamil Nadu. These States have launched various programs and initiatives aimed at protecting and restoring mangrove habitats.

Himalayan Ecosystem

The Himalayan region is crucial for climate adaptation efforts in India. Jammu and Kashmir, Sikkim, and Himachal Pradesh have developed Climate Change Cells to streamline the implementation of their respective State Actions Plans, while promoting climate-resilient agriculture and organic farming practices. Uttarakhand has set up a State Biodiversity Board, along with developing sustainable tourism to reduce the carbon footprint of the industry. Arunachal Pradesh, Assam, Nagaland, Manipur, Meghalaya, and Tripura are implementing and promoting climate-resilient agriculture practices and developing renewable energy sources to reduce reliance on fossil fuels. Assam has focused on disaster risk reduction through riverbank stabilization, the introduction of geotextile material for riverbank training, and the construction of embankments for flood protection. Assam also aims to develop alternative cultivating methods for flood-affected areas.

1.5 India's Expenditure on Adaptation Relevant Actions

In the absence of an adequate flow of international climate finance, adaptation actions in India are largely financed through domestic resources. India has been diligently working towards the fulfilment of its climate action goals in mission mode. Managing the twin responsibilities of achieving developmental goals while preserving its natural capital, India has mainstreamed climate action into the budgetary process of the country for a long time. A number of policies and measures have been put in place across key economic sectors keeping in mind the wide scope of adaptation activities. India has demonstrated leadership in integrating the adaptation criterion in the devolution of public finance from the Central Government to the State Governments. It promotes and incentivizes pro-active State and local level actions on climate change with successful examples. Some of these have been illustrated in Box 2.

A significant proportion of Government of India's spending goes towards enhancing the adaptive capacities of people and communities as well as towards building resilience. Development expenditures of several Ministries/Departments have strong adaptation components in their budgetary provisions. The expenditures are incurred at various levels of Government from the National, State to the local level.

The total adaptation relevant expenditure in 2021-22 was ₹13.35 trillion as compared to ₹ 5.06 trillion in 2015-16. The total adaptation relevant expenditure was 5.6 per cent of the GDP in 2021-2022, growing from an initial share of 3.7 per cent in 2015-16. This clearly shows that India has been making consistent efforts to integrate climate resilience and adaptation into development plans and has been spending a significant amount of resources on adaptation, despite the competing demands for limited resources in a developing economy. It is evident that, India's financial requirements for adaptation will only increase, given the vulnerabilities, increased spending on adaptation is essential for India's economy and to protect developmental gains. International climate finance holds the key to the effective implementation of adaptation plans in India.

1.6 Monitoring and Evaluation

The Monitoring and Evaluation (M&E) mechanisms, to measure the physical and financial progress of programmes, are an integral part of each Ministry of the Government of India. There exists robust M&E framework at the national and State levels to measure the developmental and climate benefits of projects supported through bilateral and multilateral agencies and national and international climate funds {National Adaptation Fund for Climate Change (NAFCC), Adaptation Fund (AF), Green Climate Fund (GCF) and Global Environment Facility (GEF)}.

Consistent with the NAPCC, all the States and UTs in the country have developed SAPCCs with some inbuilt M&E arrangements to ensure better measurement of adaptation impacts and to promote accountability and effective learning. However, the mainstreaming of the climate change agenda into the State level planning and sectoral line Departments has just been initiated and capacity building of actors for M&E of SAPCC activities is currently evolving in the country.

Box 2: Adaptation Actions in India: Some Success Stories

There are many success stories in Adaptation Action that are being reported and documented in the country. A few of those at the local level are detailed below.

Eco Village Scheme in Himachal Pradesh, India

Himachal Pradesh is a small Himalayan State having a population of 6.7 million. Nearly 90 per cent of the population of Himachal Pradesh lives in rural areas and the agrarian economy is largely sustained by the Himalayan ecosystem and its natural resources. Various socio-economic and environmental changes are threatening these resources and posing new challenges for the people of the State. To demonstrate villages as models of sustainable development, the Government of Himachal Pradesh launched the Eco Village Scheme through its Department of Environment, Science & Technology (DEST) in active collaboration with local communities.

In the first phase, five villages have been identified to be developed as eco-villages. The key elements of this include environmental sustainability through responsible natural resource management practices, community participation, use of modern and clean technology and practices, and convergence of resources available for development to promote climate resilient and ecologically sustainable development with interventions in the areas of water management, waste management, irrigation, sustainable agriculture/ horticulture, energy conservation, spring-shed, natural resources management and climate change adaptation. The approach will not only help the stakeholders who are working to implement sustainable community development programmes but will also set benchmarks for others to adopt and bring a radical change in the thinking process of the communities at large in the State, especially in inculcating environmentally responsible behaviour[15].

The ***Pradhan Mantri Fasal Bima Yojana (PMFBY) (Prime Minister's Crop Insurance Scheme)*** *provides insurance against major climatic shocks and weather related risks and are being found helpful in smoothening income fluctuations arising out of climatic and non-climatic shocks. So far, over 360 million farmer applications have been insured under PMFBY, with over ₹1070.59 billion of claims already paid under the scheme. The scheme has been able to provide financial assistance to the most vulnerable farmers, as around 85 per cent of the farmers enrolled with the scheme are small and marginal farmers.*

15 Model Eco Village Scheme, Department of Environment, Science & Technology, Government of Himachal Pradesh. Model Eco Village Scheme, Department of Environment, Science & Technology, Government of Himachal Pradesh

Agriculture Technology Management Agency (ATMA) scheme: *The Support to State Extension Programs for Extension Reforms' popularly known as the ATMA Scheme has been under implementation since 2005. The scheme provides Grants-in-Aid to State Governments with an objective to support their efforts to make the latest agricultural technologies and good agricultural practices available in different areas of agriculture and allied activities to farmers through different extension activities that include but are not limited to farmers training, demonstrations, exposure visits, Kisan Mela, mobilization of farmer groups and organizing farm schools, among others.*

The Government of India, under this scheme, also has specific provisions that are given only for women to ensure the support for Women Food Security Groups, support for Gender Coordinator and representation of Women farmers in decision making bodies. Presently, 691 districts of 28 States & 5 UTs are covered under the scheme. During 2016-17 to 2020-21, an amount of ₹27.96 billion was released to the States/UTs to carry out extension activities and total of 2,10,59,707 farmers have benefitted through different extension activities under the ATMA Scheme, out of which 53,11,274 are Women Farmers..

The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) *launched during the year 2015-16 aims to achieve better coordination, coherence and efficiency in planning for water resource management in irrigation and watershed development projects through investments. It is an umbrella scheme, consisting of two major components - Accelerated Irrigation Benefit Programme (AIBP) and Har Khet Ko Pani (HKKP) (Water to Every Farm), that are implemented by the Ministry of Jal Shakti (MoJS). Within the Har Khet Ko Pani component, there are four other components that include Command Area Development & Water Management (CAD&WM), Surface Minor Irrigation (SMI), Repair, Renovation and Restoration (RRR) of Water Bodies, and Ground Water (GW) Development.*

Additionally, two more components - Watershed Development (WD) and Per Drop More Crop (PDMC) – are a part of this initiative that are being implemented by the Department of Land Resources and Department of Agriculture and Farmers Welfare respectively. In addition, PMKSY also consists of Watershed Development component (WDC) which is being implemented by Department of Land Resources, Ministry of Rural Development.

Per Drop More Crop (PDMC) component being implemented by Department of Agriculture and Farmers Welfare (DoA&FW) was also a component of PMKSY during 2016-21, which is now being implemented separately by DoA&FW.

Under the Accelerated Irrigation Benefit Programme, new irrigation potential of 2.43 million hectares has been created during 2016-17 to 2021-22. Under the WD component, 1.64 million hectare of additional area have been brought under protective irrigation upto March 2022 and 6.74 million hectare has been covered under micro irrigation under the PDMC component upto March 2022.

Management and Rehabilitation of Coastal Habitats and Biodiversity for Climate Change Adaptation and Sustainable Livelihood in Gulf of Mannar, Tamil Nadu, India[16].

The Gulf of Mannar encompasses 21 islands (2 islands are submerged) and is a marine hotspot on the east coast of India, in the State of Tamil Nadu which harbours 4,223 floral and faunal species[17] in its area of 10,500 Km2. The coral ecosystems in this region faced extreme climate stresses like variation in sea surface temperature, sea level rise, and increase in cyclone intensity, storm surges, sedimentation and variations in nutrient profile, etc. This has resulted in adverse effects like coral bleaching, decline in fish diversity and productivity, mass mortality and migration of species, and the deterioration of ecosystem services ultimately affecting the livelihood of the dependent coastal communities.

The National Adaptation Fund on Climate Change has undertaken a project that is aimed at carrying out climate change vulnerability studies of the coastal communities and ecosystems along the 364.9 km coastline of the Gulf of Mannar which inhibits Kariachalli & Vilanguchalli Islands. This resulted in coral and seagrass rehabilitation that were carried out in 4.0 sq. km of degraded reef and seagrass habitat. Coral fragments of diverse native coral species (8-11 cm size) were extracted from the donor coral reefs and tied with rope to the cement slabs (20 cm x 5 cm x 1.5 cm) and deployed under water. About 6000 numbers. of artificial reef modules of Ferro-cement and Reinforcement steel (each of the size 2.5m width, 2m height and 1m longitudinal length) were deployed near Vaan island. More than 25 village specific activities such as, sea weed culture, ecotourism activities, provision of micro-credit revolving funds, and nurturing of Self Help Groups (SHGs), etc., in 23 project villages have been undertaken so far. This has resulted in a significant reduction in erosion/submergence of the Vaan island in the Gulf of Mannar. Coral species have been found to be settled on the Artificial Reefs modules. The modules also serve as fish breeding grounds. In short, the ecosystem, in and around the Vaan island is slowly being restored. The dependence of the fisher folk on alternate livelihood activities has increased, which led to enhanced incomes and climate resilience of these vulnerable communities and reducing the fishing pressure on coral reef ecosystem.

Addressing Climate Change: An Approach to Planning and Implementation of Climate Change Adaptation in Rural Areas of India (CCA-RAI)

The vulnerability assessment of the State of Punjab in India showed that the monsoon rains experienced during the months of June, July, August, and September are likely to increase from 4 per cent to 12.5 per cent. However, a decrease in rainy days would make rainfall more intense thereby significantly increasing surface run-off. Moreover, groundwater recharge was expected to go down in most of the districts due to very high rates of extraction for agriculture.

The CCA-RAI undertook a pilot project in collaboration with local partners in the districts of Patiala and Moga. Vulnerability assessment showed that these districts faced risks of rising temperatures and extreme rainfall events. The annual precipitation was projected to increase by 13.3-21.5 per cent by 2050, resulting in significant increased risks of flooding and loss of excess water due to increased runoffs and expansion of non-permeable surfaces. It was found that the unregulated use of groundwater for irrigation had made people in the districts highly sensitive to future climatic shocks. Water stress, is the primary impact of the existing wheat-rice crop cycle, brought about mainly by rice cultivation in the Kharif season. Farmers are reluctant to shift away from rice cultivation since they are assured of market linkages.

In collaboration with Punjab Agriculture University (PAU), the CCA-RAI project created a farmer network in Punjab to strengthen a platform which amplified the voices of conservation farmers. The platform ensured farmers get up-to-date advisories based on local farming systems and related weather forecasts, to enable them to take timely corrective measures. The pilot supported farmers in taking up Direct Seeded Rice (DSR) through intensive interaction and provided them with technical knowledge and extension support. Around 1000 acres of land have been converted to DSR by now. Farmers who adopted DSR reported at least 20-30 per cent reduction in water use with no adverse effect on income. In fact, an increase of 35 to 38 per cent in the paddy yield in the DSR sown area was observed. Using extension services support and sharing of knowledge, the project supported crop residue management as well. To help offset straw burning and the air pollution stress it causes, the pilot also helped promote the Happy Seeder machine. This is tractor-mounted and cuts rice straw while simultaneously sowing wheat into the soil and depositing the straw over the sown area as mulch helping increase soil fertility. The project was able to build both community and institutional capacity to help adapt to climate change.

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16. NAFCC Project: Management and rehabilitation of coastal habitats and biodiversity for Climate Change Adaptation and Sustainable Livelihood in Gulf of Mannar

17. Balaji (Jr), S, J K Patterson Edward and V Deepak Samuel 2012. Coastal and Marine Biodiversity of Gulf of Mannar, Southeastern India - A comprehensive updated species list. Gulf of Mannar Biosphere Reserve Trust, Publication No. 22, 128 p.

1.7 Gender Responsiveness of Adaptation Efforts in the Country

While the climate risks and hazards faced across the country affect all its citizens, the impacts do not affect all groups equally. The impacts of climate change and disasters affect weaker socio-economic groups with much higher intensity. Women, especially those from lower economic backgrounds, face some of the most severe effects of climate change. Recurring incidences of erratic rainfall and increasing possibilities of extreme events can result in the loss of agricultural produce. Women are exposed to harvest losses, which are often their sole source of food and income. Climate change may, thus, result in a consequent shrinkage of work opportunities, and would inflict a blow to the socio-economic edifice of the rural womenfolk. Second, climate variability usually impacts sectors that are traditionally associated with women, such as paddy cultivation, cotton and tea plantations, and fishing. A multiplicity of factors leads to a situation in which women find the share of the burden for adaptation falling disproportionately on them, despite their low ability to adapt. Thus, it becomes imperative to devise appropriate adaptation measures, with a special focus on women.

The Government of India recognizes that women involved in agriculture and other such climate sensitive sectors are more exposed to vulnerabilities due to climate risks as lack of access to tools and machinery makes them more exposed and increases their sensitivity to climate risks and extreme events. In India, about 65 per cent of the total female workers are engaged in one of the most climate sensitive sectors – agriculture, thereby constituting 30 per cent of the total cultivators and about 43 per cent of the total agricultural labourers in the country. [18]

Women can play important roles in the process of adaptation because of their involvement in climate-sensitive livelihoods. In addition, they are the ones who have a major role in decisions at the household levels on the types of ***chulla*** (cook-stove) used for cooking, as also in decisions related to the sanitation norms at household level. They need to be readily involved in the micro-level strategy action to combat climate change. The Government of India has been making strides in the empowerment of women, especially in the past few years. A number of initiatives have been introduced to improve gender parity and women's participation in the workforce thereby enabling greater access to as well as ownership of resources. A significant step forward in gender equality was the introduction of Clause (3) under Article 243 D of the Constitution, which ensures the participation of women in Panchayati Raj Institutions by mandating at least one-third reservation for women out of a total number of seats to be filled by direct election and the number of offices of chairpersons of Panchayats.

Recognising that national budgets benefit women and men differently, India formally adopted Gender Responsive Budgeting (GRB) in 2005- 2006. GRB does not merely involve the earmarking of funds for women; it is an exercise that scrutinises the budget through a gender lens. The Gender Budget Statement comprises two parts: Part A reflects women- specific schemes with a 100 per cent allocation for women, and Part B is composed of pro-women schemes wherein at least 30 per cent of the allocation is for women.

18. Census (2011), Primary Census Abstracts, Registrar General of India, Ministry of Home Affairs, Government of India.

The guidelines for preparation of SAPCCs urge the States and UTs to address the needs of vulnerable groups such as women, because the "poorest of the poor, especially the marginalised groups, will be the most affected by these changes". Further a concrete shift towards including gender considerations came out in 2015 when India submitted its commitment for post-2020 climate action through the NDC. The NDC considers the country's commitment to the conservation of nature "as well as the imperatives of meeting the competing demands of resources for addressing the challenges of (inter alia) gender equality and women empowerment".[19] Additionally, under the Agriculture Technology Management Agency (ATMA) scheme, for instance, there are provisions for women's food security groups (FSGs), a gender coordinator and representation of women in decision making bodies. The Sub-Mission on Agricultural Mechanisation (SMAM) also provides training programmes on gender friendly farming equipment for women farmers and gives additional subsidies to women farmers for buying farming machinery and equipment.

Gender has been made an integral component of developmental planning in the country, with key schemes of the Government of India highlighting the priorities of women. In order to address the heightened vulnerabilities faced by the women in the rural parts of the country, schemes such as Mahila Shakti Kendra, Mahila E-Haat and STEP (Support to Training and Employment Programmme for Women) have been undertaken. These schemes acknowledge the vulnerabilities faced by women who carry out the minor tasks of climate sensitive sectors such as agriculture, or gather firewood and other materials from forests, etc. The schemes address such concerns through enabling the empowerment of women by providing trainings and skill development courses to facilitate alternate livelihood opportunities. Thus, women related issues are being mainstreamed in developmental programmes of the Government of India.

1.8 Traditional and Local Knowledge Systems Relevant to Adaptation

Traditional knowledge systems include practices, innovations and customary laws that indigenous groups and communities have been using for generations for multiple purposes, the main among which include, farming techniques, resource management and medicinal purposes. India is among one of the few ancient civilizations and cultures that encompasses a multitude of traditions that are practiced across its length and breadth but are tied together with certain core values which have been observed to be in complete consonance with the need for sustainability. The heart of Indian culture and tradition lies in its diversity. Different lifestyles that match the local climatic and geographical conditions can be found across the country, ranging from the deserts of Rajasthan to the forests of the Northeast.

Traditional and local knowledge systems are a way of life in India. This is not only the case for the tribal and forest-dwelling communities, and across the country. Different communities have adopted a myriad of practices and systems, the core of which is ingrained in sustainability. India, with over 700 Scheduled Tribes that forms about 8.6 per cent.[20] of the country's total population, has several pockets of tribal

19. (2015). India's Intended Nationally Determined Contributions to UNFCCC. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India.

20. Tribal Statistics. (2017). Retrieved from Ministry of Tribal Affairs.

population in rural and forest areas where rich traditional knowledge exists and is passed on from one generation to another through folklore and oral traditions. The immense potential of traditional knowledge systems that have supported local societies in organizing lifestyles successfully in remote and fragile areas of the country has been acknowledged and appreciated by integrating them into the formal sector policies and practices.

The country's history is replete with the use of traditional knowledge and practices that have been recognized globally for healthcare and includes Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homeopathy. The Government of India, has made great efforts to preserve the traditional knowledge of medicines and improved healthcare, forming the Ministry of AYUSH in 2014 that promotes research and education in these fields to integrate traditional knowledge and practices into medical research.

Traditional knowledge systems, in recent years, have been encountering several challenges in the face of modernization, out migration of youth impacting the process of knowledge transfer, urbanization, etc. Therefore, recognizing the increased vulnerability of such communities and addressing these challenges, the Government of India has initiated the Pradhan Mantri Van Dhan Yojna, an initiative that targets livelihood generation for tribal and forest dwelling communities by harnessing the wealth of forests. It aims to tap into the traditional knowledge and skill sets of these communities by adding technology and IT to transform it at each stage and to convert the tribal wisdom into a viable economic activity through value-added products, thereby also addressing out migration of the younger generation to sustain the process of vernacular knowledge transfer among these communities.

According to the IPCC, protecting, restoring and sustainably managing carbon-rich ecosystems like forests and peatlands, as well as reducing the GHG intensity of food production, curbing food waste, and shifting to more sustainable diets can mitigate 8-14 Gt CO2 e per year from now through 2050 at relatively low costs.

The concept of LiFE, i.e., Lifestyle for Environment was introduced by the Prime Minister at the World Leaders' Summit in Glasgow at COP26, when he gave a clarion call to rekindle a global pursuit to adopt environment friendly lifestyles and practices. On 5th June 2022, Mission LiFE was launched and as a part of Mission LiFE, a comprehensive and non-exhaustive list of 75 individual LiFE actions have been identified across 7 themes – save water, save energy, reduce waste, reduce e-waste, reduce single-use plastics, adopt sustainable food systems, and adopt healthy lifestyles.

The LiFE Principles collectively define a new sustainable and resilient development paradigm to support livelihoods, create investment opportunities to promote growth, improve standards of nutrition, healthcare, education and living, and meet the socioeconomic aspirations of population.

1.9 Synergies with Multilateral Frameworks and Cooperation for Enhancing Adaptation at the National, Regional and International Level

Several of the ongoing adaptation interventions and strategies that are being undertaken by the Government of India, contribute towards achieving the goals of multilateral frameworks and cooperation while addressing climate concerns.

Table 2 enumerates the ongoing schemes, policies and programmes undertaken by the Government of India and categorizes the interventions by the key sectors targeted, and presents their linkages and synergies with different SDGs, various international Conventions and frameworks such as the UNFCCC, the UNCCD, the SFDRR, the RAMSAR Convention and the CBD. For instance, the National Mission for Sustainable Agriculture (NMSA), aims at enhancing agricultural productivity in a sustainable manner. Such schemes address the dual challenges of – increasing productivity of a sector that has over 50 per cent of the population dependent on it for livelihood as well as address climate concerns in a sector that is highly dependent on climatic variables such as rainfall, temperature, etc. and will hence be bearing the brunt of climate impacts. Through its various facets, the programme also contributes to the mandates of several international Conventions and Treaties that the country is Party to, including the Paris Agreement under the UNFCCC in terms of adapting to the changes in the climate through sustainable means. It also attempts to ensure water use efficiency thereby increasing the land under irrigation which helps improve soil quality thus reducing degradation and contributing to the CBD. The improvement in soil quality and expansion of irrigation also contributes significantly towards combating desertification under the UNCCD as well as helps to prevent droughts in the country thereby contributing to the Sendai Framework on DRR. In addition to this, it contributes to several SDGs such as SDG 1 on No poverty by attempting to double farmers' income, SDG 2 on achieving zero hunger by enhancing food availability in the country, SDG 8 on ensuring decent work and economic growth through enabling sustainability in the sector and SDG 13 on climate action through enhanced adaptation to climate risks.

Another flagship programme of the Government of India dealing with climate stressors in the agriculture sector is the National Innovations in Climate Resilient Agriculture (NICRA) that promotes research in the field to enhance the resilience of the sector to climate change and reduce its impacts by developing a thorough understanding of the climate risks faced by different regions of the country and consequent impacts that it would have on the regional crops, livestock, fisheries and the overall sector of agriculture and allied activities.

The Jal Shakti Abhiyan (water conservation campaign) under the National Water Mission is a flagship programme in the water sector that focuses on rainwater harvesting as a means to improve water availability in the country. It also contributes towards halting the depletion of groundwater tables across the country while also enabling increased soil moisture retention. As erratic patterns and extreme rainfall events are slowly replacing the earlier patterns of seasonal rainfall, such programmes enable communities to adapt to these changes while also ensuring that developmental challenges such as access and availability of water resources are adequately addressed. The programme, therefore, contributes to SDG 6 on clean water and sanitation as it enhances access to water resources for communities and SDG 13 on climate action as it enhances the adaptive capacities of communities as well as feeds into the mandates of the UNFCCC and Paris Agreement in adapting to climate change, UNCCD, in combating desertification through improved soil moisture and the Sendai Framework on Disaster Risk Reduction by reducing the risk of droughts. By halting degradation of soil through improved moisture content, it also contributes to the CBD as it promotes the protection and restoration of soil.

Table 2: Synergies of National Policies and Programmes with International Frameworks and Conventions

Sector	Projects/ Programmes		SDGs	UNFCCC / Paris Agreement	UNCCD	SFDRR	RAMSAR	CBD
	National Mission for Sustainable Agriculture (NMSA)	Rainfed Area Development (RAD)	SDG 13	√	√	√		
		Sub-Mission on Agroforestry (SMAF)	SDG 13	√	√			
		National Bamboo Mission (NBM)	SDG 12, 13					
		Soil Health Management (SHM)	SDG 13, 15	√	√	√		
		Monitoring, Modeling and Networking (CCSAMMN)	SDG 13	√		√		
	National Innovations on Climate Resilient Agriculture (NICRA)		SDG 14, 9	√	√	√		
	Pradhan Mantri Fasal Bima Yojana *Prime Minister Crop Insurance Scheme*		SDG 13			√		
	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	Accelerated Irrigation Benefit Programme (AIBP)	SDG 13, 15	√	√			√
		Command Area Development and Water Management (CAD&WM)	SDG 13, 16	√	√			√
		Her Khet ko Pani	SDG 6, 11, 13	√	√	√		√
		Per Drop More Crop (Micro Irrigation)	SDG 6, 11, 13	√	√	√		√
	Mission for Integrated Development of Horticulture (MIDH)	National Horticultural Mission (NHM)	SDG 1, 3, 9, 13	√				
		Horticulture Mission for North East and Himalayan States (HMNEHS)	SDG 1, 3, 9, 13	√				
	National Livestock Mission (NLM)	*Rastriya Gokul Mission (RGM)*	SDG 1, 8, 13, 15	√				√
		Breed Development of Livestock & Poultry	SDG 1, 8, 13, 15	√				√
		Feed and Fodder development	SDG 1, 8, 13, 15	√				
		Extension and Innovation	SDG 1, 8, 13, 15	√				
		Livestock Health and Disease Control (LH&DC)	SDG 1, 8, 13, 15	√				
		National Programme for Dairy Development (NPDD)	SDG 1, 8, 13, 15	√				√
		Livestock Census and Integrated sample Survey (LCISS)	SDG 1, 8, 13, 15	√				
		National Animal Disease Control Programme (NADCP)	SDG 1, 8, 13, 15	√				
		Dairy Infrastructure Development Fund (DIDF)	SDG 1, 8, 13, 15	√				
		Animal Husbandry Infrastructure Development Fund (AHIDF)	SDG 1, 8, 13, 15	√				
Agriculture	*Pradhan Mantri Matsya Sampada Yojana (PMMSY)*		SDG 1, 8, 13, 15	√				√

Water	National Water Mission	*Jal Shakti Abhiyan*	SDG 6, 13	√	√	√		√
		Sahi Fasal	SDG 13	√	√	√		
		R& D projects	SDG 13	√	√	√		
		Baseline studies	SDG 13	√	√	√		
		Training and Capacity Development Workshop	SDG 13	√				
		State Specific Action Plan	SDG 13	√				
	The Swachh Bharat Mission		SDG 3, 6, 8					√
	The Dam Rehabilitation and Improvement Programme		SDG 9, 13			√		
	The Jal Jeevan Mission		SDG 3, 6, 13	√				
	Namami Gange/ National Mission for Clean Ganga		SDG 3, 6, 14					√
	Atal Bhujal Yojna	Institutional Strengthening & Capacity Building Component	SDG 6, 12, 13					
		Incentive Component	SDG 6, 12, 13					
Coasts and Islands	National Coastal Mission		SDG 1, 8, 13, 14			√		√
	Integrated Coastal Zone Management Project		SDG 13	√		√		√
	Enhancing Coastal and Ocean Resource Efficiency (ENCORE)		SDG 13, 14	√				√
	Beach Environment and Aesthetics Management System (BEAMS)		SDG 13, 14	√				√
	Coastal and Marine Protected Areas		SDG 13, 14	√				√
	Blue Revolution: Integrated Development and Management of Fisheries.		SDG 8, 13, 14	√				√
Himalayan Ecosystem	Mid-Himalayan Watershed Development project		SDG 13, 15	√				√
	Assam Agricultural Competitiveness Project (Project)		SDG 1, 8					
	Securing livelihoods in Himalayas (project)		SDG 1, 8, 13	√				√
	The Meghalaya Community Led Landscape Management Project (MCLLMP)		SDG 15	√				√
	National Mission for Sustaining the Himalayan Ecosystem (NMSHE)		SDG 13	√		√		
	Hill Area Development Plan		SDG 13, 15	√				
	National Mission on Himalayan Studies (NMHS)		SDG 13	√				
Disaster Management and Infrastructure Resilience	National Cyclone Risk Mitigation Project	Early warning dissemination systems (EWDS)	SDG 13			√		
		Cyclone risk mitigation infrastructure	SDG 13			√		
		Technical assistance for multi-hazard risk management	SDG 13			√		
Forestry and Biodiversity	Compensatory Afforestation Act (CAMPA) 2016		SDG 13	√	√			
	Green India Mission (GIM)		SDG 15		√	√		
	Nagar Van UdyanYojana		SDG 11, 13	√				
	Intensification of Forest Management Scheme (IFMS)		SDG 13, 15	√		√		√
	National Plan for Conservation of Aquatic Ecosystems (NPCA)		SDG 14				√	√
	Pradhan Mantri Van Dhan Yojana		SDG 1, 2, 8, 10, 12, 13					
	Green Skill Development Programme (GSDP)		SDG 8, 13, 15	√				√

IMPLEMENTATION AND SUPPORT NEEDS FOR ADAPTATION ACTIONS IN INDIA

Chapter 02


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Introduction

India's future adaptation needs are mainly dependent on – one, an expected increase in climate impacts; and two, India's development trajectory which will necessarily require an increase in infrastructure and services to provide a decent standard of living to its population. As per the Synthesis Report of the IPCC Sixth Assessment Report (AR6) 2023, human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020. Global greenhouse gas emissions have continued to increase over 2010- 2019, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and between individuals (high confidence). At the time of the present assessment there are gaps between global ambitions and the sum of declared national ambitions. These are further compounded by gaps between declared national ambitions and current implementation for all aspects of climate action.

According to the UNFCCC NDC Synthesis Report, 2022, the combined climate pledges of 193 Parties under the Paris Agreement could put the world on track for around 2.5 degrees Celsius of warming by the end of the century. The Report also shows current commitments will increase emissions by 10.6 per cent by 2030, compared to 2010 levels. This would make it further harder for developing countries in their development path due to the adverse effects of climate change. On the development front, it is evident that India needs to integrate its adaptation planning into its developmental activities, especially since more than 50 per cent of India's population is dependent on climate-sensitive sectors like agriculture, fisheries, and forestry to draw their livelihoods.

2.1. Constraints in Planning and Implementation of Adaptation Actions in India

Several factors constrain the planning and implementation of adaptation in the country. The constraints and challenges pertaining to climate change adaptation primarily stem from the uncertainties in knowledge and understanding of the impacts of climate change that would unfold at the local levels. In addition, the context-specific nature of adaptation makes it challenging to have a one-size-fits-all solution, especially in a country as diverse as India. This has implications for technologies and institutions needed for adaptation. Further, existing developmental challenges hinder communities' ability to adapt to climate change, which often manifest as gaps in financial availability and capacity constraints. Key constraints related to adaptation action in the country have been identified as follows:

2.1.1. Data, Information, and Knowledge Constraints

Knowledge of climate change and its sectoral impact is limited among key institutions and stakeholders in the adaptation space. This is primarily driven by limited awareness and lack of knowledge resources such as technical skills, quality data, and research studies, especially at the regional and sectoral levels.

Observations, Data Collection and Monitoring Gaps

Data, and its modelling and interpretation, have been identified as an important constraint in planning and implementation of adaptation interventions. For example, in the water sector there are four areas that require greater research include: a) regional climate prediction, b) accurate precipitation forecasts, c) aerosol dynamics, and d) paleo- climate data. It is identified that one of the main reasons for limited research may be inadequate data, which might lead to incorrect modelling results for processes such as cloud formation, orographic effects, and thunder clouds. Similarly, in the Indian Himalayan Region (IHR), select glaciers are being monitored with an integrated approach (Meteorology, Hydrology, Glacier Dynamics, Seismology and Geomorphology).

Long-term glacier monitoring needs to be strengthened with an integrated approach, and new basins should be explored, particularly in Eastern Himalayas and Karakoram region. Further, less explored aspects of the cryosphere such as snow depth, snow volume, albedo, debris cover, and the effect of aerosols and permafrost on glacier dynamics need to be investigated. Additionally, there is also a difficulty in assessing data on the inundation/ submergence of vulnerable areas such as coastal regions. Because of the vast coastline and limited measurements on sea level rise, there are gaps in long-term data availability. Rapid changes in land use pattern and non-availability of the historic fine scale remotely sensed data makes the interpretation and analysis challenging. It has been observed that there is a lack of uniformity and synchronization of available data within sectors. It was identified that similar indicators and data points could not be homogenized across sectors. Methodologies for the integration of numerical predictions of climate change impacts with socio-economic vulnerability are missing. In the health sector, the understanding of Climate Sensitive Diseases (CSDs), environmental factors determining health, meteorological information, and outcomes such as morbidity and mortality are still evolving. There is a felt need for early detection tools for CSDs (rapid diagnostics, surveillance) and mathematical /prediction models for the preparedness of the population and health care system.

Information and Knowledge Gaps

One of the major gaps in adaptation action is that the risk assessment studies in India are hazard-specific and often consider only hazards. Scientific and technical studies depict areas prone to climate related hazards without establishing their impacts on society. Thus, an integration of the socio-economic, as well as cultural aspects of communities and societies, is needed while assessing specific impacts of climate risks and hazards, as they play a crucial role in adaptation planning. Even where vulnerability assessments are available, the social and economic inequalities, differential access to information and technologies, and capacities of stakeholders are not adequately captured.

Globally, analytical advances are being made on how non-climatic stressors interact with climate change and its consequences. In the Indian context, for instance, in the forestry sector, there is a clear gap in the scientific assessment of forest types and their degradation due to climatic and non-climatic stress (sensitivity) and the adaptive capacities of different forest types. In the water sector, an assessment is required to quantify the available water resources at the level of implementation and to understand groundwater-surface water interaction. Further, the current understanding of 'loss and damage' associated with climate change is inadequate for effective adaptation planning.

In the Forestry sector, there is a limited understanding of the climate- driven effects on biodiversity; composition, structure, and function; nutrient dynamics, carbon regulating services and ecosystem services of forests, and monitoring and predicting the impacts of climate change. In fact, even global studies on climate threats to different sectors, species, and ecosystems are limited and have scope for further research. For instance, the International Union for Conservation of Nature (IUCN) global threat status is unavailable for most of the threatened medicinal plants in the Indian Himalayan Region.

In the agriculture sector, as climate risks are evolving, farmers need specific knowledge of the climatic variations, intensity and implications of extreme weather events on crops, livestock and fisheries. Climate service products exist and are improving over time, but further improvements are required to address the information needs of farmers.

Dissemination Gaps

Premier research institutions in India have taken up studies pertaining to climate change which need to be compiled and their findings need to be collated, disseminated and translated into adaptation strategies.

In addition, the appropriate interface between science and practice of adaptation is often non-existent or not functioning appropriately with the result that the knowledge generated does not fully inform the implementation of adaptation interventions.

2.1.2. Constraints in the Implementation of Adaptation Options

The key constraints for implementation of adaptation options in addition to knowledge, are technology, capacity, finance, and lack of adequate participation from the private sector.

Technology Constraints

While India has established an extensive knowledge network of national and international institutions on climate adaptation, there still remains a considerable gap in adaptation technologies available to India, especially at the sub-national level. Challenges around technology transfer, technology co-creation and intellectual property rights reflect the larger debate on the responsibility of developed nations to support climate action in developing nations. The other pertinent issue for India is the need to assess technological requirements across sectors and sub-national levels to understand the scale of deployment, levels of risk (present and future) that adaptation options can address, temporal dimensions for implementation (short, medium and long term), and associated costs and benefits. Thus, the key considerations with respect to technology as an adaptation constraint include (1) availability; (2) access (including the capacity to finance, operate, and maintain); (3) acceptability to users and affected stakeholders; (4) effectiveness in managing climate risk and (5) technology transfer.

Capacity Constraints

There is a need to build capacity at all levels, and particularly at the local level. There is a lack of trained personnel on the ground to operate technical tools and devices. Capacity building and skill development of all stakeholders, across sectors and levels is imperative to enable the effective implementation of adaptation strategies on the ground and the collection of relevant data through appropriate processes. The ability to use the available information for implementation of adaptation action among various stakeholders, which requires investments in specific capacity building programmes.

Inadequate Participation from the Private Sector

Private sector engagement in climate adaptation projects is mostly limited to :

i. Addressing climate risk assessment studies and

ii. Corporate Social Responsibility (CSR) activities.

iii. Business participation in financing or to even implementing such projects for profit making remains limited. Factors like lack of localized climate information, few financing mechanisms and low returns on investment are perceived as risks by private players which deter their participation.

Financing Constraints

Adaptation activities in India have been so far predominantly financed by National and State budgets. Funding available for adaptation action in India is insufficient to cover the adaptation needs of the country. Further, State level institutions lack awareness of the different funding options available for adaptation actions or the modalities of accessing international climate finance. Adequate funds from global sources, multilateral development banks and other facilities would go a long way in strengthening the availability of finance for adaptation action in the country. Innovative financial instruments supported by developed countries and Multilateral Development Banks can be useful in facilitating flow of private sector capital towards adaptation measures in the developing countries like India.

2.2 Adaptation Priorities

The adaptation priorities for the country stem from three sources – one, from an understanding of potentially high consequences and highly likely climate risks facing the country; two, from the socio-economic context and the development needs of the country; and three, from addressing the constraints to adaptation.

This section describes the three broad categories of adaptation priorities for the country –

i. priorities related to knowledge systems on climate change risks and adaptation.

ii. priorities related to a reduction of exposure to climate risk, and

iii. priorities related to building resilience and adaptive capacity.

2.2.1 Priorities to Strengthen of Knowledge Systems and Amalgamating them to Planning and Implementation:

Key areas that would strengthen systems of knowledge development and lead to generation of new knowledge are:

i. Enhancing high-resolution climate modelling for local-level assessments of vulnerability and risks,

ii. Enhancing ground observation and data gathering networks for various hydro-meteorological phenomena for improvements in data collection and data quality,

iii. Vulnerability assessments and risk profiling: India has many development schemes suited for different regions (e.g. north- east hill regions, rain-fed areas, coastal areas), underdeveloped communities (e.g. those below the poverty line, belonging to scheduled castes and tribes, women), farmers with smaller holdings (small and marginal farmers). Strengthening this further is needed by conducting vulnerability assessments at the grass root levels. Such assessments help decision-makers and policy planners prioritize areas which need urgent adaptation actions. This can be further aided by a comprehensive localized risk profiling of the country through a bottom-up approach capturing the intricacies of the local ecosystem,

iv. Facilitating two-way Communication: In this regard, a key priority is to translate climate change relevant information to the local context in a way that is understood by the communities. Equally important is gathering ground information to assess intensity of weather events and their socio-economic impacts on the local community to guide adaptation priorities.

v. Establishing mechanisms and institutions to couple the knowledge systems to planning and implementation systems.

2.2.2 Priorities to Reduce the Exposure to Climate Risks:

The multifaceted nature of the adaptation challenge requires putting in place physical and institutional infrastructure and a range of activities that would reduce exposure and vulnerability to climate risks. Some of them could be:

i. **Enhancing Climate Services and Early Warning Systems** to reach the target recipients is a priority to address constraints of low capacity, inadequate institutions, and difficulties in maintaining systems beyond the pilot project stage.

ii. **Addressing Floods**: One of the approaches is improving the storm water infrastructure in cities, as urban floods have become a new form of disaster plaguing Indian cities in recent times and resulting in extensive losses and damages. Other ways of addressing the issue include surplus floodwater capture mechanisms that must be installed at the local levels. Concerning rural areas, there is a need to use river plans that can help to manage the flood situation and reduce losses and damages effectively. Coastal flooding is also a climate risk being faced in the country. Measures to create physical and biological barriers between the sea and land through afforestation, improved embankments, soft-hard-hybrid shoreline protection structures and seawalls and de-siltation of channels may be prioritised.

iii. **Ecosystem-based approaches:** Ecosystem-based approaches such as sustainable watershed management, coastal area protection, mangroves and seagrass restoration and strengthening, coastal area protection, coral reef conservation and restoration, etc., which require concerted action at a larger spatial scale, are important ways of adaptation that need to be scaled up in the country.

iv. **Long-term relocation of communities** along the long coastline would reduce the exposure of coastal communities to impacts of sea level rise, cyclones, storm surges and coastal flooding.

2.2.3 Priorities to Enhance Resilience and Adaptive Capacity

Strengthening existing systems and creating new systems for enhancing adaptive capacity and resilience is an important part of the adaptation planning agenda for the country. Broad domains are discussed below:

i. **Promoting research and innovation on technologies that help address climate risk:** Considering the challenges of technology transfer from developed countries, there is an urgent need to develop technologies in India, along with the vision of "Make in India" of the Hon'ble Prime Minister Shri Narendra Modi, which minimize the adverse impacts of climate change and develop the adaptive capacities of vulnerable communities. A systematic approach to research and innovation for adaptation technologies in various sectors at the national and sub-national level is required.

ii. **Ensuring credit supply in rural India:** Recognising the disparities within rural areas in terms of the risks and vulnerabilities, the Government of India has identified 184 credit-starved districts to reduce the regional disparities and assure better credit supply. Better credit access in these districts through private sector engagement would enhance their resilience and improve their capacities to respond to climate risks.

iii. **Livelihood diversification and inclusion of marginalised communities:** The climate-sensitive regions like the Indian Himalayas, coasts and islands, and arid and semi-arid regions are usually inhabited by low-income marginalised communities that are excluded from protection and services. The priority is to provide diversified livelihood options in the face of fast-evolving climate risks.

2.3 Future Resource Needs for Adaptation

The cumulative expenditure needed for adaptation in a Business as Usual (BAU) scenario, without any additionality, is estimated to be INR 56.68 trillion till 2030, assuming 2023-24 as the base year of analysis.

This estimate, based on an "infrastructure needs" approach, is developed for select sectors which are most relevant for enhancing adaptive capacity and building resilience. These sectors include agriculture, water supply and sanitation, housing, health, education, poverty alleviation, forestry and wildlife, and disaster management.

Climate impacts could lead to an incremental cost of ₹15.5 trillion by 2030, and the total requirements for building adaptation capital stock could be as high as ₹72 trillion after accounting for the country's developmental needs and climate-induced pressures. It comprises of both, the additional expenditures required due to developmental pressures as it traverses in the BAU pathways as well as addressing future climate change-induced impacts. Regarding the latter point, building a climate resilient infrastructure stock would prove to be a more preferred option as the degree of climate damage is expected to exacerbate in the future. While the extent of climate damage has been taken as 3 to 6 per cent of the investments needed for building infrastructure resilience and accounting for climate-induced damages in the current context in different sectors, i.e., till 2030, these would in all probability increase in the coming decades. Hence the aforementioned amount of ₹72 trillion, is considered to be the adaptation gap that Government of India needs to bridge in the future.

It however needs to be stated that, this adaptation gap cannot be met only through governmental resources and the financing requirements. Considering the increase in the adverse impacts of climate change as well as costs of resilience measures, significant contributions needs to be channelized through bilateral and multilateral public finance and private investments.

Estimating the cost of adaptation involves many technical and empirical limitations. The estimates are based on a number of assumptions. Although the spending on certain key sectors, such as agriculture, water, coastal, energy, and disaster management, are considered, there may still be many missing and unknown aspects. Therefore, the estimate should be taken as conservative and indicative. While individual estimates are subject to uncertainty, it is clear that the adaptation finance required is significantly higher than current adaptation finance estimation. Urgently increasing adaptation finance flows to India is a crucial requirement for India to be able to meet its long term sustainable development and low emission growth goals India's adaptation finance needs are challenging to quantify.

India very well understands the importance of adaptation planning processes which will enable to planning and attracting of larger scale finance for more resilient future strengthening adaptation actions. These planning processes are key building blocks of India's ongoing efforts to bolster adaptive capacities, attract investment in adaptation from a diversity of sources, and to help galvanise public and private sector-led actions to make societies more climate-resilient.

This AdCOM will expedite support for the formulation of NAPs and the implementation of programmes, projects and policies. The country intends to address the identified needs and priorities through a robust adaptation planning framework by developing a National Adaptation Plan for India.

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सत्यमेव जयते

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Save Energy
Reduce Waste
Reduce E-waste
Save Water
LiFE
Lifestyle for Environment
Adopt Healthy Lifestyles
Say no to Single Use Plastic
Adopt Sustainable Food Systems