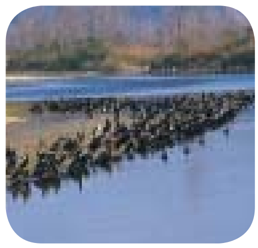
India

Second National Communication to the United Nations Framework Convention on Climate Change

Ministry of Environment & Forests
Government of India
2012

India

Second National Communication to the United Nations Framework Convention on Climate Change



Ministry of Environment & Forests
Government of India
2012

India
Second National Communication to the
United Nations Framework Convention on Climate Change

Secretary, Ministry of Environment and Forests, Government of India and
Chairman, National Steering Committee
Paryavaran Bhawan, CGO Complex
Lodhi Road, New Delhi 110003
Phone: 91-11-24360721
Fax: 91-11-24362746

National Project Director
India's Second National Communication to the UNFCCC
Room No. 112, Paryavaran Bhawan
Ministry of Environment and Forests
CGO Complex, Lodhi Road
New Delhi 110 003
Telefax: 91-11-24360861
E-mail: subodh.kumar@nic.in

Global Environment Facility
Washington DC 20433, USA

United Nations Development Programme
Lodhi Estate, New Delhi 110003

जयंती नटराजन
Jayanthi Natarajan

राज्य मंत्री (स्वतंत्र प्रभार)
पर्यावरण एवं वन
भारत सरकार
नई दिल्ली- 110 003
Minister of State (Independent Charge)
Environment & Forests
Government of India
New Delhi - 110 003

Foreword

On behalf of the Government of India, I have great pleasure in presenting India's Second National Communication in fulfilment of commitment under the United Nations Framework Convention on Climate Change. The Communication has been prepared by a national effort and contributions of experts involving more than 200 scientists and experts belonging to various institutions countrywide, constituted into more than 120 multi-disciplinary teams to work on various aspects of climate change. It is to be noted that the entire process has been participatory in nature involving numerous institutions and stakeholders alike. A National Steering Committee (NSC), with members from 21 Ministries/Departments of the Government of India, oversaw the implementation of the work programme. The Communication has been prepared in accordance with the provisions of the Articles 4.1 and 12.1 of the Convention and guidelines contained in 17/CP.8 of the Conference of Parties. Numerous Technical Consultations as well as stakeholder involvement through National Workshops were undertaken for the process of preparing the National Communication. The highest standards of scientific rigour in conducting this exercise, together with intense peer review, underpinned the implementation of the work programme of the National Communication. The stakeholder consultations, training, thematic and awareness generation events covered more than 1000 participants and were organised through 30 conferences/seminars/workshops/consultations across the country during the project implementation phase. The exercise was coordinated by the Ministry of Environment and Forests, Government of India.

The elements of information comprises, as required, information on Greenhouse Gas Inventory and Vulnerability Assessment and Adaptation besides an overview of the National Circumstances within which the challenges of climate change are being addressed and responded to.

The information provided emanates from studies conducted and constitute an improvement on the earlier studies reported in India's Initial National Communication, bringing out extant and projected high regional and sectoral variability and vulnerability. The Government visualizes the process of preparation of India's Second National Communication as an opportunity to enrich and enhance India's capabilities in identifying constraints, gaps, and related financial, technical and capacity needs to adequately fulfil our obligations under the United Nations Framework Convention on Climate Change.

This national effort has therefore built significant human and institutional capacities. However, we are aware and have identified in our Communication the constraints and the gaps that still exist, and the related financial and capacity building needs, which are required to further improve upon this effort in our future National Communications; so as to ensure continuous reporting on a consistent basis and in accordance with the extant guidelines.

I congratulate all those who have contributed directly and indirectly in this task.

(Jayanthi Natarajan)

Place : New Delhi
Dated : 12.04.2012

Contents

Executive Summary

India is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and the Government of India attaches great importance to climate change issues. The Convention aims at stabilizing the greenhouse gas concentrations in the atmosphere at safer levels that would prevent dangerous anthropogenic interference with the climate system. Eradication of poverty, avoiding risks to food production, 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 geographic area of 3.28 million km^2. Occupying almost 2.3% of the world's land area, it is the 7th largest country in the world but holds nearly 18% of the world's population. This puts the nation under great stress to ably maintain a sustainable development pathway and to harness its resources efficiently. India shelters over 1.21 billion people representing various socio-cultural groups that collectively make up the world's largest democracy.

National Circumstances

India is situated between 66°E to 98°E and 8°N to 36°N and experiences a range of physio-geographic features that are spread widely over its 28 States and 7 Union Territories. These are mainly classified into: (i) mountainous terrain (Himalayan range, Western Ghats), (ii) northern plains, (iii) peninsular plateau, (iv) deserts, (v) coastal plains (east and west coast) and (vi) island groups (Andaman & Nicobar, Lakshadweep). India juts out into the Indian Ocean, and is surrounded by the Arabian Sea on the west and the Bay of Bengal in the east. India is gifted with a variety of climatic conditions due to its distinct geography. India's climate is strongly influenced by the Himalayas in the north and the Thar desert in the west. The Himalayas act as a barrier to the frigid katabatic winds flowing down from Central Asia, keeping the bulk of the Indian sub-continent warmer than most locations at similar latitudes. All these climatic aspects influence the biology, culture and economics of the nation.

Land areas in the north of the country have a continental climate with fierce summer heat that alternates with cold winters; when temperatures plunge to freezing point. In contrast, are the coastal regions of the country, where the warmth is unvarying and the rains are frequent. The rainfall pattern varies drastically at different locations of the country, ranging from an average annual rainfall of less than 13 cm to about 1187 cm (Figure 1).

The peninsular regions, which are primarily rain-fed, extend from the humid west coast to the arid central and eastern parts of the country. The most important feature of India's climate is the season known as the 'monsoon'. The monsoon season is so important and critical to the Indian climate that the rest of the seasons are quite often referred as relative to it. The country is influenced by two seasons of rains accompanied by seasonal reversal of winds from January to July. During winters, dry and cold air blowing from northerly latitudes from a northeasterly direction prevails over the Indian region.This dry, cold wind picks up moisture from the Bay of Bengal and pours it over peninsular India. This is known as the 'northeast' monsoon. Consequent to the intense heat of the summer months, the northern Indian landmass gets heated up and draws moist winds over the oceans, causing a reversal of

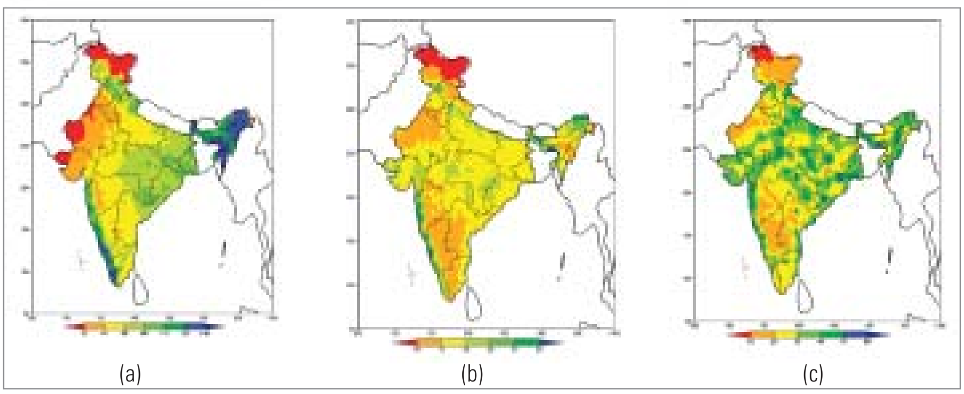


Figure 1:
(a) Mean annual number of rainy days (>2.5 mm/day), (b) Mean intensity of rainfall (mm/day), (c) One day extreme rainfall (cm/day)

the winds over the region. This is called the 'summer' or the 'southwest' monsoon.

India is a land with many rivers. There are twelve major rivers, which are spread over a catchment area of 252.8 million hectares (Mha) and cover more than 75% of the total area of the country. Rivers in India are classified as Himalayan, peninsular, coastal, and inland-drainage basin rivers.

The land use pattern of India shows that about 46.1% of the reported area for land use is under agriculture and approximately 23.9% is under forest and tree cover (Figure 2). The remaining nearly one-third land area is distributed between fallow land, other uncultivated land excluding fallow land and not available for cultivation. The land use pattern in India has been affected by a variety of factors such as population pressure, expanding urbanization, industrial growth, grazing pressure, availability of irrigation facilities, diversion of forest land to other uses, the law of inheritance, and natural calamities like flood and drought.

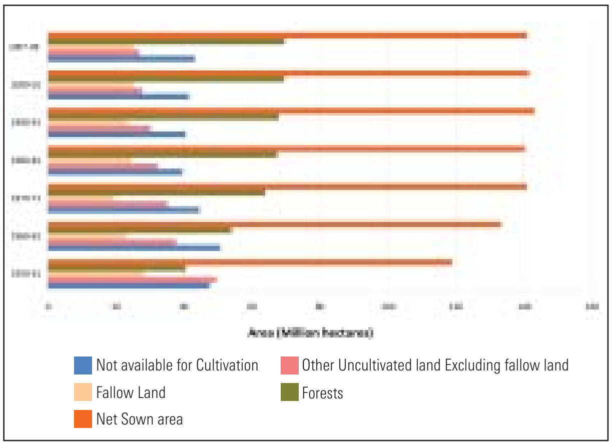


Figure 2: Indian land use changes
Source: Agricultural Statistics at a Glance, 2010

India is endowed with diverse forest types ranging from tropical wet evergreen forests in the northeast and the southwest, to tropical dry thorn forests in central and western India. According to the various 'State of Forest' reports (published by the Ministry of Environment and Forests MoEF), the forests of India can be divided into 16 major types comprising 221 sub-types. The area under forests as per land records was 6,83,100 km^2 in 1994 and 6,96,260 km^2 in 2007. India's forest cover for 2007 was assessed by the Forest Survey of India through satellite imagery interpretation at 6,90,899 km^2 (Figure 3). It is to be noted that the forest cover of India has been increasing steadily over the years due to various conservation and climate-friendly policies of the Government. This increase is despite diversion of forestland for non-forest purposes like agriculture and developmental activities such as river valley projects, industrialization, mining, and road construction.

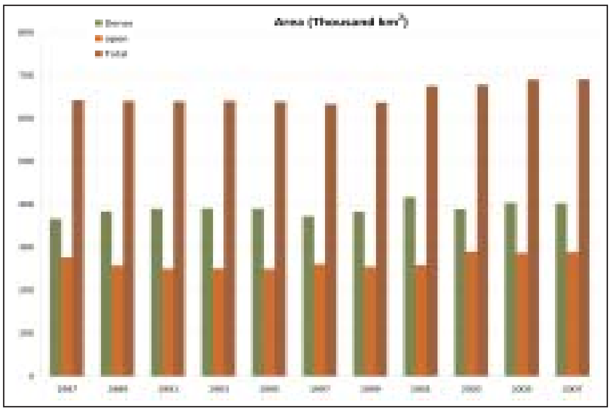


Figure 3: Indian forest cover assessments, 1987-2007
Source: State of Forest Report, 1987 - 2009

Indian society is an agrarian society with 70% of the population almost completely dependent on agriculture, even though the share of agriculture in the gross domestic product (GDP) has been continuously declining. Spatially, it is the most widespread economic pursuit, claiming more than 40% of the country's total area. Agriculture will continue to be important in India's economy in the years to come. It feeds a growing population, employs a large labour force, and provides raw material to agro-based industries. Given the physical and biogenetic diversity of the Indian subcontinent, a strategy of diversified and regionally differentiated agriculture is desirable for improving the economy and augmenting its resources. This is indeed a great policy challenge and opportunity; particularly so in an emerging environment which regards biodiversity as nature's bounty and not as a constraint to technological progress. One of the focal areas for revitalizing Indian agriculture has been crop yield, itself a function of many factors like climate, soil type and its nutrient status, management practices and other available inputs. Of these, climate plays an important role; probably more so in India, where the majority of agriculture is dependent on the monsoon and natural disasters such as droughts and floods are very frequent. Therefore, efficient crop planning requires a proper understanding of agro-climatic conditions. This calls for collection, collation, analysis and interpretation of long-term weather parameters available for each region to identify the length of the possible cropping period, taking into consideration the availability of water.

Population levels and growth rates drive national consumption of energy and other resources. India's population has steadily risen over the years, crossing the one billion mark in 2000 and increasing annually by about 15 million since then. With a population of 846 million in 1991, 914 million in 1994, 1027 million in 2001 and 1210 million in 2011, India is the second-most populous country in the world. The decadal population growth rate has, however, steadily declined from 24.8% during 1961-71 to 21.3% during 1991-2001, and 17.6% during 2001-2011. This has resulted in reducing births by almost 36 million over the last thirty years.

India's population density is very high; the density of 264 persons/km^2 in 1991 increased to 325 persons/km^2 in 2001 and 382 persons/km^2 in 2011. 12 Indian states/ union territories had a population density of less than 250 persons/km^2, 7 had between 251-500 persons/km^2, 9 had between 501-1000 persons/km^2 while 7 had above 1000 persons/km^2 according to the 2011 census (Figure 4). This, coupled with low per capita incomes and low adaptive capacity of the majority of this population, renders them vulnerable, particularly to the impacts of climate change on coastal areas and fisheries.

In 1994, India had more than 160 million households. Approximately three-fourths of these lived in rural areas, but were responsible for only one-third of the total national energy consumption (NSSO 1993-94; Census of India, 2001). Since then, demographic changes have led to an appreciable rise in the total number of households in India; with the urban share increasing faster than the rural one. There is also an increase in energy consuming appliances at all levels. Household ownership of appliances has gone up in both rural and urban areas since 2000, sometimes by a factor of 2, especially in the case of connectivity and ownership of mobile phones. Star-rated appliances with higher energy efficiency have also started penetrating the market in the last few years. With proper incentives and programmes by the government and private sector, these could provide a major thrust in the demand-side management of electricity.

The pace of economic growth is usually regarded as the primary indicator of a country's macro-economic health. By this measure, India has done very well in this decade, especially in the last five years, with GDP growth averaging an unprecedented 8.4% a year from 2005-06 to

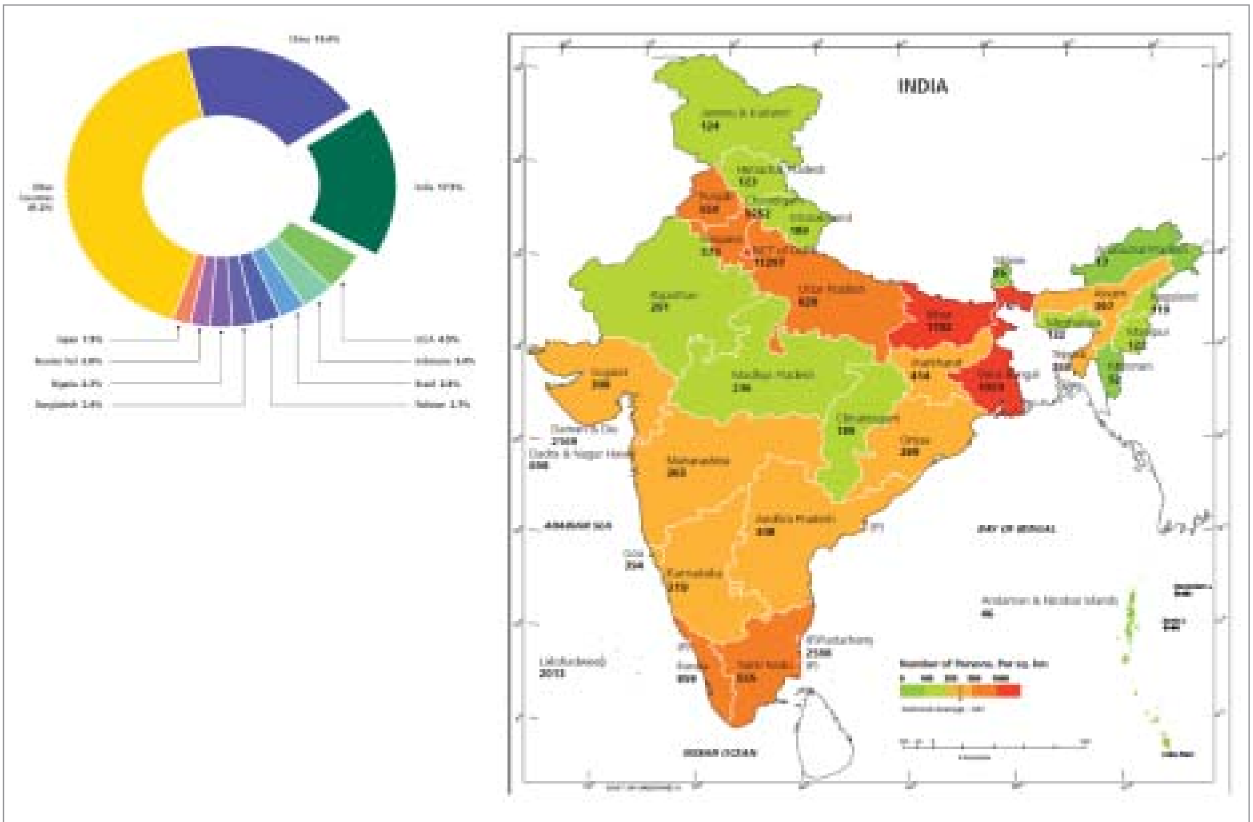


Figure 4: Indian population density, 2011

Source: Preliminary Report of Census for India, 2011

2009-10. The previous best five-year period for growth was in 1992-93 to 1996-97 (at 6.6% a year), triggered by the initial burst of economic reforms following the balance of payments crisis of 1991. That earlier spurt in investment, productivity and growth had faltered after 1996 because of several factors. As a consequence, growth had slowed to an average of 5.5% during the Ninth Five-Year Plan period, 1997-98 to 2001-02. It dropped even lower to 3.8% in 2002-03 because of a sharp, drought-induced fall in agricultural output. Since then, India has witnessed an extraordinary boom, with the aggregate investment rate surging above 37% of GDP by 2007-8 and economic growth soaring to 9% or higher in the last three years, 2008-09 to 2010-11. The proximate drivers of this growth spurt include: (i) the sustained investment boom, (ii) cumulative productivity-enhancing effects of reforms, (iii) an unusually buoyant international economic environment and (iv) a demand-and-technology driven acceleration of modern services output. Inspection of the sectoral composition of growth shows that the Ninth Plan slowdown was confined to agriculture and industry; services continued to grow and even accelerated. Industry picked up steam from 2002-03 and continued to grow robustly right through to 2010-11. Agricultural growth remained variable, substantially dependent on weather conditions.

Table 1: National circumstances, 2010	
CRITERIA	**Measure**
Population (million, 2011)	1210
Relevant area (million square kilometers)	324
GDP at Factor cost (1999-2000 prices) Rs billion	61332
GDP at Factor cost (1999-2000 prices) US$ billion	1371
GDP per capita (1999-2000 prices) US$	1133
Share of industry in GDP (percentage)	25.8
Share of services in GDP (percentage)	57.3
Share of agriculture in GDP (percentage)	16.9
Land area used for agricultural purposes (million square kilometers)	1.95
Urban population as percentage of total population	34
Forest area (million square kilometers) (2007)	0.69
Livestock population excluding poultry (million) (2003)	464
Population below poverty line (percentage) (2004)	21.8
Life expectancy at birth (years) (2006)	63.5
Literacy rate (percentage, 2011)	74.04

Sources: Economic survey 2010-11; Census of India, 2011; Agricultural Statistics at a Glance 2010; 17th Indian Livestock Census 2003; State of Forest Report 2009; Planning Commission, 2007

Note: The monthly per capita poverty lines for rural and urban areas are defined as Rs. 356.30 and Rs. 538.60 respectively for 2004-05

Energy and climate change-related concerns of the Indian economy include the growing gap between the demand and supply of energy and environmental externalities associated with energy use. The Indian economy has been growing rapidly since the 1990s, with an even higher growth in the energy sector (Figure 5). This was because the economic growth was driven by energy intensive sectors, where the energy efficiency was low by international standards. High growth of these sectors has resulted in a high elasticity of energy consumption and environmental emissions with respect to GDP. Especially in the electricity sector, the electricity consumption has grown at a rate higher than the GDP and energy for the past two decades, with the trend becoming more pronounced in the 1990s. This implies substantial increases in electric power generation and transmission capacities, petroleum products and natural gas demand and consumption.

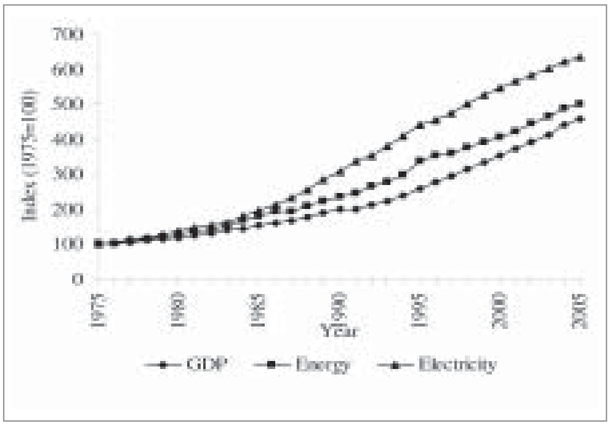


Figure 5: Growth of Energy, Electricity, and the Indian Economy
Sources: Economic Survey of India, 1991-2006; CMIE, 2003-2007; Central Statistical Organization (CSO), 2006

The rapid economic growth, expanding industrialisation, increasing incomes, rapidly rising transport and modernising agriculture are leading to a high growth in energy use in India, thereby causing serious environmental concerns. The sectoral energy consumption in India has been rising due to more production, despite a reduction in specific energy consumption patterns in almost all the sectors.

In recent years, the government has rightly recognized the energy security concerns of the nation and placed more importance on energy independence. Various initiatives have been taken towards establishing energy efficient technologies, energy conservation measures and regulatory frameworks, while diversifying energy sources to meet national goals as well as simultaneously address climate change concerns.

The reduced energy intensity of the Indian economy since 2004, has been marked by an economic growth rate of over 9% per annum, which has been achieved with an energy growth of less than 4% per annum. This reduced energy intensity, at the relatively low level of India's per-capita GDP, has been made possible by a range of factors, including India's historically sustainable patterns of consumption, enhanced competitiveness, pro-active policies to promote energy efficiency, and more recently, the use of the Clean Development Mechanism to accelerate the adoption of clean energy technologies.

Greenhouse Gas Inventory Information

This section presents a detailed description of greenhouse gas (GHG) inventory of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) emitted by sources and their removal by sinks. The sectors covered include: energy, industrial processes, agriculture, land use, land -use change and forestry, and waste for the year 2000. The reporting is in accordance with the revised guidelines 17/CP.8 for reporting National Communications from non-Annex 1 parties to the UNFCCC. The Ministry of Environment and Forests (MoEF), which is the focal point of climate change in the Indian government, published the GHG emission profile of India for the year 2007 in 2010. A brief description of the same is also provided. While reporting the GHG inventory, care has been taken to include consideration of the methodology used, the Quality assurance/ Quality control (QA/QC) measures applied, the results of the key source analysis and Tier 1 quantification of uncertainties associated with the estimates.

In 2000, India emitted 1523777.44 Gg CO_2 equivalent (1523.8 million tons of CO_2 eq.) from the energy, industrial processes, agriculture, and waste management sectors. The summary of the GHG emissions by each sector is presented in Table 2. The land use, land-use change, and forestry (LULUCF) sector was a net sink in 2000. With the inclusion of LULUCF, the net emissions in 2000 were 1301209.39 Gg of CO_2 equivalent.

The total amount of CO_2, CH_4 and N_2O emitted were 1024772.84 Gg, 19392.30 Gg, and 257.42 Gg respectively, equalling an emission of 1511811.34 Gg CO_2 eq. (excluding LULUCF) Additionally, the industrial process and product use sector emitted 0.220 Gg of Tetrafluoroethane (HFC134a), 0.420Gg of Fluoroform (HFC-23), 0.870 Gg of Tetrafluoromethane (CF_4), 0.087 Gg of Hexafluoroethane (C_2F_6) and 0.013 Gg of Sulphur hexafluoride (SF_6) which together equals 11966.1 Gg CO_2 eq. emissions. Figure 6 gives the relative contribution of the various gases to the total CO_2 equivalent emissions from the country.

The energy sector emitted 1027015.54 Gg of CO_2 eq., contributing 67% of the total GHG emissions in 2000 excluding LULUCF. The agriculture sector emitted 355600.19 Gg CO_2 eq, which was 23.3% of the total GHG emissions. The industrial processes and product use sector emitted 88608.07 Gg CO_2 eq., or 6.0% of the total. The waste sector emitted 52552.29 Gg CO_2 eq in 2000, which was 3.4% of the total GHG emissions. Figure 7 gives the relative distribution of emissions by sectors.

The relative emissions of CO_2 from the energy sector to the total GHG emissions excluding LULUCF was by far the largest in 2000. CO_2 was 92.9% of the total emissions from the energy sector. Emissions of CH_4 and N_2O originated mainly from the agriculture sector - 73.0% of total CH_4 and 75.0% of total N_2O emitted in 2000 were from the agriculture sector. The synthetic gases (HFCs, PFCs and SF_6) were entirely emitted from the industrial processes. The relative distribution for gas-by-gas emissions from each sector is presented in Figure 8.

Vulnerability Assessment And Adaptation

India has reasons to be concerned about climate change. Its large population depends upon climate-sensitive sectors like agriculture and forestry for its livelihood. Any adverse impact on water availability due to recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security, cause dieback of natural ecosystems including species that sustain the livelihood of rural households, and adversely impact the coastal system due to sea-level rise and increased extreme events. This aside, achievement of vital national development goals related to other systems such as habitats, health, energy demand and infrastructure investments would be adversely affected.

Keeping in view the limitations of the global climate models during the Initial National Communication (INC), high-resolution simulations for India were carried out using the second generation Hadley Centre Regional Climate Model (HadRM2). It was envisaged, during the Second National Communication (SNC), to add new scenarios from the bouquet of emission scenarios available from the IPCC Special Report on Emission Scenarios. Subsequently, the A1B Scenario was chosen as the most

Table 2: India's national greenhouse gas inventories (in Giga Gram) of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the year 2000.

Greenhouse gas source and sink categories	CO_2 (emissions)	CO_2 (removals)	CH_4	N_2O	HFC-134a	HFC 23	CF_4	C_2F_6	SF_6	CO_2 eq. Emissions*
Total (Net) National Emission (Giga gram per year)	**1,024,772.84**	**236,257.43**	**19,944.68**	**264.16**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**1,301,209.39**
1. All Energy	**952,212.06**		**2,991.42**	**38.66**						**1,027,015.54**
Fuel combustion										
Energy and transformation industries	541,191.33		6.96	7.78						543,749.85
Industry	228,246.91		4.29	2.40						229,079.90
Transport	95,976.83		9.50	6.22						9,8104.12
All other sectors	86,797.00		1,618.50	22.26						127,686.10
Fugitive Fuel Emission										
Oil and natural gas system			766.52							16,096.83
Coal mining			585.65							12,298.74
2. Industrial Processes	**72,560.78**		**5.39**	**12.80**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**88,608.07**
3. Agriculture			**14,088.30**	**192.73**						**355,600.19**
Enteric Fermentation			10,068.07							211,429.43
Manure Management			241.19	0.07						5,087.77
Rice Cultivation			3,540.98							74,360.56
Agricultural crop residue			238.06	6.17						6,911.96
Emission from Soils				186.49						57,810.47
4. Land use, Land-use change and Forestry*		**236,257.43**	**552.38**	**6.74**						**(222,567.43)**
Changes in Forest and other woody biomass stock		217,393.8	552.38	6.74						(203,704.42)
Forest and Grassland Conversion		18,788.08								(18,788.08)
Settlements		75.55								(75.55)
5. Other Sources as appropriate and to the extent possible			**2,307.19**	**13.23**						**52,552.29**
5a.Waste										
5b. Emissions from Bunker fuels #	**3,467.12**		**0.05**	**0.10**						**3,498.86**
5c. CO_2 emissions from biomass #	**376,005.00**									**376,005.00**

Not counted in the national totals; *Converted by using Global warming potential (GWP) indexed multipliers of 21, 310 , 1300, 11700, 6500, 9200, and 23900 for converting CH_4, N_2O , HFC-134a, HFC-23, CF_4, C_2F_6, SF_6 respectively

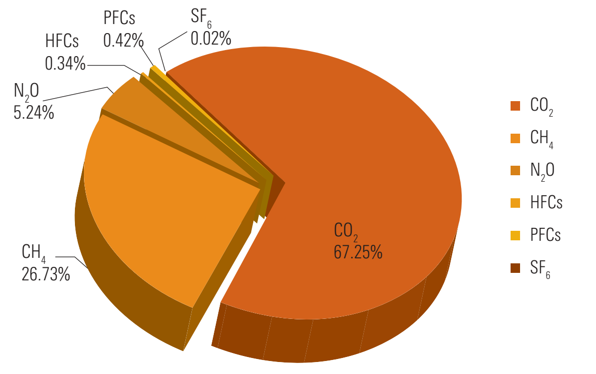


Figure 6: Distribution of Greenhouse gas emissions in 2000

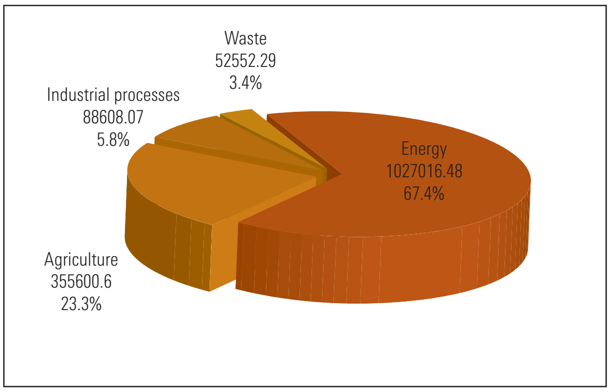


Figure 7: Greenhouse gas emission distribution by sectors in 2000

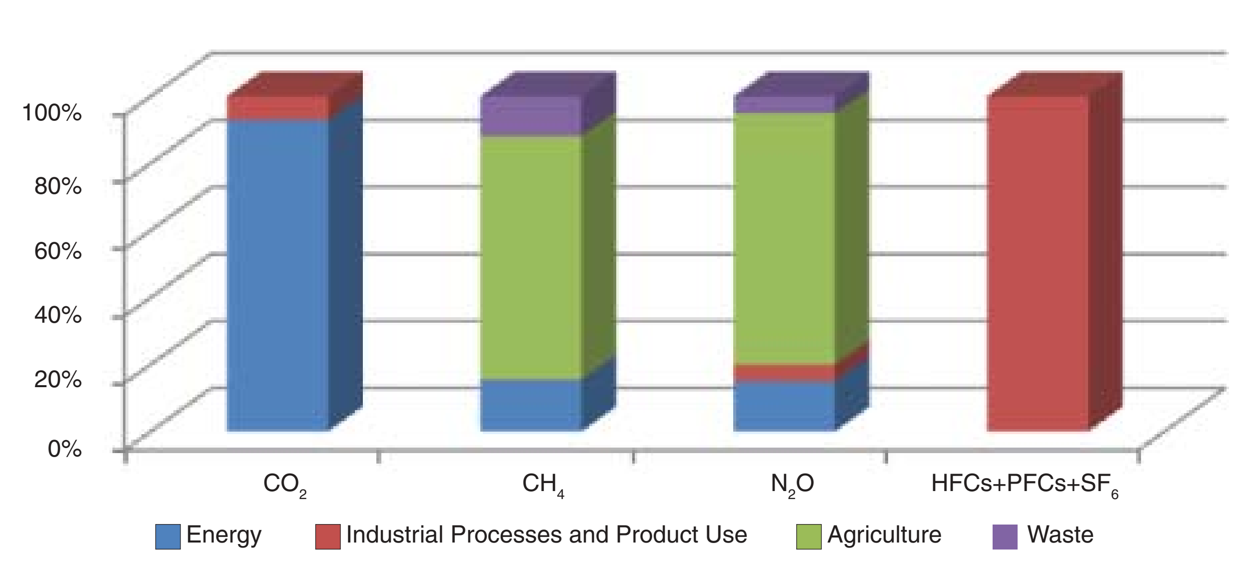


Figure 8: Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2000

appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory. India now has access to PRECIS - the latest generation of regional models from the Hadley centre. The PRECIS is an atmospheric and land surface model having 50km x 50km horizontal resolution over the South Asian domain and is run by the Indian Institute of Tropical Meteorology (IITM), Pune.

Climate Change Projections

The climate change scenarios were analysed using the above mentioned high-resolution regional climate model, PRECIS. The model simulations have been carried out for three QUMP (Quantifying Uncertainties in Model Projections) for A1B scenario for the period 1961-1990 (baseline simulation) and for three time slices - 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2098). Some basic parameters like rainfall, surface air temperature, and mean sea level pressure were analysed to get climatic projections towards the end of the present century. Three PRECIS runs: Q0, Q1 and Q14 were carried out for the period 1961-2098 and were utilized to generate an ensemble of future climate change scenarios for the Indian region. It appears that there may not be significant decrease in the monsoon rainfall in the future except in some parts of the southern peninsula (Figure 9). Q0, Q1 and Q14 simulations project 16%, 15% and 9% rise respectively in the monsoon rainfall towards the end of the 21st century.

PRECIS simulations for 2020s, 2050s and 2080s indicate an all-round warming over the Indian subcontinent. Figure 10 shows the mean annual surface air temperature from 1961(first year of model simulation) to 2098 (last year of model projections) as simulated by PRECIS. Data indicates that Q14 simulations are warmer than the remaining two simulations. The annual mean surface air temperature rise by the end of the century ranges from 3.5°C to 4.3°C.

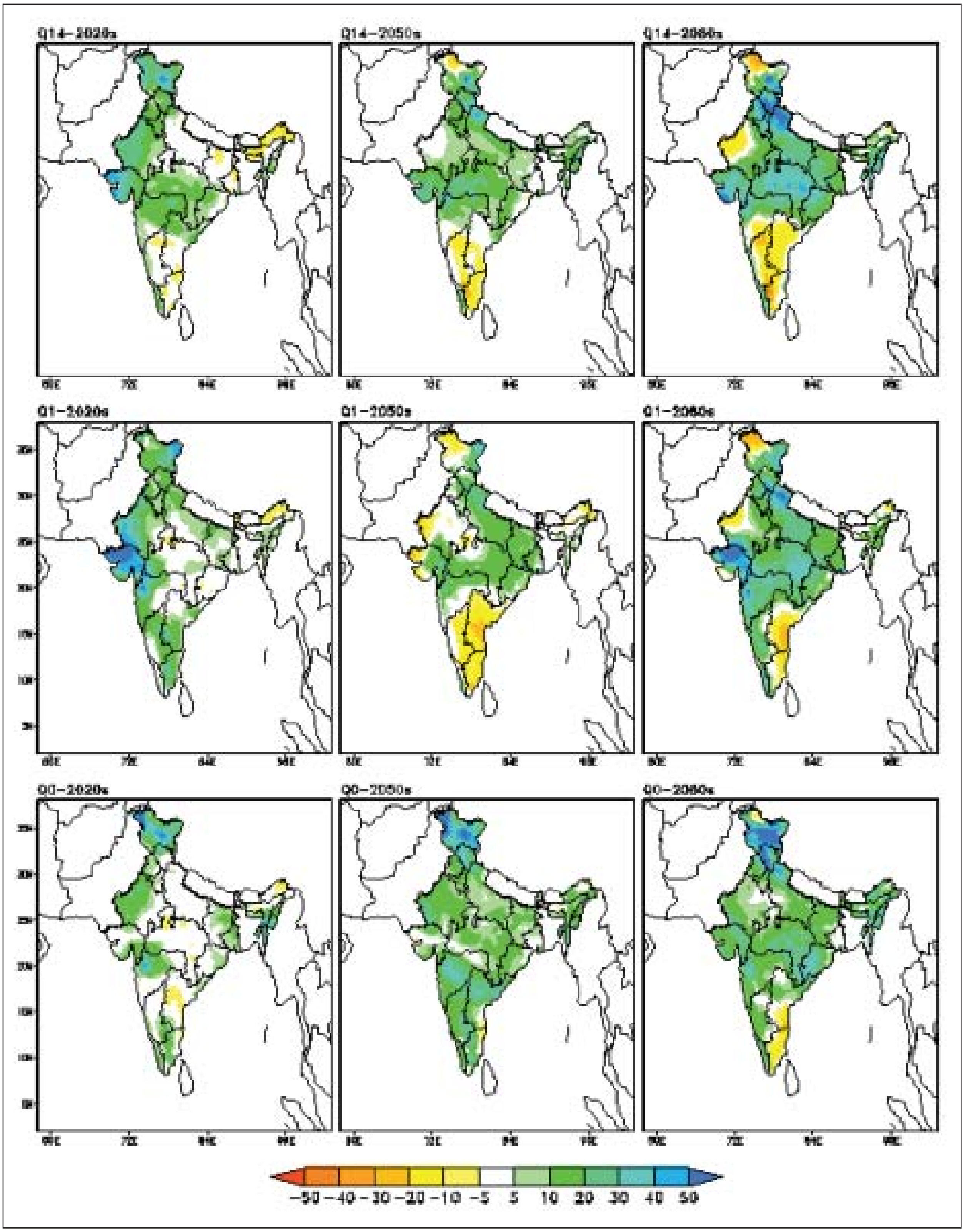


Figure 9: Simulated percentage change in mean monsoon precipitation in 2020s, 2050s and 2080s with respect to baseline (1961-1990)

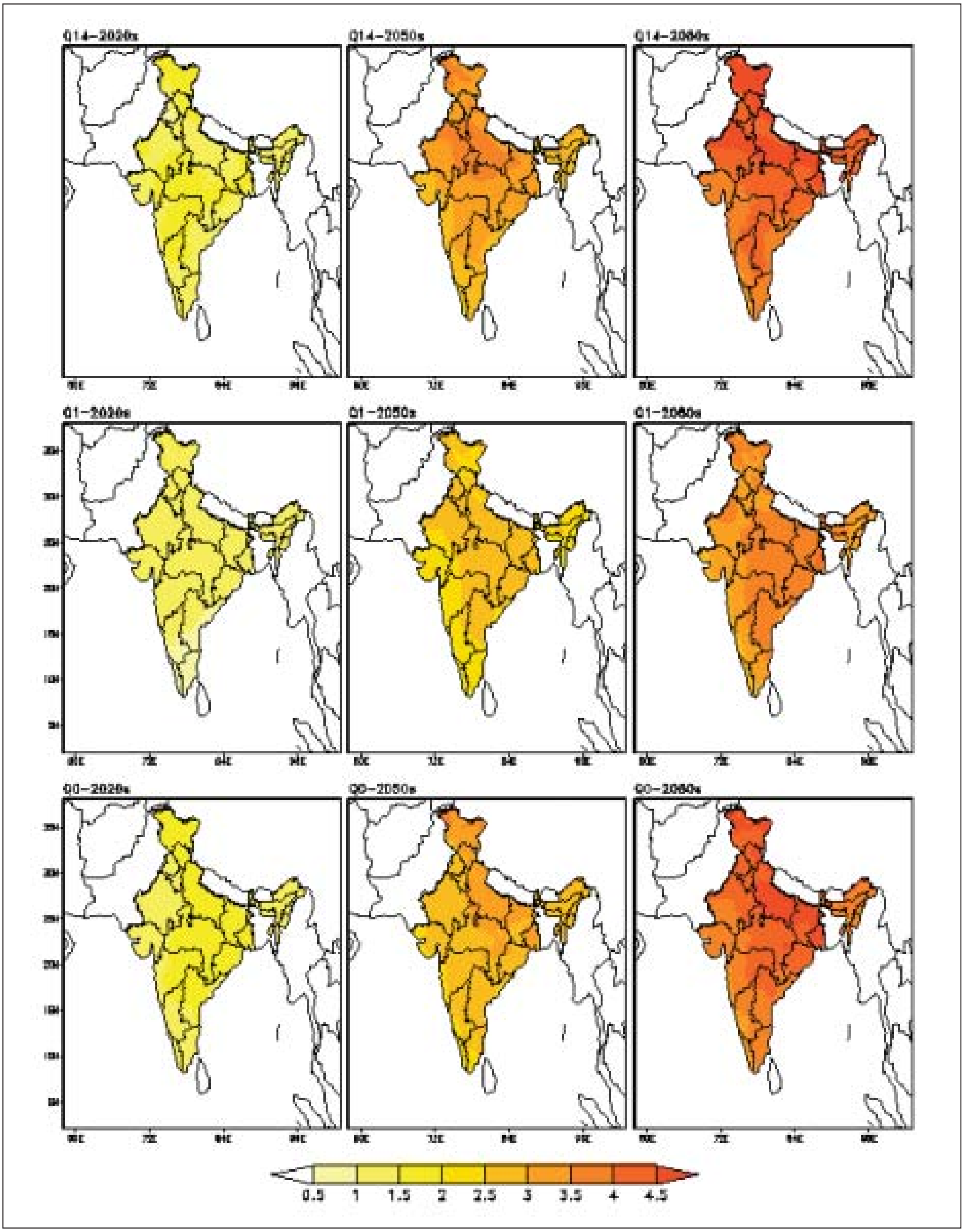


Figure 10: Simulated change in mean annual surface air temperature in 2020s, 2050s and 2080s with respect to baseline (1961-1990)

Impact Assessment

Impact Assessment on Water Resources

Changes in key climate variables; namely temperature, precipitation and humidity, may have significant long term implications for the quality and quantity of water. The possible impacts of climate change on the water resources of the river basins of India have been assessed using the hydrologic model SWAT[1] (Soil and Water Assessment Tool). The model requires information on terrain, soil profile and land-use of the area as input, which have been obtained from global sources. These three elements are assumed to be static in the future as well. The weather conditions (for model input) have been provided by the IITM Pune (PRECIS outputs). Simulated climate outputs from PRECIS regional climate model for present /baseline (1961–1990, BL), near-term (2021-2050, MC) and long-term (2071-2098, EC) for A1B IPCC SRES socio-economic scenario has been used. Q14 QUMP (Quantifying Uncertainty in Model Predictions) ensemble has been used for the simulation. Impacts of climate change and climate variability on the water resources are likely to affect irrigated agriculture, installed power capacity, environmental flows in the dry season and higher flows during the wet season, thereby causing severe droughts and flood problems in urban and rural areas.

Detailed outputs have been analysed with respect to the two major water balance components of water yield and actual evapo-transpiration (ET) that are highly influenced by the weather conditions dictated by temperature and allied parameters. The majority of river systems show an increase in precipitation at the basin level (Figure 11). Only Brahmaputra, Cauvery and Pennar show marginal decrease in precipitation under MC. The situation under EC improves, wherein all the river systems exhibit an increase in precipitation. The change in evapo-transpiration under the MC scenario exhibits an appreciable increase (close to 10%) for the Brahmaputra, Indus and Luni river basins. All other systems show marginal increase or

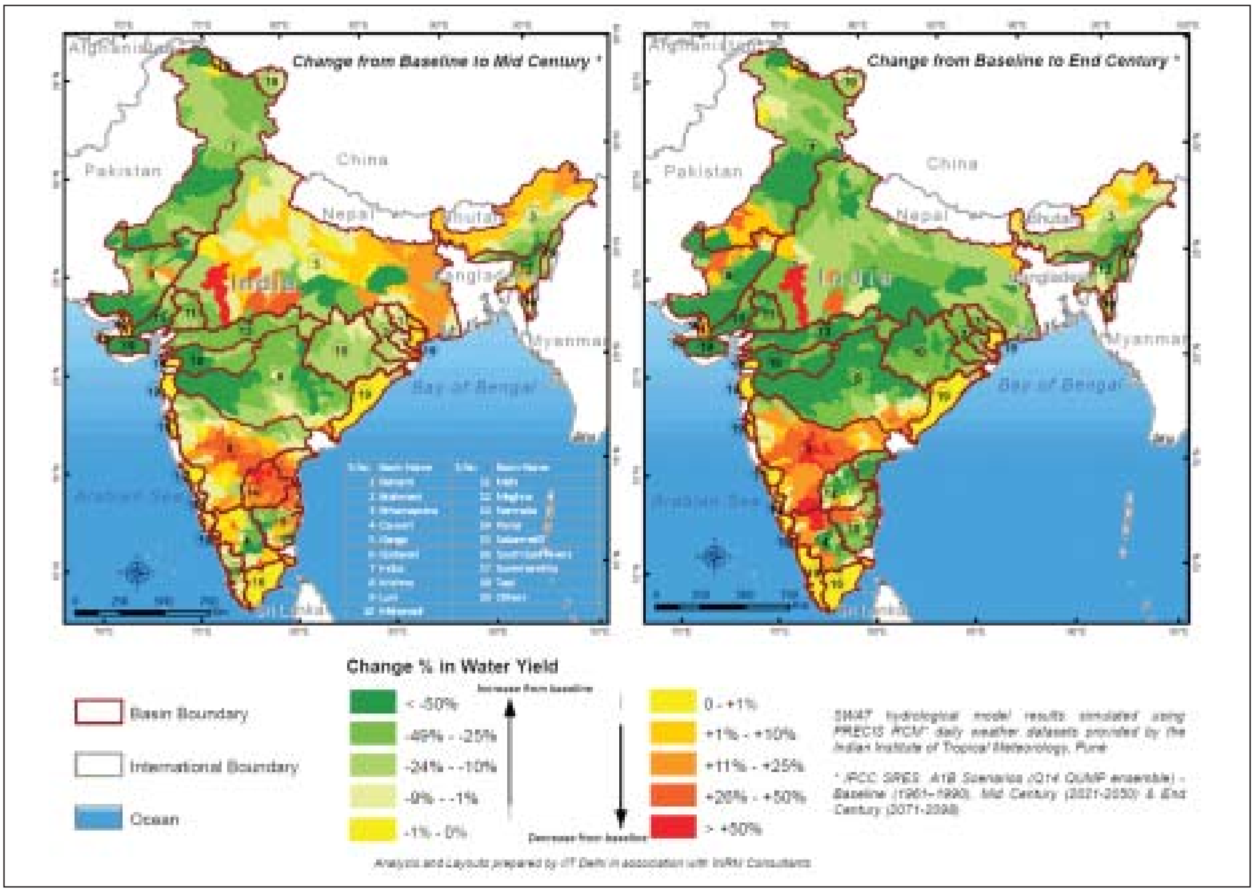


Figure 11: Percentage Change in Water Yield across India

1. The Soil and Water Assessment Tool (SWAT) model is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as to man-made interventions on water and sediment yields in un-gauged catchments. The model (a) is physically based, (b) uses readily available inputs, (c) is computationally efficient to operate and (d) is 'continuous time' and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models, it does not require much calibration and therefore can be used on un-gauged watersheds (which are in fact, the usual situation).

decrease. Only two river basins - Cauvery and Krishna - show some decrease in ET under the EC. For a majority of the river systems, the ET has increased by more than 40%. The major reason for such an increase in ET is on two accounts : (i) increase in the temperature and (ii) increase in precipitation, which enhances the opportunity of ET.

Impact Assessment on Forests

The impacts of climate change on forests in India are assessed based on the changes in area under different forest types, shifts in boundary of forest types and Net Primary Productivity (NPP). This assessment was based on: (i) spatial distribution of current climatic variables, (ii) future climate projected by relatively high-resolution regional climate models for two different periods for the A1B climate change scenario, and (iii) vegetation types, NPP and carbon stocks as simulated by the dynamic model IBIS v.2 (Integrated Biosphere Simulator).

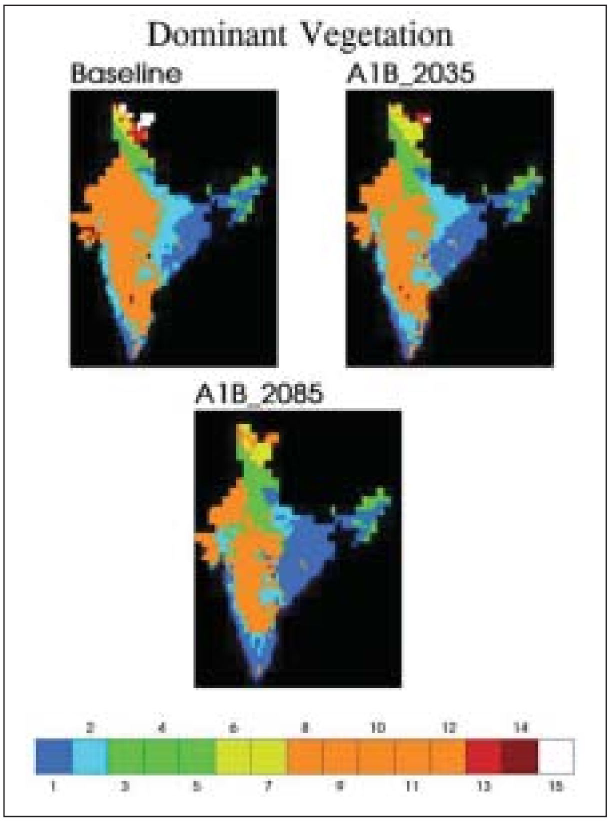


Figure 12: Forest type distribution and extent simulated by IBIS for the baseline case and A1B (2035 and 2085) scenarios. (The numbers refer to the following vegetation types 1: Tropical evergreen forest / woodland, 2: Tropical deciduous forest / woodland, 3. Temperate evergreen broadleaf forest / woodland, 4: Temperate evergreen conifer forest / woodland, 5: Temperate deciduous forest / woodland, 6: Boreal evergreen forest / woodland, 7: Boreal deciduous forest / woodland, 8: Mixed forest / woodland, 9: Savanna, 10: Grassland/ steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15. Polar desert / rock / ice)

SRES scenario A1B is considered for two future time frames: (i) Time frame of 2021-2050 (atmospheric CO_2 concentration reaches 490ppm), which is labelled as '2035', (ii) Time frame of 2071-2100 (atmospheric CO_2 concentration reaches 680ppm), which is labelled as '2085'. Observed climatology for period 1961-91 was treated as baseline for the simulations.

The vegetation distribution simulated by IBIS for baseline, and A1B scenario in the simulation grids (Figure 12) illustrates an expansion of tropical evergreen forests (IBIS vegetation type 1) in eastern India plateau in the A1B scenario. Similar trend is observed in the Western Ghats. It is interesting to note that there is almost no vegetation type change in the northeast. Further, there is a slight expansion of forests into the western part of central India.

Impact on Net Primary Productivity (NPP) and Soil Organic Carbon (SOC): The NPP tends to increase over India for the A1B scenario (Figure 13). It increases by an average of 30.3% by 2035, and by 56.2% by 2085 for A1B scenario. Notably, increase is higher in the northeastern part of India due to warmer and wetter climate predicted there.

A trend similar to NPP distribution is simulated for soil organic carbon (SOC).This is to be expected as increased NPP is the primary driver of higher litter input to the soil. However, the quantum of increase compared to baseline in this case is lower. This is due to the inertia of the SOC pool and increased soil respiration. The estimates for both NPP and SOC increase should be viewed with caution as IBIS, compared with other dynamic vegetation models, tends to simulate a fairly strong CO_2 fertilization effect. This can partly be explained by the fact that the nitrogen cycle and acclimation of soil microbiology to the higher temperatures are not explicitly taken into account in IBIS. It also does not simulate forest fires, which are very common especially in dry deciduous forests of India, dynamically. IBIS does not simulate changed pest attack dynamics and thus, the impact of increased or decreased pest attack in a changed climate is not included.

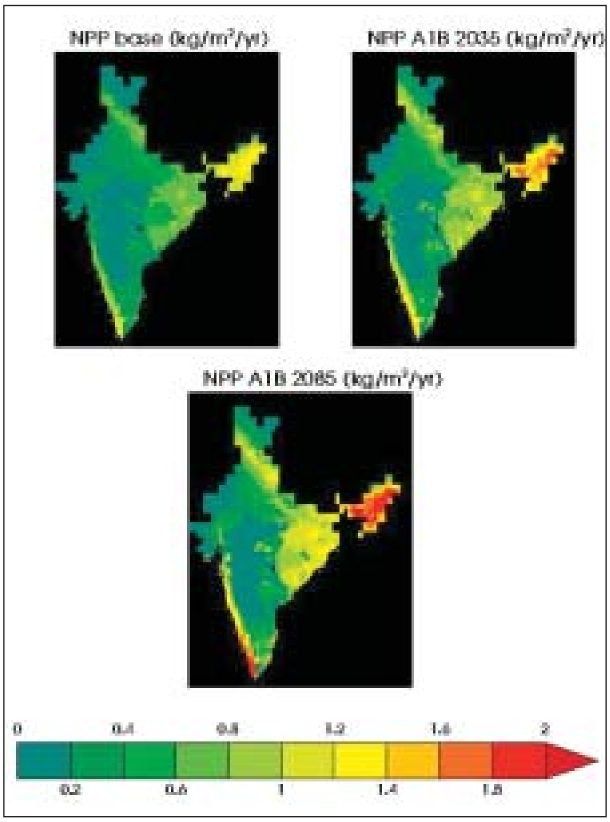


Figure 13: NPP distribution (kgC/m²/year) simulated by IBIS for baseline and A1B scenarios

Vulnerability of Indian forests: Forests in India are already subjected to multiple stresses including - over-extraction, insect outbreaks, livestock grazing, forest fires and other anthropogenic pressures. Climate change will be an additional stress. Forests are likely to be more vulnerable to climate change. Thus, a vulnerability map is developed to assess the vulnerability of different forest types and regions. A grid is marked 'vulnerable' if there is a change in vegetation, as simulated between the baseline and the future (both 2035 and 2085, and A1B SRES scenario, in this case) vegetation. This means that the future climate may not be optimal to the present vegetation in those grids. The distribution of this vulnerability in the country is shown in Figure 14.

Impact Assessment on Indian Agriculture

A combination of field studies and simulation models with comprehensive input data-sets have been used to assess possible impacts of climatic variability and climate change on Indian agriculture. This has been supplemented with statistical tools and available historical data and analysis.

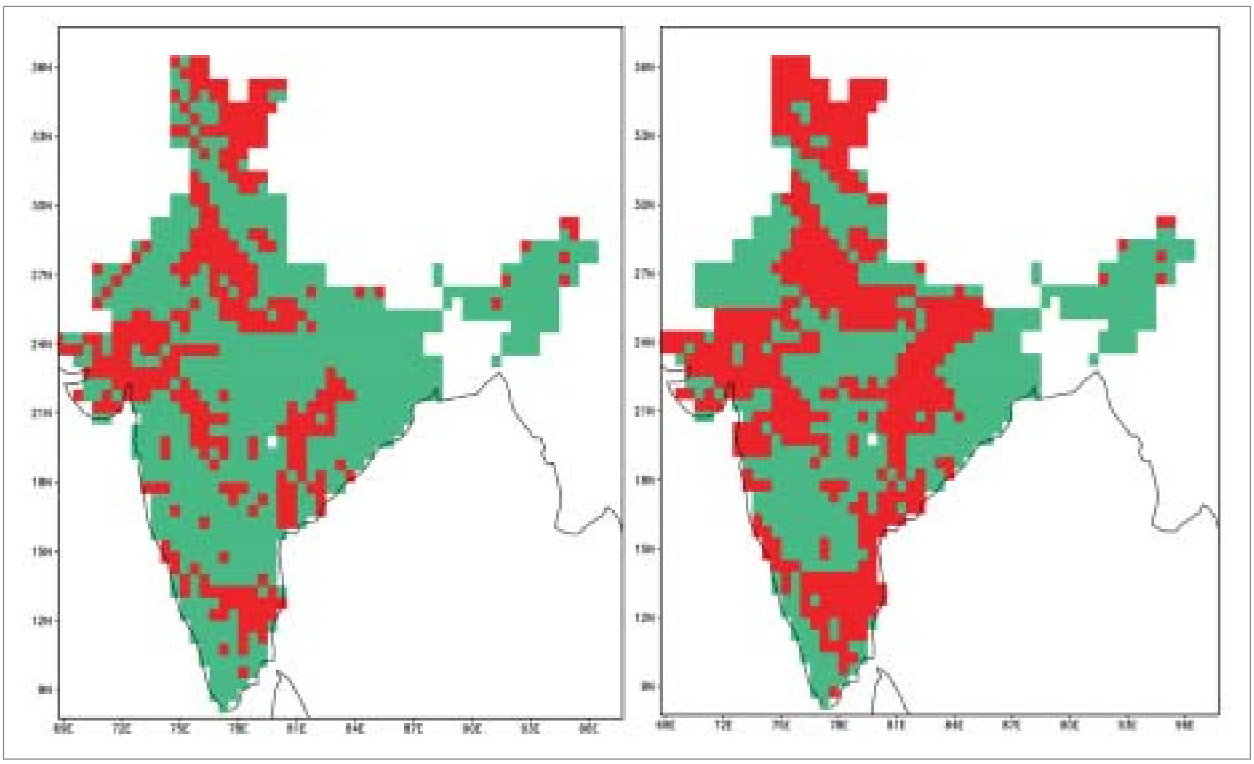


Figure 14: Vulnerable grids (marked red) in the A1B scenario. Left panel is for timeframe of 2021-2050 (30.6% vulnerable grids). The right panel is for the timeframe of 2071-2100 (45.9% grids are vulnerable).

The simulation analysis using InfoCrop[2] models were carried out with inputs of the gridded weather data , soil data , climate change scenario data , crop management and genetic coefficients for respective crop varieties wherever applicable. For plantation crops, the research information from studies in controlled environments was used to fine-tune data in the simulation models and to develop regression models for studying the climate change impacts on its productivity.

Impact of Climate change on Crop: A rise in atmospheric carbon dioxide to 550 ppm under controlled environment conditions - [Free Air CO_2 Enrichment - FACE, Open Top Chambers (OTC)] -, enhanced the yields of wheat, chickpea, green gram, pigeon pea, soybean, tomato and potato between 14% and 27%. These enhancements were largely due to the increase in the number of storage organs. In most of the crops, this was accompanied by a small reduction (2 to 10%) in the protein content. In plantation crops like coconut, areca nut and cocoa, increased CO_2 led to higher biomass.

In the case of rice - hybrid and its parental lines - elevated CO_2 positively affected a few grain quality traits such as head recovery, test weight, proportion of high density grains and germination characteristics but adversely affected traits like aroma, gelatinisation temperature (measurement of cooking quality), protein and micro-nutrient contents. Sunflower hybrids grown under elevated CO_2 conditions inside open top chambers, showed a significant increase in biomass (61-68%) and grain yield (36-70%) but the quality of the produce was adversely affected in terms of protein and micro-nutrient contents.

The magnitude of the impact of climate change on wheat production in India, assessed through simulation studies, indicated that an increase in 1°C in mean temperature, associated with CO_2 increase, would not cause any significant loss if simple adaptation strategies such as change in planting date and varieties are used. The benefits of such simple adaptation strategies, however, gradually decrease as temperature increases to 5°C. In the absence of adaptation and CO_2 fertilization benefits, a 1°C increase in temperature alone could lead to a decrease of 6 million tonnes of wheat production. This loss is likely to increase to 27.5 million tonnes in case of a 5°C increase in mean temperature.

Field experiments in Temperature Gradient Tunnels (TGTs) and by varying dates of sowing were undertaken to quantify the effects of increase in temperature on growth and yield of rice, wheat, potato, green gram, soybean, and chickpea. An increase of temperature from 1 to 4°C reduced the grain yield of rice (0 to 49%), potato (5 to 40%), green gram (13 to 30%) and soybean (11 to 36%). The linear decrease per °C temperature increase was 14%, 9.5%, 8.8%, 7.3%, and 7.2% in rice, potato, soybean, wheat, and green gram respectively. Chickpea, however, registered a 7 to 25% increase in seed yield with an increase in temperature up to 3°C, but was reduced by 13% at 4°C increase in temperature. Rice showed no significant change in yield upto an increase of 1°C temperature.

Legumes are the major rain-fed agro-ecosystems of the country. Simulation studies were conducted using InfoCrop models for soybean and groundnut and the DSSAT CROPGRO model for chickpea with projected changes in temperature, CO_2 and rainfall. The current (baseline, 1961-1990), A1B (2021-2050) and A1B (2071-2100) scenarios all indicated a positive impact of future climate (combined change in temperature, rainfall and CO_2 levels) on their productivity. Average simulated rain-fed yields under current (baseline) scenario were 2144, 2473 and 1948 kg/ha for soybean, groundnut and chickpea respectively. Soybean was observed to have a 10%, and 8 % increase in yield in A1B (2021-2050) and A1B (2071-2100) respectively. In the case of groundnut, except for A1B (2071-2100), which showed a decline of 5% in yield, the other scenarios showed 4-7% increase in rain-fed yields as compared to the current yield. Chickpea showed an increase in yield to the tune of 23% and 52% by A1B (2021-2050) and A1B (2071-2100) scenarios respectively. Across all locations, the rain-fed yields of soybean and groundnut showed significant positive association with crop season rainfall while association with temperature was non-significant. This indicates that under rain-fed conditions, the availability of water will remain a major limiting factor for the yields realized by the farmers. However, for chickpea, which is a post-rainy winter season crop, the simulated rain-fed yield showed a significant positive association with crop season temperature, while with crop season rainfall (which is received in very meagre amount) no significant association was observed. The greater positive impact of future climate on chickpea was associated with both increase in temperature and CO_2 levels as the optimum temperatures for chickpea growth and yield are between 22-28°C which is much above the

2. InfoCrop is a generic dynamic crop simulation model designed to simulate the effects of weather, soil, agronomic management and major pests on crop yield and its associated environmental impacts. The model is particularly designed for the integrated assessment of the effects of a variety of elements such as pests, soil, weather and management practices on crop yield, water, nitrogen and carbon dynamics and greenhouse gas emissions in aerobic as well as anaerobic conditions, especially for tropical regions.

prevailing crop season mean air temperatures across major chickpea growing regions in India.

Cotton is an important cash crop, which is mostly grown under rain-fed conditions, making it more vulnerable to precipitation. The model results indicate that climate change and the consequent increased temperature and altered pattern of precipitation might decrease the cotton yield of northern India to a greater extent than the southern region. The impact of climate change on rain-fed cotton, which covers more than 65 to 70% of area and depends on the monsoon is likely to be minimum, possibly because of marginal increase in rain. Moreover, the stimulating effect of CO_2 could offset the negative impact of climate on cotton production. Thus, at the national level, cotton production is unlikely to change with climate change. Adaptive measures such as changing planting time may further boost cotton production.

Potato, a tuber, is widely consumed in India. It was found that, without adaptation, the total potato production in India, under the impact of climate change, might decline by 2.61% and 15.32% in the years 2020 and 2050, respectively. The impacts on productivity and production varied among different agro-ecological zones.

Plantation crops: Using a validated coconut simulation model, the impact of elevated temperature and CO_2 on coconut yields was simulated for different agro-climatic zones. Overall results indicate that coconut yields are likely to be positively influenced by increase in CO_2 and increase in temperature of up to 2 - 3°C.

Cocoa, another plantation crop, is grown as the intercrop either under areca nut or coconut. Being a shade-crop, cocoa is influenced only indirectly by the increase in atmospheric temperature. The crop is maintained in irrigated conditions and is presently confined to limited pockets in the southern states of Karnataka and Kerala. Analysis indicated that a rise in temperature by 1°C should be beneficial for crop productivity. The improvement is likely to be about 100 kg of dry beans/ha. The cocoa growing foothills of the Western Ghats of Karnataka are more likely to benefit than central Kerala. However, crop management and irrigation supply should be maintained or improved to exploit this benefit. Further, an increase in temperature beyond 3°C is likely to reduce cocoa yields.

Vegetables and Fruits: Significant effects of increased climatic variability, if changes occur during critical periods in growth, have been observed on short season crops such as vegetables. Such crops have limited time to adapt to adverse environments. Among the vegetable crops, onion and tomato are important commercial crops grown across the country. However, the productivity levels are very low compared to major producing countries. This problem of lower productivity will be further compounded under climate change scenarios as the major onion and tomato growing regions are under tropical conditions and prevailing temperature conditions are already high. Onion and tomato are sensitive to environmental extremes.

Grape is an important commercial fruit crop in India with a productivity of 23.5 tons/ha. Grape occupies only 1% of the area with a production of 2.7% of the major fruit crops in India and also 2.8% of the world grape production. It has been adapted to tropical conditions by employing the practice of pruning twice a year. The impact of climate change on grapes would be determined by the impact on rainfall during the months of February to April, when the berries mature. In severe conditions, rainfall during the month of October, could increase the incidence of Downey mildew disease on leaves and flower clusters. The increase in minimum temperature during fruit maturation plays an important role in the anthocyanin, total phenol, total flavanoids and total acidity content of the berries, which ultimately affect the quality.

Another fruit, the productivity of which is heavily linked with climatic variations, is apple. Analysis of current and future climatic scenarios using HADRM2 model have revealed that Himalayan ecosystems will suffer from reduced winter precipitation (January-June) in sub-tropical zones, high temperature during winters and summers, change in seasonal rainfall patterns and significant reduction in snowfall. Specifically, it is seen that while the average increase in mean minimum and mean maximum temperatures in winter during the mid period (2021-2050) in scenario A1B will be by 2.43°C and 1.74°C in the sub-tropical - sub-temperate region (districts Solan, Sirmaur, Una, and Mandi), corresponding temperature changes in sub temperate - temperate regions (districts of Shimla, Kulu, Lahaul-Spiti, Kinnaur and Chamba) will be 2.77°C and 2.17°C respectively. Cumulative chill units of the coldest months have declined by 9.1 to 19.0 units per year in the last two decades in different districts of Himachal Pradesh. The rise in temperature will reduce the chilling-hours accumulation, which could be a limiting factor in more tropical areas, especially for cultivars with medium to high chilling requirement. The temperature change will benefit apple cultivation in high altitudinal regions (> 2300 meter above sea level). Kinnaur and Lahaul-Spiti districts in the northern state of Himachal Pradesh are likely to be especially benefited, due to an enhanced growing period and reduced extreme cold weather conditions.

An important component of food that is significantly increasing in demand, is Milk. Increased heat stress associated with global climate change may cause distress to dairy animals and possibly impact milk production. A Temperature - Humidity Index (THI) was used to relate animal stress with productivity of milk from buffaloes, crossbred and local cows. The THI analysis indicated that the congenial THI for production is 0.70 and is achieved during the months of January and February in most places in India (Figure 15). There is an all-round increase in THI in all the regions, which may impact the economic viability of livestock production systems. Only about 10-15% places have optimum THI for livestock productivity during summer and the hot humid season. Most places in India have THI > 75 and more than 85% of India experiences moderate to high heat stress during April, May and June. In these months, the value of THI ranges from 75-85 at 2.00 p.m when the heat is at its peak. At about 25% places in India, the THI exceeds 85 during May and June, i.e. severe stress levels are experienced. The night temperature remains high and morning THI is also high so there is no relief from heat stress. On an average, THI exceeds 75 at 75-80% places in India throughout the year.

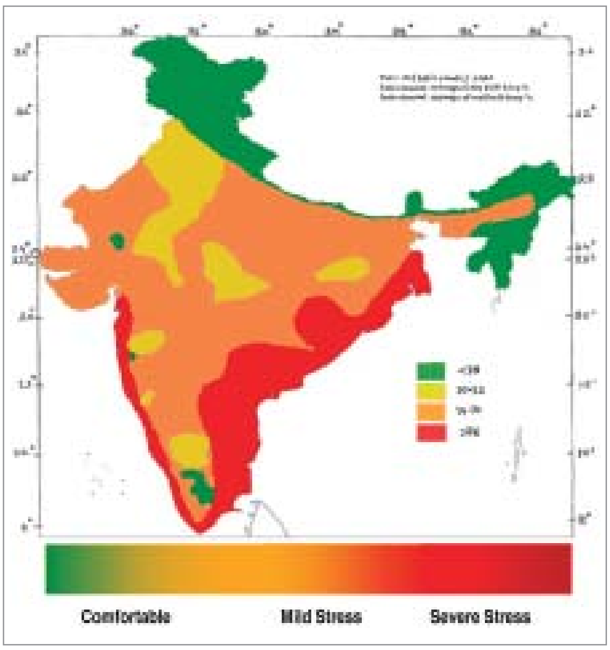


Figure 15: Temperature and Humidity Index map of India

It is estimated that India loses 1.8 million tonnes of milk production at present due to climatic stresses in different parts of the country. Global warming will further negatively impact milk production by 1.6 million tonnes by 2020 and more than 15 million tonnes by 2050, as per studies conducted by scientific institutions. High producing crossbred cows and buffaloes will be more adversely affected than indigenous cattle.

Impact Assessment on Human Health

Impact assessment of climate change on malaria is undertaken through the assessment of Transmission Windows (TWs). TWs of malaria are determined, keeping in view the lower cut-off as 18^{0}C and upper cut-off as 32^{0}C and RH from >55%. The TWs at each grid (0.44 x 0.44 deg pixel, roughly 50 x 50 km) were prepared covering India for the baseline scenario. Monthly maps were generated as having two classes - open and closed TW. Keeping in view the climatic suitability for the number of months during which transmission is open, transmission windows/ pixels were categorised as follows:

Category I: Not a single month is open
Category II: 1-3 months open
Category III: 4-6 months open
Category IV: 7-9 months
Category V:10-12 months are open continuously for malaria transmission.

Transmission windows have been determined based on temperature alone as well as with a combination of temperature and Relative Humidity (RH) and for Baseline (1960-1990) and for the projection years 2030, 2071, 2081, 2091 and 2100.

Malaria under A1B scenario: *Determination of TWs of malaria based on Temperature (T)* – Drawing on the baseline temperature from 1961-1990, three tiers of transmission windows are visible. In the northern states of India, there are 148 pixels with no transmission suitability. TW category of 1-3 months is seen in districts under Uttarakhand, Himachal Pradesh, parts of Jammu & Kashmir, Sikkim and Arunachal Pradesh. Windows of transmission increase as we progress southwards. In Rajasthan, central India, Jharkhand, Chhattisgarh, Orissa, West Bengal and most parts of the northeastern states, TW category of 7-9 months is seen. Most districts in the southern states have 10-12 months open for transmission.

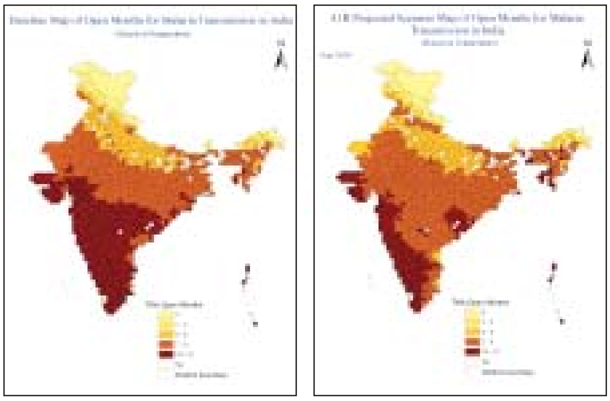


Figure 16: Projection of open transmission window of malaria by 2030 (based on temperature and A1B scenario)

Projections for 2030 indicate the opening of some months of TWs in northern states like Jammu and Kashmir, Himachal Pradesh and Uttarakhand, which were closed in the baseline period (Figure 16). There is a progression of 7-9 months category of TWs towards the northern districts. In northeastern states like Tripura, parts of Assam and Mizoram, there is an increase from 7-9 months to 10-12 months open category. In parts of Gujarat and some southern states (particularly towards the east coast) there is closure of some months of TWs i.e. 10-12 month category turning into 7-9 months. In some districts of Orissa, which is highly endemic for malaria, an increase in months of TWs is seen by 2030. Andaman & Nicobar islands remain unaffected.

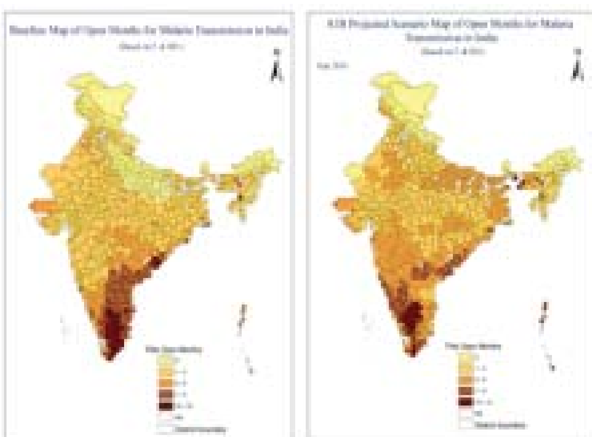


Figure 17: Projection of open transmission window of malaria by 2030 (based on temperature and Relative Humidity and A1B scenario)

Determination of Transmission windows of malaria based on Temperature - (T) and Relative Humidity (RH): Transmission windows of malaria were also determined based on a suitable range of T and RH required (Figure 17). In general, in almost all the regions, the number of open months for malaria transmission seems less than when based on temperature alone. In northeastern states, there are very few districts showing transmission for 7-9 months. Major parts of India come under the 1-3 and 4-6 months open category of TWs. Some districts on the eastern side of India from Tamil Nadu, Karnataka and Andhra Pradesh show TWs open for 7-9 and 10-12 months. Transmission of malaria is open for 1-3 or 4-6 months in states like Rajasthan, Jharkhand, Chhattisgarh and parts of Gujarat and Karnataka.

When the TWs were compared with monthly epidemiological data of the respective areas, they did not match, i.e. cases occurred in more months than determined by TWs. The TWs based on T and RH were found to be less realistic than the TWs based on temperature alone. This provides a clue that the resting places of mosquitoes have a different micro-niche, particularly for RH, as compared to outside temperatures.

Projections by the year 2030 indicate an increase in the 2nd and 4th categories of TWs towards the northern states of India. An increase in the 3rd category of TWs towards the southwestern districts in Karnataka is noticeable.

Programmes Related To Sustainable Development

India's development plans are crafted with a balanced emphasis on economic development and environment. The planning process, while targeting an accelerated economic growth, is guided by the principles of sustainable development with a commitment to a cleaner and greener environment. Planning in India seeks to increase wealth and human welfare, while simultaneously conserving the environment. It emphasizes promotion of people's participatory institutions and social mobilization, particularly through empowerment of women, for ensuring environmental sustainability of the development process.

On 30th June 2008, India announced and launched its National Action Plan on Climate Change (NAPCC). The NAPCC, guided by the principles of sustainable development (SD), aligns the environmental and economic objectives. Broadly, the NAPCC is based on the following principles:

- Protecting the poor and vulnerable sections of society through SD strategies that are sensitive to climate change,
- Achieving national growth targets by means that enhance ecological sustainability,
- Devising an efficient and cost-effective strategy for demand-side management,

- Deploying appropriate mitigation and adaptation technologies extensively and at an accelerated pace,
- Promoting SD through innovative and new forms of market, regulatory and voluntary mechanisms,
- Effecting implementation of various policies through unique linkages with civil society, local governments and public-private partnerships,
- Welcoming international cooperation for research, development, sharing and transfer of technologies driven by external funding and facilitating a global Intellectual Property Rights regime for such a technology transfer under the United Nations Framework Convention on Climate Change (UNFCCC).

The NAPCC identifies measures that promote our development objectives while also resulting in co-benefits in terms of addressing climate change. There are eight National Missions, which form the core of the NAPCC, representing "*multi-pronged, long-term and integrated strategies for achieving key goals in the context of climate change*". This underscores the fact that several of the programmes enumerated under NAPCC are already being undertaken under various schemes / programmes of the Government of India (GoI) but in the present context would require a change in "*direction, enhancement of scope and accelerated implementation*".

At the 15th Conference of Parties (COP-15) to the UNFCCC in Copenhagen, Denmark between December 7-18, 2009; India pledged to continue a constructive role in international climate diplomacy while emphasizing the need for implementing a comprehensive domestic response to reduce the emissions intensity of GDP by 20-25% by 2020, on 2005 levels (emissions from the agriculture sector not included). Some specific actions taken by the GoI with regards to climate change include:

- India's 12th Five-year plan (2012-2017) to be launched on 1st April, 2012 will have, as one of its key pillars, a low-carbon growth strategy. Detailed work in this regard, through research and other findings, has been initiated by the Government of India at all levels.
- A 'Carbon tax' on coal to fund clean energy (at the rate of USD 1 per tonne to both domestically produced and imported coal) was announced. The money collected will go into the National Clean Energy Fund, to be used for funding research, innovative projects in clean energy technologies and environmentally remedial programmes. The expected earnings from the cess is around USD 500 million for the year 2010-2011.
- India has pursued aggressive strategies on forestry and coastal management, recognizing their ecological and livelihood significance. A major coastal zone management programme has been launched to address the adaptation challenges facing over 300 million vulnerable inhabitants in these regions.
- Promoting regional and international cooperation has been one of the key achievements of the GoI regarding climate change. SAARC (South Asian Association for Regional Cooperation) adopted the Thimpu Statement on Climate Change on 29th April 2010. This statement, among other things, calls for an Inter-Governmental Expert Group on Climate Change to develop a clear policy direction for regional cooperation on climate change. Sharing of knowledge among the SAARC countries will help in better assessment of all areas related to climate change.
- The 'Bachat Lamp Yojana' (BLY) conceived as CDM Programme of Activity (PoA) for mass distribution of CFLs in India has been registered successfully by the CDM Executive Board. The programme has been developed to promote energy efficient lighting.

The past few years have witnessed the introduction of landmark environmental measures in India that have targeted conservation of rivers, improvement of urban air quality, enhanced forestation and a significant increase in installed capacity of renewable energy technologies. These and other similar measures, affirmed by the democratic and legislative processes, have been implemented by committing additional resources as well as by realigning new investments. These deliberate actions, by consciously factoring in India's commitment to UNFCCC, have reinforced the alignment of economic development to a more climate friendly and sustainable path.

A planned approach to development has been the central process of the Indian democracy, as reflected in the national Five-Year Plans, departmental annual plans, and perspective plans of various ministries of the central and state governments. For more than six decades, the guiding objectives of the Indian planning process have been: (i) sustained economic growth, (ii) poverty alleviation, (iii) food, (iv) health, (v) education and (vi) shelter for all, (vii) containing population growth, (viii) employment generation, (ix) self-reliance, (x) people's participation in planning and programme implementation and (xi) infrastructure development. In the present context of climate change, development has focused on enhancing the adaptive and mitigative capacity of the economy; and thereby the GoI has initiated policies, programmes and missions aimed in that direction. Infrastructure emerged as a key sector during the 11th plan period (2007-2012), with its role as a backbone through which the economy flourishes, and therefore the GoI initiated new policy measures to ensure infrastructure growth in line with economic growth. A key feature of the vigorous infrastructure growth policy has been the adoption of a sustainable development path wherein infrastructure choices were made, keeping in mind the long term perspective of ensuring lesser impacts due to likely climate change and avoiding critical lock-ins. Thus, measures like developing the renewable energy sector, shift towards public transport, enhancing rural and urban infrastructure and others were aimed at enhancing the adaptive and mitigative capacities of the economic systems.

A major weakness in the economy during the 10th plan was that the growth was not perceived as being sufficiently inclusive for many groups. Gender inequality was considered to be a persistent problem. The 11th plan seeks to remedy these deficiencies by accelerating the pace of growth, while also making it more inclusive. The objective of inclusiveness is reflected in the adoption of 26 'monitor-able' targets at the national level pertaining to income and poverty, education, health, women and children, infrastructure and environment.

The programmes and institutions to promote energy efficiency, energy conservation and renewable energy technologies were initiated over two decades ago in India. The reforms in the energy and power sectors have resulted in accelerated economic growth, improvements in fuel quality, technology stocks, infrastructure, management practices, and lowered the barriers to efficiency improvements. The planned actions and economic reforms have contributed positively to the rapidly declining growth rate of energy intensity in India. The Government of India, through its various institutions and resources, has also taken steps to de-couple the Indian energy system from carbon in the long run. These include measures to promote low and no-carbon fuels such as natural gas and renewable energy. The double de-coupling, first of energy growth from economic growth and second of carbon from energy, demonstrates India's active commitment and response to the objectives of UNFCCC.

Research And Systematic Observation

The Government of India attaches high priority to the promotion of R&D in the multi-disciplinary aspects of environmental protection, conservation and development; including research in climate change. Several central government ministries/departments promote, undertake and coordinate climate and climate-related research activities and programmes in India. This is done through various departments, research laboratories, universities and autonomous institutions of excellence such as the Indian Institutes of Management (IIMs), Indian Institutes of Technology (IITs) and the Indian Institute of Science (IISc) with the non-governmental and private organizations providing synergy and complementary support. The Ministry of Science and Technology (MoST), Ministry of Environment and Forests (MoEF), Earth System Science Organisation (ESSO)/Ministry of Earth Sciences (MoES), Ministry of Agriculture (MoA), Ministry of Water Resources (MoWR), Ministry of Human Resource Development (MHRD), Ministry of New and Renewable Energy (MNRE), Ministry of Defense (MoD), Ministry of Health and Family Welfare (MoHFW), and Department of Space (DoS) are the key ministries/departments of the Government of India which promote and undertake climate and climate change-related research and systematic observations in the country.

The Indian Space Research Organisation (ISRO)/ Department of Space (DOS) has been pursuing studies on climate and environment and has developed considerable understanding about the processes governing the phenomena. The Centres of ISRO/ DOS, viz. National Atmospheric Research Laboratory (NARL), Space Physics Laboratory (SPL), Physical Research Laboratory (PRL), Space Applications Centre (SAC), and ISRO Satellite Centre (ISAC), with their inherent scientific and technical strengths, are engaged in various research studies, activities related to the Earth's climate system, and in designing sensors and satellites, and ground-based observation systems for studying the climate and environmental parameters.

With a view to understanding the scientific aspects of climate, ISRO, through its ISRO Geosphere-Biosphere Programme (ISRO-GBP), with multi-institutional participation, has been pursuing studies on climate over the past two decades. The studies have addressed atmospheric aerosols, trace gases, GHGs, paleo-climate, land cover change, atmospheric boundary layer dynamics, energy and mass exchange in the vegetative systems, National Carbon Project (NCP) and Regional Climate Modelling (RCM). ISRO has also carried out extensive campaigns integrating satellite, aircraft, balloon and ground-based measurements, jointly with many sister institutions in the country.

The satellite remote sensing data have been put into use over a wide spectrum of themes, which include land use/ land cover, agriculture, water resources, surface water and ground water, coastal and ocean resources monitoring, environment, ecology and forest mapping, and infrastructure development.

Other than the government ministries, several autonomous institutions and NGOs are engaged in climate change-related research. IIM Ahmedabad and IIT Delhi are front-runners. The Indira Gandhi Institute of Development Research, an institution established by the Reserve Bank of India (RBI), is engaged in the estimation of the climatic factors that may affect India's development pathways. NGOs like The Energy and Resources Institute (TERI), Development Alternatives, Centre for Science and Environment, and the Society for Himalayan Glaciology, Hydrology, Ice, Climate and Environment operate in project-based research mode on various topics such as climate change vulnerability, impacts and related studies.

A coordinated research programme on Global and Regional Climate Change (GRCC) during the 11th Plan has been launched to build a National Climate Change Monitoring and Research Network. A programme office has been established at the ESSO/MoES headquarters to operate the GRCC programme to integrate all envisaged activities in support of supplementing 'unified scientific response' to global warming launched under the NAPCC. As a part of GRCC, a dedicated Centre for Climate Change Research (CCCR) to undertake studies on the scientific aspects of climate change has been established at the Indian Institute of Tropical Meteorology (IITM) Pune. CCCR is focusing on all scientific issues including modelling the susceptibility of various agricultural crops, their yield and diseases, water, nitrogen, ozone, GHG flux measurements and CO_2 cycle sequestration.

Preliminary research has been initiated on 'vulnerability assessment due to climate change' on various socio-economic sectors and natural ecosystems in India during the preparation of India's Initial National Communication to the UNFCCC. Indian climate change scenarios at the sub-regional level were developed to estimate impacts on ecological and socio-economic systems. In the Second National Communication to the UNFCCC, the networks are being strengthened to consolidate the impacts, vulnerability assessment and adaptation for climate change for short, medium and long–term, across regional, sub-regional and national levels. The Indian Network for Climate Change Assessment (INCCA) under MoEF conducted a major assessment: 'Climate Change and India: A 4x4 Assessment- A Sectoral and Regional Analysis'. This study was an assessment of the impact of climate change in the 2030s on four key sectors of the Indian economy, namely agriculture, water, natural ecosystems & biodiversity, and health in four climate sensitive regions of India, namely the Himalayan region, the Western Ghats, the coastal area and the north-eastern region.

Education, Training and Public Awareness

The Government of India has created mechanisms for increasing awareness on climate change issues through outreach and education initiatives. The Environmental Information System (ENVIS) centres throughout the country generate and provide environmental information to decision makers, policy planners, scientists, researchers and students through web-enabled centres.

Three major institutional mechanisms have been evolved by the Government of India so as to streamline the country's response to climate change challenges. They are: (i) Inter-Ministerial and Inter-agency Consultative Mechanism; (ii) Expert Committee on Impacts of Climate Change and (iii) the Prime Minister's Council on Climate Change.

In line with the GoI's commitment to spreading awareness about climate change education and strengthening the scientific network, the National Mission on Strategic Knowledge for Climate Change (NMSKCC) was identified to build a vibrant and dynamic knowledge system that would inform and support national action for responding effectively to the objectives of sustainable development. In order to further facilitate implementation of the National Action Plan, the National Knowledge Commission (NKC), an advisory body to the Prime Minister, was also identified as being an important component regarding climate change education. It is envisaged that the Commission will:

- Build excellence into the educational system to meet the knowledge needs/challenges and increase India's competitive advantage,
- Improve the management of institutions engaged in intellectual property rights,
- Promote knowledge applications in agriculture and

industry; and knowledge capabilities to make the government an effective, transparent and accountable service provider to the citizen,

- Promote widespread sharing of knowledge to maximize public benefit.

The scope of the efforts to develop a comprehensive understanding of environmental and climate change issues in India extends beyond the diverse sensitisation activities conducted through and by the ministry. High quality scientific research contributes to updating the wealth of available knowledge on these issues and building confidence in various climate change adaptation and mitigation efforts. INCCA (Indian Network for Climate Change Assessment), established by the MoEF in October 2009, is a network-based initiative and approach to make science, particularly the '3 Ms' – Measuring, Modelling and Monitoring – the salient input for policy-making in climate change. It brings together over 127 research institutions and over 220 scientists from across the country. Till now, INCCA has completed two assessment reports and one Science Plan. The first report of the INCCA was about India's GHG emissions inventory for 2007; the second was an assessment report titled "Climate Change and India: A 4x4 assessment- A Sectoral and Regional Analysis". Recently, the science plan on the 'Black Carbon Research Initiative: National Carbonaceous Aerosol Programme' was also launched.

Industry associations have also played an active role in awareness generation through various activities like preparation of technology transfer projects, workshops, training, publication, and interactive and knowledge-based websites.

Besides these, numerous capacity building initiatives have been undertaken in India. A vital aspect of this process has been the participation by the central and state government agencies, research institutions, non-government organizations and industry. The GoI has instituted consultative processes for climate change policies. Indian researchers have made significant contributions to international scientific assessments. Awareness workshops and seminars on the issues concerning climate change have been conducted across the country over the last decade with wide participation. However, in the wake of the complexity of climate change issues, the task is far from complete, and assessments in a range of areas and analysis of uncertainties and risks remain to be resolved.

Constraints, Gaps and Related Financial, Technical and Capacity Needs

In accordance with India's national circumstances and development priorities, a description of the constraints and gaps, and related financial, technical and capacity needs, as well as proposed activities for overcoming the gaps and constraints associated with the implementation of activities, measures and programmes envisaged under the UNFCCC, and with the preparation and improvement of national communications on a continuous basis has been highlighted. Some projects that were identified for building research capacity and climate change project implementation in India as part of the preparatory process for future national communication and some others have been identified and elucidated. The coverage is not an exhaustive elucidation of India's financial and technological needs and constraints. Some of the projects and themes are those that have been identified during the implementation of the enabling activity for the Second National Communication. With more scientific understanding and increasing awareness, further areas of work could be identified.

The Indian government visualizes the Second National Communication (SNC) as an opportunity to enrich and enhance India's experience in identifying constraints, gaps and related financial, technical and capacity needs to adequately fulfil our obligations under the United Nations Framework Convention on Climate Change, including a continuing need for improving the quality of national GHG inventories, regional and sectoral assessment of vulnerabilities and adaptation responses, and communication of information on a continuous basis.

The broad participatory domestic process for preparing India's Second National Communication has contributed to an improved understanding of the challenges associated with formulating an appropriate policy response for addressing climate change concerns in India, while simultaneously building capacity in diverse disciplines such as inventory estimation, emission coefficient measurements, quantitative vulnerability assessment, and inventory data management.

A key area requiring attention is data requirements for continuous reporting. Measures for bridging the data gaps and overcoming data barriers for the future national communication exercises would include designing compatible data reporting formats for continuous GHG inventory reporting at detailed sub-sector and technology levels, gathering reliable data for informal sectors of the economy, enhancing data depths to move to a higher tier of inventory reporting and conducting detailed and fresh measurements for Indian emission coefficients. This would entail substantial financial commitment, fresh technical inputs and building of scientific capacity (Key gaps and constraints highlighted in Table 3).

Capacity building, networking and resource commitment form the core of the institutional setting of the Indian climate change research initiatives. The approach follows a shared vision for cooperative research for strengthening and enhancing scientific knowledge, institutional capacity (instrumentation, modelling tools, data synthesis and data management), technical skills for climate change research inter-agency collaboration and networking and medium to long-term resource commitment.

The enhanced capacity is envisaged to be effectively used for refinement of GHG inventories, making future projections with reduced uncertainties and at higher resolutions, developing long-term GHG emission scenarios, for undertaking detailed impact assessments and formulation of adaptation/response strategies to combat climate change, to undertake integrated impact assessments at sub-regional and regional scales and help in diffusion of climate friendly technologies.

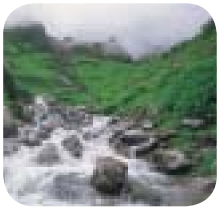
Given the magnitude of the tasks, complexities of technology solutions and diversity of adaptation actions envisaged for an improved and continuous reporting of national communications in the future, the incremental financial needs would be enormous to address and respond to the requirements of the Convention.

Given that the technology needs of developing countries in relation to climate challenges are diverse and that deployment often requires a range of activities (not only technical, but many others as well), the term 'technology transfer' provides too narrow a perspective and framework for successfully leveraging technologies for meeting climate challenges. The agenda for moving ahead must be viewed with the understanding that the necessary elements must be appropriately tailored both to the specifics of the technology as well as national circumstances. At the same time, the importance of controlling GHGs "through the application of new technologies on terms which make such an application economically and socially beneficial" must also be recognized, as highlighted in the UNFCCC. Such a technology framework should encompass the following elements: Financial assistance, Technology deployment in developed countries, Joint technology development, Knowledge sharing for enhancing deployment and Capacity building . A better understanding of the application of these elements in the context of India needs to be assessed and identified therein.

Table 3: Key gaps and constraints for sustained national communication activities

Gaps and constraints	Details	Possible approach
Data organization	Data not available in Intergovernmental Panel on Climate Change (IPCC)-friendly formats, for inventory reporting	Consistent reporting formats
	Mismatch in top-down and bottom-up data sets for same activities	Regular monitoring and consistency check on collected data
	Mismatch in sectoral details across different published documents	Consistent reporting formats
Non-availability of relevant data	Time series data for some specific inventory sub-categories, for example, municipal solid waste sites	Generate and maintain relevant data sets
	Data for informal sectors of economy	Data surveys
	Data for refining inventory to higher tier levels	Data depths to be improved
Data non-accessibility	Proprietary and trade secret data for inventory reporting at Tier-III level	Involve industry, industry associations, and monitoring institutions
	Data not in electronic formats	Standardize data reporting and centralize data in usable electronic format
	Security concerns	Protocols to access data
	Procedural delays	Awareness generation
Technical and institutional capacity needs	Training the activity data generating institutions in inventory methodologies and data formats	Extensive training programmes
	Institutionalize linkages of inventory estimation and climate change research	Wider dissemination activities
Non-representative emission coefficients	Inadequate sample size for representative emission coefficient measurements in many sub-sectors	Conduct more measurements, statistical sampling
Non-availability of resources to sustain National Communication networks		Global Environment Facility (GEF)/international timely funding

Chapter 1 National Circumstances

This chapter, in accordance with the guidelines of 17/CP.8, contains information on India's geography, climate, and economy, based on which, the country would be addressing the challenges due to climate change. These national conditions and circumstances are important as these will determine India's ability to mitigate and adapt to climate change. The chapter details the nature of India's climatic conditions and its water resources, forest endowment, and land-use characteristics. Since a large population of India is based in rural areas, the state of the country's agriculture and livestock is also detailed. The changing nature of India's demography and household characteristics, a key structural transformation, is also identified and recognized. In the context of climate change, energy use and its characteristics play a key role; therefore, in this chapter, a detailed account of the changing nature of India's energy structure is given. Institutions and governance, especially environmental governance, have been identified as key constituents of India's evolving economy; therefore, it is imperative to assess the existing state of environmental governance in the country. The economy of the country, its structure, and impact (poverty and employment) need special attention to understand the ability of the country to deal with climate change and the impact on climate change. The state of India's environmental governance and economy has been separately discussed in this chapter. In response to the imperatives of a low-carbon growth strategy, India identified low-carbon growth as a key pillar for its 12th Five-year Plan period and beyond. The chapter culminates with a summary of the recent assessment on India's low-carbon growth strategy, but not before underlying the importance of sustainable development as a key to address climate change challenges.

Contents

Chapter 1 National Circumstances

CHAPTER 1 | National Circumstances

India, flanked by the Himalayas in the north and lying in the sub-tropical terrain, is adorned with largely diverse topography, climate and biosphere, spanning across a geographic area of 3.28 million km^2. The country is situated between 66°E to 98°E and 8°N to 36°N and has a range of physio-geographic features (Figure 1.1) that are shared widely by its 28 states and 7 union territories. These features are mainly classified as mountainous terrain (Himalayan range, Western Ghats), northern plains, peninsular plateau, deserts, coastal plains (East and West Coasts), and island groups (Andaman and Nicobar, Lakshadweep). India juts out into the Indian Ocean and is surrounded by the Arabian Sea on the west and the Bay of Bengal in the east. The country also borders Pakistan, Bhutan, Bangladesh, and Myanmar. Occupying almost 2.3% of the world's land area, the country is the seventh largest in the world but holds a massive 18% of the world's population. This puts the country under great stress to ensure sustainable development and harness its resources efficiently. India shelters over 1.21 billion people representing various socio-cultural groups that collectively set up the world's largest democracy.

Climate

India's climate is strongly influenced by the Himalayas in the north and the Thar Desert in the west. The Himalayas act as a barrier to the frigid katabatic winds blowing down from Central Asia, keeping the bulk of the Indian sub-continent warmer than most locations at similar latitudes. India is gifted with a variety of climatic conditions due to its distinct geography. These climatic aspects influence the biology, culture, and economics of the country. The Himalayas shelter India from the sub-tropical winds from China and produce a tropical effect. Land areas in the north of the country have a continental climate, with fierce summer heat that alternates with cold winters when temperature plunges to freezing point. In contrast are the coastal regions of the country where the warmth is unvarying and the rains are frequent. The rainfall pattern varies surprisingly at different locations of the country, ranging from an average annual rainfall of less than 13 cm over the Thar Desert to about 1187 cm at Mawsynram in the Khasi hill district of Meghalaya (Figure 1.2). The rainfall pattern roughly reflects the different climatic aspects of the country, which vary from humid in the North East (about 180 days in a year) to arid in Rajasthan (20 days in a year)[1]. The peninsular regions, which are primarily rain-fed, extend from the humid West Coast to the arid central and eastern parts of the country. The most important feature of India's climate is the monsoon season. The monsoon season is so important and critical to the Indian climate that the rest of the seasons are quite often referred relative to it. The country is influenced by two seasons of rains accompanied by seasonal reversal of winds from January to July. During winters, dry and cold air blowing from the northerly latitudes from a north-easterly direction prevails over the Indian region. Consequent to the intense heat of the summer months, the northern Indian landmass gets heated up and draws moist winds over the oceans, causing a reversal of the winds over the region. This is called the summer or the south-west monsoon.

Figure 1.1: Physiographic zones of India
Source: State of Forest Report, 2001

1 A rainy day is defined as a day with a rainfall of 2.5 mm and above, as per the operational practice of the Indian Meteorological Department.

In India, four principal seasons can be identified in a year.

- Winter season: January and February
- Pre-monsoon or summer season: March, April and May
- South-west monsoon season: June, July, August, and September
- Post-monsoon or north-east monsoon season: October, November and December

The cold weather or the winter season starts in January over the country while January can be included in winter season for north-western parts of the country. Clear skies, fine weather, light northerly winds, low humidity and temperature, and large daytime variations of temperature are the normal features of the weather in India from December to February. The cold air mass, extending from the Siberian region, influences the Indian sub-continent (at least all of the north and most of the central India) during the winter months. The Himalayas obstruct some of the spreading cold air mass. Mean winter temperature increases from north to south up to 17°N, the decrease being sharp as one moves northwards in the north-western parts of the country. During January, mean temperature varies from 14°C to 27°C. The mean daily minimum temperature ranges from 22°C in the extreme south to 10°C in the northern plains and 6°C in Punjab. Rains during this season generally occur over the western Himalayas and extreme north-eastern parts, Tamil Nadu, and Kerala.

The mean daily temperature starts rising all over the country by the end of the winter season, and by April, the interior parts of the peninsula record mean daily temperature of 30–35°C. Central regions become warm, with day time maximum temperature reaching about 40°C at many locations. During this season, stations in Gujarat, northern Maharashtra, Rajasthan, and northern Madhya Pradesh are marked by high daytime and low night-time temperature. At many locations in these regions, the range of daytime maximum and night-time minimum temperature exceeds 15°C. In the north and north-west regions of the country, the maximum temperature rises sharply, reaching values exceeding 45°C by the end of May and early June, bringing in the harsh summers (Figure 1.3). In the coastal areas of the country, land and sea breezes predominate due to the stronger temperature contrast between the land and sea during this season. The change in the climatic conditions in summers results in the formation of many natural hazards. Thunderstorm associated with rain and sometimes hail is the predominant phenomenon of this season. Over the dry and hot plains of north-west India, dust storms (known locally as "*andhis*"), accompanied with strong dust-laden winds, occur frequently. Violent thunderstorms with strong winds and rain lasting for short duration also occur over the eastern and north-eastern regions in the states of Bihar, West Bengal, and Assam. They are called Norwesters because they generally approach a location from the north-west direction (locally they are known as "*Kal Baisakhis*" in the context of their season of occurrence).

Tropical cyclones, which are intense circulations of 200–300 km diameter, with winds blowing at velocities close to 150 km/h, form in the Bay of Bengal and the Arabian Sea during this season. These are mainly caused due to the high pressure build-up over the ocean in summers and greatly affect the coastal areas. The storms generally

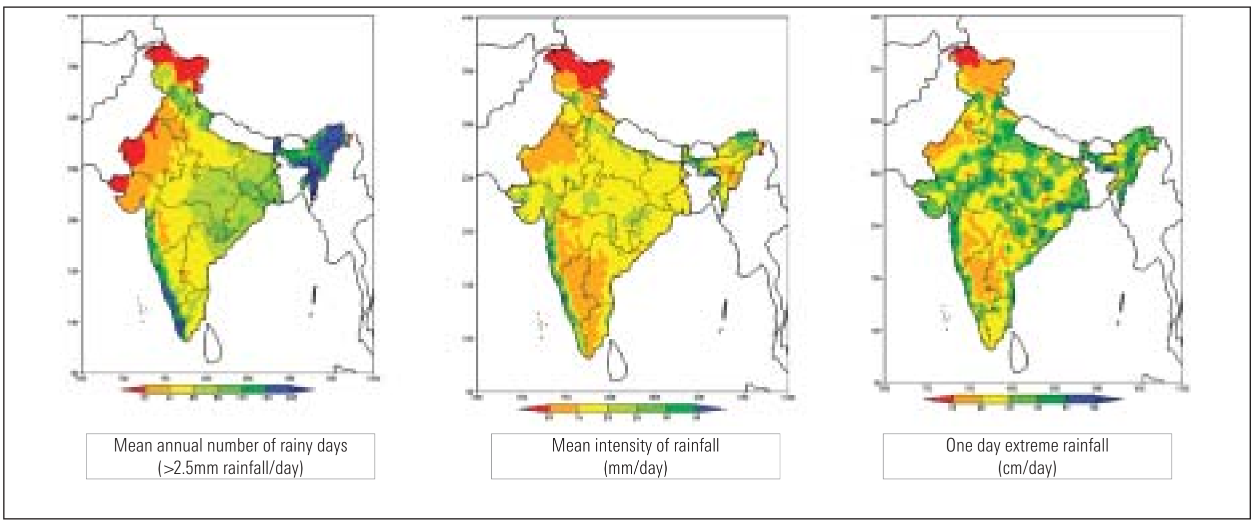


Figure 1.2: Rainfall profile of India

move in the north-westerly direction first and later take the northerly or north-easterly path. Storms forming over the Bay of Bengal are more frequent than the ones originating over the Arabian Sea. About 2.3 storms are formed on an average during a year.

South-west monsoon over India is the single most important feature of the country's climate. Although the south-west monsoon (also known as the summer monsoon) period over the country is generally taken to be four months (June–September), its actual period at a specific place differs, depending on the date of its onset and withdrawal. The duration of the monsoon varies from less than 75 days in western Rajasthan to more than 120 days over the south-western regions of the peninsular India. The proximity of the ocean plays an important factor in increasing the temperature in the southern regions. Rains during this season alone contribute to about 80% of the annual rainfall in the country. Normally, the south-west monsoon sets in over the Kerala coast, the southern tip of the country, by 1st June and then advances along the Konkan coast 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. Onset of the monsoon over the country is one of the most spectacular meteorological events every year and is looked upon with great expectations by the people of India as it heralds rainy season and the beginning of the sowing operations on a large sale. The south-west monsoon rains exhibit a striking regularity in their seasonal onset and distribution within the country, but are variable both within the season and from one year to another. Global features like El Niño, Northern Hemispheric temperature, and snow cover over Eurasia are known to influence the year-to-year variability of monsoon performance. 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 the occurrence of floods over the plains. Breaks are also associated with very uncomfortable weather due to high humidity and temperature.

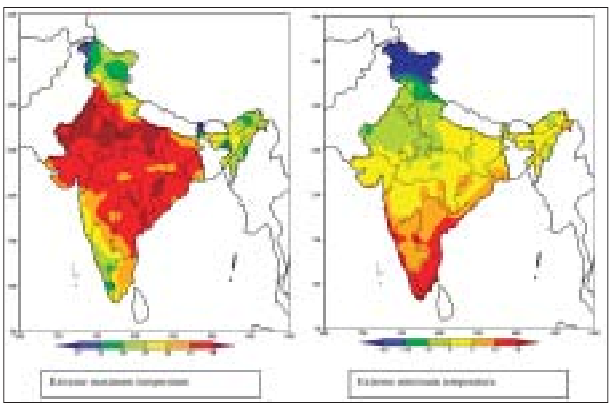


Figure 1.3: Temperature profile of India

Towards the latter half of September, the south-west monsoon current becomes feeble and starts withdrawing from the north-western parts of India. By the end of September, it withdraws from almost all parts of the country and is slowly replaced by northerly continental airflow. The post-monsoon or north-east monsoon season is a transitional season when north-easterly airflow gets established over the sub-continent. These winds produce the winter or north-east monsoon rains over the southern tip of the country during the transitional period. The Bay of Bengal during this season is a source of cyclonic systems of low pressure called the "monsoon depressions". These storms can also cause widespread damage due to high velocity winds and tidal waves in the coastal regions. They form in the northern part of the bay with an average frequency of about two to three per month and move in a northward or north-westward direction, bringing well-distributed rainfall over the central and northern parts of the country. The path taken by these depressions critically influences the distribution of rainfall over the northern and central India.

Water Resources, Land Use, and Forests

Water resources

Water is the most critical component of life support system. According to the UN World Population database, India shares nearly 18.0% of the global population, but it has only 4% of the total freshwater resources. India is a land of many rivers. There are 12 rivers, classified as major rivers, the total catchment area of which is 252.8 million hectare (Mha), covering more than 75% of the total area of the country. The rivers in India are classified as the Himalayan rivers, peninsular rivers, coastal rivers, and inland drainage basin. The Himalayan rivers are snow-fed and maintain a high-to-medium rate of flow throughout the year. The heavy annual average rainfall levels in the Himalayan catchment areas further add to their rates of flow. During the summer monsoon months of June to September, the catchment areas are prone to flooding. The volume of the rain-fed peninsular rivers also increases during the monsoon. The coastal streams, especially those in the west, are short and episodic. The rivers of the inland system, centered in the western Rajasthan, are few and sparse and frequently disappear altogether in the years of poor rainfall.

Groundwater is another major component of the total available water resources. In the coming years, the groundwater utilization for expansion of irrigated agriculture and achievement of national targets of food production is likely to increase manifold. Although groundwater resource is replenished annually, its availability is non-uniform in space and time. Extraction of large volumes of groundwater without equivalent replenishment leads to faster depletion of water table, affecting water quality. Also more energy is needed to pump out water from a deeper water table. The estimated utilizable water resources stand at 1122 km^3, with the surface water resources contributing 60% and the groundwater resources contributing the rest.

Land use

According to the "Agricutural Statistics at a Glance 2010", 46.1% of the reported area for land use estimation is under agriculture, and 23.9% under forest and tree cover (Figure 1.4). The remaining nearly one-third of the land area is distributed between fallow land, other uncultivated land excluding fallow land and not available for cultivation. The land use pattern in India has been affected by a variety of factors such as population pressure, expanding urbanization, industrial growth, grazing pressure, availability of irrigation facilities, diversion of forest land to other uses, the law of inheritance, and natural calamities like flood and drought. According to the statistics published by the Department of Agriculture and Cooperation in its publication titled "Agricultural Statistics at a Glance 2010", it can be observed that per capita availability of forest and agricultural land has shown significant declining trend over the past 50 years. For instance, the per capita availability of forest land stood at 0.113 ha in 1950/51. By 2007/08, this number has reduced at a rapid rate to 0.061 ha. Similarly per capita net area sown has reduced for the same period from 0.331 ha to 0.124 ha. However, over the years, the area under forests and agriculture has increased but remained more or less constant in the last couple of decades.

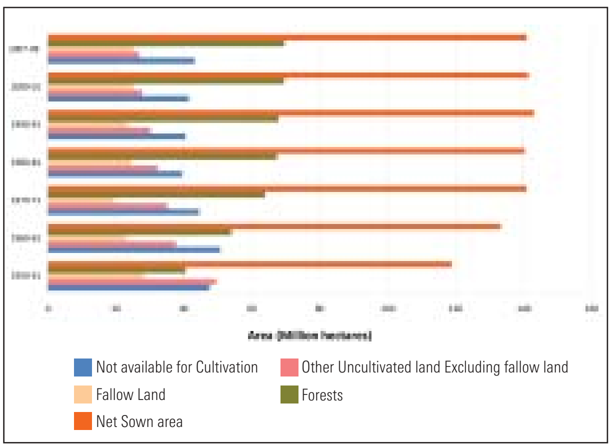


Figure 1.4: Land use changes in India
Source: Agricultural Statistics at a Glance, 2010

Forests

India is endowed with diverse forest types ranging from tropical wet evergreen forests in the North East and the South West to tropical dry thorn forests in the central and western India. According to the various State of Forest Reports (published by the Ministry of Environment and Forests), the forests of India can be divided into 16 major types comprising 221 sub-types. Area under forests, as per land records, was 683,100 km^2 in 1994 and 696,260 km^2 in 2007. However, the entire area recorded as "forest" did not bear forest cover (as this includes grassland, wasteland, and desert under the administrative control of the state forest departments). India's forest cover for 2007 was assessed by the Forest Survey of India through satellite imagery interpretation to be 690,899 km^2 (Figure 1.5). An additional area of 92,769 km^2 was marked, making the total tree and forest cover to be 23.84% of the country's geographic area in 2007. A comparison of the forest cover of India between the years 2000 and 2007 shows a net increase in forest cover by 57,502 km^2. Dense forest (>40% tree canopy cover) decreased by 14,287 km^2 (excluding dense mangroves). However, the area under mangroves declined by 157 km^2 during 2001 to 2007. It is to be noted that the forest cover of India has been increasing steadily over the years due to the adoption

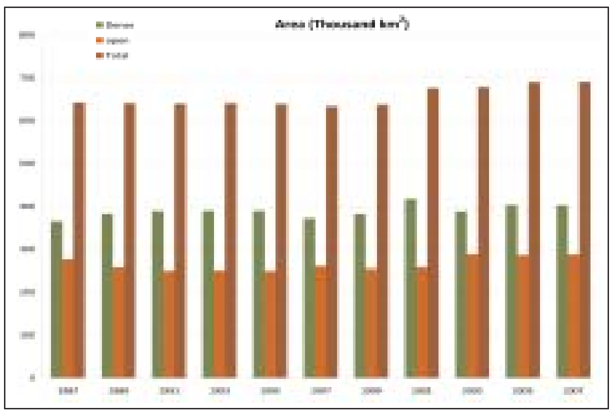


Figure 1.5: Indian forest cover assessments, 1987–2007
Source: State of Forest Report, 1987–2009

Note: Mangroves are not covered in either dense or open forests during 1987–97 but are included in the total forest area. However, they have been sub-classified into dense and open forests since 1999.

of various conservation and climate-friendly policies of the government. This increase is despite the diversion of forest land for non-forest purposes, such as agriculture, for feeding our increasing population, and developmental activities such as construction of river valley projects, industrialization, mining, and road construction.

The forests of India are a source of fuel and fodder for rural people, an industrial input for a growing economy, a habitat for thousands of plant and animal species, a sink for CO_2 emissions, and a protective cover for their soils. An effective Forest (Conservation) Act (1980), further strengthened in 1988, stipulating a massive afforestation programme, establishment of reserves, and re-vegetation of degraded lands through joint forest management and people's participation helped India to conserve its forests and put a check on the diversion of forest land to non-forest uses. In spite of such measures, the average growing stock in India is 74 m^3/ha, much lower than the global average of 110 m^3/ha. In spite of the various conservation measures, the forests themselves are degrading because of continued illegal felling, extraction of fuelwood and non-timber products, invasion by weeds, and forest fires.

Planned afforestation programmes began in the late 1950s as a government policy for conserving soil, producing industrial raw material, fuelwood, and fodder, and increasing tree cover in the urban areas. After the establishment of the Forest Development Corporations in the states and launch of social forestry projects, large-scale afforestation activity began in the year 1979. While the forest corporations continued planting industrially important species after clear felling of the commercially less valued forests, most of the plantations under social forestry were done outside the forest reserves, along rail, road, and canal sides, in other government wastelands, and in private farmlands, using short rotation species.

Despite these policy-induced forest cover enhancements, uncontrolled grazing by domestic livestock in forest areas is perhaps one of the most important reasons for the degradation of forests in India as it destroys the seedlings and young recruits, and in turn the regeneration process. It has been estimated that about 77.6% of India's forests are affected by livestock grazing. Pressure of grazing has increased tremendously owing to a continuously growing cattle population. Shifting cultivation mostly practised in the north-eastern parts of India is another factor responsible for the degradation of forests. An area of about 18,765 km^2 (0.59% of the total geographical area) is under shifting cultivation. Though the earlier practice of 15–20 years' cycle of shifting cultivation on a particular land is now reduced to 2–3 years, this agricultural practice has resulted in large-scale deforestation, and soil, nutrient, and biodiversity loss. About 53% of the forests in India are affected by fire, and of these, 8.9% report frequent fire incidences, while occasional fires affect 44.2% of the forest area in India (Dikshit et al., 2004; Bora and Saikia, 2007; Singh and Shah, 2007). These results are not indicative of the annual fire, but indicate that the areas are definitely prone to heavy or light fires, and there have been incidences of fire in the past.

Almost 53.4% of India's land area comprises arid and semi-arid regions. In these regions, cultivation is restricted to more productive but limited land, while a large animal population depends on native vegetation. The rains are erratic and often come in the form of a few heavy storms of short duration, resulting in high run-off instead of replenishing groundwater. Protective vegetation cover is sparse, and there is very little moisture for the most part of the year. India's arid zone is the most densely populated desert in the world. The growing pressure on the land due to ever increasing population (both human and cattle) and absence of any subsidiary occupation compel people to cultivate the marginal lands and graze the dunes. There is severe wind erosion in areas that have bare soils and unconsolidated geologic material like sand. The area subjected to high wind erosion is about 59.2 Mha, which includes about 7.03 Mha of cold desert in Ladakh and Lahaul valleys. In the western Rajasthan, the process of desertification is active in about 13.3 Mha (MoA, 2008). The Government of India is committed to the United Nations Convention to Combat Desertification and provides financial support and guidance for the implementation of centrally sponsored schemes such as Desert Development Programme, Drought Prone Areas Programme, and the Integrated Watershed Projects in the country.

Wetlands in India are distributed in various ecological regions ranging from the cold and arid zone of Ladakh through the wet Imphal in Manipur, and the warm and arid zone of Rajasthan–Gujarat to the tropical monsoon-influenced central India, and the wet humid zone of the southern peninsula. Recent remote sensing studies (Narayanakumar and Kumaraswamy, 2006; Thangamani and Rao, 2007) show that the total wetland area of India is 7.58 Mha; of this, 5.3 Mha is natural wetland, whereas 2.26 Mha is man-made wetland (MoA, 2008).

The wetland statistics of the country have been updated using the satellite remote sensing data of 2006-07 at 1:50,000 scale using a 19 type classification code. The results indicate total wetland area of India as 15.245 Mha; excluding the rivers, the total area estimate stands at 10 Mha. Of this, around 67.0% area is occupied by natural wetlands and the rest by manmade ones. For the first time, the inventory of high altitude wetlands (above 3000m elevation) have been carried out, which shows total 4703 wetlands occupying 126249 ha area (MoEF, 2011; Panigrahy *et al.*, 2011).

The coastal areas of India accommodate about one-fourth of the country's population that depends, to a large extent, on marine resources. Nine of the Indian states, namely, Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal, are situated along the long coastline. In addition, some of the union territories such as Pondicherry and Daman, and groups of islands, including Andaman and Nicobar in the Bay of Bengal and Lakshadweep in the Arabian Sea, also constitute coastal ecosystems of great economic and ecological importance.

Agriculture and Livestock

Agriculture

Indian society is an agrarian society, with 70% of the population almost completely dependent on agriculture, even though the share of agriculture in the gross domestic product (GDP) has been continuously declining. Spatially, it is the most widespread economic pursuit, claiming more than 40% of the country's total area. Agriculture will continue to be important in India's economy in the years to come. It feeds a growing population, employs a large labour force, and provides raw material to agro-based industries.

While it is agreed that given the physical and bio-genetic diversity of the Indian sub-continent, a strategy of diversified and regionally differentiated agriculture is desirable for improving the economy and augmenting its resources, it may also be noted that the Department of Agriculture and Co-operation (DAC) is already following a diversified and regionally differentiated strategy for improving agricultural productivity and augmenting farm output.

Crop yield is a function of many factors like climate, soil type and its nutrient status, management practices, and other available inputs. Of these, climate plays an important role, probably more so in India, where the majority of agriculture is dependent on the monsoon, and natural disasters such as droughts and floods are very frequent. Therefore, efficient crop planning requires a proper understanding of agro-climatic conditions. This calls for collection, collation, analysis, and interpretation of long-term weather parameters available for each region to identify the length of the possible cropping period, taking into consideration the availability of water.

With 329 Mha of geographical area, India presents a large number of complex agro-climatic conditions. The Planning Commission of India has delineated 15 agro-climatic regions, which were proposed to form the basis for agricultural planning in the country. This delineation was a result of the National Agricultural Research Project launched in 1979. The 15 regions are Western Himalayan, Eastern Himalayan, Lower Gangetic Plains, Middle Gangetic Plains, Upper Gangetic Plains, Trans-Gangetic Plains, Eastern Plateau and Hills, Central Plateau and Hills, Western Plateau and Hills, Southern Plateau and Hills, East Coast Plains and Hills, West Coast Plains and Ghat, Gujarat Plains and Hills, Western Dry, and the Islands region. The agro-climatic zone planning aims at scientific management of regional resources to meet the food, fibre, fodder, fuel, and fertilizer needs, without adversely affecting the status of natural resources and the environment. The Eleventh Five-year Plan has again reiterated that agricultural planning should follow the agro-climatic regions. This is now being done in phases, using satellite imagery to provide an up-to-date base for developmental projects. The database has already been created, and the preparations for satellite-based information systems are at a fairly advanced stage.

India has come a long way since the 1950s from being a food-starved to a food-sufficient country. According to the "Agricultural Statistics at a Glance 2010", food grain production has increased by over four-fold since the 1950s. Agriculture contributed 17.0% to India's GDP in 2009/10, with 70% of the country's population employed in this sector. The improvement in grain yield has been realized through the "Green Revolution", which started in 1960s, and later with improved agricultural practices and inputs. These include improved mechanized farming since the 1970s, and increased net area under irrigation (31 Mha in 1970/71, 53 Mha in 1994/95, 57 Mha in 1998/99, and 62 Mha in 2007/08) and net sown area (119 Mha in 1950/51, which has increased and almost saturated at 141 Mha over the past decade). Key indicators are depicted in Figure 1.6. Growth in total fertilizer consumption (2.6

Mt in 1970/71, 13.6 Mt in 1994/95, 16.6 Mt in 2000/01, and 24.91 Mt in 2008/09), and availability and use of high yielding variety seeds have contributed substantially to increased grain yield. Despite the above improvements, agriculture in India is still heavily dependent upon the monsoon, indicating its vulnerability to climate change.

Agriculture has been accorded high priority under the different five-year plans. The conversion of cultivable wastelands into the other categories of land use, especially into cultivated land, took place in the first two decades after Independence. Net sown area increased by 12% during 1954–2007, while the intensity of farming (area sown more than once) increased almost three-fold during the same period. India has made fair progress in developing its agriculture in the past five decades and is now almost self-sufficient in food grain production. Over 70% of the freshwater supply is used for irrigation purposes. Against the growing demand, water availability remains more or less stable in India.

Diversity in agricultural crops is an important measure

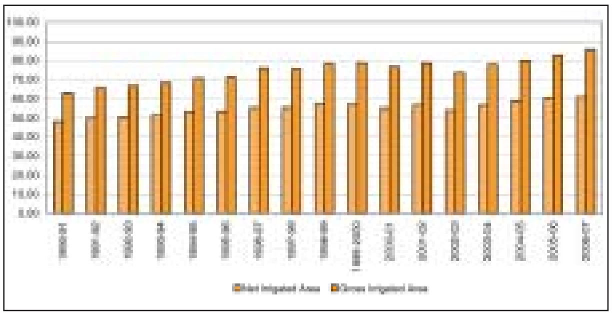


Figure 1.6: Area under irrigation (%) in India
Source: Agricultural Statistics at a Glance, 2010

of the society's ability to face the changes in the natural environment. Crop diversity is important for many reasons. First, it can be used to combat risks farmers face from pests, diseases, and variations in climate. If a farmer specializes in just one crop, failure of that crop would mean huge economic losses for him as he does not have any other crop to fall back on. If the same crop is grown over thousands of hectares, any sort of disease or pest attack would mean losses for thousands of farmers. Maintaining crop diversity also insures farmers against fluctuating market trends. Growing only one crop would make farmers very vulnerable to fluctuating prices of that crop. The problem of production risks can, to some extent, also be solved by crop insurance. However, this could be expensive. For poor farmers especially, maintaining diversity is a better way to reduce production risks. The objective of the modern agriculture is to maximize profits. In pursuit of this objective, agriculture has become more intensive and mechanized. Modern farmers tend to specialize in a few crops, usually a commercial crop. As a result, crop diversity has reduced. Today, more than 50% of the food requirements are derived form just three crops (maize, rice, and wheat) and 95% of energy requirements are derived from less than 30 crop species.

Livestock

India has 11% of the global livestock population, with still increasing growth rates. However, there is a decelerating trend in almost all species except buffalo, poultry, goats, and pigs (Figure 1.7). The populations of draught animals have witnessed a negative trend. Despite the low productivity and off-take rates, the contribution from animal husbandry and dairying was 5.21% of the GDP in 2007/08 at current prices. The Indian livestock sector employs 5.8% of Indian workforce and acts as a storehouse of capital and an insurance against crop failure. With production concentrated among small landholders, rearing livestock also helps improve income distribution.

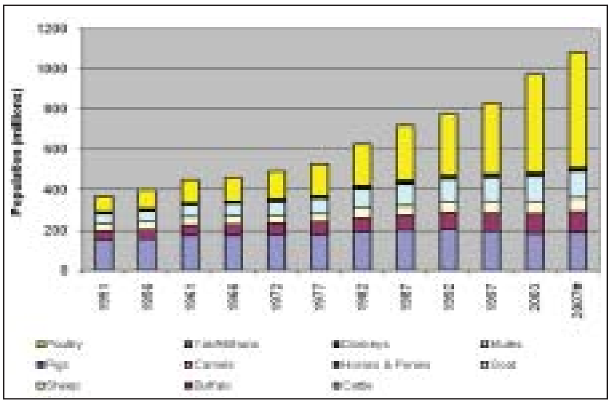


Figure 1.7: Livestock population, 1951–2007
Source: Basic Animal Husbandry Statistics, 2002; 17th Indian Livestock Census, 2003 (# - provisional estimates)

Natural Disasters

Of the total geographical area in India, about 70% of the area is under arid, semi-arid, and dry sub-humid regions. The western parts of Rajasthan and Kutch are chronically drought affected. Since early 1970s, a number of districts have been covered under the Drought Prone Areas Programmme (DPAP) to help them deal with drought-related problems. Table 1.1 provides an overview of the coverage of DPAP, by state. Besides DPAP, a special programme to deal with desertification was also launched in the states of Rajasthan, Gujarat, Haryana, Jammu and Kashmir, and Himachal Pradesh in 1977/78. The programme is subsequently extended to cover parts of Andhra Pradesh and Karnataka. The Desert Development

Table 1.1: Distribution of area covered under drought prone area programme (DPAP), by state

State	No. of districts	No. of blocks	Area (km²)
Andhra Pradesh	11	94	99,218
Bihar	6	30	9,533
Chhattisgarh	8	29	21,801
Gujarat	14	67	43,938
Himachal Pradesh	3	10	3,319
Jammu & Kashmir	2	22	14,705
Jharkhand	15	100	34,843
Karnataka	15	81	84,332
Madhya Pradesh	24	105	89,101
Maharashtra	25	149	194,473
Orissa	8	47	26,178
Rajasthan	11	32	31,969
Tamil Nadu	17	80	29,416
Uttar Pradesh	15	60	35,698
Uttarakhand	7	30	15,796
West Bengal	4	36	11,594
Total	**185**	**972**	**745,194**

Source: Ministry of Rural Development, Annual Report 2007–08

Programme focuses on the problems of desert areas and aims at minimizing the losses due to drought and controlling desertification through the rejuvenation of natural resource base of the desert area.

The coasts of India are frequently affected by cyclonic storms. The East Coast is especially vulnerable to cyclonic storms and the states of Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal are significantly affected. Table 1.2 shows the frequency of cyclonic storms across the East Coast of India, as assessed by various studies. Among the four states on the East Coast, Orissa and Andhra Pradesh are highly vulnerable.

Table 1.2: Frequency of cyclonic storms: East Coast of India

State\ Study	Mandal (1991) (1891–1990)	GTECCA (1996) (1877–1995)	Mohanty and Gupta (2002) (1891–1994)	IMD (2008) (1891–2007)
West Bengal	69 (22.40)	67 (20.93)	49 (19.14)	54 (17.64)
Orissa	98 (31.81)	106 (33.12)	94 (36.71)	106 (34.64)
Andhra Pradesh	79 (25.64)	90 (28.12)	65 (25.39)	86 (28.11)
Tamil Nadu	62 (20.12)	57 (17.81)	48 (18.75)	60 (19.61)
Total	**308 (100)**	**320 (100)**	**256 (100)**	**306 (100)**

Note: The figures in brackets show the percentages

Source: Mohanty et al., 2005; Indian Meteorological Department (IMD), 2008

India is also affected by frequent floods, leading to agricultural, property, and infrastructural losses, besides causing significant human misery. The reported total damages due to flood show an increasing trend over the years (Source: Central Water Commission, Government of India). However, it is important to normalize the damages by accounting for price changes, income changes, and population changes in flood-affected areas. As expected, the flood damages have increased over the initial years, but with better governance and information dissemination, these have started showing a declining trend.

Demographic Profile

Population levels and growth rates drive national consumption of energy and other resources, and, in turn, greenhouse gas (GHG) emissions. India's population has steadily risen over the years, crossing the one billion mark in 2000 and increasing annually by about 15 million since then. With a population of 846 million in 1991, 914 million in 1994, 1027 million in 2001, and 1210 million in 2011, India is the second most populous country in the world. The decadal population growth rate has, however, steadily declined from 24.8% during 1961–71 to 21.3% during 1991–2001 and 17.6% during 2001–2011. This has resulted in reducing births by almost 36 million over the last 30 years. Reduced decadal population growth rates would lower GHG emissions, reduce pressure on land, resources, and ecosystems, and provide higher access to social infrastructure.

India's population density is very high; the density of 264 persons/km² in 1991 increased to 325 persons/km² in 2001 and 382 persons/km² in 2011. Twelve states/union territories had population density of less than 250 persons/km², 7 had between 251 persons/km² and 500 persons/km², 9 had between 501 persons/km² and 1000 persons/km², while 7 had population density above 1000 persons/km², as per 2011 census (Figure 1.8). This coupled with low per capita incomes and low adaptive capacity of the majority of this population renders them vulnerable to the impacts of climate change on coastal areas and fisheries.

India is steadily improving on many critical demographic indicators. The average life expectancy at birth went up from 32 years in 1951 to over 64 years in 2006. Total fertility rate (TFR) declined during 1982–92, resulting

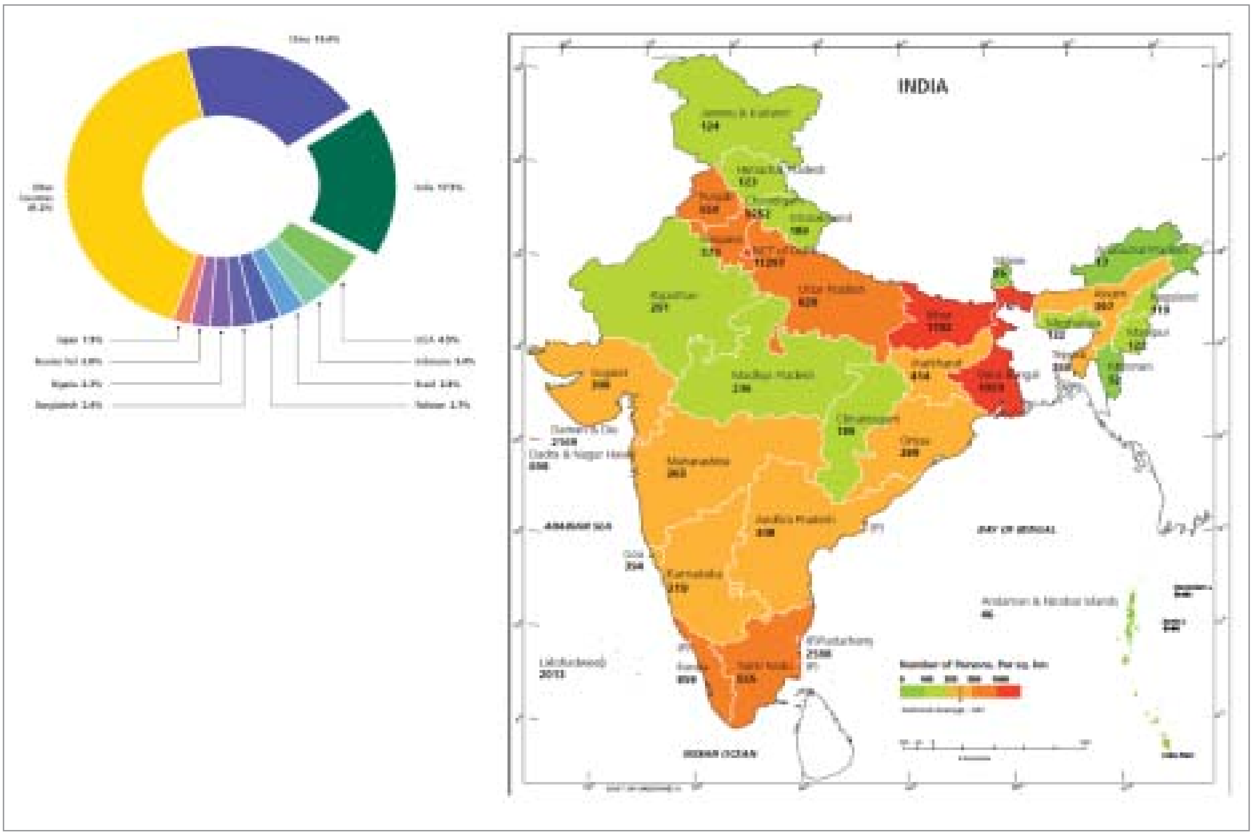


Figure 1.8: Indian population density, 2011
Source: Preliminary Report of Census for India, 2011

in the reduction of almost one child per woman, and is projected to decline further to 2.52 during 2011–16. Infant mortality rate (IMR), a sensitive indicator of health status as well as of human development, has also declined considerably for both males and females. Linking IMR with monthly per capita expenditure (MPCE) indicates that households with low MPCE have a higher infant mortality rate in India (Figure 1.9). The average literacy rate went up from less than 20% in 1951 to 74% in 2011. The poverty level went down to 22% of the total population in 2004 from 51.3% during the 1970s. In spite of these achievements, India continues to face the persistent challenge of population and poverty. About 66% of the population lives in rural areas, in about 0.641 million villages, with many living with poor communications and transport facilities. Reproductive health and basic health infrastructure require considerable strengthening despite commendable achievements in the last 60 years. Nearly 100 million people live in urban slums, with better but limited access to clean potable water, sanitation facilities, and health care services. In addition to this, there is the issue of large-scale migration of people from rural to urban areas.

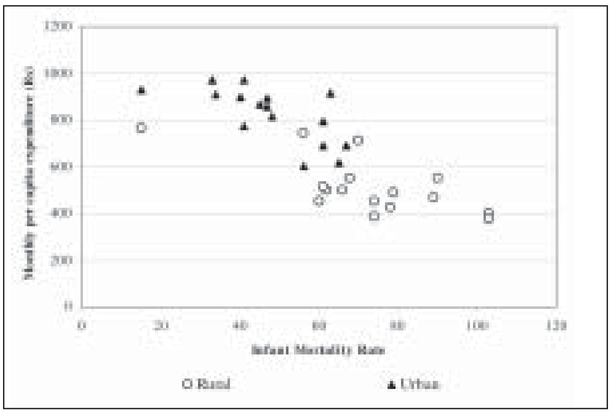


Figure 1.9: Rural and urban infant mortality rates and MPCE (monthly per capita expenditure) in 15 major Indian states
Source: National Sample Survey Organization (NSSO), 1998

India is largely rural, and the vast majority of the population continues to live in rural areas.[2] The progress of urbanization has been relatively slow in India as compared to other developing countries. The urban population increased from 19% of the total population in 1965 to 29% in 2007 (Figure 1.10). As per the 2001 Census of India, nearly two-thirds of the urban population is concentrated in 317 Class-I cities (population of over 100,000), half of which lives in 23 metropolitan areas with populations exceeding one million each. The number of urban agglomerations/cities with populations of over a million increased from 5 in 1951 to 23 in 1991 and to 37 in 2001. This rapid increase in urban population has resulted in unplanned urban development, changed consumption patterns and increased demands for transport, energy, and other infrastructure. This may reflect not only rapid economic development and industrialization, but also high levels of energy consumption and emissions. India's population pyramid shows a broad base indicative of an expanding population. This structure includes a large number of children born each year. Even if the average number of children falls substantially in future, the young age structure will generate continued growth for decades as a large number of them enter child-bearing age. Even if all Indians plan for two children per family, the population will continue to grow for the next 60 to 70 years. The energy and other resource consumption and therefore related GHG emissions would continue rising in the foreseeable future for India. India has the largest youth population in the world, which indicates a vast work force.

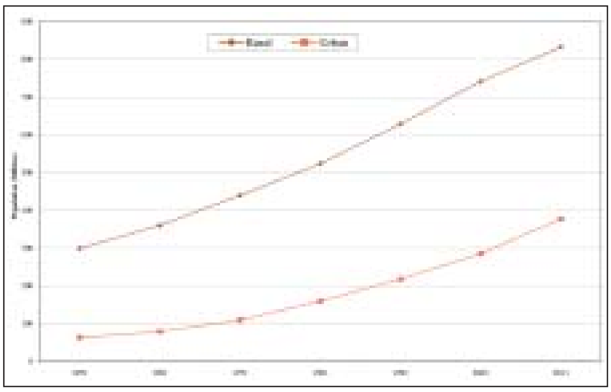


Figure 1.10: Rural–urban population profile of India
Source: Census of India, 1991 and 2001 and MoHA, 2011

Households

In 1994, India had more than 160 million households, approximately three-fourths of which were in rural areas, but accounted for only one-third of the total national energy consumption (NSSO 1993/94; Census of India, 2001). Since then, demographic changes have led to an appreciable rise in total number of households in India, with the urban share increasing faster than the rural one. There is also an increase in energy consuming appliances at all levels. However, this is an expected and desirable trend for a developing country, where appliance-possession levels per 1000 household are still abysmally low in comparison to the developed and even many developing countries. Household ownership of appliances has gone up in both rural and urban areas since 2000, sometimes by a factor of two, especially for connectivity and ownership of mobile phones. Star-rated appliances with higher energy efficiency have also started penetrating since the last couple of years, and with proper incentives and programmes by the government and private sector, could provide a major thrust in demand side management of electricity. However, the immediate national development target of doubling the per capita income by 2012 and continued 8% and above GDP growth rates into the medium term will result in increasing possession of durable goods.

The share of "*katcha*" (mud huts), "*semi-pucca*", and "*pucca*" (concrete) dwellings in total rural dwellings was 32%, 36%, and 32%, respectively, in 1993. In the urban sector, about 75% of the households resided in *pucca* structures. As incomes rise, demand for basic amenities such as housing will increase. The construction sector has major linkages with the building material industry since material accounts for more than half the construction costs in India. The building material includes cement, steel, bricks, tiles, sand, aggregates, fixtures, fittings, paints, chemicals, construction equipment, petro-products, timber, mineral products, aluminum, glass, and plastics. A rise in the demand of these materials would influence future GHG emission trajectories for India.

A large number of people are homeless in India. Economic conditions also force economically weaker sections of society to live in an inferior housing environment such

2 The conceptual unit for urban areas is a "town", whereas for the rural areas it is a "village". The classification of an area as an urban unit in Census of India (2001) is based on the following definition:

a All places declared by the state government under a statute as a municipality, corporation, cantonment board or notified town area committee, etc.

b All other places which simultaneously satisfy or are expected to satisfy the following criteria:

- A minimum population of 5000;
- At least 75% of the male working population engaged in non-agricultural economic pursuits; and
- A density of population of at least 400 per square kilometres (1000 per square mile).

as slums. The mainstream formal housing needs a faster production system, maintaining quality of houses and economy to overcome the huge shortage, which continues to be a serious challenge to public as well as private housing providers. There is a shortage of about 24.7 million houses in India, on an average (NBO, 2003). Most of the shortage (99%) is for the lower income group (LIG) and economically weaker section. Meeting these shortages would require more production of steel, cement, bricks, glass, ceramics, and energy.

Governance Profile

India is the world's largest democracy; the Legislature, the Executive, and the Judiciary constitute the three building blocks of the Indian Constitution. The Legislature enacts laws, the Executive implements them, and the Judiciary upholds them. The Indian parliament consists of two houses: the Rajya Sabha (Upper House) and the Lok Sabha (Lower House). India has a unique system of federation, which manifests unitary character. The spheres and activities of the Union and the states are clearly demarcated. The exhaustive Union list and the state list placed in the seventh schedule of the Constitution distinctly outline the respective jurisdiction and authority of the Union and the states. Some of the sectors belonging to environment and energy are listed in the concurrent list, wherein both the Union and the state have concurrent jurisdiction to enact laws. The Constitution also devolves powers to the lower levels – "power to the people" – through the institutions of *Panchayats* and *Nagar Palikas* (local municipal bodies), with a view to ensure administrative efficiency in concordance with the broader concept of good governance.

Environmental and climate change governance

The Government of India attaches high priority to the environment. The Ministry of Environment and Forests has the responsibility of planning, promoting, coordinating, and overseeing the implementation of environmental and forestry policies and programmes. It also serves as the nodal agency for international cooperation in the area of environment, including climate change. Environment ministries/departments at the state level deal with state-specific environmental issues and concerns. Scientific and technical staff, as well as institutions and experts, support environment administrations at the Union and state levels.

India has a strong & independent judiciary. Environmental issues have received a further boost through the judicial processes, which recognize the citizen's right to a clean environment as a component of The Right to Life and Liberty. Besides, matters of public interest get articulated through the vigilant media and active non-government organization (NGO) community.

Environmental concerns are integral to the governance of India. Prior to the *United Nations Conference on Human Environment*, at Stockholm, the Government of India had established a *National Committee on Environmental Planning and Coordination* (NCEPC) under the aegis of the Department of Science and Technology. This commitment was a major step taken by India, and the country was one of the pioneering countries in the world to amend its Constitution to incorporate provisions to protect its environment. The constitutional provisions are backed by a number of laws—acts, rules, and notifications. More than two dozen laws have been enacted to protect and safeguard India's environment. They cover all aspects of the environment—from pollution to conservation, from deforestation to nuclear waste disposal. Some of these laws are precursors to today's environmental movements.

India announced a National Action Plan on Climate Change (NAPCC) in 2008, which identifies measures that promote our development objectives while also resulting in co-benefits for addressing climate change. There are eight National Missions, which form the core of the NAPCC, representing a "multi-pronged, long-term and integrated strategies for achieving key goals in the context of climate change". Broadly, the Plan envisages promoting understanding of climate change with emphasis on issues related to adaptation and mitigation, energy efficiency, and natural resource conservation.

1. **National Solar Mission** (renamed as Jawaharlal Nehru National Solar Mission), under the brand name "Solar India", was launched to significantly increase the share of solar energy in the total energy mix. The objective of the Mission is to establish India as a global leader in solar energy, by creating enabling policies for its quick diffusion across the country. The immediate aim of the Mission is to set up a conducive environment for solar technology penetration in the country, both at the centralized and decentralized levels. The target under this mission is to deliver 20 GW of solar power by 2022.
2. **National Mission for Enhanced Energy Efficiency (NMEEE)** focuses on enhancing energy efficiency measures in the country (in addition to the already

existing programmes pursued by Ministry of Power [MoP] and Bureau of Energy Efficiency [BEE]) through four new initiatives. These initiatives are (i) Perform, Achieve and Trade (PAT), (ii) Market Transformation, (iii) Energy Efficiency Financing Platform, and (iv) Framework For Energy Efficient Economic Development.

3. **National Mission on Sustainable Habitat** has been launched with three main components: promoting energy efficiency in the residential and commercial sector, managing municipal solid waste, and promoting urban public transport. It is estimated, on an average, that the implementation of energy efficiency measures would help in achieving about 30% of energy savings in new residential buildings and 40% in new commercial buildings. In the case of existing buildings, these estimates are about 20% and 30%, respectively.

4. The main objective of the **National Water Mission** is, "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within states through integrated water resources development and management". The main identified goals of the mission are developing a water database in the public domain, particularly on the assessment of the impact of climate change on water resources; promoting water conservation, augmentation, and preservation; focusing attention on overexploited areas from water use perspective; and increasing water use efficiency by 20% and promoting basin-level integrated water resource management.

5. **National Mission on Green India** aims at addressing climate change by enhancing carbon sinks in sustainably managed forests and ecosystems, enhancing the resilience and ability of vulnerable species/ecosystems to adapt to the changing climate and enabling adaptation of forest-dependent local communities in the face of climatic variability. There are three main objectives of the Mission: (i) doubling the area under afforestation/eco-restoration in India in the next 10 years (total area to be afforested/eco-restored to 20 Mha), (ii) increasing the GHG removal by India's forests to 6.35% of India's annual total GHG emissions by the year 2020, and (iii) enhancing the resilience of forests/ecosystems under the Mission.

6. **National Mission on Sustaining Himalayan Ecosystem** identifies the importance of continuity and enhancing the monitoring of the Himalayan ecosystem, in particular, the state of glaciers and the impact of changes in the glacial mass and its subsequent impact on river flows. It is also identified, under the Mission, to empower local communities through *Panchayati Raj* institutions (PRIs), so as to assume greater responsibility for the management of natural resources.

7. **National Mission for Sustainable Agriculture** seeks to transform Indian agriculture into a climate resilient production system through suitable adaptation and mitigation measures in the domain of crops and animal husbandry. These interventions would be embedded in research and development activities, absorption of improved technology and best practices, creation of physical and financial infrastructure and institutional framework, facilitating access to information and promoting capacity building. While promotion of dryland agriculture would receive prime importance by way of developing suitable drought and pest-resistant crop varieties and ensuring adequacy of institutional support, NMSA would also expand its coverage to rain-fed areas for integrating farming systems with management of livestock and fisheries, so that agricultural production continues to grow in a sustainable manner.

8. **National Mission on Strategic Knowledge for Climate Change** envisions a broad-based approach, to include conducting research in the key domains of climate science; improving the global and regional climate models for the specificity and quality of climate change projections over the Indian sub-continent; strengthening of observational networks and data gathering and assimilation; and creating an essential research infrastructure.

The Ministry of Environment and Forests institutionalized a network-based structure, Indian Network for Climate Change Assessment (INCCA), which is in line with the government's commitment towards enhancing capacities to understand the science of climate change as well as the associated capabilities of impact assessment. INCCA has produced two major assessments since its inception, namely, " India: Greenhouse Gas Emissions 2007" and "Climate Change and India: A 4 × 4 Assessment – A Sectoral and Regional Analysis for 2030s".

INCCA, launched on 14 October 2009, is a network comprising 127 institutions countrywide. The essence of this network is to enhance the capacity of Indian science in terms of the "3 Ms" – Measurement, Modelling, and Monitoring – so as to achieve informed policy-making.

Several agencies are involved in resource management in India, and there is a degree of overlap in their responsibilities and jurisdiction. The allocation of resources to various sectors is determined by the Planning Commission working within the framework of the five-year plans. Environment management is guided at the central level by the Ministry of Environment and Forests and at state levels by the state departments of environment. Natural resources (like water, forests, oceans, etc.) are managed by separate ministries and departments. Inter-ministerial coordination committees and working groups deal with the cooperation and conflict of interest issues. Indeed, in a large country, this is perhaps inevitable. The implementation of government policies on resource use is directed by the multi-tiered administrative structure. The administrative units at the central and state levels coordinate resource allocation and project implementation. However, the implementation of all programmes is done at the field level under the overall supervision of the district collector. Local bodies such as *Panchayats* and city councils also have a stake in implementing various schemes in accordance with the instructions and directives of the district administration. Several participatory management schemes dealing with environmental issues have been successfully carried out at the local level.

Most environmental legislations in India are based on active state intervention to preserve, protect, and improve the environment. Some important Acts related to the protection of environment are the Animal Welfare Act (1960), Indian Wildlife (Protection) Act (1972), Water Prevention and Control of Pollution Act (1974), Forest (Conservation) Act (1980), Air (Prevention and Control of Pollution) Act (1981), Environment (Protection) Act (1986), Public Liability Insurance Act (1991), Biological Diversity Act (2002), Tribal Right Act (2006), and Green Tribunal Act (2010).

Economic Profile

The pace of economic growth is usually regarded as the primary indicator of a country's macroeconomic health. By this measure, India has done very well in this decade, especially in the most recent five years, with GDP growth averaging an unprecedented 8.4% a year over 2005/06–2009/10. The previous best five-year period for growth was in 1992/93–1996/97 (at 6.6% a year), triggered by the initial burst of economic reforms following the balance of payments crisis of 1991 (Table 1.3). That earlier spurt in investment, productivity, and growth had faltered after 1996 because of several factors, including the headwinds from the East Asian financial crisis, the initial uncertainties of coalitional governance, and a sustained deterioration in the fiscal deficit caused primarily by the large public pay increases following the Fifth Pay Commission. As a consequence, growth had slowed down to an average of 5.5% during the Ninth Five-year Plan period—1997/98 to 2001/02. It dropped even lower to 3.8% in 2002/03 because of a sharp, drought-induced fall in agricultural output.

Since then, India has witnessed an extraordinary boom, with the aggregate investment rate surging above 37% of GDP by 2007/8 and economic growth soaring to 9% or higher in the last three years, 2008/09–2010/11. The proximate drivers of this growth spurt included the sustained investment boom, cumulative productivity enhancing effects of reforms, an unusually buoyant international economic environment, and a demand-and-technology driven acceleration of modern services output. Inspection of the sectoral composition of growth shows that the Ninth Plan slowdown was confined to agriculture and industry, while services continued to grow fast and even accelerated (Table 1.3). Moreover, the expansion of services accelerated further in the years after 2002/03, propelled by high rates of growth in communications (especially telecom), business services (especially information technology), and finance. Industry picked up steam from 2002/03 and continued to grow robustly right through to 2010/11. Agricultural growth remained variable, substantially dependent on weather conditions. The sector has been unusually buoyant in the last three years, contributing significantly to the 9% plus rate of overall economic growth. India was and is among a few economies to sustain a healthy growth rate during the recent global financial crisis.

The exceptionally rapid growth in India's services sector is reflected in the contribution of this sector to the overall economic growth since 1991/92 (Figure 1.11). In the five years between 1991/92 and 1996/97, services contributed just about half of the total growth in GDP. In the subsequent five years till 2001/02, the sector's contribution rose sharply to 68% and has remained at a high 64% in the six years since 2001/02. These shares would be even higher if the construction sub-sector was included under services instead of industry. Perhaps equally noteworthy but more disquieting is the low and declining contribution of agriculture to GDP growth after 1996/97, even though over half of India's labour force is

Table 1.3: Growth rate of real gross domestic product (GDP) (in percent per year)									
	1992/93–1996/97	1997/98–2001/02	2002/03–2006/07	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
GDP	6.6	5.5	7.8	3.8	8.5	7.5	9.4	9.6	9.0
Agriculture	4.8	2.5	2.5	-7.2	10.0	0.0	5.9	3.8	4.5
Industries	7.3	4.3	9.2	7.1	7.4	10.3	10.1	11.0	8.5
Services	7.3	7.9	9.3	7.5	8.5	9.1	10.3	11.1	10.8
Per capita	4.4	3.5	6.1	2.3	6.9	5.8	7.7	8.1	7.5
Source: Central Statistical Organization, Government of India, 2009									

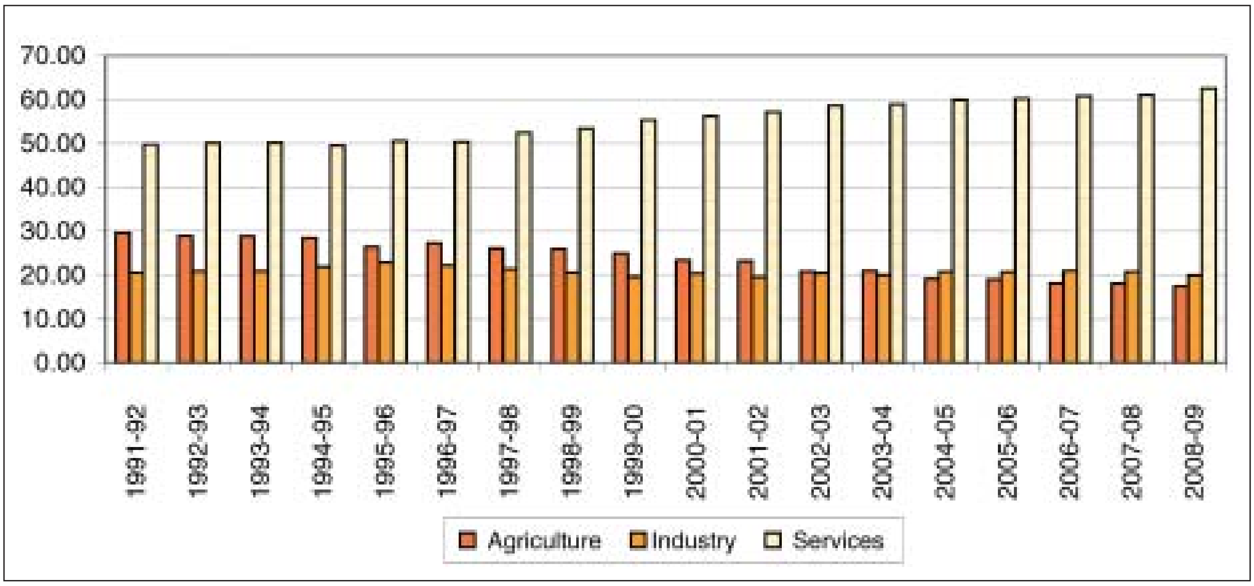


Figure 1.11: Sectoral composition of gross domestic product in India (in %)
Source: Central Statistical Organization, Government of India, 2009

still employed in this sector. In the six years after 2001/02, agriculture contributed only 7% of the total growth of GDP.

In terms of other macro indicators, inflation was not a significant macro policy problem during 2000s. Until early 2008, low world inflation, liberal trade policies followed by India, declining fiscal deficits, and anticipatory monetary policies ensured that inflationary pressures are kept under control. However, inflation has now become an important concern, triggered, among other factors, by the global financial crisis.

The key socio-economic indicators for 2010 are presented in Table 1.4. Despite this rapid economic growth, the per capita GDP is one of the lowest, and it is a fact that one-fourth of India's population of over 1.21 billion is still below the poverty line and that 44% of the Indian population has an income below $1/day. The country's Human Development Index is only at 0.612 as compared to China (0.663) and to developed countries such as Germany (0.885), Japan (0.884), and USA (0.902). The Technology Achievement Index of India is 0.201, which is comparable to China, but way below the developed countries (UNDP, 2010).

Social development depends, to a great extent, on economic development. For many decades, India followed a mixed economy model, wherein central planning co-existed with private enterprise. Agricultural activities, however, have rested almost entirely with private farmers. Industrial investment was sought to be controlled through industrial licensing until 1991.

In that year, a major programme of reforms was initiated, under which industrial licensing was abolished and trade

Table 1.4: National circumstances, 2010	
Criteria	**Measure**
Population (million, 2011)	1210
Relevant area (million square kilometres)	324
GDP at factor cost (1999/2000 prices), Rs billion	61332
GDP at factor cost (1999/2000 prices), $ billion	1371
GDP per capita (1999/2000 prices), $	1133
Share of industry in GDP (percentage)	25.8
Share of services in GDP (percentage)	57.3
Share of agriculture in GDP (percentage)	16.9
Land area used for agricultural purposes (million square kilometres)	1.95
Urban population as percentage of total population	34
Forest area (million square kilometres) (2007)	0.69
Livestock population excluding poultry (million) (2003)	464
Population below poverty line (percentage) (2004)	21.8
Life expectancy at birth (years) (2006)	63.5
Literacy rate (percentage 2011)	74.04
GDP – gross domestic product	
Sources: Economic survey 2010-11; Census of India, 2011; Agricultural Statistics at a Glance 2010; 17th Indian Livestock Census 2003; State of Forest Report 2009; Planning Commission, 2007	
Note: The monthly per capita poverty lines for rural and urban areas are defined as Rs 356.30 and Rs 538.60, respectively, for 2004/05.	

constraints were relaxed, protection was reduced, and a greater emphasis was laid on the private sector.

Gross domestic product and its structure

The Indian economy has taken rapid strides in the last 64 years after Independence, achieving food self-sufficiency for a growing population, increasing per capita GDP by over four-folds, creating a strong and diversified industrial base, developing technological capabilities in sophisticated areas, and establishing linkages with an integrated world economy. GDP growth rates of 7% to 9% in recent years (2005–10) have been some of the highest in the world. Enormous strides have been taken in every sector of development, be it in terms of output, per capita incomes, reduction in illiteracy and fertility rates, manpower training, building urban and rural infrastructure, and scientific and technological advances.

The primary sector (particularly agriculture) remains the bedrock of the Indian economy, although its share in the total GDP declined from over 50% in the early 1950s to about 17% in 2010/11. At the same time, the shares of manufacturing, transportation, banking, and service sectors have more than doubled in the last 64 years. The growth of the Indian economy is also accompanied by a change in its structure (Figure 1.12).

There have been serious deficiencies as well, especially the slow progress in alleviation of poverty and in generating adequate employment opportunities. It is now well recognized that unless India's growth is sustained at 8–10% for several years to come, along with disbursement of fruits of growth, especially to people below poverty

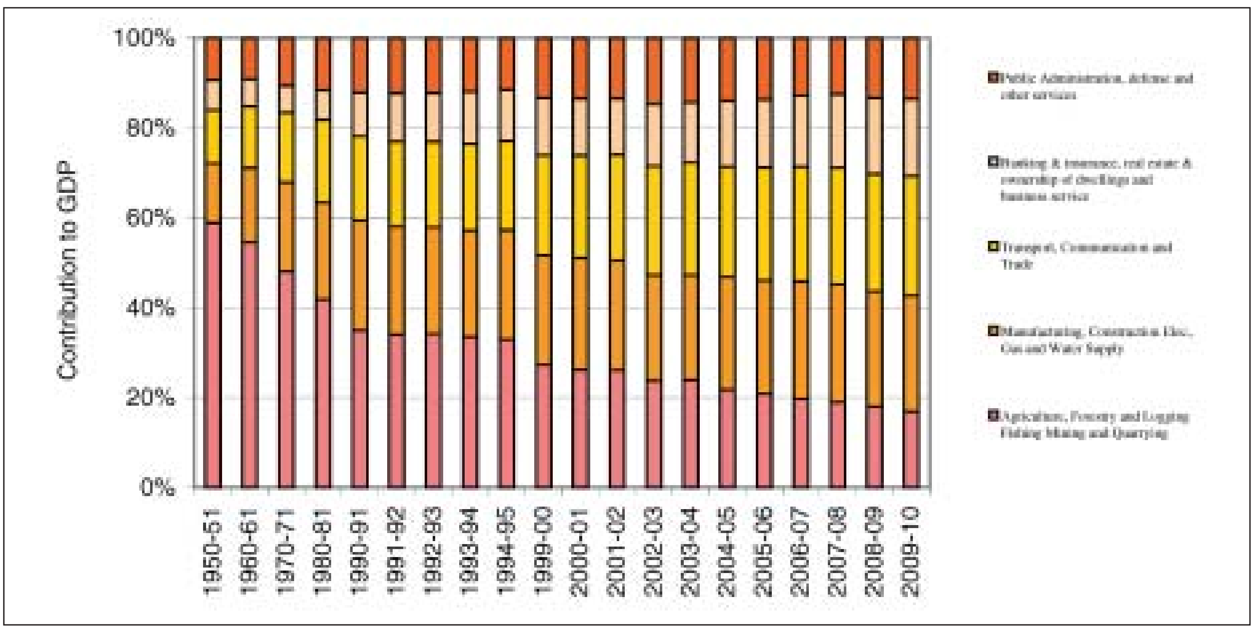


Figure 1.12: Contribution to gross domestic product, by sector (at factor cost)
Source: Economic Survey, Government of India, 2010/11

line, adequate resources cannot be mobilized to tackle the challenges of social development in which India lags behind many developed countries and even a few emerging economies.

The Indian budget

The national expenditure can be divided into two broad categories of "plan" and "non-plan", as well as "developmental" and "non-developmental". The total expenditure as a percentage of GDP has shown a gradual decrease since 1980. This may be due to the active participation of stakeholder organizations and the initiatives of NGOs. There has not been a marked decrease during the period 1991/2000, which may be attributed to the liberalization of the economy, wherein the government incurred a considerable amount of developmental expenditure.

On a combined basis (central and state governments), India has been running large fiscal deficits for over 30 years. Until recently, in any given year, India's fiscal deficit would typically figure among the top seven or eight countries in the world. The combined fiscal deficit had climbed above 9% of GDP in the years preceding the 1991 economic crisis. Rising fiscal profligacy was generally seen as an important contributory factor to that crisis. Concerted efforts by the central government brought the deficit down to a manageable 6.5% of GDP by the mid-1990s. This consolidation was reversed in the next five years because of the large public pay increases after 1996/97, low revenue buoyancy, and weak expenditure control policies. By 2001/02, the fiscal deficit was nearly 10% of GDP, and the revenue deficit (approximately government dis-savings) was at a record 7%. A sustained effort at fiscal consolidation resumed after 2002/03 and brought the combined fiscal deficit down to 5% of GDP in 2007/08 and the revenue deficit to below 1%.

The key policies that induced favourable fiscal developments varied across the two levels of government. At the central level, the enactment of the Fiscal Responsibility and Budget Management (FRBM) law in 2003/04 capped several years of technocratic and political efforts and gave a significant stimulus to the cause of fiscal consolidation. The second major policy initiative at the central level was a concerted and sustained programme to raise the tax–GDP ratio through better application of information technology and other means to strengthen tax administration.

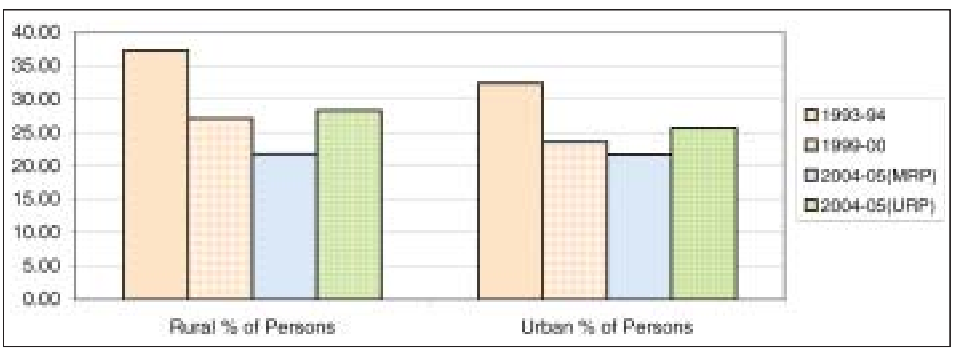
At the state level, the big improvements in fiscal consolidation occurred after 2003/04. Four major factors were at work. First, the remarkable growth in central tax revenues, noted above, also benefited the states. Second, following the recommendations of the Twelfth Finance Commission (TFC), the non-tax revenue receipts of the states were buoyed by larger transfers of devolution grants from the central government. Third, the TFC recommendations on debt relief and debt write-offs also catalysed the adoption of fiscal responsibility laws by nearly all the states, since these benefits were made conditional on the enactment of such laws. Fourth, after a long and tortuous process of technical work and political negotiation, nearly three quarters of the states reformed their sales taxes to a set of broadly uniform state value-added-taxes in April 2005. The indirect tax reforms through the introduction of goods and services tax in 2011 are expected to bring about further changes in the tax revenues at both centre and states.

In the light of the above discussion on the Indian budget, it is deemed necessary to highlight the constraints on Indian financial resources. India has been striving hard to achieve fiscal prudence through various measures highlighted above and therefore, climate change related challenges pose an additional burden on India's financial resources, which needs a detailed assessment about the needs and sources.

Poverty

Despite the growth in the population from 350 million in 1947 to more than a billion today and despite the low level

Figure 1.13: Poverty in rural and urban India: 1993/94–2004/05
Source: Reserve Bank of India, 2009



of economic development at the time of Independence, India has made significant progress in poverty reduction. The percentage of people below poverty line has decreased significantly. Yet, a large number of people remain below the poverty line (Figure 1.13).

The poverty line was originally defined in 1961 based on the income needed to provide adequate calorie intake, two pairs of clothing, and minimal amount of other essentials. This poverty line has been updated over the years to account for changes in prices. The estimates are based on large-scale sample surveys of household consumption, carried out periodically by the National Sample Survey Organization (NSSO).

Prior to Independence, India suffered from frequent, devastating famines and stagnation in growth. Therefore reduction in poverty and enhancement in agricultural development have been the central themes of India's development strategy. Uplifting the poor and integrating them into the mainstream form a part of the recurrent theme of India's five-year plans. Universal access to education is enshrined in the Constitution. India has established a wide array of anti-poverty programmes, and much of India's thinking on poverty has been mainstreamed internationally. India has successfully eliminated famines and severe epidemics. It has made progress in reducing poverty and in its social indicators, which is commendable considering the fact that at the time of Independence in 1947, the country was among the poorest in the world. Its vibrant democracy and free press have been major factors in these achievements.

The incidence of poverty began to decline steadily since the mid-1970s, which roughly coincided with a rise in the growth of GDP and agriculture. Since 1980, India's trend of 5.8% growth rate is the highest among large countries outside East Asia. Empirical analyses suggest that agricultural growth and human development were key factors in the decline in poverty across the country. However, the development strategy of the 1970s and 1980s, based on an extensive system of protection, regulation, expansion of public sector in the economy, and worsening fiscal deficits in the 1980s, proved unsustainable. In 1991, a crisis in the balance of payments and the fiscal situation was met by stabilization and reforms that opened up the economy, reduced the role of the public sector, and liberalized and strengthened the financial sector over the next few years. These policies generated a surprisingly quick recovery and an unprecedented 7.7% per annum average growth followed for three consecutive years. This led to increase in productivity at the macro-economic level and a booming private sector. During the 1990s, an agricultural growth of 3.3% per annum was maintained, which was about the same as in the 1980s but much higher than the declining rate of population growth, estimated at about 1.6% per annum.

Sixty-four years after Independence, a vast number of people still live below the poverty line in India, making poverty eradication one of the most challenging problems. Poverty is a global concern and its eradication is considered integral to humanity's quest for sustainable development. Reduction of poverty in India is, therefore, vital for the attainment of national as well as international goals. Poverty eradication has been one of the major objectives of the development planning process. Percentage of population below poverty line declined from about 37% in 1993/94 to 22% in 2004/05 in rural India. In urban India, the poverty decline over the same period was from 32% to 22%. The poverty decline is more modest if estimates are made on the basis of uniform recall period as against the mixed recall period in the expenditure survey.

To meet UN Millennium Development Goals, national and state planning targets, and inclusive growth agenda of the Government of India, poverty alleviation remains a top priority. This would imply higher resource and energy consumption, and higher economic activities. The Indian government is, however, committed to aligning sustainable development and climate change concerns.

The high incidence of poverty underlines the need for rapid economic development to create more remunerative employment opportunities and to invest in social infrastructure of health and education. These developmental priorities would enhance our energy consumption and therefore related GHG emissions.

Employment

India has a vast population of workforce in the age group of 18–60 years, and providing employment to them is a major challenge. As per the 61st Round NSS (2004/05), the employment grew by 1.97% per annum in rural India

Table 1.5: Labour force participation rates

	Usual status			Current daily status		
	1993/94	1999/2000	2004/05	1993/94	1999/2000	2004/05
Rural Males	56.1	54.0	55.5	53.4	51.5	53.1
Rural Females	33.0	30.2	33.3	23.2	22.0	23.7
Urban Males	54.3	54.2	57.0	53.2	52.8	56.1
Urban Females	16.5	14.7	17.8	13.2	12.3	15.0

Source: National Sample Survey Organization, 1993/94–2007/08

during the period 1999/2000–2004/05, while it grew by 3.22% per annum in urban India during the same period (Table 1.5).

There has been a significant decline in agriculture as a share of rural employment, while the share of manufacturing employment has not gone up commensurately for rural male workers. Instead, the more noteworthy shift for rural males has been to construction, with some increase in the share of trade, hotels, and restaurants. For urban males, on the other hand, the share of trade, hotels, and restaurants has actually declined, as it has for other services. Manufacturing is back to the shares of a decade ago, still accounting for less than a quarter of the urban male workforce. The only consistent increases in shares have been in construction, and to a lesser extent transport and related activities. Interestingly, the big shift for urban women workers has been to manufacturing, the share of which has increased by more than 4% points. A substantial part of this is in the form of self-employment. Other services continue to account for the largest proportion of women workers. Analysis of real wages suggests that for most categories of regular workers, the recent period has not been one of rising real wages. While real wages have increased slightly for rural male regular employees, the rate of increase has certainly decelerated compared to the previous period. The economy has, therefore, experienced a peculiar tendency of falling real wages along with relatively less regular employment for most workers.

It is often held that the rapid growth in modern information technology (IT)-driven services in India offers an opportunity to exploit the demographic dividend. Placed in the context of the economy as a whole, the sector's revenues now amount to about 4.5% of GDP. This makes it an important segment of the non-agricultural sector. However, the sector's contribution to employment does not compare with its role in the generation of income and foreign exchange. The total IT industry, including both hardware and software elements, as well as IT-enabled services still employ only slightly more than 1 million workers, out of an estimated total workforce in India of more than 415 million, and urban workforce of about 110 million.

Energy Profile

The fact that energy as an input to any activity is one of the important pillars of the modern economy makes the energy policy inseparable from the entire national development strategy. The entire fabric of the developmental policy contains the elements of energy strategy, which are rarely out of line with similar policies in other economic sectors. Thus, the path traversed by the Indian energy policy can be viewed in the light of the overall developmental strategy adopted by India after Independence.

Energy and climate change related concerns of the Indian economy include the growing gap between the demand and supply of energy, and environmental externalities associated with energy use. The Indian economy is growing rapidly since 1990s, with an even higher growth in the energy sector (Figure 1.14). The latter was because the economic growth was driven by energy-intensive sectors, where energy efficiency was low by international standards. These sectors are power generation, steel, cement, refineries, chemicals, fertilizer, and transport. High growth in these sectors has resulted in a high elasticity of energy consumption and environmental emissions with respect to GDP. Especially in the electricity sector, the electricity consumption has grown at a rate higher than the GDP and energy for the past two decades, with the trend becoming more pronounced in the 1990s. This implies

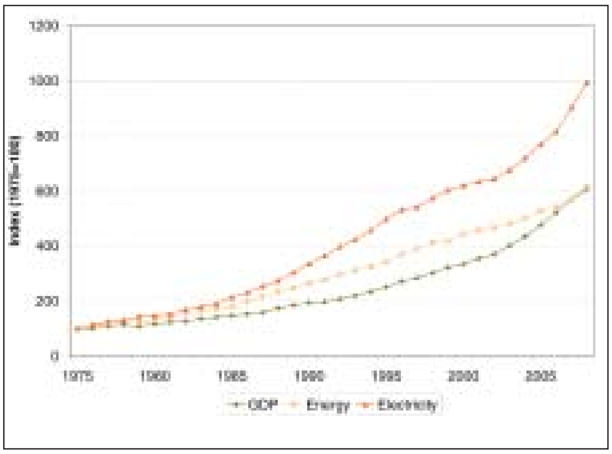


Figure 1.14: Growth of energy, electricity, and the Indian economy
Sources: Economic Survey of India, 1991–2006; CMIE, 2003-2007; Central Statistical Organization (CSO), 2006

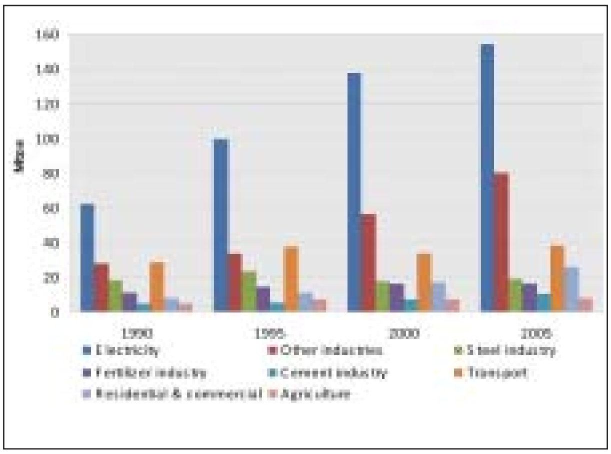


Figure 1.15: Sectoral energy consumption trends in India
Source: Center for Monitoring of Indian Economy, 2008

substantial increases in electric power generation and transmission capacities, and demand and consumption of petroleum product and natural gas.

The rapid economic growth, expanding industrialization, increasing incomes, rapidly rising transport, and modernizing agriculture are leading to a high growth in energy use in India, thereby causing serious environmental concerns. The sectoral energy consumption in India has been arising due to more production, despite a reduction in specific energy consumption patterns in almost all the sectors (Figure 1.15).

In the recent years, the government has rightly recognized the energy security concerns of the country, and more importance is being placed on energy independence. The Government of India has taken various initiatives towards diversification of energy sources, energy-efficient technologies, energy conservation measures, regulatory frameworks, etc. to meet the national goals as well as simultaneously addressing climate change concerns. India is probably the only country in the world with a full-fledged ministry dedicated to the production of energy from renewable energy sources. Additionally, India is emerging as a growing market for solar, wind, and hydroelectric power. The Government of India has an ambitious mission of "Power for all by 2012".

The reduced energy intensity of the Indian economy, in the period since 2004, has been marked by an economic growth rate of over 9% per annum, which has been achieved with an energy growth of less than 4% per annum. This reduced energy intensity, at the relatively low level of India's per capita GDP, has been made possible by a range of factors, including India's historically sustainable patterns of consumption, enhanced competitiveness, proactive policies to promote energy efficiency, and more recently, the use of the Clean Development Mechanism to accelerate the adoption of clean energy technologies.

Energy conservation potential for the economy as a whole has been assessed as 23% with maximum potential in the industrial and agricultural sectors. Energy conservation and increased efficiency are gradually taking an important place in the energy and industry sector plan in India. India has installed state-of-the-art energy-efficient technologies to curtail the energy bills. Increased competition due to the liberalization of the economy, the increase in energy prices, and the promotion of energy efficiency schemes with the introduction of the Energy Conservation Act in 2001 have contributed to reductions in the energy intensities of the service and industry sectors. The Government of India has committed to improve energy efficiency of GDP by 20–25% during 2005–20. Various programmes and schemes have been initiated towards this end, including PAT for nine energy-intensive sectors.

The consumption of commercial fuel (coal, oil, natural gas) for production of power and other uses has been teadily rising over the years, with domestically abundant coal continuing to be the dominant source. Coal meets 63% of India's total commercial energy requirement, followed by petroleum products (30%) and natural gas. Nearly 70% of the power requirement in India presently is met by thermal power plants. The total coal reserves in India are 211 billion tonnes (MoC, 2009), and by current estimates the reserves are enough to meet India's power needs for at least another 100 years. However, due to expanding coal demand, coal imports have been rising rapidly

Table 1.6: Trends in commercial energy production

	Units	1960/61	1970/71	1980/81	1990/91	2001/02	2009/10
Coal	Mt	55.67	72.95	114.01	211.73	325.65	532.06
Lignite	Mt	0.05	3.39	4.80	14.07	24.30	34.07
Crude oil	Mt	0.45	6.82	10.51	33.02	32.03	33.70
Natural gas	BCM	–	1.44	2.35	17.90	29.69	32.90
Hydro power	BkWh	7.84	25.25	46.54	71.66	82.8	106.70
Nuclear power	BkWh	–	2.42	3.00	6.14	16.92	18.60
Wind power	BkWh	–	–	–	0.03	1.70	4.00

Source: Planning Commission, 2007; Economic Survey of India, 2010/11

since the last decade. The commercial energy/power consumption in India is distributed among agriculture, industry, transport, domestic, and other sectors. As can be easily inferred, all the energy demands of India cannot be met by coal alone, as the agriculture sector alternatively uses coal-powered electricity as well as oil, the transport sector is totally dependent on availability of petrol and diesel, and also fuel switching in some of the power plants from coal to oil/natural gas has taken place. In order to meet the growing demand for oil, India imports about 70% of the total crude oil requirements. Other than consumption of fossil fuel energy, about 90% of the rural and 30% of urban households in India consume a large quantity of traditional fuels or non-commercial energy such as firewood, dung cake, chips, etc. The total renewable energy consumption in India, including biomass energy, amounts to about 30% of the total energy consumption, the rest being fossil fuel consumption. As a large part of the energy is still derived from fossil fuel, energy security is a matter of concern for India, although in the future it is expected that alternate sources of energy like biofuels would also be available. However, as mentioned earlier, coal being abundant, cheap, and locally available, it will be the mainstay of energy in the country for many years to come.

Primary energy supply

India has seen an expansion in the total energy use during the past five decades, with a shift from non-commercial to commercial sources of energy. Accordingly, the production of commercial sources of energy has increased significantly. Table 1.6 indicates the trends in the production of various primary commercial energy resources.

The total primary energy supply (TPES) in India has grown at an annual rate of 3.8% during 1953–2010, reaching a level of 715 Mtoe (million tonnes of oil equivalent) in the year 2010. Much of this growth has been contributed by commercial energy supply, which grew at a rate of 5.6% per annum, in contrast to 1.7% per annum growth

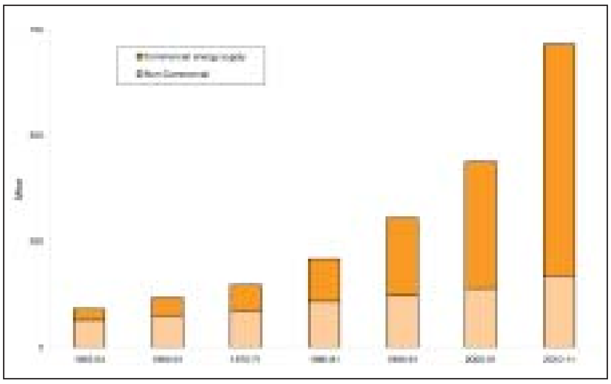


Figure 1.16: Decadal trend in total primary energy supply (Mtoe)
Source: Planning Commission, 2007; Economic Survey of India, 2010/11

experienced by non-commercial energy. As a result of this high growth, the share of commercial energy has increased from 28% in 1953/54 to 76% in 2010/11, with an associated decline in the share of non-commercial energy (Figure 1.16).

The period of 1953–60 was one of high growth with commercial energy supply growing at a rate of 6.5%, but the growth slackened slightly during the next two decades only to pick up during 1980–90. The growth in the past decade has also been impressive in view of several adverse international developments such as the Asian financial crisis of 1997. Growth rates in TPES, by decade, primary commercial energy supply, and primary non-commercial energy supply indicate a progressive increase in commercialization of the Indian energy sector. However, despite reaching such high growth rates in TPES, the per capita energy consumption at 426 kgoe in 2001 was one of the lowest in the world, though it has increased by a factor of 1.71 since 1953.

As stated earlier, coal remains the dominant fuel in our energy mix with a share of 38%, up from 26% in 1953/54 (Figures 1.17 and 1.18). Another fuel that has gained prominence is petroleum. From a share of just 2% in 1953/54 (as all petroleum was imported into India at that time), it has risen to about 26% in 2010/11. The share of natural gas has also increased from virtually nil to 6% in 2001/02. The geological coal reserves, estimated at 221 billion tonnes, are expected to last the longest, given the current consumption and production trends. India is not expected to be self-sufficient in hydrocarbons. India has only 0.4% of the world's proven reserves of crude oil, while the domestic crude oil consumption is estimated at 2.8% of the world's consumption.

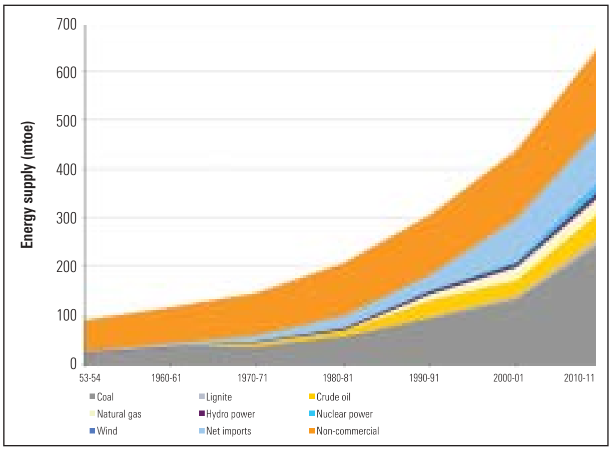


Figure 1.17: Trends of primary energy supply, by fuel, in Mtoe
Source: Planning Commission, 2007; Economic Survey of India, 2010/11

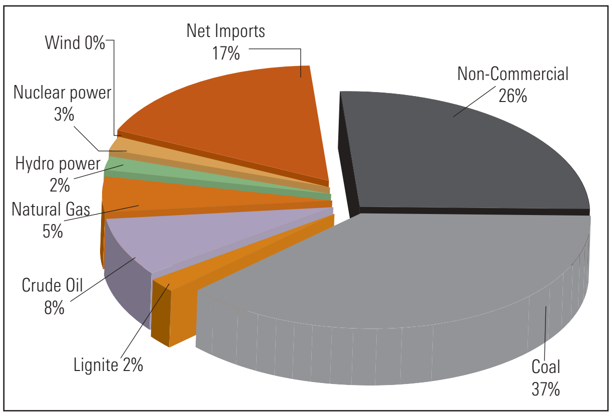


Figure 1.18: Share in primary energy supply, 2010/11
Source: Planning Commission, 2007; Economic Survey of India, 2010/11

Primary energy demand

The demand for petroleum products was estimated at 104.80 Mt during 2001/02, excluding the liquid fuel requirement for power generation. During the first four years of the Ninth Five-year Plan (1997–2002), the consumption of petroleum products grew at a rate of 5.8%. The consumption of petroleum products during 2001/02 was 100.43 Mt, thereby registering a growth of about 4.9% during the Ninth Plan period as against the target of 5.77% (Planning Commission, 2002). The lower growth is mainly due to the slowdown in the economy, improvement of roads (including construction of bridges and bypasses), and introduction of fuel-efficient vehicles.

The sluggish economic growth and non-materialization of new coal-based thermal power generation capacity during 1997/99 have adversely affected the coal demand. Coal consumption registered a marginal growth of 2% during this period against the initially envisaged annual demand growth of 6.85% in the Ninth Plan (1997–2002). Thus, during the Mid-Term Appraisal of the Ninth Plan, coal demand in the terminal year of the Plan was revised downwards from 412.20 Mt to 370.80 Mt of raw coal, implying an average annual compounded growth of 4.6%. However, the anticipated coal consumption of 348.43 Mt (excluding 4.93 Mt of washery middlings) in 2001/02 would imply a growth of only 3.32% per annum in coal consumption against the revised Ninth Plan target of 4.6%. This shortfall has been mainly due to a 49% slippage in the addition of coal-based power generation capacity. As against a target of 15,102 MW of incremental coal-based generation capacity, only 7680 MW (51%) has been realized during the Ninth Plan.

India is a developing country and three-quarters of the population lives in rural areas. Vast informal and traditional sectors with weak markets co-exist with the growing formal and modern sectors. The traditional to modern transitional dynamics are expected to continue in the foreseeable future, further adding to the growth in energy demands. The future dynamics of energy consumption and technology selection in various sectors in India will thus determine their long-term implications for the energy and environmental concerns.

Comparison with the world energy consumption: India ranks sixth in the world in terms of energy demand, accounting for 3.5% of the world's commercial energy demand in 2001 (Figure 1.19). The world's total primary commercial energy supply (TPCES) grew at a compounded annual growth rate of 2.4% over the period 1965–2002 with the Middle East and the Asia-Pacific regions displaying the highest growth rates. Within the Asia-Pacific region, India has exhibited one of the fastest growth rates in the commercial energy supply. On the

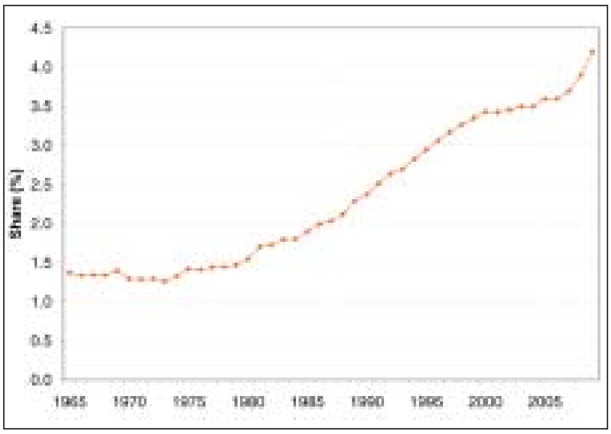


Figure 1.19: India's share (%) in total world commercial energy consumption
Source: British Petroleum, Statistical Review of World Energy, 2010

whole, the share of India in the total world commercial energy supply increased from 1.4% in 1965 to 3.5% in 2001.

In India, over 450 million people do not have access to electricity. In order to deliver a sustained growth of above 8% during next two decades, India would at least need to grow its primary energy supply by three to four times, whereas the electricity supply needs to grow at the rate of five to seven times the present consumption. Meeting the basic needs of access to energy and the same time addressing the growing concerns of climate change are a challenge for India. Enhancing energy supply and access to energy are key components of the national development strategy. At the same time, the focus of policies and programmes on reducing energy intensity and enhancing energy efficiency is stressed.

However, despite achieving such high growth rates in energy consumption, the per capita energy consumption in India is still low according to the global standards, and the energy efficiency of GDP (PPP basis) is among the best. This holds true even if it is compared with other countries at similar stage of development (Table 1.7).

Power Sector

The Indian Constitution has included electricity in the concurrent list, which means that both the centre and the states share the responsibility for the enactment of legislation in this sector. The very first attempts at introducing legislation in this sector were made as early as 1887. However, these attempts were restricted to ensuring safety for personnel and property. The first legislation, that is, the Indian Electricity Act was passed only in 1910, followed by other Acts. Until recently, the Indian Electricity Act (1910), the Electricity Supply Act (1948), and the Electricity Regulatory Commissions Act (1998) were the main regulations for the sector. The Electricity Regulation Act of 1998 initiated the setting up of the Central Electricity Regulatory Commission and has provisions for setting up state electricity regulatory commissions. The introduction of the Electricity Act (2003) has replaced the previous Acts and consolidated them. Apart from the national-level Acts, each state is governed by its individual legislations.

The power sector outlay as a proportion of the total outlay by the central and state governments has been declining. This has been mainly on account of the drive to enhance private sector investment in the power sector. The states have practically stopped investing in new generation projects. The share of the central power sector in the

Table 1.7: Economy and energy

	GDP per capita (PPP, $), 2007	CO_2 emissions per capita (metric tonnes), 2007	Electricity consumption per capita (kWh), 2007	GDP per unit of energy use (PPP, $ per kg of oil equivalent), 2007	Traditional fuel consumption (as % of total energy use), 2007
India	2753	1.43	542*	5.41	27.4
Developing countries		3.70	1945	4.90	17.6
OECD countries	32,647	10.96	8417	7.19	4.0
High income countries		12.49	9524	6.98	4.0
Middle income countries		3.31	1621	4.71	13.0
Low income countries		0.28	216	3.50	64.0
World	9972	4.63	2846	5.81	10.0

OECD – Organisation for Economic Co-operation and Development; GDP – gross domestic product

Source: United Nations Human Development Report, 2009; World Bank Databank, 2010

*However, as per Central Electricity Authority (CEA), per capita electricity consumption is 671 kWh in the year 2006-07. CEA has calculated per capita electricity consumption by using formula = (Gross Energy Generation + Net Import)/mid-year population total central sector outlay also declined from 13% to 10% during 1991–2001. The growth in power generation capacity (Figure 1.20), which increased by almost seven-fold between 1970 and 2000, was accompanied by a greater diversity of technology mix. The capacity mix in 2000 included a substantial share of coal (61%) and a significant but declining share of large hydro-based power (24%). Almost all the coal-based power plants use sub-critical pulverized coal technology. Gas-based power, which has come up mainly during the 1990s, has gained an 8% share. Nuclear power has 2% share, and the share of renewables is about 1.5%. In the past decade, generation capacity grew at a rate of 4.4% annually, whereas electricity generation has grown at a rate of 7% due to improved plant utilization. There has been a decline in the hydrothermal ratio for power generation. Thermal

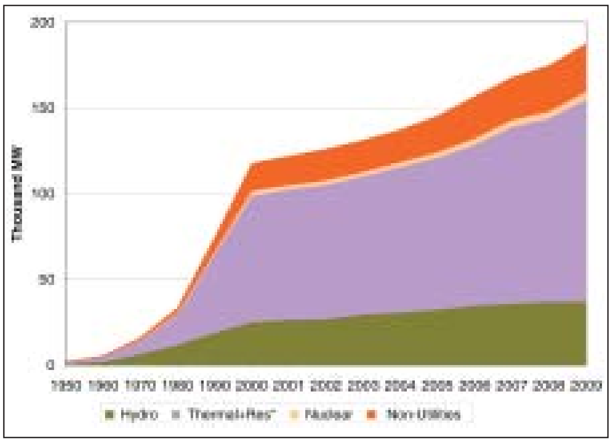


Figure 1.20: Power generation capacity
Source: Economic Survey of India, 2010/11, Government of India (* includes non-conventional energy sources other then wind. Hydro includes wind)

power share expanded due to shorter lead-time relative to hydro plants, increasing opposition to large hydro projects on social and environmental grounds, and higher political risks of hydro projects due to inter-state disputes on power and water sharing. This has added to the peak power problem. India has a hydro potential of 84 GW, but only about one-third of it has been exploited so far.

Gas-fired power has grown from almost nil to one-twelfth of total generation in the past decade due to the low risk associated with lower capital requirements, shorter construction periods, and higher efficiencies. Compared to the use of coal for power generation, gas use has lower environmental impacts. With the increase in private participation in the power sector, plants are being built in coastal areas near ports with terminals capable of handling liquefied natural gas (LNG). However, inland use of imported LNG remains expensive compared to coal, so natural gas is competitive in these regions, only if transported by pipeline directly from the production field. Nuclear power from India's 10 nuclear reactors contributes less than 3% to total generation. There has been a considerable improvement in capacity factor of these plants during the past five years, and they now operate above 80% as compared to 60% earlier. Renewable energy has a small share in the capacity presently. However, India has a significant programme to support renewable power, targeting 10% of new capacity additions by 2012.

Electricity generation has the largest share in the primary energy consumption in India, with 40% of primary energy and 70% of coal use. Despite enhanced competition from other fuels, coal remains the mainstay of power generation. Domestic availability helps coal to retain competitive advantage over imported fuels that have associated risks from fuel security and exchange rate uncertainties in the long run. A sizeable infrastructure of mining and manufacturing industries and transport has evolved around the coal-based power. But lately, certain factors have influenced the investment in power generation to shift to other fuels. The slow additions to domestic coal mining capacity, inadequate coal transportation linkages, relaxation of fuel imports, and investments by international power companies that import own fuel needs have been responsible for the preference accorded to gas.

Faced with an unreliable external power supply, many energy-intensive industries such as aluminum, steel, and fertilizer have invested in on-site power generation, which is growing at an annual rate of 8% (CMIE, 2001). Captive power generation has grown from about 1.6 GW in 1970 to almost 14 GW in 2000, with almost half being coal-based. Many captive generating plants have excess capacity, which could supply power to the grid, given the right policy incentives.

Transmission and distribution (T&D) losses now amount to over one-fifth of generated electricity. High losses cripple the financial viability of state-owned power transport system, resulting in a persistent lack of funds for expanding and improving the network. However, the ongoing power sector reforms have targeted T&D as a prime area, and multiple improvements are happening.

Transport

Transport is a critical infrastructure for development. The sector accounts for a major share of consumption of petroleum products in India. It is responsible for an

Table 1.8: Total number of registered motor vehicles in India during 1951–2006 (in thousand)						
Year as on 31 March	All vehicles	Two wheelers	Cars, jeeps and taxis	Buses	Goods vehicles	Others[a]
1951	306	27	159	34	82	4
1961	665	88	310	57	168	42
1971	1865	576	682	94	343	170
1981	5391	2618	1160	162	554	897
1991	21,374	14,200	2954	331	1356	2533
2001	54,991	38,556	7058	634[b]	2948	5795
2005	81,501	58,799	10,320	892[b]	4031	7451
2006 (P)	89,618	64,743	11,526	992[b]	4436	7921

[a]Others include tractors, trailers, three wheelers (passenger vehicles) and other miscellaneous vehicles that are not separately classified.

[b]Includes omni buses.

(P): Provisional.

Source: Road Transport Yearbook, 2006–07

appreciable share of pollution, both local and global. Local pollutants get concentrated in the urban areas. Transport activities occupy central position in local pollution in many urban areas of developing countries. The emission of global pollutants, especially CO_2, from transport is also a problem of increasing concern in the global environmental scenario.

Managing the transport sector while minimizing externalities such as local pollution, congestion, and GHG emissions is a major challenge. Rapid urbanization is now taking place in India. It is expected that more than 50% of the population of India may reside in urban areas by 2025, a substantial increase from 34% in 2011. Efficient transport system is a critical infrastructure requirement for the cities for economic productivity and quality of life. Sustainable urban transport system should be economically and socially equitable as well as efficient. The inability of the low-income groups to access affordable transportation system imposes hardships on them. Their time and energy are wasted in commuting, trapping them in a vicious circle of poverty and inefficiency.

The growth of registered motor vehicles in various cities of India is shown in Table 1.8. Metropolitan cities account for about one-third of total vehicles in India. These trends indicate that the growth rate of vehicles could be high as the cities grow. As a number of towns in India are growing very rapidly, a very high level of vehicle growth can be expected in the future. Thus, though the growth of transport in metropolis might be slowing down, it is growing faster in smaller cities. Some cities like Mumbai and Kolkata are very congested. Chandigarh is very spacious. Pune is also less congested. Delhi has a large fleet of buses and a good ratio of road length per person.

India largely depends on external sources for meeting its requirement of petroleum products. Table 1.9 shows the supply and consumption of petroleum products in India. The significant supply demand gap poses considerable energy security concerns for India. The table also shows the CO_2 emissions due to the consumption of petroleum products. The rising demand for petroleum products increased the CO_2 emission by more than 2.3 times over the period 1990–2008. Biofuel blending policy by the Government of India is exploring alternate sources of energy as one of its main objectives.

Table 1.9: Consumption and supply of petroleum products in India			
Year	Total consumption of petroleum products (thousand barrels per day)	Total oil supply (thousand barrels per day)	CO_2 emission (million metric tonnes)
1995	1574.7	769.7	216.8
1996	1680.9	750.9	228.8
1997	1765.5	779.6	240.9
1998	1844.4	761.3	257.5
1999	2031.3	764.8	268.0
2000	2127.4	770.1	281.6
2001	2183.7	781.6	281.1
2002	2263.4	812.7	300.5
2003	2346.3	815.0	295.1
2004	2429.6	851.4	306.0
2005	2512.4	835.2	314.2
2006	2690.9	860.4	349.2
2007	2845.0	887.3	369.2
2008	2962.0	889.7	384.4

Source: Energy Information Administration (EIA), US. Department of Energy (online database)

Reforms and Greenhouse Gas Emissions

The momentous economy-wide reforms initiated in India in 1991 included various sectors and activities that emit GHGs as well as other pollutants. A significant area in this context is energy, including electricity, hydrocarbons, and coal sectors.

The Energy Conservation Act (2001)

The Energy Conservation Act (2001) was enacted in September 2001 to look after all the matters related to the efficient use of energy and its conservation. Under the Act, the Bureau of Energy Efficiency was set up to discharge the activities entrusted under the Act. The Bureau is expected to look into the energy consumption norms for each energy-intensive industry and encourage proper labelling of energy consumption indicators on every electrical appliance. The Bureau also provides guidelines for energy conservation building codes and takes measures to create awareness and disseminate information for efficient use of energy and its conservation. It also aims at strengthening consultancy services in the field of energy conservation and developing testing and certification procedure and promoting testing facilities for certification and testing for energy consumption of equipment and appliances.

Reforms in the electricity sector

The mounting power shortages and the critical financial condition of state electricity boards (SEBs), which rendered them unable to add significantly to the power generation capacity in India, prompted the government in 1991 to encourage private sector participation with the objective of mobilizing additional resources for the sector. To facilitate private sector investments in the sector, the Electricity Act was amended in 1991. Other possibilities of augmenting the electricity generation capacity like co-generation, captive power plants, and improved productivity were considered in the "Private Power Policy", also announced in 1991.

The Electricity Regulatory Commission Act was promulgated in 1998 for setting up of independent regulatory bodies both at the central and state levels with an important function of looking into all aspects of tariff fixation and matters incidental thereto.

The Ninth Five-year Plan recognized that the irrational and un-remunerative tariff structure not only raises serious doubts about the ability of the states to contribute their share to capacity addition but also makes private investors wary of the investments in the sector. To tackle this issue, a Common Minimum National Action Plan on Power (CMNAPP) was agreed upon by the state chief ministers in December 1996 as the government realized that without the consent of the state chief ministers, such reforms could not make much headway (MoP, 1996).

Renovation and modernization, and distribution reforms

The poor financial health of the SEBs/state gencos due to various reasons has seriously affected their ability to invest in new power generation capacity, augment T&D networks, induce system improvements, undertake renovation and modernization (R&M) of old stations for improving efficiency, and make investments in energy conservation and environment performance schemes.

The major reasons for poor financial health of SEBs are (i) high aggregate technical and commercial losses (40–45%), (ii) average revenue less than average cost of supply, (ii) low plant load factor, and (iv) high operation and maintenance costs in distribution. The Ministry of Power has taken a number of steps to usher in reforms to improve the financial health of SEBs/gencos. Accelerated Power development and Reforms Programme (APDRP) initiated by the Ministry of Power includes R&M programme of old thermal power stations for improving efficiency and distribution reforms programme by assisting the states technically and financially. Reforms in the R&M of old thermal power stations will result in improvement in efficiency, that is, availability of additional power with the same amount of coal burnt and, hence, lower GHG emissions. Similarly, reduction in technical losses will result in the availability of extra power in the grid, thereby offsetting the new power capacity to be added (primarily from coal, the mainstay of Indian power sector) and thus reducing the GHG emissions. Reduction in commercial losses through 100% metering, billing, and collection would also result in energy conservation since the consumer would use power more judiciously.

The Electricity Act (2003)

The Government of India has recently enacted the Electricity Act (2003). The Act seeks to promote competition in the electricity sector in India by decoupling the generation, T&D, and supply of electricity. The Act also envisages the preparation of a National Electricity Policy (including tariff) for the development of the power system based on optimal utilization of natural resource. In consonance with this policy, the central electricity authority will prepare the National Electricity Plan once in every five years.

The Act has de-licensed the generation of electricity in India. Clause (7) of the Act states "any generating company may establish, operate, and maintain a station without obtaining a license under this Act if it complies with the technical standards relating to the connectivity with the Grid".

The Act has also heralded a move away from the single buyer model that was followed during the 1990s. Under this model, the private power producers were allowed to sell power to SEBs only. But the financial difficulties faced by the SEBs proved to be a major constraint for private participation. Under the new Act, the generator and the consumer can individually negotiate the power purchase and use the common access T&D system to meet the contractual obligations.

Thus, the Electricity Act (2003) maintains the trend in electricity reforms witnessed the world over by exposing the generation and the supply side of the market to competition but placing T&D sections under incentive regulation.

The Act has made the tariff policy one of the cornerstones of the regulatory process. Under the Act, either the state or the central regulatory commission is required to play an important role in tariff setting by the natural monopoly segments of the electricity supply chain and ensure that such tariff is set through a transparent process of bidding in accordance with the guidelines issued by the central government. The Ministry of Power has recently come out with a discussion paper on the tariff policy. According to the paper, the tariff has to take into account the objectives of (i) promotion of efficiency, (ii) introduction of competition and creation of enabling environment for the same, (iii) rationalization of electricity tariff, (iv) protection of consumer interests, and (v) transparency in subsidy administration (MoP, 2003).

Reforms in the hydrocarbons sector

The country imports about 83% of its requirement of crude oil to meet the increasing demand, resulting in substantial outgo of foreign exchange. With the country's rapid economic growth, the consumption of petroleum products is growing at a healthy rate of 4.6%. Even though production of domestic crude oil has increased to 37.685MMT in 2010-11, the consumption of petroleum products in the country is continually rising and has increased from 113MMT in 2005-06 to 142MMT in 2010-11.

Figure 1.21: Share of petroleum imports in total consumption (%)
Source: Planning Commission, 2007; Economic Survey of India, 2010/11

However, the growth in consumption of petroleum products has led to an increase in dependence on crude oil imports. Government of India has been making focused efforts to accelerate and expand exploration and production (E&P) efforts in the country to augment oil and gas production to bridge the growing deficit in the demand and availability of oil and gas. New Exploration Licensing Policy (NELP) was accordingly formulated in 1997-98 which provides a level playing field to the private investor including foreign companies by giving them the same fiscal and contract terms as applicable to National Oil Companies for the exploration acreages offered. Under NELP, so far, eight rounds of bids have been concluded and production-sharing contracts for 235 exploration blocks have been signed. In order to harness the hydrocarbon potential of the country, the ninth round of NELP (NELP-IX) was launched in October 2010 in New Delhi. Investment commitment under NELP is about USD 11 billion on exploration, against which actual expenditure so far is about USD 8.51 billion. In addition, a USD 7.37 billion investment has been made on development of discoveries. Thus, the actual investment made by E&P companies under NELP is of the order of USD 15.88 billion.

The government control on the hydrocarbon sector, through Administered Price Mechanism (APM) was removed in a phased manner from 1998 to 2002. APM was completely dismantled on 31.03.02. For increasing the use of LPG as a cooking fuel instead of wood, coal etc. in rural India, as per 'Vision 2015', a target has been given to the Public Sector Oil Marketing Companies to raise the overall LPG population coverage to 75% in the country by releasing 5.5 crore new LPG connections by 2015. As the urban centres are more or less covered by the LPG network, future growth envisaged under 'Vision – 2015' will be concentrated in the rural and under-covered areas. The usage of LPG in replacement of other fuels such as wood, coal, kerosene etc is advantageous from the environmental point of view.

Petroleum product pipeline policy

Pipelines are the most convenient, cheapest and environment friendly mode for transportation of crude petroleum and petroleum products. With a view to preparing a roadmap for development of pipeline infrastructure in the country, keeping in view the growth in the refining capacity and consumption of petroleum products, the Government is preparing an 'Oil Pipelines – Vision 2030'. The 'Oil Pipelines-Vision 2030' will intend to provide an executable and implementable framework for development of the oil pipeline network in the country.

Auto fuel policy

The Auto Fuel Policy, approved by the Government in 2003, gave a roadmap for upgradation of the quality of auto fuels (Petrol and Diesel) to Bharat Stage (BS) IV in 13 identified cities (Delhi/NCR, Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad (including Secunderabad), Ahmedabad, Pune, Surat, Kanpur, Agra, Solapur and Lucknow) and BS-III in the rest of the country effective 1.4.2010. Supply of BS-IV Petrol and Diesel commenced from 1st April, 2010 in all the 13 identified cities as per the roadmap laid down in Auto Fuel Policy. BS-III fuels were introduced in the country in a phased manner with the last phase being completed in September 2010. Though BS-IV auto fuels are in supply in 13 major cities including National Capital Region (NCR), the NCR alone consists of 108 towns (of which 17 are class I cities) and more than 7500 rural settlements. Efforts are being made to progressively expand coverage of BS-IV fuels with introduction of these fuels in 50 more cities by 2015. An 'Industry Group of Officers' has been formed with representatives from PSU Oil Marketing Companies. The group will identify these additional cities considering the pollution levels and the vehicle population. Inclusion of all state capitals and cities with population of more than 1 crore will be emphasized while selecting the additional cities for extension of BS-IV auto fuels.

Reforms in the coal sector

Towards reforming the coal sector, the government has recently constituted the Expenditure Reforms Commission (ERC). The major recommendations of the Commission are as follows:

- Remove all restrictions on the entry of the private sector in the exploration and production of coal by amending the Coal Mines Nationalization Act (1973).
- Amend the Coal Bearing Areas (Acquisition and Development) Act (1957) and set up an independent regulatory body to allow for level playing field to the private sector.
- Restructure the industry by doing away with the holding company (CIL) and coal controller, among other things.
- Amend the Coal Mines (Conservation and Development) Act (1974) to put responsibility on both public and private sectors for scientific mining, conservation, safety and health, protection of environment, etc.
- Permit states to develop lignite resources outside the command areas of the Neyveli Lignite Corporation.
- Reorient the overall strategy to take into consideration the role of coal in energy security.

Prior to 1st January 2000, the central government was empowered under the Colliery Control Order, 1945, to fix the prices of coal, by grade and colliery. However, following the Colliery Control Order, 2000, the prices for all grades of coking and non-coking coal have been deregulated. The current basic price of coal varies from Rs 1450 per tonne to Rs 250 per tonne for different grades.

The provisions inter alia resettlement, sharing of profits with the states and restoration of mined areas have been clearly identified in the latest 'Mines and Minerals (Development & Regulation) Bill 2011', approved by the Cabinet.

Low Carbon Strategy

The interim report of the Expert Group on "Low Carbon Strategies for Inclusive Growth" was released by the Planning Commission in May 2011. The report underscored India's commitment to reducing emissions intensity of its economy and the voluntary measures it has promised to undertake before the international community.

The report analyses two scenarios. The first scenario, at the lower end of emissions intensity reduction range, is called the Determined Effort Scenario, which essentially means vigorous and effective implementation of existing mitigation policies. The report did highlight the supporting need of continuously upgrading technologies in all sectors and finance from both public and private sources, in addition to effective policy coordination between different agencies.

The second scenario, which aims at a higher level of reduction in emission, is called the Aggressive Effort Scenario. This scenario, apart from the continuation of existing policies, would require design and implementation of new policies. It will also need large amounts of additional finance and considerable innovation. It highlighted the need for international financial support and technology transfer in meeting the aggressive targets. The analysis projects a range for GHG emission intensity reduction in 2020 for 8% and 9% real GDP growth.

The options considered suggest that with determined efforts, India can bring down the emission intensity of its GDP by 23–25% over the 2005 levels, and with aggressive efforts, the emission intensity can be brought down by as much as 33–35% over the 2005 level.

The Expert Group has emphasized action on the following points:

(i) **Power:** The expert group has suggested action both on supply and demand side. One the supply side, it is emphasized that there is a need to adopt supercritical technologies in coal based thermal power generation as quickly as possible. It is also suggested that gas (being in limited supply) is to be used in combined heat and power systems in large establishments. Emphasis is given to the development of renewable technologies (solar, wind and second generation bio-fuels) and hydro-power (in a sustainable manner). On the demand side it is suggested to accelerate the adoption of super-efficient electrical appliances and enhancing the efficiency of agricultural pump-sets and industrial equipments. Emphasis is also laid on modernization of transmission and distribution systems to bring down the technical and commercial losses to the world average levels, while at the same time ensuring universal electricity access (forcing the need for adoption of new and frontier technologies such as smart grids).

(ii) **Transport:** It is suggested that there has to be an increase in the share of rail in overall freight transport (by improving the efficiency of rail freight transport and making its price competitive). Emphasis is also laid on improving the share and efficiency of public transport system and there is a recognised further need to improve the fuel efficiency of our vehicles.

(iii) **Industry:** The expert group has made specific recommendations for sectors like Iron & Steel and Cement. It is identified that green-field plants in these sectors adopt best available technology; while existing plants (small and medium) modernize and adopt green technology at an accelerated phase (supported through financing mechanisms that are equitable and transparent).

(iv) **Buildings:** Change in the design and structure of building can act as a multiplier in reducing overall energy demand (in addition to efficient appliances). The group recognised the need to evolve and institutionalize Green Building Codes at all levels of Government.

(v) **Forestry:** There is tremendous scope for increasing the stock and quality of existing forests. Green India Mission is considered to be an important vehicle to achieve the above stated goal.

Since this is an Interim report, the final report is likely to contain details of technology, policy and finance options that are necessary to pursue a low emission, inclusive growth trajectory in the future. It has also been recognised that there is a broader issue of adapting agricultural practices to serious alterations in climatic conditions, and to managing our water resources in a more comprehensive and efficient fashion.

It is also underscored that all levels of government need to act together to combat the challenge of climate change. The state governments need to develop a state action plan for climate change that can be dovetailed to the National Action Plan on Climate Change (NAPCC), by identifying vulnerable areas and communities, and by developing state-specific action programmes for the above mentioned areas.

In implementing low-carbon strategies for inclusive growth, the report underscores the importance of an appropriate institutional set-up. The report suggests a general guideline for policy and institutional design in the context of low carbon growth, which comprises measures such that the policies are incentive compatible and promote technological and institutional innovation, involve capacity building of multiple stakeholders, need to harness the creative potential of all non-state actors, and need to facilitate coordination so as to reduce transaction costs in the implementation of mitigation strategies. The low carbon strategy also suggested pointing out that while setting priorities, both “co-benefits” and “consequential losses” need to be considered. The document also reiterates that imposing a carbon tax would not be possible at present but at least fossil fuel pricing could be done at economic costs to remove relative distortions.

A possible implication is that it could lead to competition for limited land and water resources in the country, particularly for biofuels, biomass, and forestry initiatives that enhance carbon sequestration. It is essential that the low carbon strategy be planned in such a way that excessive pressure on land, including rain-fed farming land, is avoided, so as to avoid an adverse impact on food security and livelihood of the poor.

India's Commitment to Climate Change and Sustainable Development

India attaches great importance to climate change. Climate change and sustainable development go hand-in-hand with India's progress. India has reasons to be concerned about the adverse impacts of climate change since vast populations depend on climate-sensitive sectors for their livelihoods. India's commitment to United Nations Framework Convention on Climate Change (UNFCCC) is reflected in various initiatives taken nationally, such as including climate change in the Indian planning process and resource allocation, formulating National Action Plan for Climate Change with a focus on eight missions, enhancing resilience of poor communities through programmes such as National Rural Employment Guarantee Act (NREGA), and promoting research and development in environmental areas. Environmental protection and sustainable development have emerged as key national priorities and manifest in India's approach to socio-economic development and poverty eradication.

References and Sources

Attri, S.D. and Tyagi, Ajit, 2010. Climate Profile of India, Met. Monograph No. Environment Meterology-01/2010, 1-122

Auto Fuel Policy, 2003. Ministry of Petroleum and Natural Gas, Government of India, New Delhi

Biological Diversity Act, 2002. Ministry of Environment and Forests, Government of India

Bora, A.K. and Saikia, D., 2007. *Shifting cultivation in Assam: A management approach*. Indian Journal of Landscape Systems and Ecological Studies, 30 (2), 196–202

BP (British Petroleum), 2010. *Statistical Review of World Energy,* June 2010, BP

Census of India, 1991 and 2001. Government of India Press, New Delhi

CMIE (Centre for Monitoring of Indian Economy), 1999. *Energy*. CMIE, Economic Intelligence Service, Mumbai

CMIE (Centre for Monitoring of Indian Economy), 2001. *Energy*. CMIE, Economic Intelligence Service, Mumbai

CMIE (Centre for Monitoring of Indian Economy), 2003–07. *Energy*. CMIE, Economic Intelligence Service, Mumbai

CMIE (Centre for Monitoring of Indian Economy), 2008. *Economy*. CMIE, Economic Intelligence Service, Mumbai

CSO (Central Statistical Organization), 2006. *National Income Statistics*. Ministry of Statistics and Programme Implementation, Government of India, New Delhi

CSO (Central Statistical Organization), 2009. *National Accounts Statistics*. Ministry of Statistics and Programme Implementation, Government of India, New Delhi

CWC (Central Water Commission), 1953–2007. *Flood Damages in India 1953–2007*. Ministry of Water Resources, Government of India, New Delhi

Dikshit, K. R., Datye, V.S., Diddee, J.N., and Jog, S.R., 2004. *The 'Tisali' system of farming – A relict of shifting cultivation in Western Ghats: A case study of Koyna Valley*. Transactions of the Institute of Indian Geographers, 26 (2), 34–76

EIA (Energy Information Administration). *Petroleum Products in India. Independent Statistics and Analysis*. US EIA, US Department of Energy. Available at http://www.eia.gov/

Electricity Act, 2003. Ministry of Power, Government of India, New Delhi

Electricity Regulatory Commissions Act, 1998. Ministry of Power, Government of India, New Delhi

Energy Conservation Act, 2001. Ministry of Power, Government of India, New Delhi

Environment Protection Act, 1986. Ministry of Environment and Forests, Government of India, New Delhi

ESI (Economic Survey of India), 1991–2006. *Economic Survey of India*. Ministry of Finance, Government of India, New Delhi

ESI (Economic Survey of India), 2010/11. *Economic Survey of India*. Ministry of Finance, Government of India, New Delhi

Forest (Conservation) Act, 1980. Ministry of Environment and Forests, Government of India, New Delhi.

IIPS (International Institute for Population Studies), 2000. *National Family Health Survey* -2. IIPS, Mumbai

IIPS (International Institute for Population Studies), 2006. *Reproductive and Child Health: District Level Household Survey 2002–04*. IIPS, Mumbai

IMD (India Meteorological Department), 2008. *Electronic Atlas of Tracks of Cyclones and Depressions in the Bay of Bengal and the Arabian Sea*, CD Rom, Version 1.0, IMD, New Delhi

Joji, V. S. and Nair, A. S. K., 2004. *Sustainability of land resources of Vamanapuram River Basin, southern Kerala, India*. Geographical Review of India, 66 (2), 153–162

MoA (Ministry of Agriculture), 2002. *Basic Animal Husbandry Statistics 2002*. MoA, Department of Animal Husbandry and Dairying, Government of India, New Delhi

MoA (Ministry of Agriculture), 2003. *17th Indian Livestock Census*, 2003. Department of Animal Husbandry, Dairying and Fisheries, MoA, Government of India, New Delhi

MoA (Ministry of Agriculture), 2006. *Basic Animal Husbandry Statistics 2006*. Animal Husbandry Statistics Division, Department of Animal Husbandry, Dairying and Fisheries, MoA, Government of India. Available at http://dahd.nic.in/stat_files/BAHS2006web.pdf

MoA (Ministry of Agriculture), 2008. *Agricultural Statistics at a Glance 2008*. MoA, Government of India, New Delhi

MoC (Ministry of Coal), 2009. *Coal Directory of India*. Department of Coal, MoC, Government of India, Calcutta

MoEF (Ministry of Environment and Forests), 1987–2009. State of Forest Reports. Forest Survey of India, MoEF, New Delhi

MoEF (Ministry of Environment and Forests), 2001. *State of Forest Report*, 2001. Forest Survey of India, MoEF, New Delhi

MoHA (Ministry of Home Affairs), 2011. *Preliminary Report of Census for India 2011*. Office of the Registrar General and Census Commissioner, MoHA, Government of India, New Delhi

Mohanty, P. K., Panda U. S. and Mohapatra G. M., 2005. *Tropical Cyclone Climatology and Role of GPS and GIS*. Paper presented at National Seminar on, GIS Applications in Rural Development, NIRD, Hyderabad

MoP (Ministry of Power), 1996. *Common Minimum National Action Plan on Power*. MoP, Government of India, New Delhi

MoP (Ministry of Power), 2000. *Sixteenth Electric Power Survey of India*. Central Electricity Authority, MoP, Government of India, New Delhi

MoRD (Ministry of Rural Development), 2008. *Annual Report 2007–08*. MoRD, Government of India

MoRTH (Ministry of Road Transport and Highways), 2007. *Road Transport Yearbook, 2006-2007*. MoRTH, New Delhi

NAPCC (National Action Plan on Climate Change), 2008. *National Action Plan on Climate Change.* Prime Minister's Office, Government of India, New Delhi

Narayanakumar, R. and Kumaraswamy, K., 2006. *Landuse and Landcover in Oussudu Lake Environs: A Remote Sensing Based Study*. The Deccan Geographer, 44 (1), 43–50

NBO (National Buildings Organisation), 2003. *Handbook of Housing Statistics, 2003*. NBO, Ministry of Housing and Urban Poverty Alleviation, Government of India, New Delhi

NSSO (National Sample Survey Organisation), 1998. *Consumer Expenditure, Education, Health and Aged in India, National Sample Survey 52nd round*. Ministry of Statistics and Programme Implementation, Government of India, New Delhi

NSSO (National Sample Survey Organisation), 1993/94–2007/08. *Employment and Unemployment*.

NSSO, Ministry of Statistics and Programme Implementation, Government of India, New Delhi

Planning Commission, 2002. *Tenth Five Year Plan: 2002–2007*. Planning Commission, Government of India, New Delhi

Planning Commission, 2007. *Eleventh Five Year Plan- Vol. I, II and III*. Planning Commission, Government of India, New Delhi

Planning Commission, 2011. *Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth*. Planning Commission, Government of India, New Delhi

RBI (Reserve Bank of India), 2009. *Handbook of Statistics on the Indian Economy 2008-09*. RBI, Mumbai

Registrar General of India, 1999. *Compendium of India's Fertility and Mortality Indicators 1971–1997 based on Sample Registration System*. Office of the Registrar General of India, New Delhi

Registrar General of India, 2005. *Sample Registration System Statistical Report: 2003*. Office of the Registrar General of India, New Delhi

Registrar General of India, 2006. *SRS Based Abridged Life Tables 1999–2003*. Office of the Registrar General of India, New Delhi

Singh, A. L. and Shah, B., 2007. *Shifting cultivation and landuse/landcover changes in North-East India*. The Deccan Geographer, 45 (1), 59–70

TERI (The Energy and Resources Institute), 2009. *TERI Energy Data Directory & Yearbook*. TERI, New Delhi

Thangamani, V. and Rao, M. S., 2007. *Land capability of Palar Basin using remote sensing technique*. The Deccan Geographer, 5 (1), 9–18

UN (United Nations), 2005. *World Population Prospects: The 2004 Revision*. UN Population Division

UNDP (United Nations Development Programme), 2009. *Human Development Report: 2009*. UNDP, Oxford University Press, New Delhi

UNDP (United Nations Development Programme), 2010. *Human Development Report: 2010*. UNDP, Oxford University Press, New Delhi

World Bank Databank, 2010. On-line data Bank. Available at http://data.worldbank.org/

Chapter 2

National Greenhouse Gas Inventory Information

This chapter presents a detailed description of the greenhouse gas (GHG) inventory of the emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) by sources and their removal by sinks, for the year 2000. The sectors covered include energy, industrial processes & product use, agriculture, land use, land-use change and forestry (LULUCF), and waste. The reporting is in accordance with the revised guidelines 17/CP.8 meant for reporting National Communications (NC) from Non-Annex 1 Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The Ministry of Environment and Forests (MoEF), which is the focal point of climate change in the Indian government, published the GHG emission profile of India for the year 2007 in 2010. A brief description of the same is also included in this chapter. The GHG emission levels of 1994 (reported in the Initial National Communication [INC]) have also been compared with the GHG estimates for 2000 and 2007. While reporting the GHG inventory, this chapter also gives a detailed account of the methodology used, the quality assurance/quality control (QA/QC) measures applied, the results of the key source analysis, and Tier-I quantification of the uncertainties associated with the estimates.

Contents

Chapter 2 National Greenhouse Gas Inventory Information

CHAPTER 2

National Greenhouse Gas Inventory Information

Introduction

The 17/CP.8 guidelines require each Non-Annex I Party to provide, in its national inventory, information on GHGs, namely, CO_2, CH_4, and N_2O, emitted from the anthropogenic sources. Also, the Non-Annex I Parties are encouraged, as appropriate, to provide information on the anthropogenic emissions of HFCs, PFCs, and SF_6 by sources. Further, the Non-Annex 1 parties need to provide, to the extent possible, information on emissions from international aviation and marine bunker fuels separately in their inventories. Emission estimates from these sources should not be included in the national totals. This chapter provides information on the above-mentioned six gases in terms of their emission by sources and their removal by sinks. It also takes into account the emissions from international bunkers and biomass burning.

Box 2.1: Global Warming Potential (GWP) values (100-year time horizon) used in this study

Gas	GWP
CO_2	1
CH_4	21
N_2O	310
HFC-134a	1300
HFC-23	11,700
CF_4	6500
C_2F_6	9200
SF_6	23,900

Note: The CH_4 GWP includes the direct effects along with the indirect effects due to the production of tropospheric ozone and stratospheric water vapour. The indirect effect due to the production of CO_2 is not included.

CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride

Source: IPCC (1996)

Further, this chapter provides information on GHGs in terms of CO_2 equivalent (CO_2 eq.) using Global Warming Potential (GWP) values provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. The "1996 IPCC GWP values" given in the report are based on the effects of GHGs over a 100-year time horizon (Box 2.1). The reference gas used is CO_2; therefore, GWP-weighted emissions are measured in CO_2 eq.. All gases in this chapter have been presented in the units of Gg CO_2 eq.

An Overview of the National Greenhouse Gas Inventory Management and Preparation

Inventory management

The GHG inventory process is coordinated by the MoEF through its Project Management Cell (PMC) under the overall guidance of the National Project Director, who is also a senior-level official in the ministry. The PMC has a GHG inventory expert, who is responsible for inventory planning and management. The PMC is responsible for ensuring not only the conformity of the inventory with the updated UNFCCC Reporting Guidelines but also the integrity of the inventory, communication of data, and information exchange with all the involved partners. The implementation arrangement for preparing GHG inventory is shown in Figure 2.1.

The process of the preparation of the inventory comprises sub-contracting arrangements with the institutions identified, with defined roles and responsibilities, type of participation in the inventory development process, use of data, communication and publication of work related to data collection, generation, and estimation, and emission factor development. The GHG Inventory Working Group comprising all the members involved in the preparation of GHG inventory process meets at least twice a year to take stock of the state of the inventory and discuss priorities in the inventory development process. Once the inventory is prepared, it goes through a peer review process by the GHG Inventory Working Group members. The revised inventory is then subjected to a final review through technical consultations. These technical consultations comprise expert meetings, reviews and deliberations. The inventory is also reviewed by the National Steering Committee (NSC), which comprises members from relevant ministries. Apart from reviewing the inventory, the NSC also reviews the inventory development process from time to time to ensure that the process is on track.

It also facilitates interactions of the institutions under its jurisdiction with the institutions involved in the GHG inventory process so as to have better access to data and other related issues, and endorses the submission of the inventory for the final official approval by the cabinet.

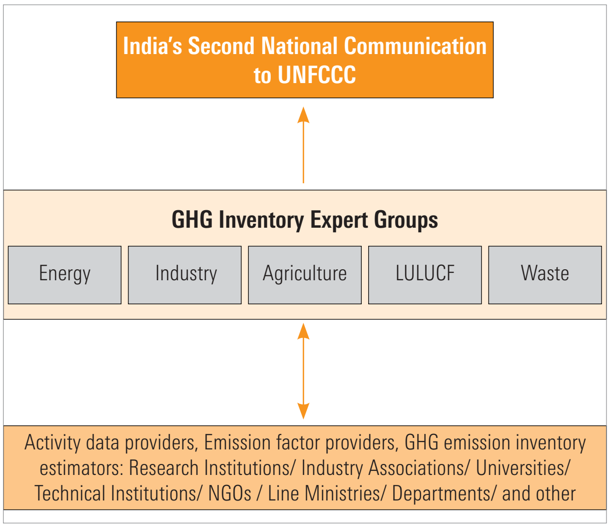


Figure 2.1: Implementation arrangement for inventory preparation

Institutional arrangement for inventory preparation

The GHG inventory is prepared by the scientists and experts drawn from a network of a diverse mix of institutions across the country, which have the capacity to generate information, on a regular basis, on the inventories of GHG emission by sources and their removals by sinks. These institutions are part of energy, industry, agriculture, LULUCF, and waste sectors. These institutions are national research institutions, technical institutions, universities, industry associations, non-governmental organizations, and those belonging to the private sector. The institutional arrangement for the preparation of the GHG inventory is shown in Figure 2.2. Apart from estimating the GHG inventories, these institutions also collect activity data from relevant sources and are also involved in the process of generating country-specific emission factors. Developing country-specific emission factors, especially for the key emitting sources, has been the thrust area since the INC process begun, as it makes the inventory more representative of the circumstances under which the emissions take place and the estimates more scientifically robust. This effort is supported by key ministries such as the Ministry of Power, Ministry of Coal, Ministry of Petroleum and Natural Gas, Ministry of Surface Transport, Ministry of Shipping, Ministry of Aviation, Ministry of Heavy Industries, Ministry of Iron and Steel, Ministry of Agriculture, Ministry of Environment and Forests, Ministry of Urban Development, and Ministry of Statistics and Programme Implementation. These ministries represent the source of activity data for the majority of the source categories.

Inventory planning, preparation, reporting, documentation and archiving procedures

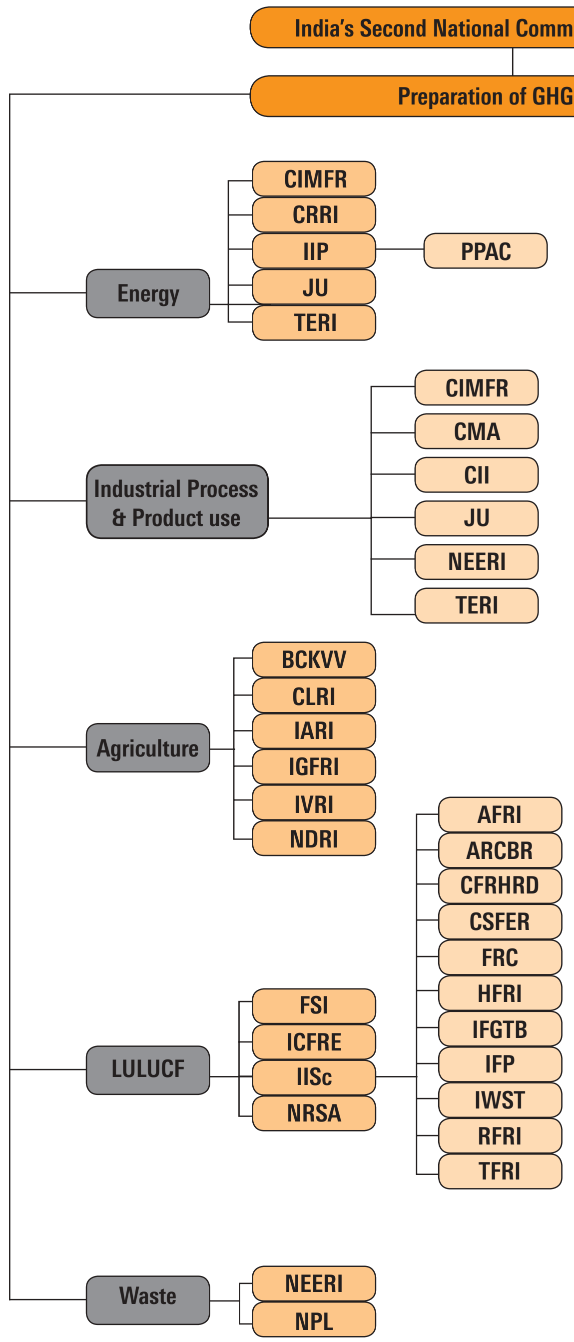
The inventory preparation cycle consists of (i) inventory planning, (ii) inventory preparation, (iii) reporting, (iv) documentation, and (iv) archiving procedures. The cycle is shown in Figure 2.3.

Inventory planning: The inventory planning cycle starts with the identification of the activities to be undertaken to achieve the stated objectives of the GHG inventory preparation, which takes into account the review comments from the previous GHG inventory preparation effort undertaken in the INC. The data gaps are identified, the QA/QC is planned, and steps are taken for reducing uncertainties and estimating the same. For each activity, institutions that would undertake the work for the activity assigned to them are identified. Technical Terms of Reference (ToR) are drafted for each activity by the project management team. The technical ToR includes the outline of the expected deliverables along with the timelines. These ToRs form part of the contracts signed by the identified institutions and the facilitating agency that houses the National Communication Project Management Cell. The entire planning is presented to the NSC for its approval.

Inventory preparation and reporting: Once the contracts are signed, the preparation step starts with the submission of an initial report by the institution within the first three months of the signing of the contract. In the initial report, the contracting agencies are encouraged to provide the status of the availability of the activity data, sources from where the activity data will be sourced, the methodology to be used, and the emission factors to be applied. Subsequently, three more reports are prepared by the contracted institution, termed as interim report, draft final report, and the reviewed final report. During all the stages, the data provided in the reports is peer reviewed as well as reviewed through technical consultations by experts. In case there is any difficulty in accessing data, the MoEF requests the relevant ministry to directly source the data through its own agencies/channels.

Data documentation and archiving: All the inventory data is assembled and put together into a common reporting format along the lines of the CRF reporter of the

UNFCCC. Archiving of the data takes place at two ends: one at the institution end, which is contracted to carry out the preparation of the inventory from various source categories; and the other at the PMC end of the MoEF. Every week, back-up of all the inventory data is taken and stored. Data is also archived as hard copies of reports received at the PMC. The background documents for each of the inventory preparation activities are available at the institutional end.



ACRONYMS

AFRI : Arid Forest Research Institute
ARCBR : Advanced Research Centre for Bamboo and Rattans
BCKVV : Bidhan Chandra Krishi Vishwa Vidyalaya
CFRHRD : Centre for Forestry Research and Human Resource Development
CII : Confederation of Indian Industry
CIMFR : Central Institute of Mining and Fuel Research
CLRI : Central Leather Research Institute
CMA : Cement Manufacturers Association
CRRI : Central Road Research Institute
CSFER : Centre for Social Forestry and Eco-Rehabilitation
FSI : Forest Survey of India
FRC : Forest Research Centre
HFRI : Himalayan Forest Research Institute
IARI : Indian Agricultural Research Institute
ICFRE : Indian Council of Forestry Research and Education
IFGTB : Institute of Forest Genetics and Tree Breeding
IFP : Institute of Forest Productivity
IGFRI : Indian Grassland and Fodder Research Institute
IIP : Indian Institute of Petroleum
IISc : Indian Institute of Science
IVRI : Indian Veterinary Research Institute
IWST : Institute of Woods Science and Technology
JU : Jadavpur University
NDRI : National Dairy Research Institute
NEERI : National Environmental Engineering Research Institute
NPL : National Physical Laboratory
NRSA : National Remote Sensing Agency
PPAC : Petroleum Planning and Analysis Cell
RFRI : Rain Forest Research Institute
TERI : The Energy and Resources Institute
TFRI : Tropical Forest Research Institute

Figure 2.2: Institutional arrangement for the preparation of the greenhouse gas inventory

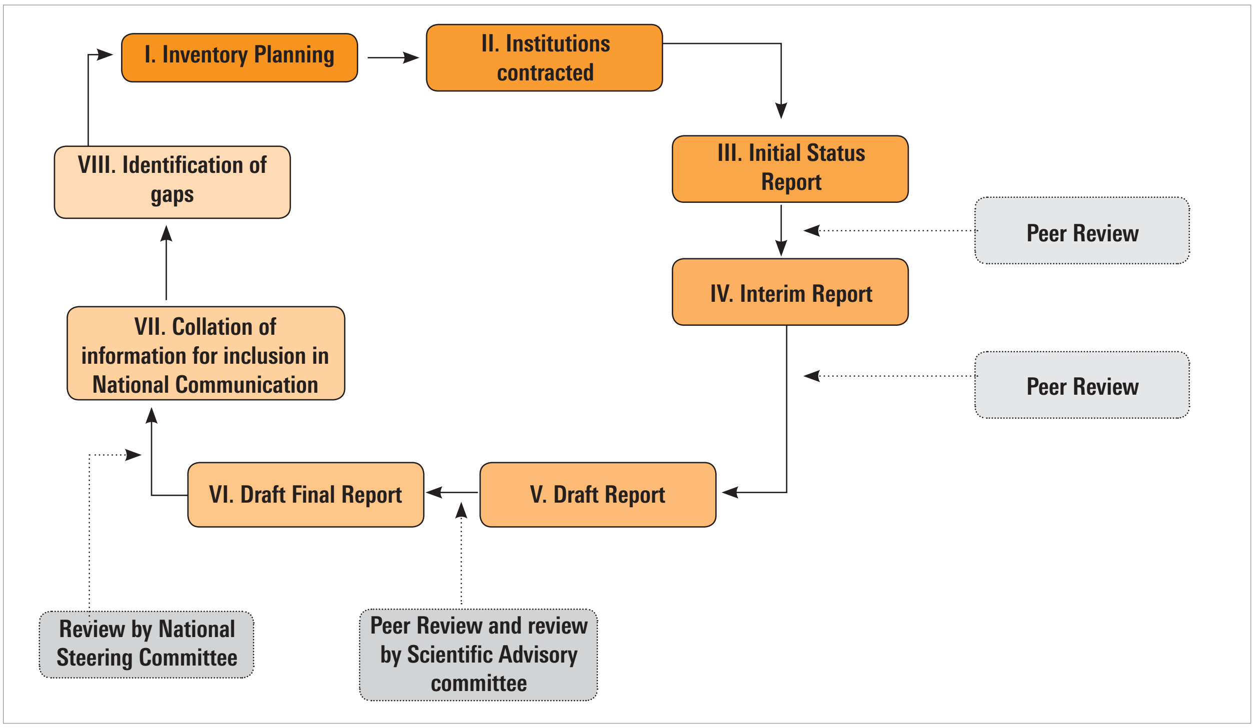


Figure 2.3: Greenhouse gas inventory preparation cycle

Greenhouse Gas Emissions in 2000

This section presents the estimates of CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 emitted by sources and their removal by sinks, covering the sectors of energy, industrial processes and product use (IPPU), agriculture, LULUCF, and waste. Against this backdrop, it explains the methodology used, the QA/QC measures applied, and the results of the key source analysis while presenting a Tier-I quantification of the uncertainties associated with the estimates.

Activity data, emission factors, and methodological tiers used

Activity data: Activity data has been primarily derived from the published documents of the various ministries and organizations of the Government of India, from industry associations (such as the Cement Manufacturers' Association [CMA] of India), and from reputed data organizations such as the Center for Monitoring of Indian Economy (CMIE).

Emission factors: The emission factors used in this report are a mix of default emission factors available in the IPCC publications (1996, 2000, 2003, and 2006) and country-specific emission factors. Default emission factors have been used for those gases and categories for which country-specific factors are not available. Some of the country-specific emission factors used in this assessment include emission factors of CO_2 from coal (Choudhary et al., 2004), CH_4 from coal mining (Singh, 2004), N_2O from nitric acid production (Rao et al., 2004), CO_2 from cement (Rao et al., 2004), CH_4 from rice (Gupta et al., 2004, Indian Agricultural Research Institution publications), CH_4 from enteric fermentation in livestock (Swamy et al., 2006, National Dairy Research Institute publications), N_2O from soils (Pathak et al., 2002), and CH_4 from municipal solid waste (Jha et al., 2007), amongst others.

Methodology: For a comprehensive, complete, comparable, transparent, and accurate (CCCTA) coverage, to the extent capacities permit, the methodology used follows the IPCC Revised Guidelines 1996, supported by the IPCC Good Practice Guidance (GPG) 2000 and 2003. The LULUCF sector estimations are made using the IPCC GPG 2003. The estimation also integrates some of the default emission factors from the IPCC 2006 Guidelines. The tiers of estimate range between Tier-I, -II, and -III . Higher tier implies a more data-intensive effort (Box 2.2). For example, CH_4 from rice cultivation is estimated by using Tier-III approach, wherein the total rice area is divided into areas characterizing different water management practices in the country. The GHG emission factors used for estimating CH_4 from these areas are actual measurements carried out, which represent CH_4 emission/unit area, covering different water management practices. Efforts are generally made to use a Tier-II or -III approach (that is, a data-intensive approach) for categories that are identified as key source categories. Table 2.1 presents the summary of methodological tiers and the type of emissions factors used for the different source categories.

Box 2.2: Tiers of estimation

Tier-I approach employs activity data that is relatively coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps.

Tier-II uses the same methodological approach as Tier 1 but applies emission factors and activity data that are defined by the country.

Tier-III approach uses higher order methods, including models and inventory measurement systems tailored to address national circumstances, repeated over time and driven by disaggregated levels.

Table 2.1: Type of emission factor and level of methodological tiers used for greenhouse gas (GHG) estimates

	CO_2		CH_4		N_2O	
	Method applied	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
1. Energy						
A. Fuel combustion activities						
1.Energy industries	T1, T2	CS, D	T1	D	T1	D
2. Manufacturing industries and construction	T1, T2	CS, D	T1	D	T1	D
3. Transport	T1, T2	CS, D	T1	D	T1	D
4. Other sectors	T1	CS, D	T1	D	T1	D
B. Fugitive emission from fuels						
1. Solid fuels			T2	CS		
2. Oil and natural gas			T1	D		
2. Industrial processes						
A. Mineral products						
1. Cement production	T2	CS, D	T2	D	T2	D
2. Lime production	T1	D	T1	D	T1	D
3. Limestone and dolomite use	T1	D	T1	D	T1	D
4. Soda ash production and use	T1	D				
5. Glass		D				
B. Chemicals	T1	D	T1	D	TI	D
1. Ammonia production						
2. Nitric acid production	T1	CS, D	T1	D	TI	D
C. Metal production						
1. Iron and steel production	TI	D	TI	D	TI	D
2. Ferro-alloys production	TI	D	TI	D	TI	D
3. Aluminum production	TI	CS, D	TI	D	TI	D
4.Lead production	TI	D	TI	D	TI	D
5. Zinc production	TI	D	TI	D	TI	D
6. Magnesium production	TI	D	TI	D	TI	D
D. Other production						
1.Production of halocarbons						
E. Non-energy product use						
1. Lubricant	TI	D	T1	D	T1	D
2. Paraffin wax	TI	D	T1	D	T1	D
3. Agriculture						
A. Enteric fermentation			T3	CS	T2	D

B. Manure management			T1	CS, D	T1	CS, D
C. Rice cultivation			T3	CS		
D. Agricultural soils					T2	CS, D
E. Field burning of agricultural residues			T1	CS, D	T1	CS, D
4. Land use, land-use change and forestry						
A. Forest land	T2	CS, D				
B. Cropland	T2	CS, D				
C. Grassland	T2	D				
D. Wetland	T2	D				
E. Other land	T2	D				
F. Settlement	T2	D				
5. Waste						
A. Solid waste disposal on land						
1. Managed waste disposal on land			T2	CS, D		
B. Waste water handling						
1. Industrial waste water			T1, T2	CS, D		
2. Domestic and commercial waste water			T1	D		
Memo items						
International bunkers						
Civil aviation	T1	D	T1	D	T1	D
Navigation	T1	D	T1	D	T1	D
Biomass combustion	T1	CS, D				
T1 – Tier-I; T2 – Tier-II; T3 – Tier-III; CS – country specific; D – default						

Quality assurance and quality control procedures

First, a QA/QC plan was developed, which took into account, other than the quality of the data, the cycle of inventory preparation and adherence of the contracting agencies to that plan. All contributors to the inventory were also provided with a QC checklist in line with Table 8.1 in the UNFCCC GPG 2000 (IPCC GPG, 2000). The contributors completed the checklists during the period of data collection and GHG inventory preparation. The compilation of the QA/QC checklist was done at the PMC. The general QA/QC checks for all inventory preparations include cross-checking the reliability of the activity data collected from the secondary sources for proper documentation and record; cross-checking for transcription errors in the activity data; consistency, completeness, and integrity of the database; documentation and reporting of the rationale of assumptions used for activity data; documentation and reporting of gaps in the database; consistency in labelling of units in ensuing calculations; and completeness checks on the reported data sets for designated years.

The activity data sources such as the various ministries, industry associations, and the remote sensing agency, however, were not directly approached with the QA/QC list. The entire process is envisaged to be strengthened further by making the data sources as well as the process compliant to standard ISO/ BIS QA/QC procedures, which are modified for inventory preparation.

Greenhouse gas emissions in 2000 – A Summary

In 2000, India emitted 1,523,777.44 Gg CO_2 eq. (1523.78 Mt of CO_2 eq.) from the energy, industrial processes & product use, agriculture, and waste management sectors. The summary of the emissions of GHG by each sector is presented in Table 2.2. A detailed table is given at the end of the chapter (Annexure 1). The LULUCF sector was a net sink in 2000. With the inclusion of LULUCF, the net emission in 2000 was 1,301,209.39 Gg of CO_2 eq. (1301.21Mt of CO_2 eq.).

The total CO_2, CH_4, and N_2O emitted were 1,024,772.84 Gg, 19,392.30 Gg, and 257.42 Gg, respectively, equalling an emission of 1,542,240.94 Gg CO_2 eq. Additionally, the IPPU sector emitted 0.220 Gg of HFC-134a, 0.420 Gg of HFC-23, 0.870 Gg of tetrafluoromethane (CF_4), 0.087 Gg of hexafluoroethane (C_2F_6), and 0.013 Gg of SF_6, which together equalled 11,966.1 Gg CO_2 eq. emissions. Figure 2.4 gives the relative contribution of the various gases to the total CO_2 eq. emissions from the country.

The energy sector emitted 1,027,016.48 Gg of CO_2 eq., accounting for 67.4% of the total GHG emissions in 2000, excluding LULUCF. The agriculture sector emitted 355,600.6 Gg CO_2 eq., which was 23.3% of the total GHG emissions. The IPPU sector emitted 88,608.07 Gg CO_2 eq., or 5.8% of the total GHG emissions. The waste sector emitted 52,552.29 Gg CO_2 eq. in 2000, which was 3.5% of the total GHG emissions. Figure 2.5 gives the relative distribution of emissions by sector.

The emissions of CO_2 from the energy sector relative to the total GHG emissions, excluding LULUCF, were by far the largest in 2000. The contribution of CO_2 was 92.7% of the total emissions from the energy sector. The agriculture sector mainly accounted for the emissions of CH_4 and N_2O, with 73.0% of the total CH_4 and 75.0% of the total N_2O emitted in 2000 being attributed to the agriculture sector. The synthetic gases (HFCs, PFCs, and SF_6) were entirely emitted from the industrial processes. The relative distribution for gases emitted from each sector is presented in Figure 2.6.

Table 2.2: Greenhouse gas emissions, by sector, for India in 2000

	CO_2 emission (Gg)	CO_2 removal (Gg)	CH_4 (Gg)	N_2O (Gg)	HFC-134a (Gg)	HFC -23 (Gg)	CF_4 (Gg)	C_2F_6 (Gg)	SF_6 (Gg)	CO_2 # equivalent (Gg)
1. Energy	952,212.06		2,991.42	38.66						**1,027,016.48**
2. Industrial processes and product use	72,560.78		5.39	12.80	0.220	0.420	0.870	0.087	0.013	**88,608.07**
3.Agriculture			14,088.30	192.73						**355,600.60**
4. Waste			2,307.19	13.23						**52,552.29**
Total (excluding LULUCF)	**1,024,772.84**		**19,392.30**	**257.42**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**1,523,777.44**
Total (with LULUCF)		**236,257.43**	**552.38**	**6.74**						**1,301,209.39**
Memo items										
International bunkers	3,467.12		0.05	0.10						3,498.86
Aviation	3,194.12		0.02	0.089						3,222.13
Maritime/ navigation	273.00		0.03	0.010						276.73
CO_2 from biomass	376,005.00									376,005.00

Calculated using Global Warming Potential given in Box 2.1

CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride

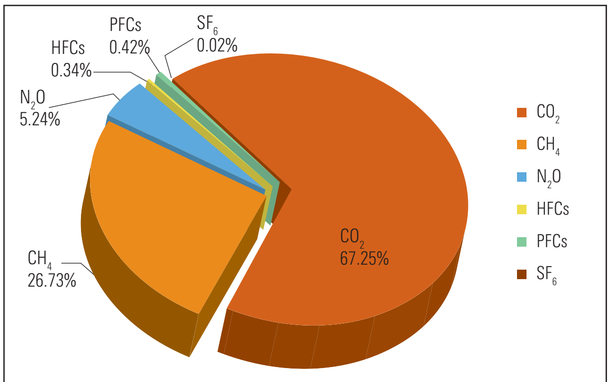


Figure 2.4: Distribution of emissions, by gas, in 2000

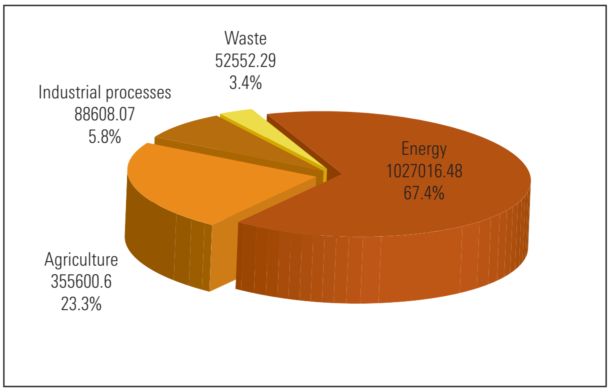


Figure 2.5: Greenhouse gas emission distribution, by sector in 2000 (Figures in Gg of CO_2 eq.)

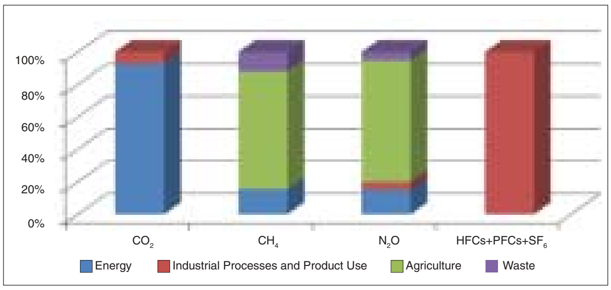


Figure 2.6: Relative contributions of the individual sectors (excluding land use, land-use change and forestry) to greenhouse gas emissions in 2000

Energy

Emissions from the energy sector consist of the following.

- 1A. Fossil fuel combustion and biomass
    - 1A1: Energy industries—Electricity generation, petroleum refining, and solid fuel manufacturing
    - 1A2: Manufacturing industries—Cement, iron and steel, food and beverage, textile/ leather, non-specific industries, non-ferrous metals, chemicals, pulp and paper, non-metallic minerals, mining and quarrying
    - 1A3: Transport—Road, railways, aviation, and navigation
    - 1A4: Other sectors—residential, institutional/ commercial, agriculture/fisheries
- 1B. Fugitive emissions
    - 1B1: Coal mining
    - 1B2: Oil and natural gas

Methodology, activity data, and emission factors

The IPCC 1996 Revised Guidelines (IPCC, 1996) were adopted for estimating the emissions from the above categories. As stated earlier in the chapter, activity data in terms of consumption of various fossil fuels has been taken from the reports of the relevant ministries of the government, which keep track of the activities. The emission factors of fossil fuels, such as coal, oil, and natural gas, are the most important considerations in estimating the GHG emissions from the combustion of these fuels. In India, coal as a fuel constitutes more than 50% of the total fossil fuel mix in the country, used for energy-related activities. Country-specific CO_2 emission factors derived on the basis of the net calorific values (NCVs) of different types of coal produced in the country, namely, coking, non-coking, and lignite (NATCOM, 2004; Choudhary et al., 2004), have been used in this assessment.

The energy sector accounts for GHG emissions from fossil fuel combustion and fugitive emissions from the handling of fossil fuel. Fossil fuel combustion emissions form more than 90% of the total emissions from the energy sector. Amongst all the fossil fuels that are combusted, coal is the dominating fuel. Since the completion of the INC, continuous efforts have been made to update the NCVs, and thus the CO_2 emission factors of the different types of coal used in India. The integrated NCVs of the samples taken in the latest years are considered, and hence the CO_2 emission factors are within 5% of the values estimated during INC. The CO_2 emission factors of coking coal, non-coking coal, and lignite used in the current estimates are 93.61 t/TJ, 95.81 t/TJ, and 106.51 t/ TJ, respectively. Details of the measurements carried out can be found in the INC (NATCOM, 2004, p. 37).

The CO_2 emission factors used for various fuels in the present estimations are provided in Table 2.3. The non-CO_2 emissions have been estimated using non-CO_2 default emission factors for different fuel types.

Table 2.3: Greenhouse gas (GHG) emission factors used in the energy sector estimation

Category no.	Fuel	CO_2 (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)	Source
1A1: Energy industries 1A2: Manufacturing industries 1A4: Other sectors	Coking coal	93.61			Choudhury *et al.*, 2006; IPCC, 2006
	Non-coking coal	95.81			Choudhury *et al.* 2004; IPCC, 2006
	Lignite	106.51			Choudhury *et al.* 2004, IPCC, 2006
	Diesel	74.10			IPCC, 2006
	Petrol	69.30			IPCC, 2006

	Kerosene	71.90			IPCC, 2006
	Fuel oil	77.40			IPCC, 2006
	Light distillates	74.10			IPCC, 2006
	Compressed natural gas (CNG)	56.10			IPCC, 2006
	Liquefied petroleum gas (LPG)	63.10			IPCC, 2006
	Lubricants	73.30			IPCC, 2006
	Aviation turbine fuel (ATF)	71.50			IPCC, 2006
1A3a: Road transport	Petrol	69.3	19.8	1.92	IPCC, 2006
	Diesel	74.1	3.9	3.9	IPCC, 2006
	Light distillate oil (LDO)	74.1	3.9	3.9	IPCC, 2006
	Fuel oil (FO)	77.4	7	2	IPCC, 2006
	CNG	56.1	92	3	IPCC, 2006
	LPG	63.1	62	0.2	IPCC, 2006
	Lubricants	73.3	3	0.6	IPCC, 2006
1A3b: Aviation	ATF	71.5	0.5	2	IPCC, 2006
	Diesel	74.1	3.9	3.9	IPCC, 2006
	LDO	74.1	3.9	3.9	IPCC, 2006
	FO	77.4	7.0	2.0	IPCC, 2006
1A3c: Railways	Coal	95.81	2	1.5	IPCC, 2006
	Diesel	74.1	4.15	28.6	IPCC, 2006
	Petrol	69.3	33	3.2	IPCC, 2006
	LDO	74.1	3	0.6	IPCC, 2006
	FO	77.4	3	0.6	IPCC, 2006
	Kerosene	71.9	10	0.6	IPCC, 2006
	Fuel wood	NA	300	4	IPCC, 2006
1A3d: Navigation	Diesel	74.1	3.9	3.9	IPCC, 2006
	LDO	74.1	3.9	3.9	IPCC, 2006
	FO	77.4	7	2	IPCC, 2006

Overview of greenhouse gas emissions from the energy sector

The energy sector in 2000 emitted 1,027,016.48 Gg of CO_2 eq., which was 67.4% of the total national GHG emissions, excluding LULUCF. Of the total GHG emissions from the energy sector, fossil fuel combustion based emissions accounted for 97.2% of the total CO_2 eq., and 2.8% of the emissions were from fugitive emissions. The distribution of CO_2 eq. emissions, by category, is shown in Figure 2.7.

Of the total 1,027,016.48 Gg emitted as CO_2 eq. in 2000, 92.7% was emitted as CO_2, 6.1% was emitted as CH_4, and only 1.2% was emitted as N_2O. The distribution of emissions from the energy sector is shown in Figure 2.8.

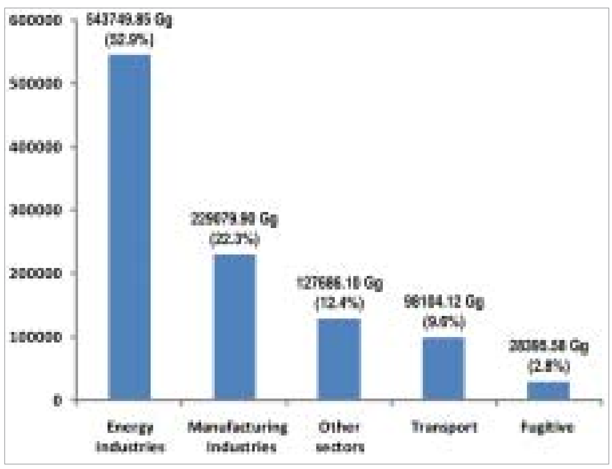


Figure 2.7: Distribution of CO_2 eq. emissions (in Gg) across the energy sector categories in 2000

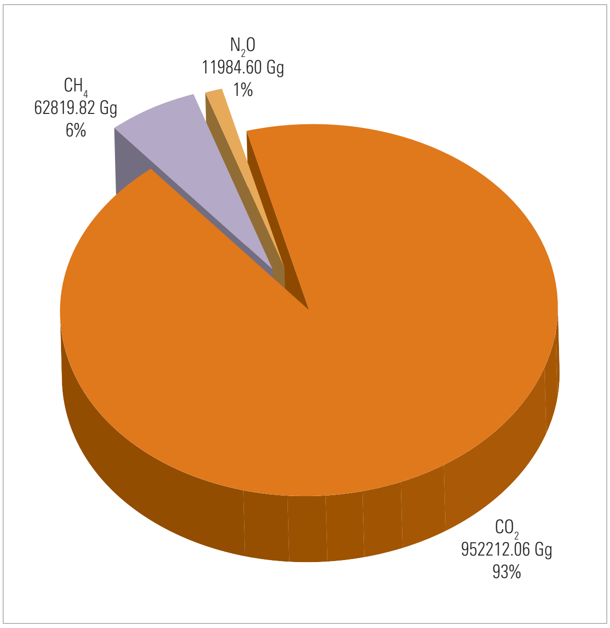


Figure 2.8: Greenhouse gas emission distribution in the energy sector in 2000. (Gg CO_2 eq.)

Energy industries (1A1)

Emissions from the energy industries include emissions from fossil fuel combustion for electricity generation and solid fuel manufacturing. Information on the use of fossil fuels for solid fuel manufacturing is available only since 2003; so this category has not been included in the national totals. The energy industries in 2000 emitted 543,749.85 Gg CO_2, which is 53% of the total GHG emissions from the energy sector. Of this, 541,191.33 Gg was emitted as CO_2, 6.96 Gg as CH_4, and 7.78 Gg as N_2O.

Electricity generation

In 2000, India generated 485.4[1] billion units of electricity (Annual Report, Ministry of Power, 2002) of the total installed capacity in 2000, 72% was thermal, 24% hydro, 3% nuclear, and 1% renewable. The emissions in the electricity generation sector are purely from the combustion of fossil fuel to produce thermal energy. The thermal energy consists of coal, oil, and natural gas. The thermal energy mix for electricity generation was 90% coal, 8% gas, and 2% oil, in 2000. The emission estimates have been made using the IPCC 1996 Revised Guidelines for preparing national GHG inventories by sources and removal by sinks. In this assessment, the emission factors for coal are country-specific (NATCOM, 2004) and for others, default factors are taken from the IPCC 2006 Guidelines. India emitted 525,023.42 Gg CO_2 eq. in 2000, which was 96.6% of the total CO_2 eq. emitted from electricity production. The CO_2 eq. emissions from the electricity sector constituted 522.495.43 Gg of CO_2, 5.99 Gg of CH_4, and 7.75 Gg of N_2O. Emissions reported from electricity generation include emissions from grid-based power plants as well as emissions due to captive generation of electricity using fossil fuels in various industries.

The average value of NCV of fuel (non-coking coal) has been taken as 19.63 TJ/kt while estimating CO_2 emissions across all sectors. However, the actual emissions from power sector may vary depending upon the actual value of NCV of fuel consumed in the sector.

Refinery

India refined 112.54 million metric tonnes of oil through its refineries in 2000. The energy consumption in the refineries led to the emission of 18,726.43 Gg CO_2 eq. This is 3.4% of the total GHG emissions from the energy industries. Though solid fuel manufacturing existed in 2000, no systematic information on the amount of solid fuel manufactured is available, as this information was mostly available with the small-scale sector and not collected by the Ministry of Coal. However, on the basis of the data gap pointed out in INC, the Ministry of Coal started collecting the requisite data from 2004, and the emission estimates have been therefore done for the year 2007.

Manufacturing industries (1A2)

The manufacturing industries, in 2000, together emitted 229,079.90 Gg CO_2 eq., and these emissions were 22.3% of the total CO_2 eq. emissions from the energy sector. GHG emissions from fossil fuel combustion in cement, iron and steel, non-ferrous metals, chemicals, pulp and paper, food and beverages, non-metallic minerals, mining and quarrying, textile and leather, and other non-specific industries have been presented here. Of the total CO_2 eq. emissions from the manufacturing industries due to fossil fuel combustion, 228,246.91 Gg was emitted as CO_2, 4.29 Gg as CH_4, and 2.40 Gg was emitted as N_2O. It must be reiterated that capital goods sector has a multiplier impact on energy use. There is therefore a need to introduce energy audit of the present designs of the capital goods sector. As a next step, plans are needed to reduce energy consumption to the level of international best practices.

Cement

The Indian cement industry is the second largest in capacity and production in the world. Rapid growth in

1. The Ministry of Power (MoP) report contains the generation figures for 1999/2000 and 2000/01. From this, the calendar year generation was estimated by adding nine months of 1999/2000 and three months of 2000/01.

production took place in the decade between 2000 and 2010. Cement production in 2009 stood at 219.51 Mt compared to 94.2 Mt in 2000/01 (CMA, 2009). The cement production process incorporates energy consumption in all its stages, namely, (i) mining and transportation of limestone and other raw materials, (ii) use of power for raw material grinding and raw meal preparation, (iii) use of fuel (mainly coal, minor quantities of pet coke or lignite) in raw meal burning to get clinker, and (iv) use of power in grinding of clinker with gypsum with or without other additives to get cement of different varieties. The grinding units use either or both grid and captive power. In 2000, the cement industry in India emitted 39,696 Gg of CO_2 due to fuel combustion in the various stages mentioned above. This is 17.3% of the total CO_2 eq. emissions from the manufacturing industries.

Iron and steel

Iron and steel production involves energy-intensive processes. The international norm of energy consumption is 4.5–5.5 Giga calories per tonne of crude steel. With the adoption of modern technology and equipment, beneficiation of raw materials, and use of high grade imported coking coal, Indian steel plants have been able to achieve energy consumption at the level of 6.5–7.0 Giga calories per tonne of crude steel. Further, steps are being taken to achieve much lower energy consumption by the end of the Eleventh Five-year Plan (Annual Report 2009/10, Ministry of Steel). With the steady growth in the steel industry, increasing attention is being paid to environment management. In 2000, due to the consumption of fossil fuels, the iron and steel industry emitted 52,641.44 Gg CO_2 eq. This is 23.0% of the total CO_2 eq. emissions from the manufacturing industries.

Non-ferrous metals

The non-ferrous metals included here are aluminium, copper, lead, zinc, and tin. Alumina produced from bauxite is the basic raw material for the production of aluminium metal through electrolytic process. Aluminium production grew from 0.6 Mt in 2000 to 1.2 Mt in 2008 (Source: Indian Bureau of Mines Publications). The present installed capacity of refined copper has reached at about 1 Mt per year. India's position has shifted from being a net importer of copper to a net exporter. The main demand for refined copper is in the electrical and electronic sectors, construction sector, consumer durables, and transport sector. Lead and zinc are among the most widely used non-ferrous metals in the world. The copper production has increased from 260,000 tonnes in 2000/01 to 501,400 tonnes in 2007/08 (Source: Indian Bureau of Mines Publications). Galvanizing is by far the most important zinc consuming industry, and the battery sector is the prime lead consuming industry. Amount of lead produced increased from 35,000 tonnes in 1999/2000 to nearly 58,000 tonnes in 2007/08 (Source: Indian Bureau of Mines Publications). Zinc metal production has gone up from 170,000 tonnes to 450,000 tonnes during the same period. Coal, furnace oil, and electricity are the primary energy inputs in metal production for converting extracted ore into usable metal. Electricity is the major energy input. Hence, all primary metal producers in India have installed their own captive power plants to get cheaper and uninterrupted power for their use. Majority of electricity consumed in this industry is supplied by the captive power plants. The total GHG emissions from the production of non-ferrous metals in 2000 due to the use of fossil fuel combustion was 1894.52 Gg CO_2 eq., which is 0.8% of the total GHG emitted from the energy consumption in the manufacturing industries.

Chemicals

The chemical sector consists of various chemicals like chlor-alkali, inorganic chemicals, organic chemicals, dye-stuffs and dye intermediates, agro–chemicals, and alcohol-based chemicals (Refer to the working paper of the Planning Commission on chemical industries for the 12th plan for categorization). The sector is highly science based and provides valuable chemicals for various end products such as textiles, paper, paints and varnishes, and leather, which are required in almost all spheres of life. The energy mix used in the chemical industry comprises 60% oil and less than 10% coal; and the rest is gas. In 2000, the chemical industries together emitted 34,612.32 Gg CO_2 eq., which is 15.1% of the total GHG emitted from the energy consumption in the manufacturing industries.

Pulp and paper

India is the 15th largest paper producer in the world. Indian paper mills can be categorized based on the raw materials used—wood/forest-based mills, agro-residue based mills, and waste paper-based mills. Due to the stringent regulation and increasing raw material prices, the companies are increasingly using more non-wood based raw material over the years. In 2006, about 70% of the total production was based on non-wood raw material. Between 2002 and 2006, the paper board production increased from 5.2 Mt to 6.5 Mt. The amount of energy consumed in the pulp and paper industry is about 1.38

Mtoe (PAT 2011), and the total amount of GHG emitted in 2000 due to the use of fuel was 5358.71 Gg of CO_2 eq., which is 2.3% of the total GHG emitted from the energy consumption in the manufacturing industries.

Food and beverages

Food processing involves any type of value addition to the agricultural or horticultural produce and also includes processes such as grading, sorting, and packaging, which enhance the shelf life of food products, providing linkages and synergies between the industry and agriculture. The government has accorded this a high priority, with a number of fiscal relief and incentives, so as to encourage commercialization and value addition to agricultural produce, for minimizing pre/post-harvest wastage, generating employment, and increasing export. India's food processing sector covers a wide range of products like fruit and vegetables; meat and poultry; milk and milk products; alcoholic beverages; fisheries; plantation; grain processing; and other consumer product groups like confectionery, chocolates, and cocoa products, soya-based products, mineral water, and high protein foods. Alcoholic beverages have been categorized as the new high opportunity sector in India. Liquor manufactured in India is categorized as Indian made foreign liquor (IMFL). The sector is still barred from importing potable alcohol as it is subject to government licensing. In the meanwhile, India has recently started producing wine for domestic consumption. Production processes use fossil fuel as the feedstock, and the GHG emission in 2000 from this sector was 24,660.34 Gg CO_2 eq., which is 10.8% of the total GHG emitted from the energy consumption in the manufacturing industries.

Non-metallic minerals

The major non-metallic minerals in India include limestone, phosphorite/rock phosphate, dolomite and barytes (3% each), gypsum and kaolin, garnet (abrasive), magnesite, silica sand, sillimanite and talc/soapstone/steatite, and other minor non-metallic minerals. The total amount of GHG emitted for processing the production of these non-metallic minerals in 2000 was 1014.23 Gg of CO_2 eq., which is 0.4% of the total GHG emitted from the energy consumption in the manufacturing industries.

Mining and quarrying

Mining and quarrying of all minerals, be it metallic, non-metallic, or others, requires energy. The total amount of GHG released due to fossil fuel use for the process of mining and quarrying in 2000 was 2518.16 Gg CO_2 eq., which is 1.1% of the total GHG emitted from the energy consumption in the manufacturing industries.

Textile/leather

The Indian textile industry is in a stronger position now than it was in the last six decades. The industry, which was growing at a rate of 3–4% up to 1990s, has now accelerated to an annual growth rate of 9–10% (based on the Working Group Report on Textile Industries by the Planning Commission). The Indian textile industry consumes a diverse range of fibres and yarns, but is predominantly cotton-based. The use of wood-based fuel and coal along with oil is common in the industry. The leather industry in India is spread over organized and unorganized sectors. The small-scale cottage industry production accounts for 75% of the total production (Source: Publications of the Department of Industrial Policy and Promotion, Ministry of Commerce and Industry). Energy is used in the tanning section, pre-tanning section as well as for the finished products. Other than the grid electricity, fossil fuels are also used directly. In 2000, the textile and leather industry, due to the use of direct fossil fuels, together emitted 7699.48 Gg CO_2 eq., which is 3.4% of the total GHG emitted from the energy consumption in the manufacturing industries.

Non-specific industries

The non-specific industries considered here are the industries such as rubber, plastic, watches, clocks, transport equipment, furniture. The non-specific sector comprises mainly small and medium enterprises, and operates on electricity generated through captive power generation. The non-specific industries identified in this study together emitted 58,984.70 Gg CO_2 eq. in 2000, which is 25.7% of the total GHG emitted from the energy consumption in the manufacturing industries. This is the highest emitting source; however, further sample survey, by industry, would be required in future to reduce the uncertainties in the assessment of the amount of fuel consumed and type of fuel consumed in these industries.

Transport (1A3)

India's transport system is one of the largest, handling, on an average, 800 billion tonne-km of freight and 2300 billion passenger-km. It consumes more than 50% of the total liquid fuel consumed in the country (Planning Commission, 2002). The total GHG emission from the transport sector in 2000 was 98,104.12 Gg CO_2 eq. This is 9.6% of the total CO_2 eq. emissions from the energy sector and is 6.3% of the total GHG emission from the country, in 2000. Of the total CO_2 eq. emissions from the transport sector in 2000, 95,976.83 Gg was emitted as CO_2, 9.50 Gg as CH_4, and 6.22 Gg was emitted as N_2O.

Road transport

The road transport sector is the largest consumer of commercial fuel energy within the transportation system in India and accounts for nearly 35% of the total liquid commercial fuel consumption by all sectors. Gasoline and diesel consumption for road transportation has quadrupled between 1980 and 2000 due to about nine times increase in the number of vehicles and four-fold increase in freight and passenger travel demands.

Road transport is characterized by heterogeneous gasoline-fuelled light vehicles and diesel-fuelled heavier vehicles. In 2000, this sector, of the total consumption of petroleum products in the country, consumed 6% gasoline and 29% diesel (MoPNG, 2002/03), with 83% of the total fuel consumed being diesel within the road transport sector. The distribution of gasoline, diesel, light distillate oil (LDO), fuel oil (FO), and lubricant use in the road transport sector is shown in Table 2.4. Based on the consumption of different types of fuel by different vehicle types, it is estimated that the road transport sector emitted 86,946.62 Gg CO_2 eq. in 2000, which is 88.6% of the total CO_2 eq. emitted from the transport sector.

The transport sector has been subjected to emission norms since 1989, which cover the norms for CO, oxides of nitrogen (NOx), non-methane volatile organic compounds (NMVOC), hydrocarbon, and particulate matter. The Indian emission regulations for idle emission limits came into effect in 1989. These idle emission regulations were soon replaced by mass emission limits for both gasoline (1991) and diesel (1992) vehicles, which were gradually made more stringent during the 1990s. Since the year 2000, India started adopting European emission norms, renamed as Bharat emission norms and implemented fuel regulations for four-wheeled light-duty and for heavy-duty vehicles. India's own emission regulations are still applicable to two- and three-wheeled vehicles. Current requirement is that all transport vehicles carry a fitness certificate, which is renewed each year after the first two years of new vehicle registration. On October 6, 2003, the National Auto Fuel Policy was announced, which envisages a phased programme for introducing Euro 2–4 emission norms, which are termed as Bharat stage II, III, and IV, and implementing fuel regulations by 2010. The emission norms cover diesel-driven heavy vehicles (applicable to vehicles with gross vehicle weight [GVW] > 3500 kg—trucks and buses), light-duty diesel vehicles (with GVW ranging between 2500 kg and 3500 kg), light-duty gasoline-driven vehicles, two- and three-wheelers running on diesel and gasoline, and agriculture tractors.

Railways

Railways in 1950/51 had a market share of 88% of freight and 68% of the passenger business in land transport, and in 1999/2000, it handled 40% of freight and about 20% of passenger market share (ASS, 2000). In 2000, only 6.2% of the transport sector emissions were from railways (6071.83 Gg CO_2 eq). For estimating GHG emissions from railways, only direct fossil fuel and fuelwood used for locomotive purposes have been accounted for. Emission due to the usage of grid-based electricity in train operations is included in 1A1a electricity generation. The fuel consumed comprised 99% diesel and the rest was in the form of LDO, FO, petrol and kerosene, and to a very small extent, wood.

Table 2.4: Distribution of fuel consumption in the road transport sector between 1980 and 2000 (10^3 tonnes)

Year	Gasoline 2W/3W	Gasoline car/taxi	Gasoline other uses[a]	Diesel MCV/HCV	Diesel LCV	Diesel other uses[b]	LDO	FO	Lubricants two-stroke 2W/3W
1980	964	542	8.1	5002	2144	3063	NA	NA	37
1985	1418	798	11.7	7148	3063	4376	NA	NA	54
1990	2281	1283	18.7	10,376	4447	6353	1.3	36.0	87
1995	2882	1621	23.6	15,140	6489	9269	1.8	9.5	110
2000	4099	2306	33.6	18,772	8045	11,493	3.0	5.3	130

NA– not available; documentation began from 1990 onwards; 2W/3W – two wheelers and three wheelers; MCV – medium commercial vehicle; HCV – high commercial vehicle; LCV – light commercial vehicle; LDO – light distillate oil; FO – fuel oil

[a] Gasoline other uses means gasoline consumption in railways and other take-away through network of retail outlets

[b] Diesel other uses includes diesel consumption in railways, aviation, shipping, agriculture, energy and transformation industries and other industries

Source: Singh et al. (2008)

Aviation

The Indian aviation sector in early 2000 started integrating with the global industry, facilitating economic travel through low-cost carriers. However, even in 2005, it was handling only 0.5% of the total passengers handled by the railways. Between 2000 and 2010, there has been an increase in passengers by more than 80% (60% increase in domestic traffic and 20% increase in international traffic). In addition, civil aviation also handles freight traffic, which has grown by 175% since 2000. In 2000, the civil aviation sector emitted only 4.1% of the total CO_2 eq. emissions (4058.69 Gg CO_2 eq.). Additionally, emissions from the international aviation have been reported by international bunkers. This has been possible as segregated data for aviation turbine fuel (ATF) off-take for domestic and international aviation is available, in addition to other fuel use for ground operations, along with number of flights for domestic and international passenger and freight operations.

Maritime transport (Navigation)

Maritime transportation includes emissions due to transport in the inland waterways and also any forays into the international waters for domestic purpose such as fisheries and cruises along the coast line. Although India has inland waterways with a navigable length of 15,544 km, only 37% of this length (5700 km) is currently used for navigation by mechanized vessels. However, the share of freight and passenger transport is only 7% of the total transport. In 2000, the total fuel consumed in India for inland transport and international navigation was 16,974.80 TJ (MoPNG, 2007). Of this, navigation through internal waterways consumed 78% of the total fuel and navigation through international waterways consumed the rest of it. Consequently, this sector emitted 1026.98 Gg CO_2 eq., which is 1.0% of the total CO_2 eq. emissions from the transport sector.

Other sectors (1A4)

Cooking, lighting, space heating, space cooling, refrigeration, and pumping characterize the residential, commercial, and agriculture sectors included in this category. The fuels consumed are electricity (for lighting, heating, cooling, and pumping), liquefied petroleum gas (LPG; for cooking), kerosene (for lighting and cooking), diesel (for generating power for pumping and lighting), and coal, charcoal, and fuelwood (for cooking). In 2000, these sectors together emitted 127,686.10 Gg of CO_2 eq., which is 12.4% of the total CO_2 eq. from the energy sector. This excludes the GHG emission due to grid use of electricity.

Seventy five percent of the total GHG emissions from the category 1A4 are from the residential sector (95,896.00 Gg CO_2 eq.). The residential sector has a rural and urban spread, and it combusts both fossil fuel as well as biomass. Biomass still comprises a substantial amount of fuel mix used in rural India. CH_4 from biomass combustion in the residential sector is reported in the energy sector; however, CO_2 from biomass is reported as a memo item and is not included in the national totals.

The commercial, residential, and agriculture sectors also witness extensive use of captive power generated from diesel use. This source is scattered, and a systematic collection could not be carried out. The fuel consumption in these private generator sets could be substantial. Lack of data for this consumption is a gap area that requires further research to improve the Indian inventory estimates. In this context, three studies covering three metropolitan cities in India, namely, Gurgaon (it is a part of the national capital region with high density of commercial offices), Bengaluru (an established centre thriving on software development sector, has both high level of commercial as well residential activities), and Lucknow (comparatively less commercially active, but nevertheless is increasingly inching towards becoming a mega-urban centre in India), were carried out. All these three cities face electricity outages and mostly use generator sets operating on diesel. Box 2.3 presents a summary of the study on Bengaluru.

Fugitive emissions (1B)

Fugitive emissions include emission estimates of CH_4 from coal mining and handling of oil and natural gas. Both underground mining and open cast or above-ground mining are practised in India. Based on mine-specific measurement of the rate of emission, all the underground coal mines in India have been categorized into Degree I[2], Degree II[3], and Degree III[4] by the Directorate General of

2 Degree I Seams: Coal seams in which the inflammable gas in the general body of air does not exceed 0.1%, and the rate of emission of such gas is not >1m^3 per tonne of coal produced.

3 Degree II Seams: Coal seams in which inflammable gas in the general body of air is more than 0.1% or the rate of emission of inflammable gas per tonne of coal produced is 1–10 m^3.

4 Degree III Seams: Coal seams in which the rate of emission of inflammable gas per tonne of coal produced exceeds 10 m^3.

Box 2.3: Greenhouse gas emissions due to fuel consumption in generator sets in the city of Bengaluru, Karnataka, India

Bengaluru is one of the metropolitan cities in India with a substantial presence of small- and medium-scale commercial establishments, large residential complexes, and individual households. On an average, Bengaluru faces 1.7 h/month of outages. To be operational, these establishments depend on small captive power generated by diesel generator (gen) sets. Three approaches were used to arrive at the total diesel consumed by these gen sets:

- ❖ Approach 1: Assessment of direct sales at petrol pumps.
- ❖ Approach 2: Primary sample survey at consumers' end.
- ❖ Approach 3: Diesel consumed during total power cuts in Bengaluru.

Approach 1: Assessment of direct sales at petrol pump

Bengaluru city has 200 fuel stations, with six different companies supplying fuel. Depending on the number of the pumping stations of each company, field survey of 100 stations in the city was done and following relationship was derived.

Total diesel consumption = $\sum_{i,j}\left(\frac{pd}{fs}\times FS\right)_{i,j}$

where fs is the number of sampled fuel stations of a particular company, FS is the total fuel stations of a company, and pd is the petrol and diesel sold at the sampled fuel station. Here i is the total number of companies, and j is the total number of petrol stations of each company. The study indicates that the total diesel sold in cans in Bengaluru is 124.9 million litres, which is 10.9% of the total diesel sold in Bengaluru.

Approach 2: Primary sample survey at consumers end

Total diesel consumption = $\sum_{i}\left(eg\times E\times\frac{fc}{eg}\right)_{i}$

where eg is the energy generated per establishment (kWh), E is the number of establishments, fc/eg is fuel consumed per unit of energy generated in litres/kWh, and i is the category of establishments under consideration.

About 520 samples were taken to assess the level of fuel consumption for Individual households having gen sets with capacity <15 kVA, and of large residential complexes and small and medium enterprises with captive power capacities <50 kVA and even higher.

For the total number of 542,800 establishments, Bengaluru produces 20,155,034,970 KWh of electricity and consumes 123.17 million litres of diesel. This indicates that the share of diesel consumption for diesel gen sets is almost 11.05% of the total diesel consumption in Bengaluru.

Approach 3: Assessment of diesel consumed during total power cuts in Bengaluru

It is estimated that, on an average, Bengaluru faces 1.7 h of electricity outages/month. During this period

- ❖ Industries consume, annually, 1111 kilolitres of diesel, which is 9% of the total diesel consumed in the diesel gen sets in Bengaluru.
- ❖ Commercial sector consumes 4429 kilolitres annually during outages. It accounts for 35% of the total diesel consumption in the diesel gen sets.
- ❖ Households consume 7121 kilolitres of diesel, accounting for 56% of the total diesel consumed in the diesel gen sets.
- ❖ Diesel gen sets <15kVA capacity consume 38 million litres per year, accounting for 31.5% of the total fuel consumption in the diesel gen sets in Bengaluru.

Conclusion:

The total amount of diesel sold in the market through pump stations is 572,472,570 litres/year. Of this, our survey indicates, 10,698,150 litres/year is sold in loose cans, which directly goes for the consumption in the diesel gen sets. Therefore, 18.9% of the total diesel sold in the state is used in diesel gen sets.

Mines Safety (DGMS, 1967). There is no such classification for surface coal mines as the associated CH_4 emission is not very large, and emitted gas immediately diffuses to the atmosphere. The method for estimating the emission factors is given in Box 2.4.

The value of fugitive emissions from coal mines in India for the year 2000 was 12,298.74 CO_2 eq., which is 43% of the total CH_4 released from category 1B. In case of handling and distribution of oil and natural gas, the release of gas occurs through leakages in pipelines, due to evaporation and accidental releases, and from venting and flaring managed as a part of normal operations at field processing facilities and oil refineries. Venting and flaring emissions occur at several stages of the oil and gas production process, and the single process for handling oil and natural gas can contribute to GHG emissions to two or more categories of emissions. For estimating the CH_4 released from these processes, the IPCC default emission factors given in IPCC (2006) were used. Consequently, it is estimated that in 2000, the process of handling of oil

Box 2.4: Estimating methane emission factors for coal mines

A. Underground mines: Measurements made in three different gassy underground mines take into account (i) the velocity of air passing through the return airways separately in each ventilating districts and in the main return with the help of Von anemometer, (ii) cross-sectional area of each return airway by multiplying the average width and height of the airway, and (iii) percentage of methane (CH_4) in the air samples collected in the return airway and also in the general body air by gas chromatography. Quantity of air was calculated by multiplying the air velocity and cross-sectional area of the return airway. Daily coal production data was collected during the period of investigation. CH_4 emission factor was calculated as follows:

$$\text{Emission factor } (m^3/t) = \frac{(G \times 60 \times 24)}{Production(TPD)}$$

Here G is CH_4 in m^3/min.

B. Surface mines: Rectangular chambers with internal dimensions of 2×1.5×1 cubic feet, closed from five sides but open floor and fitted with a nozzle for gas collection were used to measure CH_4 flux. These chambers were placed on the benches of surface mines for a period of time. CH_4 percentage inside the chamber was determined by gas chromatograph. The area of freshly exposed coal face was also measured in the surface mines to calculate CH_4 flux. Daily coal production data was collected during the period of investigation. CH_4 emission factor for surface mining was calculated as follows:

Release of CH_4 from the mine (Goc)/day = (B × GC × 24) m^3 per day

where Gc is CH_4 inside the perspex box/h and B is the surface area of coal covered by the box. Hence

Emission factor (m^3/t) = Goc/production in tonnes per day.

C. Post mining: Emission factors for coal handling activities were determined for coal samples collected from different categories of mines. A known weight of coal was crushed to fine powders in an airtight steel vessel, and the volume of gas released was measured to calculate the CH_4 emission factor for post mining activities. Emission factor for post mining activities, therefore, was calculated as the volume of gas released by given sample/weight of the sample.

Emission factors developed for coal mining in India

			EF (m^3 CH_4/tonne of coal)
Underground mines	During mining	Deg. I	2.91
		Deg. II	13.08
		Deg. III	23.64
	Post mining	Deg. I	0.98
		Deg. II	2.15
		Deg.III	3.12
Surface mining	Mining		1.18
	Post mining		0.15

and natural gas led to the emission of 16,096.83 Gg of CO_2 eq., which is 57% of the total CO_2 eq. emissions due to all fugitive emissions, as mentioned in category 1B.

Industrial Processes and Product Use

The IPPU sector includes the emission estimates of CO_2, CH_4, N_2O, HFC-13$_4$a, HFC-23, CF_4, C_2F_6, and SF_6 from the following sources:

- 2A: Mineral industries—Cement, lime, limestone and dolomite use, soda ash production, and glass.
- 2B: Chemicals—Ammonia, nitric acid production, carbide production, titanium dioxide production, methanol production, ethylene, ethylene dichloride (EDC) and vinyl chloride monomer (VCM), ethylene oxide, acrylonitrile, carbon black, and caprolactam.
- 2C: Metal production—Iron and steel, ferro-alloys production, aluminium, lead, zinc, and magnesium.
- 2D: Other production—Production of halocarbons HFC-134a and HFC-23 and consumption of SF_6.
- 2E: Non-energy product use—Use of lubricants and paraffin wax.

Methodology, activity data, and emission factors

For estimating the GHG emissions from the IPPU sector, the IPCC 1996 Revised Guidelines (IPCC, 1996) have been used for each of the categories mentioned above. The activity data for the various industries are sourced from national statistical organizations, from listed companies, the annual reports of ministries of the Government of

Table 2.5: Greenhouse gas emission factors used in the emission estimates

No.	Category	Gas	Emission factor used	Source
2A1	Cement production	CO_2	0.537 t CO_2/t clinker produced (incorporates CKD)	Initial National Communication (INC)
		SO_2	0.003 t SO_2/t cement produced	IPCC, 1996 Guidelines
2A3	Glass production	CO_2	0.21 t CO_2/t glass (container glass) ; 0.22 t CO_2/t glass (fibre glass) ; 0.03 t CO_2/t glass (specialty glass)	IPCC 2006 Guidelines
2A4b	Other sources of soda ash	CO_2	0.41492 t CO_2/t carbonate	IPCC 2006 Guidelines
2B1	Ammonia production	CO_2	Carbon content of natural gas has been taken as 99.5% and carbon oxidation factor has been taken as 14.4 kg C/GJ	USEPA
			Fuel requirement = middle point value of the range 7.72–10.5 million kcal/tonne of ammonia	Suggested by experts from Fertilizer Association of India
2B4	Caprolactam production	N_2O	9 kg N_2O/t chemical produced	IPCC 2006 Guidelines
2B5	Carbide production	CO_2	1.1 t CO_2/t CaC_2 produced	IPCC 2006 Guidelines
2B6	Titanium dioxide production	CO_2	1.385 t CO_2/t TiO_2 produced	IPCC 2006 Guidelines (average of emission factors)
2B8a	Methanol	CO_2	0.67 t CO_2/t methanol produced	IPCC 2006 Guidelines
		CH_4	2.3 kg CH_4/t methanol produced	IPCC 2006 Guidelines
2B8b	Ethylene	CO_2	1.73 t CO_2/t ethylene produced	IPCC 2006 Guidelines
		CH_4	3 kg CH_4/t ethylene produced	IPCC 2006 Guidelines
2B8c	EDC and VCM	CO_2	0.296 t CO_2/t EDC produced ; 0.47 t CO_2/t VCM produced	IPCC 2006 Guidelines
2B8d	Ethylene oxide	CO_2	0.863 t CO_2/t ethylene oxide produced	IPCC 2006 Guidelines
		CH_4	1.79 kg CH_4/t ethylene oxide produced	IPCC 2006 Guidelines
2B8e	Acrylonitrile	CO_2	1 t CO_2/t acrylonitrile produced	IPCC 2006 Guidelines
		CH_4	0.18 kg CH_4/t acrylonitrile produced	IPCC 2006 Guidelines
2B8f	Carbon black	CO_2	2.62 t CO_2/t carbon black produced	IPCC 2006 Guidelines
		CH_4	0.06 kg CH_4/t carbon black produced	IPCC 2006 Guidelines

2B9	Fluorochemical production	HFC-23	0.03 kg HFC-23/kg HCFC-22 produced	Country-specific emission factor considered from monitoring report of Gujarat Fluorochemical Ltd. (major producers of HCFC-22)
2C1	Iron and steel production	CO_2	1.46 t CO_2/t production (BOF) ; 0.08 t CO2/t production (EAF) ; 1.72 t CO_2/t production (OHF) ; 0.7 t CO_2/t production (DRI)	IPCC 2006 Guidelines
2C2	Ferro-alloys production	CO_2	4.8 t CO_2/t ferro-silicon produced; 1.5 t CO_2/t ferro-manganese produced; 1.1 kg CH_4/t ferro-silicon produced	IPCC 2006 Guidelines
		CH_4	1.1 kg CH_4/t ferro-silicon produced	IPCC 2006 Guidelines
2C3	Aluminium production	CO_2	1.65 t CO_2/t aluminium produced	IPCC 2006 Guidelines (average of emission factors)
		CF_4	1.4 kg CF_4/t aluminium produced	IPCC 1996 Guidelines (weighted average of all plants worldwide)
		C_2F_6	According to IPCC 1996 Guidelines, the default rate for C_2F_6 emissions is 1/10 that of CF_4 emissions (0.1 C_2F_6/CF_4)	IPCC 1996 Guidelines
2C4	Magnesium production	SF_6	Consumption = emission	IPCC 1996 revised guidelines
2C5	Lead production	CO_2	0.58 t CO_2/t lead produced (imperial smelting furnace) ; 0.25 t CO_2/t lead produced (direct smelting) ; 0.2 t CO_2/t lead produced (secondary production)	IPCC 2006 Guidelines
2C6	Zinc production	CO_2	0.53 t CO2/t zinc produced (pyrometallurgical process)	IPCC 2006 Guidelines
2D1	Lubricant use	CO_2	20 t-C/TJ (carbon content) ; 0.2 (ODU factor)	IPCC 2006 Guidelines
2D2	Paraffin wax use	CO_2	20 t-C/TJ (carbon content) ; 0.2 (ODU factor)	IPCC 2006 Guidelines

CO_2 – carbon dioxide; SO_2 – sulphur dioxide; CH_4 – methane; N_2O – nitrous oxide; CaC_2 – calcium carbide; TiO_2 – titanium dioxide; EDC – ethylene dichloride; VCM – vinyl chloride monomer; HFC – hydrofluorocarbon; HCFC – hydrochlorofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride; ODU – oxidized during use; CKD – clinker-to-dust; BOF – basic oxygen furnace; EAF – electric arc furnace; OHF – open hearth furnace

India, research organizations, trade magazines, and other publications of the sector associations (see References and Sources).The emission factors used are presented in Table 2.5.

Overview of greenhouse gas emissions from the industrial processes and product use sector

The IPPU sector emitted 88608.07 Gg of CO_2 eq. of GHGs. On a gas-by-gas basis, the CO_2 emissions are given in Figure 2.9 ,Table 2.6 gives details of the emissions of GHGs, by category, from the IPPU sector.

Mineral industries (2A)

The focus of this section is on estimating the CO_2 emitted from calcination of carbonate materials in the production and use of a variety of mineral industry products. There are two broad pathways for the release of CO_2 from carbonates: (i) calcination and (ii) the acid-induced release of CO_2. The primary process resulting in the release of CO_2 is the calcination of carbonate compounds, during which, through heating, a metallic oxide is formed. The

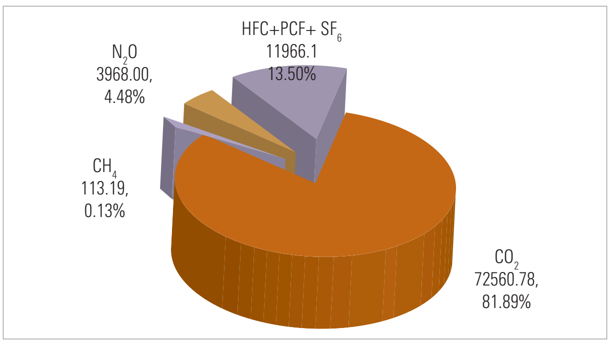


Figure 2.9: Greenhouse gas emission distribution from the industrial processes and product use sector (in Gg CO_2 eq.)

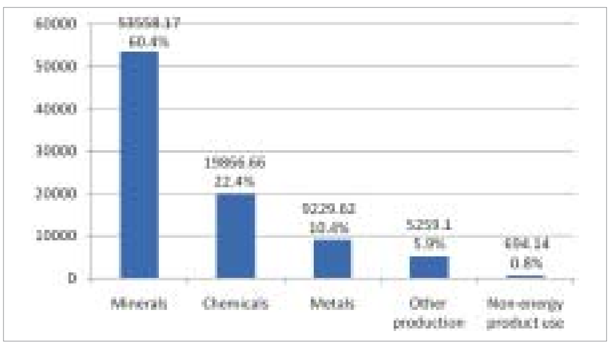


Figure 2.10: Distribution of CO_2 eq. emissions across the categories of the industrial processes and product use sector in 2000 (in Gg CO_2 eq.)

Table 2.6: Greenhouse gas emissions from the industrial processes and product use sector (in Gg for the year 2000)									
	CO_2	CH_4	N_2O	HFC-134a	HFC-23	CF_4	C_2F_6	SF_6	CO_2 eq.
2. Industrial process	**72,560.78**	**5.39**	**12.80**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**88,608.07**
A. Minerals	**53,558.17**								**53,558.17**
1. Cement production	44,056.00								44,056.00
2. Lime production	2,921.00								2,921.00
3. Limestone and dolomite use	5,961.68								5,961.68
4. Soda ash production and use	463.94								463.94
5. Glass	155.54								155.54
B. Chemicals	**15,785.98**	**5.34**	**12.80**						**19,866.66**
1. Ammonia production	11,067.30								11,067.30
2. Nitric acid production	0.00		11.75						3,643.83
3. Carbide production	102.72								102.72
4. Titanium dioxide production	43.75								43.75
5. Methanol production	229.84	0.79							246.41
6. Ethylene production	3,317.23	4.42							3,410.15
7. EDC and VCM production	233.23								233.23
8. Ethylene oxide production	51.29	0.11							53.53
9. Acrylonitrile production	26.98	0.0049							27.08
10. Carbon black production	713.64	0.02							713.98
11. Caprolactam			1.05						324.69
C. Metal Production	**2,522.5**	**0.05**				**0.870**	**0.087**	**0.01**	**9,229.62**
1. Iron and steel production									
2. Ferro-alloys production	1,467.55	0.05							1,468.65
3. Aluminium production	1,025.31					0.87	0.09		7,480.38
4. Lead production	23.22								23.22
5. Zinc production	6.42								6.42
6. Magnesium production								0.01	250.95
D. Other production				**0.220**	**0.420**			**0.0025**	**5,259.10**
1. Production of halocarbons				0.220	0.42				5,199.35
2. Consumption of SF_6								0.0025	59.75
E. Non-energy product use	**694.14**								**694.14**
1. Lubricant	672.91								672.91
2. Paraffin wax	21.23								21.23

CO_2 – carbon dioxide; SO_2 – sulphur dioxide; CH_4 – methane; N_2O – nitrous oxide; EDC – ethylene dichloride; VCM – vinyl chloride monomer; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride processes included here are the processes of production of cement, glass, limestone, dolomite, and soda ash, and limestone and dolomite use. CO_2 eq. emission from the cement production was 44,056.0 Gg of CO_2, which is 82.8% of the total CO_2 eq. emissions from the mineral industries, followed by limestone and dolomite use (10.82%), and limestone production (5.30%). Soda ash and glass production account for 0.84% and 0.28% of the total GHG emissions from the mineral production sector, respectively.

Chemical industries (2B)

The chemical industry covers the production of ammonia, nitric acid, carbide, titanium dioxide, methanol, ethylene, EDC and VCM, acronytrile, carbon black, and caprolactam. Ammonia is a major industrial chemical and the most important nitrogenous material produced. Ammonia gas is used directly for fertilizer production; in heat treating and paper pulping; in nitric acid, nitrates, nitric acid ester, and nitro compound manufacture; in making explosives of various types, and as a refrigerant. Amines, amides, and miscellaneous other organic compounds, such as urea, are made from ammonia. During the production of nitric acid, N_2O is generated as an unintended by-product of the high-temperature catalytic oxidation of ammonia. The amount of N_2O formed depends, inter alia, on combustion conditions (pressure, temperature), catalyst composition and age, and burner design.

All the chemical industries considered here together emitted 19,866.66 Gg of CO_2 eq. in 2000. Amongst all the chemical industries, ammonia production industry resulted in the maximum emissions (55.7% of the total CO_2 eq. emissions from all chemical industries (see Box 2.5) for the method to calculate CO_2 emission factor from ammonia production). Considering that ammonia production industry is a major emitter within the chemical industries and within the industrial processes sector, efforts were made to determine the emission factor of CO_2 from ammonia production process (Box 2.4). Of the total CO_2 eq. emissions from the chemical industries, 18.34% of the total CO_2 eq. emissions (3643.83 Gg CO_2 eq.) were from nitric acid production and 17.2% of the emissions (3410.15 Gg CO_2 eq.) were from ethylene production.

Box 2.5: Sample Calculation for CO_2 emission factor from ammonia production

As per the IPCC 2006 Guidelines

$$EFCO_2\ (CO_2 \text{ in kg}) = AP \bullet FR \bullet CCF \bullet COF \bullet 44/12 - RCO_2$$

where AP = ammonia production, tonnes (not available directly, to be indirectly calculated from urea production) = 1 tonne, to estimate emissions per tonne of ammonia produced; CCF = carbon content factor; FR = fuel requirement per unit of output (GJ/tonne ammonia produced (default given = 29, actual = 31–33); COF = carbon dioxide factor of fuel; RCO_2 = CO_2 recovered in kg for downstream use (urea production).

This formula gives fuel requirement in terms of energy per tonne of ammonia. The data received from industry gives values in terms of tonnes of fuel per tonne of ammonia produced. The most common feed and fuel is natural gas, the net calorific value (NCV) of which is 10000–14000 kcal/ kg. There is a high variability in this value. Some organizations report NCV as 10,000 kcal/nM^3. But it would vary according to methane percentage. Again there is a wide variation in the density of natural gas, that is, 0.6 to 0.9 kg/nM^3. But the most common value in the Indian scenario is 0.75 kg/nM^3. So the calculation goes on an average as

FR (fuel requirement per unit output) = (1000 nM^3/tonne of ammonia (fuel plus feed) x 0.75 kg/nM^3 x 10,000 kcal/kg x 4.18 kJ/ kcal x 10E–6) GJ/ tonne of ammonia = 31.5 (This value may go up to 34 if higher values of gas density and NCV are assumed.)

CCF= 15.3 (default, Table 3.1 IPCC 2006 Guidelines)

COF = 1 (default, Table 3.1 IPCC 2006 Guidelines)

RCO_2 = mostly recovered more than 95%. Most of the ammonia plants in India utilize CO_2 produced for urea manufacturing, except very few plants. Therefore, 95% utilization is a reasonable assumption.

Thus, ECO_2= (1) x (31 to 33) x 15.3 x 1 x 44/12= 1739 kg (1.739 tonnes) CO_2 to 1907 kg (1.907 tonnes) CO_2 per tonne of ammonia produced.

Considering 95% utilization of CO_2 in urea production

ECO_2= (1.739 to 1.907) tonnes x 1000 x 0.05 = 86–96 kg CO_2/tonne ammonia

The actual emissions of CO_2 can be calculated as

CO_2 emissions (tonnes/year) = annual urea production x (86–96) x 0.566 x 10E–3 Gg CO_2 per year

The other significant emissions from this category were from carbon black production (3.59% of the total CO_2 eq. emissions from the Chemical industries). The rest of the emission sources included had insignificant emissions as compared to the total emissions from this category.

Metal production (2C)

This section covers the emissions due to the production process of iron and steel, including the production of metallurgical coke (emissions due to the production process of iron and steel is covered elsewhere), ferro-alloy, aluminium, magnesium, lead, and zinc. The Indian iron and steel industry is nearly a century old, with Tata Iron & Steel Co (Tata Steel) being the first integrated steel plant to be set up in 1907. It was the first core sector to be completely freed from the licensing regime (in 1990/91) and the pricing and distribution controls. The liberalization of industrial policy and other initiatives taken by the government have given a definite impetus for entry, participation, and growth of the private sector in the steel industry. Steel industry was de-licensed and decontrolled in 1991 and 1992, respectively. Today, India is the seventh largest crude steel producer of steel in the world. In 2008/09, production of finished (carbon) steel was 59.02 Mt as compared to 29.77 Mt in 2000/01. Production of pig iron has increased from about 3.0 Mt in 2000/01 to 5.299 Mt in 2008/09 (Source: Ministry of Steel). Also steel is produced through direct reduced iron (DRI) process from iron ore powder through heating and chemical reduction by natural gas. In 2000/01, through DRI process, India produced 3.11 Mt of steel, which increased to 12.5 Mt in 2005/06.

Ferro-alloys are used primarily in steel making as de-oxidant and alloying agent. Depending on the process of steel making and the product quality envisaged, the requirement of ferro-alloys varies widely. Ferro-alloy product range in India includes manganese alloys (50%), chrome alloys (35%), ferro-silicon (9%) and noble alloys (6%). In 2000/01, manganese alloy produced was 446 Mt, Cr alloy produced was 381.9 Mt, ferro-silicon produced was 67.3 Mt, and the production of noble alloys was about 6.5 million tonnes. The growth of ferro-alloys production rides on steel production, and currently the production is more than 80% of the capacity (IMY, 2008).

The aluminium industry in India is strategically well-placed and ranks as the eighth largest producer of aluminium in the world, with discernible growth plans and prospects for the future. India's rich bauxite mineral base renders a competitive edge to the industry as compared to its counterparts globally. The overall total annual installed capacity of aluminium in the country has risen to 1.2 Mt per year. The production of aluminium has increased from about 700 Mt in 2000/01 to 1239.5 Mt in 2007/08 (IMY, 2008).

The metal production processes together emitted 9229.62 Gg of CO_2 eq. This includes emissions of CO_2, CH_4, N_2O, CF_4, C_2F_6, and SF_6. CF_4 and C_2F_6 result from the production process of aluminium and SF_6 from the production process of magnesium. Aluminium production leads to 81.0% of the total CO_2 eq. emissions from the Category 2C, followed by that from ferro-alloys (16.0%). The rest of the emissions are from magnesium, lead, and zinc production processes. Please note that emissions due to Iron and Steel production have been considered in the Energy sector and therefore are not reported in this category.

Production of halocarbons and consumption of sulphur hexafluoride (2D)

Other production led to the emission of 5259.10 Gg of CO_2 eq. Of this, 98.9% of the CO_2 eq. emissions were from the production of halocarbons HFC-134a and HFC-23. HFC-23 is generated as a by-product during the manufacture of HCFC-22. HCFC-22 is used as a refrigerant, as a blend component in foam blowing, and as a chemical feedstock for manufacturing synthetic polymers. Chlorofluorocarbon (CFC)-12, which is used in the refrigeration and air conditioning (RAC) sector, has to be phased out. This will be possibly replaced by HFC-134a. HFC-134a has been introduced in India for domestic and commercial refrigeration including air-conditioning, especially in the car segment. It is a replacement of CFC-12, which is an ozone depleting substance. The rest of the emissions, that is, 1.1% of the CO_2 eq. emissions, are from the consumption of SF_6. The major application of SF_6 (with a GWP of 23,900) is in electrical industries, mainly in transformers and circuit breakers. SF_6 is also used in magnesium production as a cover gas in foundries to avoid the oxidation of molten magnesium.

Non-energy product use

The products covered here are lubricants, paraffin waxes, bitumen/asphalt, and solvents. Emissions from further uses or disposal of the products after first use (that is, the combustion of waste oils such as used lubricants) are to be estimated and reported in the waste sector when incinerated or in the energy sector when energy recovery takes place. The products that have been covered in this assessment include lubricants and paraffin wax.

Lubricants are mostly used in industrial and transportation applications. Lubricants are produced either at refineries through separation from crude oil or at petrochemical facilities. They can be subdivided into (i) motor oils and industrial oils, and (ii) greases, which differ in terms of physical characteristics (for example, viscosity), commercial applications, and environmental fate. The use of lubricants in engines is primarily for their lubricating properties, and the associated emissions are, therefore, considered as non-combustion emissions to be reported in the IPPU sector.

Products included under waxes are petroleum jelly, paraffin waxes, and other waxes, including ozokerite (mixtures of saturated hydrocarbons). Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. These waxes are categorized by oil content and the amount of refinement. Waxes are used in a number of different applications. Paraffin waxes are used in applications such as making candles and corrugated boxes, paper coating, board sizing, food production, wax polishes, surfactants (as used in detergents), and many others. Emissions from the use of waxes result primarily when the waxes or derivatives of paraffins are combusted during use (for example, candles), and when they are incinerated with or without heat recovery or in waste water treatment (for surfactants). In the cases of incineration and waste water treatment, the emissions should be reported in the energy and waste sectors, respectively. Total GHG emission from the use of lubricants and paraffin wax for non-energy purposes was 694.14 Gg CO_2 eq., in 2000.

Agriculture

This section provides information on the estimation of the GHG emissions from the agriculture sector, from the following source categories:

- 3A: Enteric fermentation
- 3B: Manure management
- 3C: Rice cultivation
- 3D: Agriculture soils
- 3E: Field burning of agricultural residue

Methodology, activity data, and emission factors

The methodologies for estimating GHGs – CH_4 and N_2O – emitted from all the above categories are based on the methodologies provided in the Agriculture section of the IPCC 1996 Revised Guidelines. A Tier-III approach has been followed for enteric fermentation as the livestock population classified as cattle and buffalo has been sub-classified into indigenous and cross-bred types. Each of these has been further divided into three age groups. The CH_4 emission factors used for the major livestock categories such as cattle and buffalo are country specific. The activity data is mainly sourced from the reports of the Ministry of Agriculture (see the various reports mentioned in the References and sources section). Similarly, for estimating CH_4 from rice cultivation, Tier-III approach has been used, whereby the entire rice crop area has been divided into four rice ecosystems and they have been further divided based on actual water management practices followed in India. The emission factors used are also based on measurements carried out continuously by different groups since early 1990s. For estimating GHGs from burning of crop residue, default IPCC emission factors have been applied. For estimating N_2O from soils, direct and indirect emissions have been estimated, which are based on expert judgment. Table 2.7 lists the emission factors used in the agriculture sector.

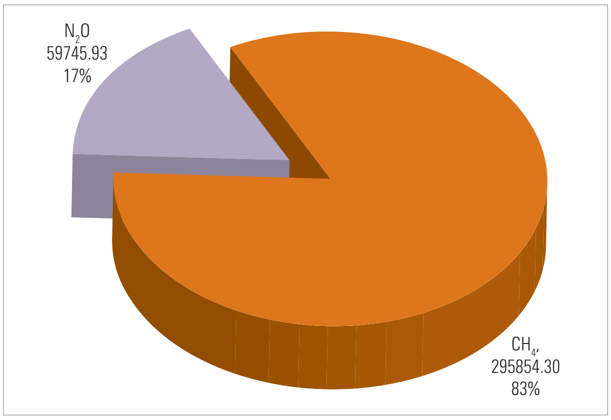


Figure 2.11: Distribution of greenhouse gases emitted from the agriculture sector (in Gg of CO_2 eq.) in 2000.

Table 2.7: Greenhouse gas emission factors used in the agriculture sector

Category	Sub-category	Emission factor	Source
3A: Enteric fermentation			
Dairy cattle	Indigenous	28±5 kg CH_4/head/year	NATCOM, 2004
	Cross-bred	43±5 kg CH_4/head/year	NATCOM, 2004
Non-dairy cattle (indigenous)	0–1 year	9±5 kg CH_4/head/year	NATCOM, 2004
	1–3 years	23±8 kg CH_4/head/year	NATCOM, 2004

	Adult	32+6 kg CH_4/head/year	NATCOM, 2004
Non-dairy cattle (cross-bred)	0–1 year	11±3 kg CH_4/head/year	NATCOM, 2004
	1–2 ½ years	26±5 kg CH_4/head/year	NATCOM, 2004
	Adult	33±4 kg CH_4/head/year	NATCOM, 2004
Dairy buffalo		50±17 kg CH_4/head/year	NATCOM, 2004
Non-dairy buffalo	0–1 year	8±3 kg CH_4/head/year	NATCOM, 2004
	1–2 ½ years	22±6 kg CH_4/head/year	NATCOM, 2004
	Adult	44±11 kg CH_4/head/year	NATCOM, 2004
Sheep		4±1 kg CH_4/head/year	IPCC, 1996
Goat		4±1 kg CH_4/head/year	IPCC, 1996
Horses and ponies		18 kg CH_4/head/year	IPCC, 1996
Donkeys		10 kg CH_4/head/year	IPCC, 1996
Camels		46 kg CH_4/head/year	IPCC, 1996
Pigs		1 kg CH_4/head/year	IPCC, 1996
3B: Manure management			
Dairy cattle	Indigenous	3.5±0.2 kg CH_4/head/year	NATCOM, 2004
	Cross-bred	3.8±0.8 kg CH_4/head/year	NATCOM, 2004
Non-dairy cattle (indigenous)	0–1 year	1.2±0.1 kg CH_4/head/year	NATCOM, 2004
	1–3 years	2.8±0.2 kg CH_4/head/year	NATCOM, 2004
	Adult	2.9±1.4 kg CH_4/head/year	NATCOM, 2004
Non-dairy cattle (cross-bred)	0–1 year	1.1±0.1 kg CH_4/head/year	NATCOM, 2004
	1–2 ½ years	2.3±0.2 kg CH_4/head/year	NATCOM, 2004
	Adult	2.5±0.9 kg CH_4/head/year	NATCOM, 2004
Dairy buffalo		4.4±0.6 kg CH_4/head/year	NATCOM, 2004
Non-dairy buffalo	0–1 year	1.8±0.1 kg CH_4/head/year	NATCOM, 2004
	1–2 ½ years	3.4±0.2 kg CH_4/head/year	NATCOM, 2004
	Adult	4.0±0.2 kg CH_4/head/year	NATCOM, 2004
Sheep		0.3 kg CH_4/head/year	IPCC, 1996
Goat		0.2 kg CH_4/head/year	IPCC, 1996
Horses and ponies		1.6 kg CH_4/head/year	IPCC, 1996
Donkeys		0.9 kg CH_4/head/year	IPCC, 1996
Camels		1.6 kg CH_4/head/year	IPCC, 1996
Pigs		4.0 kg CH_4/head/year	IPCC, 1996
3C: Rice cultivation			
Irrigated	Continuously flooded	162 kg CH_4/ha	SNC Measurement
	Single aeration	66 kg CH_4/ha	SNC Measurement
	Multiple aeration	18 kg CH_4/ha	SNC Measurement
Rain-fed	Drought prone	66 kg CH_4/ha	SNC Measurement
	Flood prone	190 kg CH_4/ha	SNC Measurement
Deep water	Deep water	190 kg CH_4/ha	SNC Measurement
Upland		0	

Overview of greenhouse gas emissions from the agriculture sector

The agriculture sector emitted 355,600.60 Gg of CO_2 eq. in the year 2000. Of this, 83% was emitted as CH_4 and 17% was emitted as N_2O (Figure 2.11). Distribution of emission by sources within the agriculture sector is shown in Figure 2.12. The detailed emissions of all GHG, by sector, are presented in Table 2.8a.

Enteric fermentation (3A)

Population of various species of livestock contributing to CH_4 emission was taken from livestock census 1997 and 2003, done by the Animal Husbandry Department of India. The total population of the cross-bred cattle as well as buffaloes has increased from 18.6% in 1997 to 20.28 % in 2003, whereas marginal increase in sheep and pig population was observed during the same period while goat population remained stagnant. As compared to the 1992 population, there was a 6.5% (1997) and 15.6% (2003) increase recorded in cross-bred cattle and buffalo, respectively. There was a decrease in the population of indigenous cattle, from 37.57% to 33.76% of the total livestock, and the population of the cattle decreased by 5.5% in 1997 and 15.5 % in 2003 when compared to their population in 1992. The population of horses and ponies, donkeys, mules, and camels also decreased. However, mithun and pig population has shown a marginal increase. For 2000, interpolation of cattle population has been done using the compound annual growth rate (CAGR) between 1997 and 2003 statistics.

In order to estimate CH_4 emissions from livestock, the cattle population has been divided into dairy and non-dairy categories, with sub-classification into indigenous and cross-bred types for different age groups (MoA, 2005). The dairy cattle have been characterized as cross-bred and indigenous. The cross-bred has high milk yield and calves once in a year. The indigenous cattle have the typical characteristic of having lower body weights as compared to cross-breds and they have lower milk yield and also calve once a year. The lactating buffaloes are classified as dairy buffaloes. Non-dairy cattle and buffaloes include calves below one year, adults beyond calving age, and those within one to two years of age. The livestock considered in this estimation also include sheep, goat, horses, ponies, mules, donkeys, yaks, pigs, mithun, and poultry. The emission factors used for cows, sheep, and buffaloes have been derived from literature review, which are based on measurements and estimates based on feed intake by these species, especially for the cross-

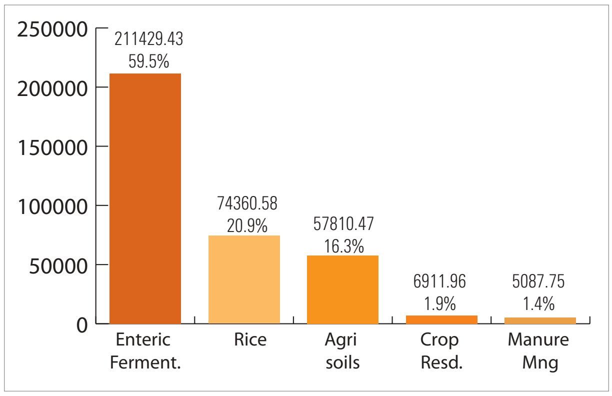


Figure 2.12: Distribution of emissons, by sector, from the agriculture sector (in Gg of CO_2 eq.)

Table 2.8a: Greenhouse gas emissions from the agriculture sector in 2007

Category		CO_2	CH_4	N_2O	CO_2 equivalent
	Sub-category	(Gg)	(Gg)	(Gg)	(Gg)
Agriculture			**14,088.30**	**192.73**	**355,600.19**
3A: Enteric fermentation			**10,068.07**		**211,429.43**
Dairy cattle	Indigenous		2,150.31		45,156.51
	Cross-bred		630.92		13,249.32
Non-dairy cattle (indigenous)	0–1 year		83.63		1,756.23
	1–3 years		223.87		4,701.27
	Adult		1,977.03		41,517.63
Non-dairy cattle (Cross-bred)	0–1 year		35.21		739.41
	1–3 years		46.01		966.21
	Adult		106.13		2,228.73
Dairy buffalo			3,922.69		82,376.49

Non-dairy buffalo	0–1 year		52.84		1,109.64
	1–3 years		84.36		1,771.56
	Adult	390.18			8,193.78
Sheep		16.46			345.66
Goat		271.02			5,691.42
Horses/ ponies/mules		9.96			209.16
Donkeys		7.34			154.14
Camels		32.17			675.58
Pigs		28.13			590.73
3B: Manure management			**241.19**	**0.0734**	**5,087.75**
Cross-bred cattle			21	0.0051	442.581
Indigenous cattle			99.4	0.0315	2097.165
Buffalo			101.03	0.0301	2130.961
Goat			7.81	0.0018	164.568
Sheep			6.59	0.0023	139.103
Horses and ponies			0.29	0.0001	6.121
Donkeys			0.21	0.0001	4.441
Camels			0.41	0.0001	8.641
Pigs			4.45	0.0004	93.574
3C: Rice cultivation			**3,540.98**		**74,360.58**
Irrigated	Continuously flooded	1,111.11			23,333.31
	Single aeration	598.37			12,565.77
	Multiple aeration	174.56			3,665.76
Rain-fed	Drought prone	570.41			11,978.61
	flood prone	827.14			17,369.94
Deep water	Deep water	259.39			5,447.19
Upland	Upland	0			0
3D: Agriculture soils				**186.49**	**57,810.47**
	Direct			155.06	48,067.17
	Indirect			31.43	9,743.30
3E: Field burning of crop residue			**238.06**	**6.17**	**6,911.96**

bred and indigenous cattle in India. The other emission factors used are the default emission factors taken from IPCC 1996 Revised Guidelines. In 2000, enteric fermentation in livestock resulted in 10,068.07 Gg CH_4. Of the large ruminants, 40% of the emission was from the dairy buffaloes, and only 29% of the emission resulted from dairy cattle. This indicated farmers' preference for dairy buffalos over dairy cattle due to the larger milk production potential of the former. Similarly, amongst the small ruminant, 74% of the emissions were from goat, again indicating the farmers' preference for small ruminants (Figure 2.13).

As stated above, attempts were made in the SNC process to sample the feed intake of the different cattle types at national level, and a study was carried out to estimate the feed intake and hence the emissions for a state that has significant small ruminants. In this respect Tamil Nadu was chosen as the state for the case study and measurements were undertaken.

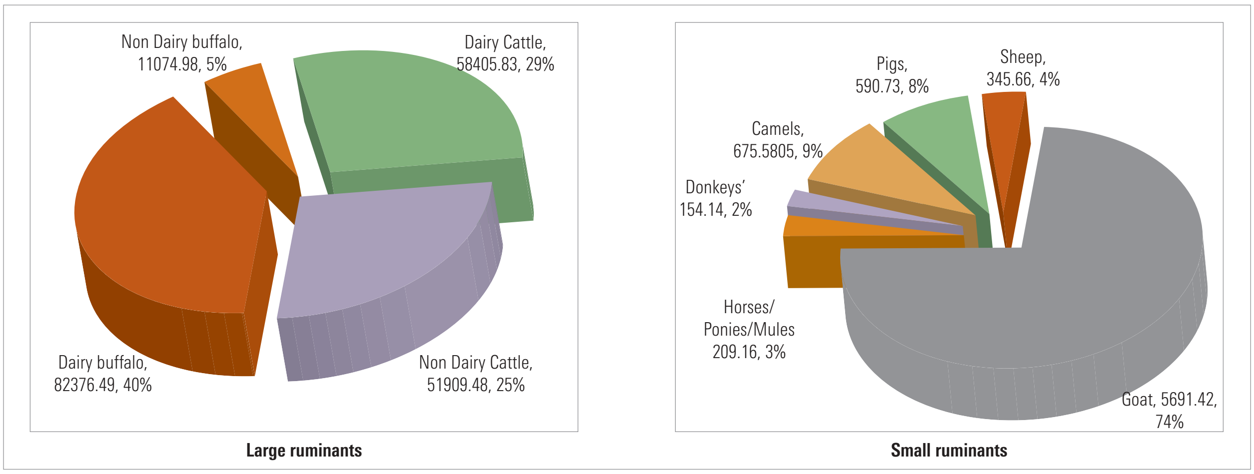


Figure 2.13: Distribution of greenhouse gas emissions amongst large and small ruminants

Manure management (3B)

Not much systematic management of manure from livestock is done in India. It is mainly converted into dung cakes and is used for energy purposes in rural areas. The dung of stall-fed cattle and buffaloes, irrespective of their age, production status, and feeding, is collected, and on an average, 50% is converted into dung cakes daily in the morning, mainly by the women folk of the households in India. The collected dung is mixed with the residual feed (mainly straws) of the animals and dung cake of circular shape (weighing 0.5–2.5 kg) is prepared by hand and put out in the sun for drying. Drying is generally completed within three to five days during the summer season and 7–10 days during the winter season. After drying, the dung cakes are staked into a conical structure, which is plastered with dung on the upper surface before the onset of the monsoon season. Some farmers store this source of fuel in the closed rooms. Under the prevailing situation, CH_4 emission is not expected from the dung cake. It is contrary to the IPCC (1997) report, which indicates 5–10% methane emission during the course of drying of dung cakes.

The inventory estimations using Tier-III approach with same country- specific emission factors and livestock population of Census 2003 resulted in total emission of 11750 Gg CH4 (10655 Gg from enteric fermentation, 1095 Gg from manure management). Using the remote sensing derived livestock available feed fodder area, the average methane flux was computed as 74.4 kg per ha (Chhabra *et al*., 2009, Fig. 2.13a)

Dung cake is made almost in all the states in India except in Himachal Pradesh, Jammu and Kashmir, and north-eastern regions. Fuel requirements in these states are generally met through fuelwood. Dung of all other species such as pigs, camels, goats, and sheep is not utilized for making dung cakes. Indian farmers still depend on organic manure for maintaining the soil fertility as this system is sustainable for the economy of the farmers. To convert the cattle and buffalo dung into manure, excess dung remaining from dung cake making is collected on the heap near to the cattle shed. The residual feed (unfit for mixing in dung cake) and ash (available due to the use of dung cake as a source of fuel) are also put on the heap. However, during the monsoon season when dung cake is not made due to the rains, the entire quantity of daily collection of dung goes to this heap. The dung thus collected is exposed to the weather conditions, and CH_4 emission is expected from the inner core of the heap

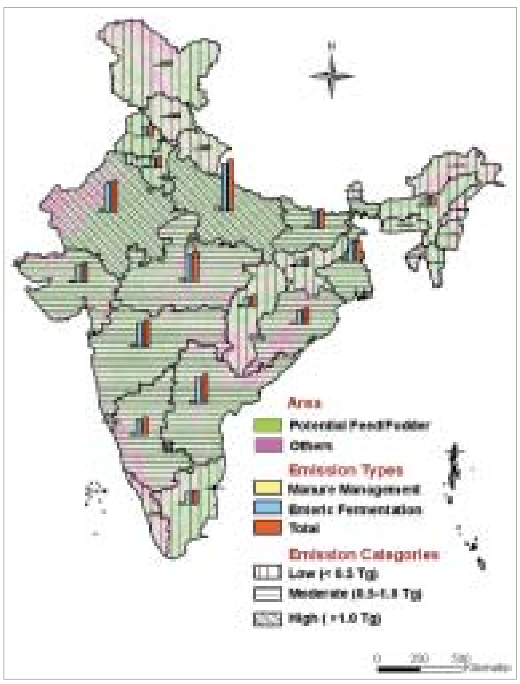


Fig. 2.13a: Spatial pattern of methane emission from livestock (2003). State level emission overlaid on remote sensing derived feed-fodder area.

due to the anaerobic fermentation of organic matter. IPCC (1997) also endorses this fact. The manure thus prepared is generally carted to the fields at the time of soil preparations after the monsoon season or at the time of need. In 2000, due to the process of making dung cake in India, 5087.75 Gg CO_2 eq. was emitted, of which 241.19 Gg was emitted as CH_4 and 0.07 Gg was emitted as N_2O.

Rice cultivation (3C)

India, on an average, cultivates rice on 43 million ha of land, of which 52.6% is irrigated, 32.4% is rain-fed lowland, 12% is rain-fed upland, and 3% is deepwater rice. The annual amount of CH_4 emitted from a given area of rice is a function of the crop duration, water regimes, and organic soil amendments. The CH_4 emissions were estimated by multiplying the seasonal emission factors by the annual harvested areas. Harvested area for each sub-unit (state) was multiplied by the respective emission factor, representative of the conditions that define the sub-unit (state). The total annual emissions are equal to the sum of emissions from each sub-unit of harvested area. The total harvested area of rice for the year 2000 was 44.77 M ha. Using the above approach, emission of CH_4, by state, was estimated to be 3.54 Tg for the year 2000, which is 20.9% of the total GHG emitted from the agriculture sector. A total of 1.1 Tg of CH_4 was emitted from the irrigated continuously flooded rice ecosystem, followed by 0.8 Tg and 0.6 Tg of release from the rain-fed flood-prone and irrigated single aeration rice ecosystems, respectively. The emission distribution from each ecosystem is given in Figure 2.14a.

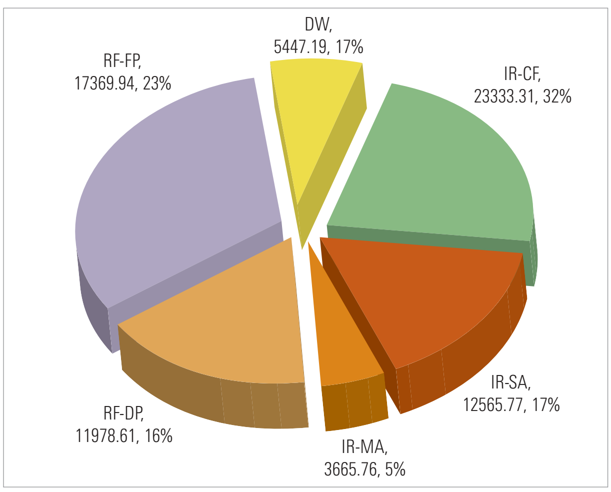


Figure 2.14a: Distribution of emission from rice cultivation, by ecosystem type

RF-FP: Rain Fed Flood Prone
RF-DP: Rain Fed Drought Prone
DW: Deep Water
IR-CF: Irrigated Continuously Flooded
IR-SA: Irrigated Single Aeration
IR-MA: Irrigated Multiple Aeration

The methane emission coefficients from different cultural types of rice fields in India (as per IPCC) were updated using a detailed field campaign during 2004-06. Around 471 locations in the country representing different cultural types of rice fields were sampled for total seasonal methane flux during 2004-06 period through a coordinated research team led by Space Applications Centre, ISRO. Satellite remote sensing data along with ancillary data on rainfall, slope, soil were used to generate the rice cultural type map of India. The strata-wise emission coefficients were used to calculate seasonal and annual methane emission from rice fields in spatio-temporal domain (Manjunath et al., 2008). The total CH4 emission from Indian rice-ecosystems for the year 2005-06 estimated was 3.386 Tg (Table 2.8b, Fig. 2.14b)

Table 2.8b: Methane emission from Indian rice ecosystems using remote sensing and GIS techniques:

Type	Rice cultural types (%)	Emission factor (kg/ha)	Sampling locations (number)	CH4 Emission (Tg)
Irrigated Continuous (wet season)	27.95	75.1±56.8	178	0.919
Irrigated Continuous (Dry season)	10.81	78.3±33	74	0.393
Irrigated Intermittent	8.8	55±25.5	87	0.228
Flood Prone	9.63	137.8±50.7	60	0.558
Drought Prone	42.82	62.4±50.2	62	1.288
Deep Water		343.8±232.6	10	
Total	43.1 (M ha)	74.05±43.28	471	3.386

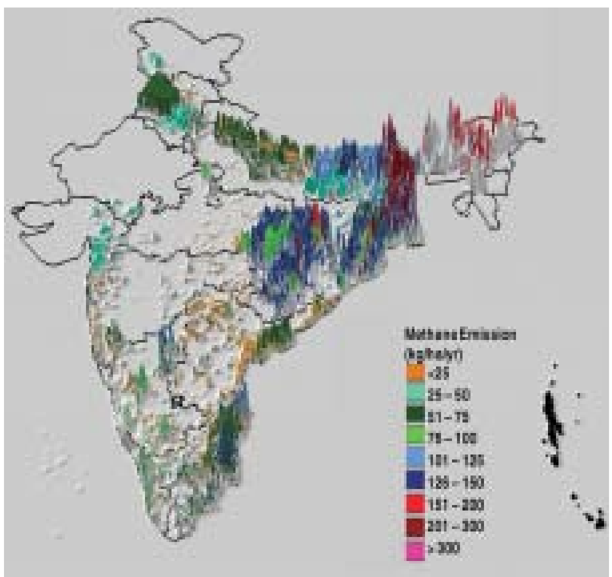


Figure 2.14b: Perspective view of methane emission from rice fields of India.

Box 2.6: Methane emission factor measurements in continuously flooded fields in eastern part of India

In the Initial National Communications, it was highlighted that the eastern states of Bihar, West Bengal, and Orissa together account for more than 50% of the methane (CH_4) emission from India from rice cultivation. The highest emitting category within these states was the continuously flooded field. Considering that the continuously flooded fields are higher emitters – in 2000, 32% of the emissions came from continuously flooded fields – efforts were made to measure the emission factors, especially for these categories in the states of Orissa and West Bengal, where this practice is most prevalent.

CH_4 sampling was done in two sites of continuously irrigated paddy fields, namely, village Khanyan (Block- Pandua, Dist. - Hooghly) and village Badla (Block - Bainchi, Dist. - Burdwan) in West Bengal and in two sites of deep water paddy, namely, village Nandika (Block - Jaleswar, Dist. - Balasore) and village Nimpur (Block - Jaleswar, Dist. - Balasore) in Orissa. Cultivated rice varieties were MTU-1010 and MTU-7029 in West Bengal and Swarna and Hybrid Swarna in Orissa. Throughout the growing stage, CH_4 flux was higher in continuously irrigated system as compared to deep water system, with their values being 2.2–788.1 mg CH_4/m^2/day and 1.2-170.3 mg CH_4/m^2/day, respectively (Tables 1, 2, 3, and 4). Irrespective of the sites, there was an increase in the magnitude of emission from tillering stage to maturity of the crop, and the maximum peak was observed at flowering stage (42–56 DAT). In case of Khanyan, the maximum peak was observed on 77 and 63 DAT for field 1 and field 2, respectively. On the other hand, in Badla, the maximum peak varied from field to field. The highest peaks were attained on 63, 42, and 49 DAT for field 1, field 2, and field 3, respectively. Thereafter the flux recorded a decrease, attaining lowest value at harvesting. However, in the village Nandika, the highest peak was observed on 49, 49, and 56 DAT in field 1, field 2, and field 3, respectively, whereas, in village Nimpur, the highest peak was observed on 28, 49, and 28 DAT in field 1, field 2, and field 3, respectively.

Table 1: Methane (CH_4) emission ($mg/m^2/d$) from paddy fields of Khanyan (West Bengal)

DAT	35	42	49	56	63	70	77	84	91	98
Field 1	415.025	500.112	424.122	123.800	135.471	223.987	777.593	147.100	144.305	3.222
Field 2	683.228	611.228	665.766	587.734	788.167	480.513	340.484	101.338	182.680	12.973
Field 3	671.512	534.005	538.046	456.002	362.048	368.225	122.756	29.290	157.993	3.020
Date	1/9/09	7/9/09	14/9/09	21/9/09	28/9/09	5/10/09	12/10/09	19/10/09	26/10/09	2/11/09

Table 2: Methane (CH_4) emission ($mg/m^2/d$) from paddy fields of Badla (West Bengal)

DAT	35	42	49	56	63	70	77	84	91	98
Field 1	335.079	513.559	400.214	511.692	729.305	322.104	451.354	115.468	122.001	2.225
Field 2	507.426	768.221	693.244	538.420	629.114	390.197	305.343	102.091	301.290	9.001
Field 3	663.095	568.335	692.242	366.477	500.281	455.852	319.533	14.477	28.190	5.208
Date	1/9/09	7/9/09	14/9/09	21/9/09	28/9/09	5/10/09	12/10/09	19/10/09	26/10/09	2/11/09

Table 3: Nitrous oxide (N_2O) emission (mg/m²/d) from paddy fields of Khanyan (West Bengal)										
DAT	35	42	49	56	63	70	77	84	91	98
Field 1	7.59	1.02	1.39	2.70	2.38	2.20	1.24	1.70	1.18	0.55
Field 2	1.27	3.19	7.06	1.02	0.25	0.51	1.01	1.09	2.38	1.10
Field 3	1.50	0.37	5.19	1.11	0.22	0.97	1.17	1.11	0.71	2.06
Date	1/9/09	7/9/09	14/9/09	21/9/09	28/9/09	5/10/09	12/10/09	19/10/09	26/10/09	2/11/09

Table 4: Nitrous oxide (N_2O) emission (mg/m²/d) from paddy fields of Badla (West Bengal)										
DAT	35	42	49	56	63	70	77	84	91	98
Field 1	1.29	1.20	2.30	3.71	1.44	1.97	1.21	1.47	1.26	1.54
Field 2	1.93	2.31	6.31	2.20	1.02	0.93	1.03	1.03	2.38	1.30
Field 3	2.77	0.29	4.22	1.93	0.54	0.59	1.33	1.32	1.07	2.26
Date	1/9/09	7/9/09	14/9/09	21/9/09	28/9/09	5/10/09	12/10/09	19/10/09	26/10/09	2/11/09

Agriculture soils (3D)

Two pathways of N_2O emissions from soils exist—direct and indirect. Direct N_2O emission was estimated using net N-additions to soils (synthetic or organic fertilizers, deposited manure, crop residues) and mineralization of Nitrogen in soil due to cultivation/land-use change on mineral soils. The indirect N_2O emission was estimated from the volatilization of ammonia and NOx from the managed soils, subsequent re-deposition of these gases and their products (NH_4 and NO_3) to soils, and after leaching and run-off of N, mainly as NO_3 from the managed soils. Total emissions of N_2O from the managed soils will be estimated. Direct emissions of N_2O from the managed soils are estimated separately from indirect emissions, though using a common set of activity data, including application of synthetic N fertilizers and organic N (animal manure, compost, green manure), deposition of dung N as manure, presence of N in crop residues (above-ground and below-ground), and presence of N in mineral soils that is mineralized in association with the loss of soil C. In total, 186.49 Gg of N_2O (57,810.47 Gg CO_2 eq.) was emitted from soils. Of these, direct emission was 83% of the total emitted from the soils and was equivalent to 155.06 Gg (48,067.17 Gg CO_2 eq.).

Burning of agriculture crop residue (3E)

Crop residue is burned in the fields in many Indian states, particularly in Punjab, Haryana, and western Uttar Pradesh, producing CO, CH_4, N_2O, NOx, NMHCs, SO_2, and many other gases. In our assessment, we have reported only CH_4 and N_2O. Data on the burning of crop residue has been obtained from the states of Uttar Pradesh, Punjab, West Bengal, Haryana, Bihar, Madhya Pradesh, Himachal Pradesh, Maharashtra, Gujarat, Chhattisgarh, Jharkhand, Tamil Nadu, Uttarakhand, and Karnataka as they are the states following this activity. Generally, the residues of nine crops – rice, wheat, cotton, maize, millet, sugar cane, jute, rapeseed-mustard, and groundnut – are burnt in the field. The estimation of emission of targeted species was arrived at by estimating the amount of biomass actually burnt in the field using the IPCC Revised Inventory Preparation Guidelines (IPCC, 1996). Currently, wastes from nine crops, namely, rice, wheat, cotton, maize, millet, sugar cane, jute, rapeseed-mustard, and groundnut, are subjected to burning. Crop production figures, by state, for 2000/01 (MoA, 2002) were used as the basic activity data. Ratio of the residue to economic yield was taken from Bandyopadhayay et al. (2001) . Fractions of residues burnt in the field were taken from Gadde et al. (2009) for rice and data on the fraction of residues oxidized was obtained from IPCC (1996) and Streets et al. (2003). Emission ratio was calculated using emission factors given by Andreae and Merlet (2001), which are the default factors mentioned in IPCC (2006) National Inventory Preparation Guidelines. Based on this, the total emission estimated from this category for 2000 was 238.06 Gg CH_4 and 6.17 Gg of N_2O, equalling 6911.96 Gg CO_2 eq.

Land use, Land-use Change and Forestry – 2000

LULUCF is a key component of the GHG inventory. It involves estimation of carbon stock changes, CO_2 emissions and removals, and non-CO_2 GHG emissions. The IPCC has developed three GHG inventory guidelines for the land use sector, namely, Revised 1996 Guidelines for LUCF (IPCC, 1996); IPCC Good Practice Guidelines for LULUCF (IPCC, 2003); and the latest IPCC 2006 Guidelines, which include agriculture forest and other land categories (AFOLU). India used the Revised 1996 Guidelines for LULUCF sector for the preparation of GHG inventory information for its INC. The inventory showed that LULUCF sector was a marginal source of GHG emissions (14.2 Mt of CO_2 eq.) for the inventory year 1994. The revised 1996 IPCC Guideline has many limitations, and the inventory estimation is incomplete since all the land categories are not included, and the uncertainty of GHG inventory is estimated to be high. Thus, the IPCC developed GPG for the land use sectors, covering all the land use categories for the inventory. The developing countries (Non-Annex I countries) are encouraged to use the IPCC-GPG 2003 approach in preparing GHG inventory for the LULUCF sector. In this assessment, the national GHG inventory from the LULUCF sector of India for the year 2000 is undertaken by using the IPCC-GPG 2003 approach.

Methodology for greenhouse gas inventory

Land use pattern and land use change matrix for India

Land use and land use change data was generated using remotely sensed data for 1994/95 and 2004/05 for the five classes, namely, forest, cropland (agriculture), grassland (including scrub), settlement, and other land. The definitions for the different land categories are as follows:

- Forest land: All lands more than 1 ha in area, with a tree canopy density of more than 10%.
- Cropland: Includes all croplands or net sown area and fallow land area.
- Grasslands: The areas covered with grassy and herbaceous growth as well as degraded forest with less than 10% tree canopy density.
- Other land: Includes all non-vegetated areas, snow, surface waterbody.
- Settlement: Includes the major built-up areas and human habitations.

In order to take into account the phenological calendar of crops, forest, and grassland, satellite remotely sensed data for the major seasons were acquired for the year 1994/95 (IRS 1B LISS I data of March 1994 to March 1995 having spatial resolution of 72.5 m); and similarly, the IRS P6 AWiFS sensor data having resolution of 56 m data was acquired for the year 2004/05. The 2004/05 AWiFS data for different seasons was geo-rectified and re-sampled to LISS I resolution, that is, 72.5 m. The re-sampling of AWiFS data was done in order to carry out one-to-one change analysis with reference to the image generated from LISS I data of 1994/95. All the data sets of LISS I 1994/95 (slave) were registered with reference to 2004/05 AWiFS data (master). The RMS error was brought to less than a pixel.

The IRS P6 AWiFS data sets of 2004/05 for different seasons were digitally classified for the five classes as described above. Similarly, the IRS 1B LISS I data sets of 1994/95 were also classified for the above-mentioned classes. LULC maps were interpreted for the forest layer by the Forest Survey of India (FSI) and integrated into the LULC map generated at the National Remote Sensing Centre. The classification accuracy of the LULC maps in all the cases was ~90%. The decadal (1994/94–2004/05) change analysis was carried out using digital image processing.

The land use pattern for the year 2000, the year of the GHG inventory, was derived by averaging the change in the area under different land categories between 1994 and 2004. The area under the IPCC land categories for 2000/01 is given in Table 2.9. Wetland category is not included since it was not possible to obtain the data to meet the definition of wetland/flooded land according to the IPCC. It can be observed that cropland accounted for 53.6% of the geographic area of India, followed by forest land accounting for 20.5%.

Forest land

Activity data and emission factors for forest land

In India, forest land is defined as “all lands, more than 1

Table 2.9: Land use pattern according to the IPCC land categories during 2000/01

		2000/01 (area in Mha)	IPCC land category	2000/01 (area in Mha)
Forest land		67.462	FL-FL	67.073
			L-FL	0.389
Cropland	Net crop area	141.360	CL-CL	176.074
	Fallow land	34.816	L-CL	0.102
Grassland		38.779	GL-GL	38.779
Settlement		1.717	SL-SL	1.662
			L-SL	0.055
Other land		44.592	OL-OL	44.592
Total land				

Fl – forest land; CL – cropland; GL – grassland; OL – other land; SL – settlement; L – land

ha in area, with a tree canopy density of more than 10%". The FSI periodically monitors the area under forest and publishes the data once in two years. The forest carbon pool estimates are primarily based on the extrapolation of growing stock (volume) data since the existing forest inventories were not designed for direct carbon stock assessment. As per the IPCC guidelines, carbon stock in the forests includes five pools: above-ground biomass (AGB), below-ground biomass (BGB), litter, dead wood, and soil organic carbon (SOC). The approach and methods adopted to prepare forest land GHG inventory are as follows:

- Carbon stock change method adopted for estimating GHG emissions and removals for forest land.
- Developed the land use matrices for the period 1994 to 2004 for
  - forest land remaining forest land and
  - land converted into forest land.
- Activities implemented for forest land remaining forest land
  - Stratify forest land in India into various existing sub-categories.
  - Estimate changes in C stocks from forest land remaining forest land for the following carbon pools: AGB, BGB, dead wood, litter, and SOC.
  - Assess source-specific uncertainties associated with forest land remaining forest land and emissions and removal factors and activity data.
- Activities undertaken for land converted to forest land
  - Stratify forest lands into homogeneous sub-categories for land converted to forest land.
  - Estimate Carbon stock changes for land use conversion to forest land for the following carbon pools:
    - Changes in C stocks in AGB and BGB
    - Changes in C stocks in dead organic matter that includes dead wood and litter
    - Changes in C stock in soils
  - Assess source-specific uncertainties associated with forest land remaining forest land and emissions and removal factors and activity data.
- Develop a quality assurance and quality control plan.

Methodology to develop activity data and land use matrices for the period 1994–2004

Forest cover mapping: Though the forest cover data for India is available with the FSI since 1984 with a two-year interval, there has been a significant change in the interpretational techniques and its scale, particularly since 2001. Prior to 2001, the interpretation of satellite data was manual/visual and scale of interpretation was 1: 250,000, giving the minimum mapable area as 25 ha. Since 2001, the procedure became digital, thus making the interpretation more objective on a scale of 1: 50,000, giving a minimum mapping unit (MMU) as 1 ha. Therefore, the data of 2004 was not directly comparable with that of 1994.

Forest type mapping: The FSI has mapped the forest types of India based on Champion and Seth classification (1968) on 1:50,000 scale, according to 200 types described in the classification. The forest type maps of the entire country, by district, have been prepared. Using the forest type maps, distribution of forest cover in different forest types has been determined for India. By regrouping the detailed forest types, 14 forest type group classes and one plantation group were developed for the current inventory estimation.

Stratification of activity data: Carbon stored in the vegetation, the principal variable, depends on the canopy density and forest type. These two indicators have been considered as stratification variables. Spatial information based on canopy density is available from the "forest cover mapping". This was supplemented with the information generated, by forest type, under the national forest type mapping project carried out by the FSI. This gave three canopy density classes and 15 type group classes, thus resulting in 45 classes in all.

On the 1994 forest cover maps, the forest type information of 2004 was projected as the best approximation in the absence of any information about the geographic distribution of forest types of India in 1994. This approximation draws strength from the fact that forest type of an area does not change within a span of 20–30 years.

Using this type/density classification, the area statistics (activity data) of the following categories were generated by a series of steps of intersection and differencing of maps using GIS techniques:

- Forest land remaining forest land during 1994 to 2004 in all 45 classes
- Non-forest land converted to forest land during 1994 to 2004 in all 45 classes

Methodology to develop emission factors

National Forest Inventory (NFI) for woody biomass and carbon: Under the NFI programme, the FSI is preparing a national forest inventory since 2002, following a stratified and systematic sampling approach and collecting the sample plot data from forest lands distributed across India in different physiographic and climatic zones. As per the new design, data from about 21,000 sample plots (size 0.1 ha) has already been collected between the years 2002 and 2008. In each sample plot, all tree species of diameter 10 cm (DBH) and above were measured. The woody volume of trees of each sample plot was calculated using volume equations developed by the FSI for various species.

Carbon and biomass of shrubs, herbs, climbers, dead wood, and litter: For estimating biomass of non-trees, dead wood and litter, the data of forest inventory made during 2002/08 was analysed for each physiographic zone to ascertain the important tree species and optimum number of plots required for each combination of forest type and forest density. It revealed that about 15 sample plots for each combination would suffice for estimating the biomass/carbon factors for these components, if 30% permissible error is considered (these components contribute very little to total carbon pools). In 5 m × 5 m plots, all dead wood above 5 cm diameter was collected, weighed, and recorded. In 3 m × 3 m plots, all woody litter, that is, all branches below 5 cm diameter, were collected, weighed, and recorded. All shrubs and climbers in 3 m × 3 m plots were uprooted, weighed, and recorded in the prescribed format. In 1 m × 1 m plots, all herbs were uprooted, weighed, and recorded. In all the three plots, the name of the dominant species was also recorded. Dry biomass was converted to carbon stock.

Greenhouse gas emissions and removal estimates for forest land

Stock change method is adopted for estimating the CO_2 emissions and removals for forest land. GHG emissions and removal estimates are reported for the year 2000. The carbon stock estimates for 1994 and 2004 are made and then averaged on an annual basis and used for the year 2000.

Area under forest land: The land use matrix for forest land remaining forest land and land converted to forest land as in 2004 compared to 1994 is given in Table 2.10. It can be observed that the area under forest land remaining forest land was estimated to be 65.12 Mha and the land converted to forest during the period 1994 to 2004 was estimated to be 3.88 Mha.

Carbon stock estimates for forest land: Carbon stock estimates for different carbon pools for the forest land remaining forest land during 1994–2004 as well as for the land area converted to forest land during the same period is given in Table 2.11. The carbon stock in forest

Table 2.10: Area under forest land remaining forest land and land converted to forest

Land Use	Forest land remaining forest land (km^2)	Land converted to forest land (km^2)
VDF	78,770	4702
MDF	301,926	18,022
OF	270,599	16,152
Total	**651,294**	**38,877**

VDF – very dense forest; MDF – moderately dense forest; OF – open forest

Table 2.11: Change in carbon stock from forest land remaining forest land including land converted to forest land

Component	Carbon stock in forest land in 1994 (MtC)	Carbon stock in forest land remaining forest land in 2004 (MtC)	Net change in carbon stock in forest land remaining forest land (MtC)	Annual change in carbon stock during 1994–2004 (MtC) – forest land remaining forest land	Carbon stock change in land converted to forest land in 2004 (MtC)	Annual change in carbon stock in land converted to forest land during the period 1994–2004 (MtC)
Above-ground biomass	1,784	1,983	199	19.9	118	11.8
Below-ground biomass	563	626	63	6.3	37	3.7
Dead wood	19	24	5	0.5	1	0.1
Litter	104	114	10	1.0	7	0.7
Soil	3,601	3,542	–59	–5.9	211	21.1
Total	**6,071**	**6,289**	**217**	**21.8**	**375**	**37.5**

land during 1994 was estimated to be 6071 MtC. The carbon stock in forest land remaining forest during 2004 was estimated to be 6288 MtC. The carbon stock in land converted to forest was estimated to be 375 MtC during 2004. Thus, the total carbon stock in 2004, including forest land remaining forest land and land converted to forest, is estimated to be 6663 MtC. The carbon stock estimates of 1994 and 2004 are used for deriving net CO_2 emissions/ removal for the year 2000.

Non-CO_2 gases emissions from biomass burning in forest land

Non-CO_2 GHG emissions are estimated for the forest land subjected to burning. Activity data for the area of the forest burnt and the fraction/quantity of the biomass burnt per hectare was obtained from field studies conducted by the FSI and is given in Table 2.12.

Method for estimating non-CO_2 gases

The IPCC GPG method is adopted for estimating the GHG emissions from forest fire. The following equation from IPCC GPG is used for estimating the non CO_2 gases emissions.

Estimation of GHGs directly released in fires

$$Lfire = A \times B \times C \times D \times 10^{-6}$$

Lfire = quantity of GHG released due to fire, tonnes of GHG

A= area burnt, ha

B= mass of "available" fuel, kg d.m./ ha

C= combustion efficiency (or fraction of the biomass combusted), dimensionless

D= emission factor, g/(kg d.m.)

Cropland

Area under cropland, which is the net sown area, was estimated to be 141 Mha during 2000/01. However, cropland includes both the net sown area during 2000 as well as the fallow land area given in Table 2.9. The total area under cropland for year 2000 was estimated to be

Table 2.12: Area subjected to forest fire in 2000 and quantity of biomass burnt

Category	Average area burnt in ha	Biomass burnt kg/ha
Mild fire	1,393,432	2660
Moderate	1,154,268	7270
Heavy	372,251	29,450

The non-CO_2 GHG emissions from biomass burning in forest land are given in Table 2.13 for CH_4, NOx, N_2O, and CO.

176.074 Mha. Methods for estimating the area under cropland, using remote sensing, is explained earlier. Cropland includes all annual and perennial crops as well as temporary fallow land (that is, land set at rest for one or several years before being cultivated again). Annual crops may include cereals, oilseeds, vegetables, root crops, and forages. Perennial crops can include trees and shrubs, in combination with herbaceous crops (for example, agro-forestry), or orchards, vineyards, and plantations. CO_2 emissions and removals are estimated only for the perennial tree biomass in croplands.

Method for estimating the perennial tree biomass: The FSI has made an assessment of trees outside the forests. Trees outside the forests include tree cover comprising small patches of trees (<1.0 ha) in plantations and woodlots, scattered trees and farms, homesteads and urban areas as well as trees along linear features such as road, canals, and cropland bunds. The estimates refer to the year 2001.

Table 2.13: Non-CO_2 greenhouse gas emissions from forest biomass burning

Category	Area burnt (ha)	Biomass burnt in t/ha	Mass of available fuel (kg d.m./ha)	Emission factor for each GHG (g /kg d.m.)	Emissions from fires (Gg)
CH_4 (GWP = 21)					
Mild fire	1,393,432	2.66	2,660	9	33.36
Moderate fire	1,154,268	7.27	7,270	9	75.52
Heavy fire	372,251	29.45	29,450	9	98.67
Average	2,919,951	13.12	13,126.66	9	344.96
Total	2,919,951	tonnes of CH_4			552.51
N_2O (GWP = 310)					
Mild fire	1,393,432	2.66	2660	0.11	0.41
Moderate fire	1,154,268	7.27	7270	0.11	0.92
Heavy fire	372,251	29.45	29,450	0.11	1.21
Average	2,919,951	13.12	13,126.66	0.11	4.22
Total	2,919,951	tonnes of N_2O			6.75

Area under cropland: The area under crops varies from year to year, depending on the monsoon rainfall. In India, conversion of forest land to cropland is banned. Thus, only degraded grassland or long-term fallow land is converted to crops. The remaining area is left fallow. In India, cropland includes area sown or cultivated during the year as well as the area left fallow during the year. Thus, the total area under the cropland was estimated to be 176.07 Mha for the year 2000/01.

Biomass carbon stock: Carbon stock change from cropland remaining cropland is estimated by taking the tree biomass carbon stock at two periods, namely, years 2001 and 2003 (Table 2.14), for which data is available on the growing stock or AGB stock. The FSI has provided the growing stock of trees outside the forest (non-forest land, which includes the cropland). The annual rate of change estimated for the period 2001–03 is used for the year 2000, since there is only a marginal change in the biomass carbon stock. Carbon stock change in land converted to cropland is also estimated using the same FSI data source. The total biomass stock change is estimated by using a root:shoot ratio as well as the biomass expansion factor, and the value is given in Table 2.14. The overall annual change in the total biomass carbon stock is estimated to be 0.044 tC/ha/year, or 9.71 Mt of biomass carbon/year for all non-forest land categories.

SOC stock: SOC stock difference is estimated based on the annual change in the SOC obtained from different studies at state level for India. The SOC stock change data is compiled for all non-forest land categories, but largely for cropland category for which literature values are available. It can be observed that of the 20 states, for which data is compiled, 11 states seem to experience annual reduction in the carbon stocks in croplands and 9 states are estimated to experience an increase in the carbon stock. Thus, an overall rate of change of SOC is estimated to be 0.043 tC/ ha/year (Table 2.15).

Table 2.14: Estimates of biomass in trees outside the forest, including cropland, grassland, and settlements

Physiographic zones	Growing stock (million m^3)	
	2001	**2003**
Western Himalayas	115.214	194.23
Eastern Himalayas	70.485	67.47
North East	48.311	99.39
Northern Plains	103.727	113.803
Eastern Plains	81.088	91.437
Western Plains	100.158	82.215
Central Highlands	140.637	106.806
North Deccan	87.299	71.157
East Deccan	177.342	175.255
South Deccan	179.675	147.608
Western Ghats	97.588	109.273
Eastern Ghats	114.54	89.839
West Coast	169.823	158.329
East Coast	146.451	109.439
Total in Mm^3	**1,632.338**	**1,616.244**
Total AGB biomass stock in tonnes	914.109	905.096
Annual rate of change AGB	4.50 Mt biomass/year	
Annual rate of change in total biomass incorporating BGB (0.27) and Biomass expansion factor (3.4)	19.43 Mt of biomass/year 9.71 Mt of biomass carbon/year	
Rate of change in biomass carbon in tC/ha/year	0.044 tC/ha/year	

AGB – above-ground biomass; BGB – below-ground biomass

Source: FSI (2003 and 2005)

Table 2.15: Rate of change in soil carbon compiled at state level for non-forest land categories (cropland, grassland)

State	Rate of change in SOC (tC/ha/year)
Jharkhand	-0.50
Rajasthan	-0.44
Haryana	-0.33
Tamil Nadu	-0.32
Karnataka	-0.13
Madhya Pradesh	-0.07
Uttar Pradesh	-0.03
Himachal Pradesh	0.03
Punjab	0.10
Bihar	0.11
West Bengal	0.34
Andhra Pradesh	0.44
Gujarat	0.53
Uttarakhand	0.55
Kerala	1.16
Orissa	1.49
Assam	-0.77
Madhya Pradesh	-0.66
Uttar Pradesh	-0.88
West Bengal	-0.48
Average SOC	0.043

SOC – soil organic carbon

Source: Compiled from a large number of studies by IISc Bengaluru

Biomass and soil carbon rates of change and stocks: The total biomass and soil carbon stock change in cropland remaining cropland and land converted to cropland was estimated to be 15,327.31 Gg during 2000 (Table 2.16).

Grassland

The area under grassland was estimated to be 38.77 Mha for the year 2000/01(Table 2.9). During the period 1994–2004, the area under grassland declined by 1.77 Mha. In India, grassland includes a large number of categories, other than forest lands and croplands. Grasslands are largely used for livestock grazing. Area under grassland has declined, which indicates that there is no conversion of other land categories to grassland.

Method for estimating CO_2 emissions and removals: Tier-II approach is used for estimating CO_2 emissions and removals from grasslands. The approach for estimating the area is described in the earlier section. Biomass stock change in the grasslands category is estimated using the method and source of data described for croplands. The data for biomass stock and stock change is mainly sourced from the study on "Trees Outside Forests", conducted by the FSI for non-forest land categories, including grassland. SOC stock change for grasslands is estimated using the method and source of data described for croplands.

Biomass and soil carbon stock change in grassland: The total biomass and soil carbon stock change in grassland was estimated to be 3460.773 Gg for 2000 (Table 2.17).

Wetland (flooded land)

The area under waterbodies is estimated to be about 7 Mha, and it varies from year to year, depending on rainfall and stream flow. It is not clear as to what percent of this total area of 7 Mha under waterbodies is submerged under water for different periods or seasons. Data on the number of days land submerged under water is not available for the flooded area. This land is incorporated under the category "other land". Thus, no GHG emission estimates are made for wetlands.

Settlements

The area under settlement during 2000 was estimated to be 1.71 Mha. The area under settlement increased from 1.38 Mha to 1.93 Mha during the period 1994–2004, that is, by 0.55. The average annual growth in area under settlements is estimated to be about 5500 ha. The biomass stock change is estimated using the method and data described for croplands. The data for biomass

Table 2.16: Biomass and soil carbon stock change in cropland during 2000

Land category	Area ('000 ha)	Rate of change in biomass stock (perennial) in tC/ha/year	Total biomass carbon stock change in Gg	Rate of change in SOC in tC/ha/year	Total SOC stock change in Gg	Total change in biomass and soil carbon in cropland (Gg)
Cropland remaining cropland	176,074	0.044	7,747.25	0.043	7,571.18	15,318.44
Land converted to cropland	102	0.044	4.48	0.043	4.38	8.87
Total	**176,176**		**7,751.73**		**7,575.56**	**15,327.31**

SOC – soil organic carbon

Table 2.17: Biomass and soil carbon stock change in grassland						
Land category	**Area ('000 ha)**	**Rate of change in biomass stock (perennial) in tC/ha/year**	**Total biomass carbon stock change in Gg**	**Rate of change in SOC in tC/ha/year**	**Total SOC stock change in Gg**	**Total change in biomass and soil carbon in cropland (Gg)**
Grassland Remaining	38,779	0.044	1,750.276	0.043	1,710.497	3,460.773

Table 2.18: Biomass carbon stock change in settlement during 2000			
Land category	**Area ('000 ha)**	**Rate of change in biomass stock (perennial) in tC/ha/year**	**Total biomass carbon stock change in Gg**
Settlement remaining settlement	1.662	0.044	73.13
Land converted to settlement	0.055	0.044	2.42
Total	1.717	0.044	75.55

Table 2.19: Greenhouse gas emissions from the land use, land-use change and forestry sector for India (Gg)					
Land category	**Sub-category**	**Annual CO_2 emissions/ removals**	**CH_4**	**N_2O**	**Total**
Forest land	Forest land remaining forest land	–79,918.80	11,600.00	2,090.00	–66,228.80
	Land converted to forest land	–137,475.00			–137,475.00
Cropland	Cropland remaining cropland	–15,318.44			-15,318.44
	Land converted to cropland	–8.87			–8.87
Grassland	Grassland remaining grassland	–3,460.77			–3,460.77
Settlement	Settlement remaining settlement	–73.13			–73.13
	Land converted to settlement	–2.42			–2.42
Total		**–236,257.43**	**11,600.00**	**2,090.00**	**–222,567.43**
CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide					

stock change is mainly sourced from the study on "Trees Outside Forests", conducted by the FSI for non-forest land categories, including settlements. The biomass carbon stock change in settlements was estimated to be 75.55 Gg during 2000 (Table 2.18).

Other land

Other land includes snow cover area, rocky surface, waterbodies, etc. The area under other land for year 2000 was estimated to be 44.59 Mha. It declined from 45.99 Mha in 1994 to 43.45 Mha in 2004, at an annual rate of 254,600 ha (Table 2.9). No GHG emissions and removal estimates are made for other land. Further, there is no conversion of forest land or cropland or grassland to other land.

Greenhouse gas emissions and removals from land use, land-use change and forestry

GHG emissions are estimated using the IPCC GPG approach for the five land categories (excluding wetlands). Tier-II and Tier-III methods are largely adopted for the GHG inventory estimation. Emissions and removal estimates for each land category are described in the respective land category sections. The total national CO_2 and non-CO_2 gas emissions and removal estimates for all the land categories are presented in Table 2.19. It can be observed from the table that the forest land dominates CO_2 removal. The LULUCF sector was a net sink of 222,567.43 Gg CO_2 eq., or 222 Mt CO_2 eq. for India during 2000.

Waste

The waste sector includes the GHG emission estimates from the following categories:

- 4a: Solid waste disposal
- 4b: Waste water handling

Methodology, activity data, and emission factors

IPCC 2006 Guidelines provide a Tier-III approach for the estimate of CH_4 emission from domestic and industrial waste water for an individual country. In India, emissions from domestic waste water handling are estimated for both urban and rural centres. Domestic waste water has been categorized into urban high, urban low, and rural, since the characteristics of the municipal waste water vary from place to place and depend on factors such as economic status, food habits of the community, water supply status, and climatic conditions of the area. Majority of the rural centres do not have proper sewage system and hence quantification of the waste water generated, collected, and treated becomes difficult. Also, in many rural areas, open defecation is common, and sewage from domestic water use reaches nearby surface waterbodies.

Domestic methane emissions

Emissions were estimated by Tier-II method by incorporating country-specific emission factors and country-specific data. Emissions have been arrived at using reliable and accepted secondary data generated by various government and private agencies working in the respective areas in the country. The annual CH_4 emissions from domestic waste water are estimated using Equation (1).

$$Td = \left[\sum_{i,j} (Ui \bullet Tij \bullet EFi) \right] (TOW - S) - R \qquad (1)$$

where,

Td = total domestic methane emission

Ui = fraction of population in income group i in the inventory year

Tij = degree of utilization of treatment/discharge pathway or system, j, for each income group fraction, i in inventory year

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

EFi = emission factor, kg CH_4 /kg biological oxygen demand (BOD)

TOW = total organics in wastewater in the inventory year, kg BOD/year

S = organic component removed as sludge in the inventory year, kg BOD/year

R = amount of CH_4 recovered in the inventory year, kg CH_4/year.

Estimation of emission factor

The emission factor is a function of the maximum CH_4 producing potential (B0) and the methane correction factor (MCF) for the waste water treatment and discharge system, as shown in Equation (2). Table 2.20 presents the emission factors derived for the estimates for the waste treatment pathway.

$$EFj = Bo \times MCFj \qquad (2)$$

Where,

B0 = maximum CH_4 producing potential, CH_4/kg BOD (default value 0.6)

MCF = methane correction factor (IPCC 2006)

Table 2.20: Emission factor for domestic waste water

Treatment pathway	B_0	MCF	Emission factor
Domestic		0.5	0.3
Septic system		0.1	0.0
Latrine	0.6	0.5	0.3
Sewer		0.1	0.06
Other		00	00
None			

MCF – methane correction factor

Estimation for total organically degradable waste

Total organic degradable waste in domestic waste water is represented in Equation (3).

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365 \qquad (3)$$

Where,

P = population in inventory year, (person)

BOD = per capita BOD in inventory year, g/person/day

I = correction factor for additional industrial BOD discharged into sewers (for collected the default value is 1.25, for uncollected the default is 1.00)

The urban high-income and urban low-income fractions were determined by expert judgement when statistical or other comparable information was not available.

In the case of industrial waste waters, data on quantity of industrial waste waters treated along with the treatment in the sewage treatment plant is not available. Hence, CH_4 emissions are estimated using IPCC 2006 Guidelines. The estimates are the function of industrial production, as most of the industries depend on carbon in one form or the other. In India, Tier-II approach is used for the estimation of CH_4 emission from industrial waste water. The general equation to estimate CH_4 emissions from industrial waste water is presented as Equation (4).

$$Ti = \sum_i (TOWi - Si)EFi - Ri \quad (4)$$

where

Ti = CH_4 emission in inventory year, kg CH_4/year

I = industrial sector

TOWi = total organically degradable material in waste water for industry i in the inventory year, kg chemical oxygen demand (COD)/year

Si = organic component removed as sludge in the inventory year, kg COD/year (default Value 0. 35)

EFi = emission factor for industry I, kg CH_4 kg/COD for treatment/discharge pathway or system used in the inventory year

Ri = amount of CH_4 recovered in the inventory year, kg CH_4/year

Estimation for total organically degradable waste

The equation for total organically degradable material in domestic waste water is

$$TOW = P \bullet W \bullet COD \quad (5)$$

where,

P = total industrial production for industrial sector I, t/year

W = waste water generated, m^3/t product

COD = chemical oxygen demand, kg COD/m^3.

Estimation of emission factor

There are significant differences in the CH_4 emitting potential of different types of industrial waste water. To the extent possible, data should be collected to determine the maximum CH_4 producing capacity (Bo) in each industry. As mentioned before, the MCF indicates the extent to which the CH_4 producing potential (Bo) is realized in each type of treatment method. Thus, it is an indication of the degree to which the system is anaerobic, as shown in Equation (6).

$$EFj = Bo \times MCFj \quad (6)$$

where

B0 = maximum methane producing potential, CH_4/kg BOD (default value 0.6)

MCFj = methane correction factor (IPCC 2006).

Industrial CH_4 emissions were estimated following IPCC 2006 Guidelines. Data on industrial waste water is complex due to different processes and products involved in generating different quantity and quality of wastes. The data was obtained through extensive literature search and industrial visits. Default values are utilized and marked with reference for unreliable data sets. The guidelines are intended for countries that require to inventorize emissions through a systematic procedure. Assessment of CH_4 production potential from industrial waste water stream is based on the selection of industrial sectors that have degradable organic matter (DOC) in their waste water, examples being integrated pulp and paper unit, fertilizer, sugar and distillery, tannery, and dairy industries. Industrial production data was obtained from national statistics, regulatory agencies, and industry associations. Emission factors for industrial waste water are given in Table 2.21.

Table 2.21: Emission factor for industrial waste water

Industry	Emission factor
Pulp and paper	0.2
Sugar	0.2
Tannery	0.05
Fertilizers	0.05
Dairy	0.2

Estimation of nitrous oxide

N_2O emission can occur from waste water after the disposal of effluent into waterways, lakes or sea. No higher tiers are given to estimate N_2O from waste water effluent. The simplified general equation to estimate N_2O from waste water is

$$N_2O_{Emissions} = N_{Effluents} \times EF_{Effluents} \times 44/28 \quad (7)$$

where,

$N_2O_{emissions}$ = N_2O emissions in inventory year, kg N_2O/year

$N_{Effluent}$ = nitrogen in the effluent discharged to aquatic environments, kg N/year

$EF_{Effluent}$ = Emission factor for N_2O emissions from discharged waste water, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

Estimation of total nitrogen in the waste water effluent

Waste water from industrial or commercial sources, which is discharged into the sewer, may contain proteins (for example, from grocery stores and butchers). The default value for this fraction is 1.25. The total nitrogen in the effluent is estimated as follows:

$$Neffluents = (P \times Pr \times FNPR \times F_{NON\text{-}CON} \times F_{IND\text{-}COM}) - N_{SLUDGE} \quad (8)$$

where

P = human population

Pr = annual per capita protein consumption, kg/person/year

FNPR = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON\text{-}CON}$ = factor for non-consumed protein added to the waste water

$FI_{ND\text{-}COM}$ = factor for industrial and commercial co-discharged protein into the sewer system

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/year

Estimation of methane emission from landfill site

Basic equations used in estimation

First order decay (FOD) model was used in estimation. In a first order reaction, the amount of product is always proportional to the amount of reactive material. Thus, the total mass or the decomposing material currently in the site contributes to CH_4 production. FOD model is built on an ex-potential factor that describes the reaction of degradable material which is degraded into CH_4 and CO_2, each year. Key input in the model is the amount of DOC in waste disposed of in the solid waste disposal facility. The spreadsheet keeps a running total of the amount of decomposable DOC in the disposal site, taking account of the amount deposited each year and the amount remaining from previous years.

Studies conducted by National Environmental Engineering Research Institute (NEERI) revealed that there is a wide variation in per capita waste generation. Lower values in many cities were observed due to inadequate collection system, poor collection efficiency, scattered storage points, and poor road condition. The average value (0.55 kg/capita/day) of these quantities has been taken into consideration in estimation. The value is well close to the average regional value for South Central Asia. The average composition data of the waste has been used in the estimation of DOC. The basis for the calculation is the amount of decomposable DOC (DDOCm).

$$DDOCm = W \times DOC \times DOCf \times MCF \quad \text{...............(9)}$$

DDOCm = amount of decomposable degradable organic carbon deposited, Gg

W = mass of waste deposited, Gg

DOC = degradable organic carbon in the year of deposition (fraction)

DOCf = fraction of DOC that can decompose

MCF = methane correction factor (fraction)

Overview of greenhouse gas emissions from the waste sector

The total GHG released from the waste sector in 2000 was 52,552.29 Gg CO_2 eq., of which 2307.19 Gg was emitted as CH_4 and 13.23 Gg was emitted as N_2O (Table 2.22). Figure 2.15 shows the absolute values of GHG emission from the waste sector and also the emission distribution across its sub-categories.

Solid waste disposal (4A1)

Solid waste management practices lead to the release of CH_4. CH_4 is produced and released into the atmosphere

Table 2.22: Greenhouse gas emissions from the waste sector in 2000 (expressed in Gg)

Category	CO_2	CH_4	N_2O	CO_2 eq.
4. Waste		**2,307.19**	**13.23**	**52,552.29**
A. Solid waste disposal on land		**488.19**		**10,251.99**
1. Managed waste disposal on land		488.19		10,251.99
B. Waste water handling		**1,819.00**	**13.23**	**42,3331.30**
1. Industrial waste water		1,103.00		23,163.00
2. Domestic and commercial waste water		716.00	13.23	19,137.30

CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide

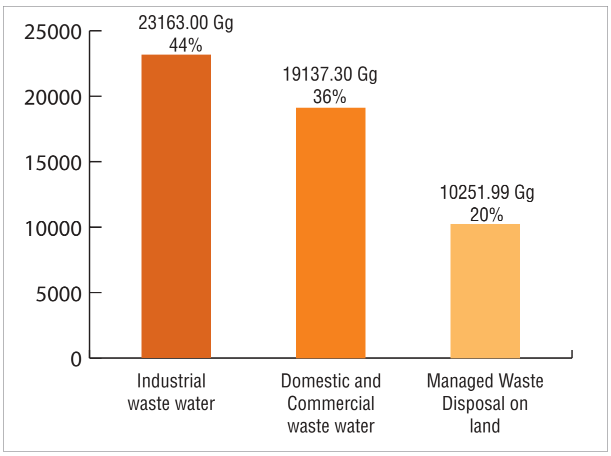


Figure 2.15: Distribution of greenhouse gas emissions across the waste sector categories (in Gg of CO_2 eq.)

as a by-product of the anaerobic decomposition of solid waste, whereby methanogenic bacteria break down organic matter in the waste. Similarly, waste water becomes a source of CH_4 when treated or disposed of anaerobically. It can also be a source of N_2O emissions due to the protein content in the domestically generated waste water. Systematic disposal of waste is not carried out in most of the Indian cities. The landfill sites are not properly constructed, and operation and maintenance of the landfill are poor. FOD method assumes that carbon in waste decays to produce CH_4 and CO_2. This means that emission of CH_4 from waste deposited in a disposal site is higher in the first few years after deposition and then gradually declines as the degradable carbon is used up. It is assumed that in 50 years, CH_4 emission comes down to insignificant level. Hence, it is necessary to estimate or collect 50-year data on waste disposal. In India, though waste disposal data for the past 50 years is not available, urban population data is readily available. It is quite reasonable to assume that the waste quantity is proportional to urban population for estimation, in the absence of data, by year.

Extensive studies on quantity and composition of municipal solid waste are available (NEERI, 2005), which serve as the basis for the estimation of CH_4 at the national level. There is a wide variation in per capita waste generation. Lower values in many cities are observed due to inadequate collection system, poor collection efficiency, scattered storage points, and poor road condition. The average value (0.55 kg/capital/day) of these quantities has been taken into consideration for estimation. For the estimates, an average of six-month delay period is assumed before the decay reaction starts. On an average, 70% of the waste generated reaches the landfill site in India, as observed in the past study. This value has been used in the estimation. Waste generation rate is assessed from sampling studies to be 0.55 kg/capita/day. DOC is estimated to be 0.11 based on the composition of waste. MCF for unmanaged, shallow disposal site is taken to be 0.4. Oxidation factor for unmanaged and uncategorized solid waste disposal is assumed to be 0. Fraction of CH_4 in generated landfill gas (F) is taken to be 0.5, and no CH_4 recovery is assumed. Fraction of DOC that decomposes is taken to be 0.5. Decay rate constant is taken as 0.17/ year.

Based on these assumptions, and using the first order decay method as given in the IPCC 2006 Guidelines for this sector, the total GHG emissions from this sector is estimated to be 10,251.99 Gg CO_2 eq.

Waste water

CH_4 is emitted from waste water when it is treated or disposed anaerobically. Waste water originates from a variety of domestic, commercial, and industrial sources, and may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed of untreated in nearby areas or via an outfall.

Domestic waste water

Emissions from domestic waste water handling are estimated for both urban and rural centres. Domestic waste water has been categorized into urban high, urban low, and rural, since the characteristics of the municipal waste water vary from place to place and depend on factors such as economic status, food habits of the community, water supply status, and climatic conditions of the area. In India, it is estimated that about 22,900 million litres per day (MLD) of domestic waste water is generated from urban centres (Class I and II cities) against 13,500 MLD of industrial waste water generated. The rural water generated is not handled in any way; therefore, as it decomposes in an aerobic condition, it is not a source of CH_4. Waste water treatment and discharge pathways for the waste water generated in the urban areas is substantial, and about 49.2% of the waste water generated from the urban centres is not collected, and further, treatment is done for only 72% of what is collected. Anaerobic route as a treatment is used in about a quarter of the waste water treated. It yields about 0.6 kg of CH_4 per kg biological oxygen demand (BOD) (NSSO, 2002) treated theoretically. The use of advanced technologies in waste water treatment in India is still at infancy stage as waste water treatment is provided only in Class I and II cities. Sewage contributes to 60% of the total pollution load in terms of BOD, which is beneficial if recovered through the anaerobic route.

CH_4 emission estimates have been made using Tier-II approach of the IPCC by incorporating country-specific emission factors and country-specific data. Domestic waste water disposal and treatment resulted in the emission of 19,137.30 Gg of CO_2 eq., of which 716.0 Gg was emitted as CH_4 and 13.23 Gg was emitted as N_2O.

Industrial waste water

CH_4 emission from waste water has been estimated based on the waste water produced in industries, using the IPCC 2006 Guidelines. Emission factors are based on CH_4 emission per tonne of product used and are taken from industry sources. Steel, fertilizer, beer, meat production, sugar, coffee, soft drinks, pulp and paper, petroleum refineries, rubber, and tannery industries accounting for more than 95% of CH_4 from this category have been included for estimating CH_4 from industrial waste water. Box 2.7 gives an account of the waste water generated from these industries in 2000. However the waste water generation from integrated iron and steel plants have been regulated at $16m^3$ per tonne of product and the Ministry is striving to achieve these norms and beyond it. In some industries, CH_4 is recovered, and in the present calculations, CH_4 recovered for energy purposes in sugar, beer, and dairy industries has been subtracted from the total CH_4 estimated to be emitted from these industries (recovery rate was 70%, 75%, and 75%, respectively, for sugar, beer, and dairy industries). The total amount of CH_4 emitted from waste water in industries in 2000 was 1103 Gg, or 23,163.0 Gg CO_2 eq.

Box 2.7: Waste water generation in different industries in India

Industry	Waste water generation, m^3/tonne of product	
	Range	Average
Iron and steel	–	60
Fertilizers	3.5–10.2	8
Beer	–	9
Dairy	–	3
Meat	–	11.7
Sugar	0.2–1.8	1.0
Coffee	–	5
Soft drink	–	3.7
Pulp and paper	–	230
Petroleum	–	0.7
Textile	65–104	84.5
Rubber	–	26.3
Leather	30–40	2

Key Source Analysis - 2000

Key source analysis leads to the identification of sources with significant impact on total emissions or trend, accounting for up to 95% of the total emissions. The key source analysis is carried out to prioritize higher tier methodologies for key sectors, to design additional requirements of QA/QC for key sources, and to allocate and make best use of available resources for sources with significant impact on total emission estimate, which would lead to a reduction in the uncertainties in the estimates to the maximum extent possible. In order to identify the key sources, both Tier-I level and trend analysis has been carried out as per the IPCC Good Practice Guidance (IPCC, 2000). The analysis is without LULUCF and includes only the CO_2, CH_4 and N_2O emissions, as together they constitute 99.23% of the total CO_2 eq. emissions from India.

Level analysis (Table 2.23a) identifies 25 source categories amongst a total of 64 as key source categories, the GHG emissions from which cumulatively add up to nearly 95% of the total CO_2 eq. emissions in 2000. Fifteen of the 25 key categories identified are from the energy sector, and of these, 80% of the categories are CO_2 emitting sources.

Table 2.23a: Key source analysis for the year 2000 – level assessment

Sl no.	IPCC source category	Sector	Emission (Gg)	Gas	% of total emissions	Cumulative emissions (% of total)
1	Electricity production	Energy	5,22,495.43	CO_2	34.29%	34.29%
2	Enteric fermentation	Agriculture	2,11,429.43	CH_4	13.88%	48.16%
3	Road transport	Energy	85,515.82	CO_2	5.61%	53.78%
4	Rice cultivation	Agriculture	74,360.58	CH_4	4.888%	58.66%
5	Non-specific industries	Energy	58,717.17	CO_2	3.85%	62.51%
6	Agricultural soils	Agriculture	57,810.47	N_2O	3.79%	66.30%
7	Residential	Energy	55,182.00	CO_2	3.62%	69.93%
8	Iron and steel	Energy	52,366.02	CO_2	3.44%	73.36%
9	Cement production	IPPU	44,056.00	CO_2	2.89%	76.25%
10	Cement	Energy	39,696.00	CO_2	2.61%	78.86%
11	Chemicals	Energy	34,482.44	CO_2	2.26%	81.12%
12	Residential	Energy	33,894.00	CH_4	2.22%	83.35%
13	Agricultural/fisheries	Energy	28,347.00	CO_2	1.86%	85.21%
14	Food and beverages	Energy	24,577.85	CO_2	1.61%	86.82%
15	Industrial waste water	Waste	23,163.00	CH_4	1.52%	88.34%

16	Refinery	Energy	18,695.90	CO_2	1.23%	89.57%
17	Domestic and commercial waste water	Waste	15,036.00	CH_4	0.99%	90.55%
18	Natural gas	Energy	14,668.29	CH_4	0.96%	91.52%
19	Ammonia production	IPPU	11,067.30	CO_2	0.73%	92.24%
20	Solid waste disposal on land	Waste	10,251.99	CH_4	0.67%	92.91%
21	Textile/leather	Energy	7,669.09	CO_2	0.50%	93.42%
22	Open cast mining	Energy	7,273.37	CH_4	0.48%	93.90%
23	Limestone/Dolomite use	IPPU	5,961.68	CO_2	0.39%	94.29%
24	Metal production	IPPU	5,655.00	CF_4	0.37%	94.66%
25	Railways	Energy	5,426.32	CO_2	0.36%	95.01%

Table 2.23b: Key source analysis for the year 2000 – trend assessment

A			B	C	D	E	F	G
	IPCC source categories	Sector	Direct greenhouse gas	Base year estimate CO_2 eq. (Gg) (1994)	Current year estimate CO_2 eq. (Gg) (2000)	Trend assessment	Contribution to trend (%)	Cumulative total of column F (in %)
1	Electricity production	Energy	CO_2	357,268.70	522,495.43	0.054708167	27.50%	27.50%
2	Enteric fermentation	Agriculture	CH_4	194,079.25	211,429.43	0.031113131	15.64%	43.14%
3	Road transport	Energy	CO_2	83,190.11	85,515.82	0.017630588	8.86%	52.01%
4	Rice cultivation	Agriculture	CH_4	69,533.23	74,360.58	0.012313731	6.19%	58.20%
5	Non-specific industries	Energy	CO_2	40,714.49	58,717.17	0.005540071	2.79%	60.98%
6	Agricultural soils	Agriculture	N_2O	51,206.02	57,810.47	0.006506116	3.27%	64.25%
7	Residential	Energy	CO_2	43,794	55,182.00	0.000742261	0.37%	64.62%
8	Iron and steel	Energy	CO_2	27,064.98	52,366.02	0.01488518	7.48%	72.11%
9	Cement production	IPPU	CO_2	29,108	44,056.00	0.005706056	2.87%	74.98%
10	Cement	Energy	CO_2	31,203.32	39,696.00	0.000210692	0.11%	75.08%
11	Chemicals	Energy	CO_2	30,957.43	34,482.44	0.004326417	2.17%	77.26%
12	Residential	Energy	CH_4	28,288.35	33,894.00	0.001950004	0.98%	78.24%
13	Agricultural/fisheries	Energy	CO_2	24,912.19	28,347.00	0.002979034	1.50%	79.73%
14	Food and beverages	Energy	CO_2	2,142.57	24,577.85	0.01834471	9.22%	88.96%
15	Industrial waste water		CH_4	24,773.67	23,163.00	0.007185409	3.61%	92.57%

Table 2.24: Tier-I uncertainty analysis – CO_2

IPCC source category	Sector	Gas	Base Year emissions 1994 (Gg CO_2eq)	Year 2000 emissions (Gg CO_2eq)	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty as % of total national emissions in year	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
Electricity production	Energy	CO_2	357,268.7047	522495.4275	10	5	11.18033989	3.783469216	0.31165259	5.961071526	5.969212769
Road transport	Energy	CO_2	83,190.10986	85515.81	5	0	5	0.276929437	0	0.487818489	0.487818489
Nonspecific industries	Energy	CO_2	40,714.48724	58717.17021	20	5	20.61552813	0.783993183	0.032273527	1.339790678	1.340179332
Cement production	Industrial Process	CO_2	29,108.33704	45602.04	40	10	41.23105626	1.217759247	0.07537153	2.081067186	2.082431631
Residential	Energy	CO_2	43,794	55182	25	5	25.49509757	0.91118554	0.002551399	1.573907788	1.573909856
Iron & steeel	Energy	CO_2	27,064.98	52366.02138	20	5	20.61552813	0.699192478	0.075227968	1.19487208	1.197237877
Cement production	Energy	CO_2	29,108	44056	20	5	20.61552813	0.588236857	0.031452758	1.005256518	1.00574845
Cement	Energy	CO_2	31,203.32	39696	20	5	20.61552813	0.530022024	0.003345237	0.905771354	0.905777531
Agricultural/fisheries	Energy	CO_2	24,912.18811	28347	25	5	25.49509757	0.468076121	-0.010821295	0.808516619	0.808589032
Food & beverages	Energy	CO_2	2,142.567318	24577.84567	20	5	20.61552813	0.328164034	0.0883718	0.560809869	0.567729939

Only 15 categories have been identified as key source categories as per the trend analysis of 2000 with respect to 1994 (see Table 2.23b), which are also in common with the first 15 key source categories identified through level analysis.

Uncertainty Analysis – 2000

Uncertainties are generally associated with the activity data, emission factors being measured or extracted from the literature, and assumptions based on expert judgement. In this assessment, the Tier-I approach has been used as given in IPCC Good Practice Guidance 2000. This methodology uses estimation of uncertainties by source category, using the error propagation equation, and simple combination of uncertainties by source category to estimate overall uncertainty for one year and the uncertainty in the trend. The uncertainty analysis has only been carried out for the common key sources identified by level and trend analysis. The percentage of uncertainties associated with the activity data has been discussed with the researchers who do the estimation, and is based on their expert judgement. The emission factor uncertainties are related to the standard deviation of the measured emission factors, and if taken from the literature, then the uncertainties mentioned in the said literature are considered. Tables 2.24, 2.25, and 2.26 give uncertainty in CO_2, CH_4, and N_2O, respectively, emitted from key sources.

It might be pointed out here that a lot of work requires to be done for a more advanced level of uncertainty analysis, as direct linkages need to be established by the GHG inventory management with the activity data generators, who can provide the statistical analysis of the uncertainties associated with their own data sets. More data generated for the uncertainty analysis will enable India to use Tier-II approach as well as the approach that employs the Monte Carlo method.

Summary of Greenhouse Gas Emissions in 2007

Although India is required to report its GHG inventory for 2000 during the process of SNC, as a proactive measure towards its responsibilities to the challenges imposed by climate change, the country estimated its GHG inventory for the year 2007. This section summarizes the results from the estimation study carried out for 2007. The energy sector emitted 1,374,097.88 Gg of CO_2 eq., of which 1,271,723.14 Gg was emitted as CO_2, 4,059.51 Gg as CH_4, and 55.24 Gg was emitted as N_2O. The industrial process sector emitted 142,206.26 Gg of CO_2 eq. Total CO_2 emission from this sector was 106,303.43 Gg, CH_4 emission was 10.65 Gg, and N_2O emission was 17.13 Gg. The agriculture sector emitted 372,653.07 Gg of CO_2 eq., of which 14,310.68 Gg of CH_4 and 232.67 Gg of N_2O were emitted. The waste sector emitted 57,726.81 Gg of CO_2 eq., of which 2,515.51Gg of CH_4 and 15.81 Gg of

Table 2.25: Tier-I uncertainty analysis – CH_4

IPCC source category	Sector	Gas	Base Year emissions 1995 (Gg CO_2eq)	Year 2000 emissions (Gg CO_2eq)	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty as % of total national emissions in year	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
Enteric Fermentation	Agriculture	CH_4	195,692.05	211,429.43	5	50	50.24938	6.880957	-1.60509	1.238245	2.3
Rice Cultivation	Agriculture	CH_4	69,551.49	74,360.56	0.2	8	8.0025	0.385408	-0.09656	0.348396	0.36
Residential	Energy	CH_4	29,547.00	33,894.00	10	150	150.333	3.30012	-0.48325	0.397003	0.63
Industrial Wastewater	Waste	CH_4	24,570.00	23,163.00	10.00	125.00	125.3994	1.881234	-0.85469	0.27131	0.9

Table 2.26: Tier-I uncertainty analysis – N_2O

IPCC source category	Sector	Gas	Base Year emissions 1995 (Gg CO_2eq)	Year 2000 emissions (Gg CO_2eq)	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Combined uncertainty as % of total national emissions in year	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
Agricultural Soils (Direct+ Indirect)	Agriculture	N_2O	52,390.45	57,810.47	25	100	103.0776	3.859435	-0.76054	1.692846	1.86

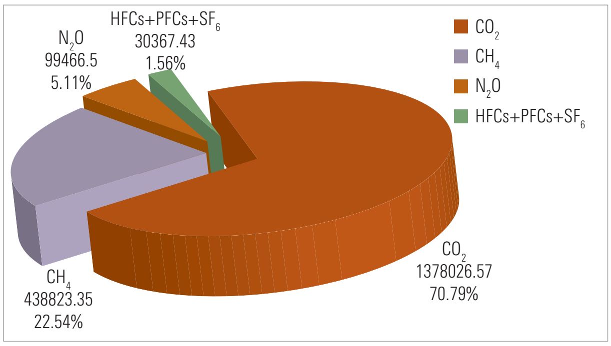


Figure 2.16: Greenhouse gas distribution in 2007

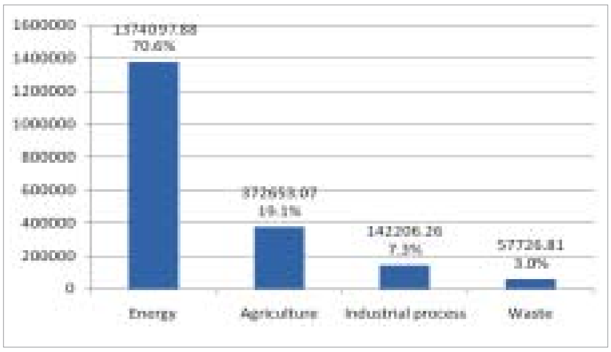


Figure 2.17: Distribution of greenhouse gas emissions, by sector, in 2007

N_2O were emitted. The distribution of emissions across sectors is given in Figure 2.17 & across gases is given in Figure 2.16.

Table 2.27 gives the emission of GHGs for energy, IPPU, agriculture, LULUCF, and waste sectors at a gross level.

Trends in Greenhouse Gas Emissions

Trends of emissions by gas

The CO_2 eq. emissions without LULUCF increased from 1,190,256.6 Gg in 1994 to 1,946,684.02 Gg in 2007. The CAGR between 1994 and 2000 was 4.2%, which decreased to 3.8% between 2000 and 2007. CO_2 emissions increased from 755,356.6 Gg in 1994 to 1,024,772.84 Gg in 2000. The CAGR of CO_2 for this period was 5.2%. In 2007, CO_2 emissions increased to 1,378,026.57 Gg and the CAGR between 2000 and 2007 was 4.3%. CH_4 emissions between 1994 and 2000 increased from 379,596 Gg to 407,238.29. CAGR in this sector, between 1994 and 2000, was only 1.2%. In 2007, CH_4 emissions increased to 438,823 Gg, rising at a CAGR of 1.1% between 2000 and 2007. The N_2O emissions increased from 55,318 Gg to 79,799.45 Gg CO_2 eq between 1994 & 2000. The CAGR was 6.3%. In 2007, N_2O emissions rose to 99,467.00 Gg. The CAGR was found to be 3.2%. The HFCs, PFCs, and SF_6 have only been estimated for the periods 2000 and 2007. The total synthetic gas emissions have risen from 11,965 Gg to 30,367 Gg between these two periods, and the CAGR has been of the order of 14.2%. Figure 2.18 gives the trends of emissions for the years 1994, 2000, and 2007.

The distribution of emissions, by gas, over the three years indicates that CO_2 is the dominant gas emitted (Figure 2.19). Its share increased from 64% in 1994 to 67.3% in 2000 and 71% in 2007. The share of CH_4, however, reduced over these years. In 1994, its share was 31%, and it decreased to 26% in 2000 and in 2007 its share further reduced to 22%. The share of N_2O has remained nearly the same over the years, at 5%. However, the use and production of halocarbons and the percentage share of emissions of HFCs, PFCs, and SF_6 have increased from 1% to 2% between 2000 and 2007. In 1994, the emission estimates of these gases were not carried out.

Trends of greenhouse gas emissions, by sector

The energy sector emissions increased from 743,810.00 Gg in 1994 to 1,027,016.48 Gg in 2000. The CAGR between the two periods was 5.5%. In 2007, the energy

Table 2.27: Greenhouse gas emissions, in 2007, by sources and their removal by sinks (expressed in Gg)

Sector	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC-134a	HFC-23	CF_4	C_2F_6	SF_6	CO_2 equivalent
1. Energy	1,271,723.14		4,059.51	55.24						1,374,097.88
2. Industrial processes	106,303.43		10.65	17.13	1.67	1.24	1.47	0.15	0.12	142,206.26
3. Agriculture			14,310.68	232.67						372,653.07
4. Waste			2,515.51	15.81						57,726.81
Total without LULUCF	**1,378,026.57**	**0.00**	**20,896.35**	**320.86**	**1.67**	**1.24**	**1.47**	**0.15**	**0.12**	**1,946,684.02**
Total with LULUCF	**1,476,356.57**	**275,358.00**	**20,896.35**	**320.86**	**1.67**	**1.24**	**1.47**	**0.15**	**0.12**	**1,771,662.02**
Memo item										
International bunkers	3,454.00		0.03	0.096						3,484.45
Aviation	3,326.00		0.02	0.093						3,355.31
Marine	128.00		0.01	0.00						129.14
CO_2 from Biomass	566,788.00									566,788.00

CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride

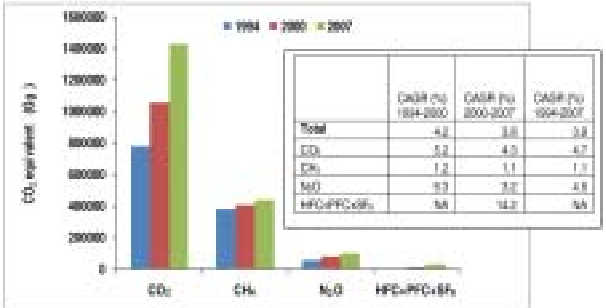
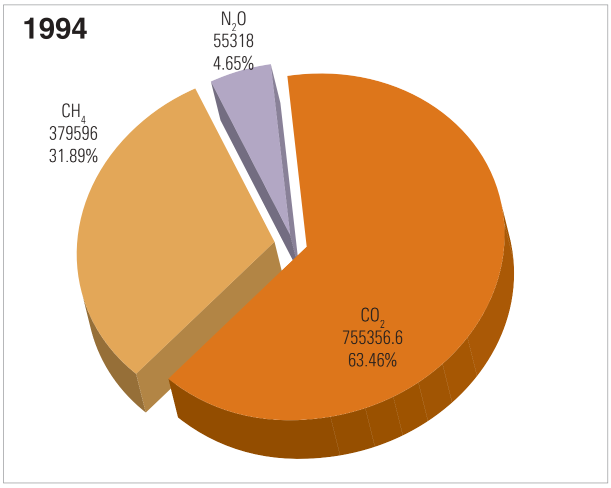
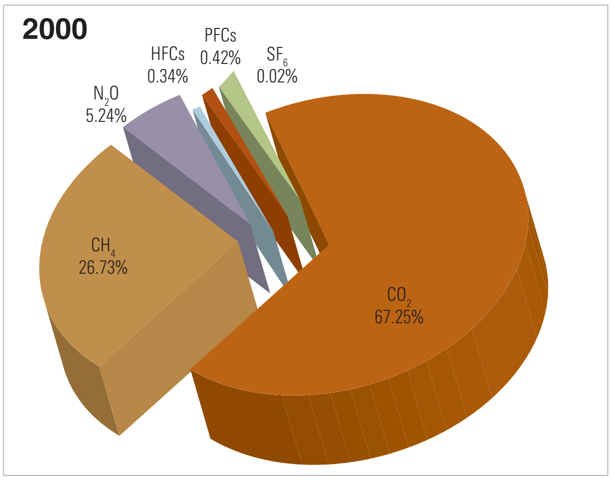


Figure 2.18: Trends of greenhouse gas emissions for 1994, 2000, and 2007





sector emissions grew to 1,374,097.88 Gg, with the CAGR between the two periods reducing to 4.2%. The net CAGR in CO_2 eq. emissions from energy sector between 1994 and 2007 was 4.8%.

The industrial process emissions increased from 78,718.60 Gg in 1994 to 88,608.07 Gg in 2000. The CAGR between the two periods is 2.0%. The emissions from this sector increased to 142,206.26 Gg in 2007, and the CAGR between 2000 and 2007 rose to 7.0%. However, the net CAGR in CO_2 eq. emissions from industrial process sector between 1994 and 2007 was only 4.7%.

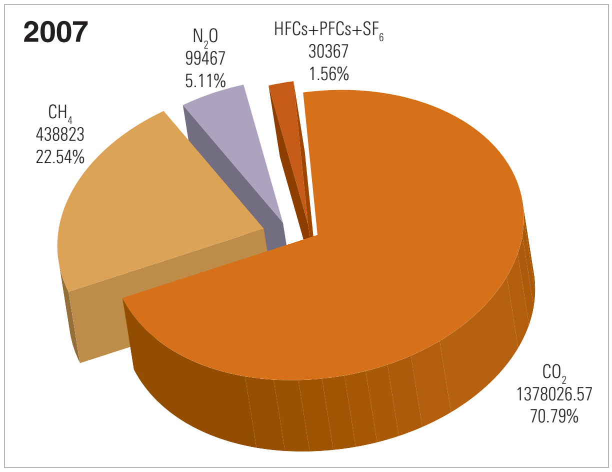


Figure 2.19: Trends of greenhouse gas emissions for 1994, 2000, and 2007

The CO_2 eq. emissions from the agriculture sector increased from 344,485 Gg to 355,600 Gg CO_2 eq. between 1994 and 2000. The annual CAGR was only 0.5%. In 2007, the emissions only rose to 57,727 Gg CO_2 eq. The annual growth rate between 2000 and 2007 was only 0.7%. The overall growth rate between 1994 and 2007 was only 0.6% from the agriculture sector. The agriculture sector emissions are dominated by the emissions from enteric fermentation from livestock, which contributes about 60% of the total emissions from the agriculture sector. It has been noticed that over a period of time, emissions have been going down, especially because the cattle population has decreased from 204.58 million in 1992 to about 190 million in 2000. Also, there has been a decrease in the population of horses, ponies, camels, and donkeys during the same period. This might be one of the reasons of lower growth rate of emissions in the agriculture sector, as the emission from other dominant emitting source – rice cultivation – has remained the same.

The GHG emission from waste has increased from 23,233 Gg CO_2 eq. in 1994 to 57,727 Gg CO_2 eq. in 2007. The CAGR between the two periods stands at 7.3%. The high rate of growth can be attributed to higher generation of municipal solid waste as urbanization is spreading across India along with increasing consumption rates. Figure 2.20 shows the absolute level of emissions for 1994, 2000, and 2007 along with the CAGRs.

The relative contribution of each sector, namely, energy, industrial processes, agriculture, and waste, towards total GHG emissions for 1994, 2000, and 2007 indicates that the energy sector remains the highest contributor to total

	CAGR (%) 1994-2000	CAGR (%) 2000-2007	CAGR (%) 1994-2007
Total	4.2	3.6	3.8
Energy	5.5	4.2	4.8
Industrial Process	2.0	7.0	4.7
Agriculture	0.5	0.7	0.6
Waste	14.6	1.4	7.3

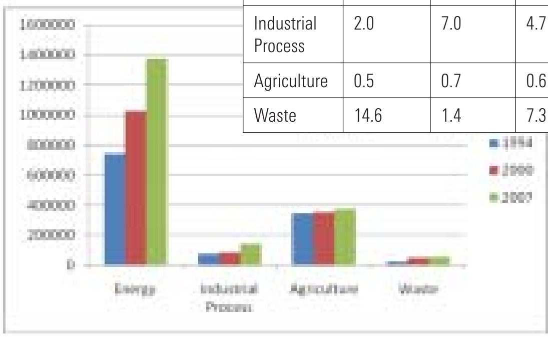


Figure 2.20: Trends of greenhouse gas emissions, by sector

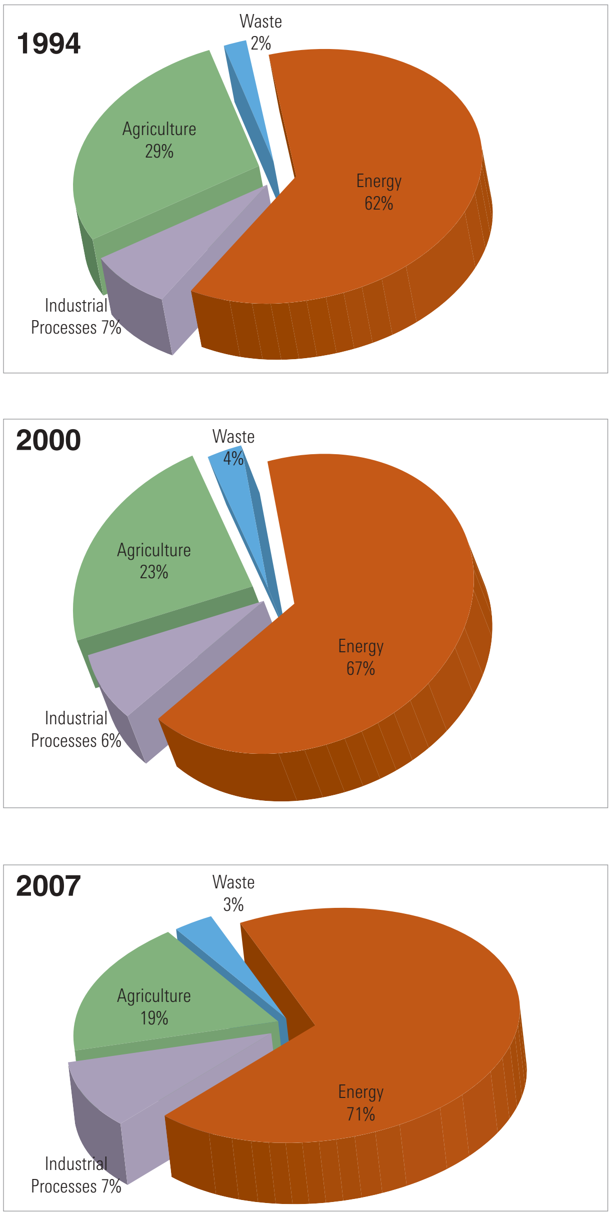


Figure 2.21: Distribution of greenhouse gas emissions, by sector

GHG emission in each year. The contribution from the energy sector increased from 62% to 67% from 1994 and 2000, further increasing to 71% in 2007. Contribution from the industrial processes remained nearly constant at 7 % from 1994 to 2007. The waste sector has also increased its contribution. The contribution by the agriculture sector has decreased significantly from 29% to 19% within the span of 13 years (Figure 2.21).

Improvements Made in the Greenhouse Gas Inventory between the Initial National Communication and the Second National Communication

The INC reported the GHG emissions using the 1996 IPCC Guidelines and the IPCC Good Practice Guidance 2000. During the SNC, both 1996 Guidelines along with the Good Practice Guidance of 2000 and 2003 have been used. The SNC especially has prepared inventory of GHG emissions by sources and removal by sinks from the LULUCF sector using the IPCC 2003 Good Practice Guidance guidelines. Also the GHG emissions from the waste sector have been assessed using the first order decay method.

New gases have been included in this reporting, namely, HFC-132a, HFC-23, CF_4, C_2F_6, and SF_6. These have been estimated from aluminium production, magnesium production, and production and use of halocarbons. Also, the default emission factors used in the 2000 and 2007 assessment have been taken from the 2006 Guidelines, especially for the energy and industrial process sectors, for gases and categories for which India-specific emission factors either do not exist or could not be used because of their limitations in sample size.

For the first time, key source analysis has been done using both trend and level approaches. Similarly, uncertainty analysis has been carried out using, to the extent possible for the 2000, GHG inventory. The improvements made between the GHG emission estimates made in 1994 and in the SNC are summarized in Table 2.28.

In 1994, only 7% of the emissions had been made using the Tier-III approach, and in 2000 and 2007 assessments, Tier-III approach has been extended to 12% of the emissions. Emission factors were a mix of default factors taken from IPCC and country-specific emission factors. Also, 26% of the source categories used CS factors. Emission factors were also a mix of default and country-specific factors, but led to improved accuracy as more number of country-specific emission factors have been used in this assessment (35% of the source categories used country-specific factors). Additional new country-specific emission coefficients have been determined, such as that for CO_2 emission from ammonia production, and some of the emission coefficients such as CO_2 emission coefficient from coal mining, CH_4 emission from rice cultivation, and CH_4 emission from enteric fermentation have been upgraded by undertaking more measurements.

Table 2.28: Key methodological features in inventory preparation for years 1994, 2000, and 2007

1994 GHG inventory	2000 and 2007 GHG inventory
Estimates made using only revised 1996 IPCC Guidelines.	Estimates made using revised IPCC 1996 Guidelines (1996), IPCC Good Practice Guidance (2000), the LULUCF Good Practice Guidance (2003), IPCC 2006 Guidelines
LULUCF included emissions from changes in forest land only	Carbon pools in addition to forests have been considered in the LULUCF sector (cropland, grassland, settlements, flooded land and other land).
Emission factors were a mix of default factors taken from IPCC and CS emission factors; 26% of the source categories used CS factors.	Emission factors were also a mix of default and CS but leading to improved accuracy as more number of CS emission factors been used in this assessment (35% of the source categories used CS factors).
CO_2 emission coefficient of coal CO_2 emission from one steel plant CO_2 emission from two power plants N_2O emission from nitric acid production CH_4 emission coefficient from enteric fermentation CH_4 emission coefficient from rice cultivation CH_4 emission factor from MSW in two cities	CO_2 emission coefficient from ammonia CO_2 emission coefficient of coal CO_2 emission extended to two more steel plants CO_2 emission extended to one more power plant N_2O emission from nitric acid production CH_4 emission coefficient from enteric fermentation CH_4 emission coefficient from rice cultivation CH_4 emission factor from MSW in new cities
CO_2 , CH_4, and N_2O emission coefficients of fossil fuel other than coal taken from IPCC 1996 Guidelines	CO_2 , CH_4, and N_2O emission coefficients of fossil fuel other than coal updated from IPCC 2006 Guidelines
-	Key source analysis by level and trend approach carried out as per the methodology indicated in IPCC 2000 Good Practice Guidance
	Uncertainty analysis using Tier-I approach presented as per the methodology in the IPCC 2000 Good Practice Guidance
CO_2, CH_4, and N_2O reported	CO_2, CH_4 , N_2O , HFC-132a, HFC-23, CF_4, C_2F_6, SF_6 reported
In 1994, 7% of the total CO_2 eq. emissions were made using Tier-III approach	For 2000 and 2007, 12% of the emissions are assessed using Tier-III approach, implying greater accuracy

GHG – greenhouse gas; IPCC – Intergovernmental Panel on Climate Change; LULUCF – land use, land-use change and forestry; CS – country specific; MSW – municipal solid waste; CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride

Annexure I. Detailed greenhouse gas emissions from India, in 2000, by sources and removal by sinks										
	CO_2 emission	CO_2 removal	CH_4	N_2O	HFC-134a	HFC-23	CF_4	C_2F_6	SF_6	CO_2 equivalent
Total (Gg)	**1,024,772.84**	**236,257.43**	**19,944.68**	**264.16**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**1,301,209.39**
1. Energy (Gg)	**952,212.06**		**2,991.42**	**38.66**						**1,027,015.54**
A. Fuel combustion activities	952,212.06		1,639.25	38.66						998,619.97
1. Energy industries	541,191.33		6.96	7.78						543,749.85
a. Electricity production	522,495.43		5.99	7.75						525,023.42
b. Refinery	18,695.90		0.97	0.03						18,726.43
c. Manufacturing of solid fuel	Not estimated		NE	NE						NE
2. Manufacturing industries and construction	228,246.91		4.29	2.40						229,079.90
a. Cement	39,696.00									39,696.00
b. Iron and steel	52,366.02		0.64	0.85						52,641.44
c. Non-ferrous metals	1,885.88		0.03	0.03						1,894.52
d. Chemicals	34,482.44		1.10	0.34						34,612.32
e. Pulp and paper	5,331.75		0.06	0.08						5,358.71
f. Food and beverages	24,577.85		0.99	0.20						24,660.34
g. Non-metallic minerals	1,010.93		0.04	0.01						1,014.23
h. Mining and quarrying	2,509.79		0.10	0.02						2,518.16
i. Textile/leather	7,669.09		0.21	0.08						7,699.48
j. Non-specific industries	58,717.17		1.11	0.79						58,984.70
3. Transport	95,976.83		9.50	6.22						98,104.12
a. Road transport	85,515.82		9.08	4.00						86,946.62
b. Civil aviation	4,021.98		0.04	0.12						4,058.69
c. Railways	5,426.32		0.31	2.06						6,071.83
d. Navigation	1,012.71		0.07	0.04						1,026.98
4. Other sectors	86,797.00		1,618.50	22.26						127,686.10
a. Commercials/ institutional	3,268.00		0.50	0.03						3,287.80
b. Residential	55,182.00		1,614.00	22.00						95,896.00
c. Agricultural/ fisheries	28,347.00		4.00	0.23						28,502.30
B. Fugitive emission from fuels			1,352.17							28,395.58
1. Solid fuels			585.65							12,298.74
a. Above-ground mining			239.30							5,025.37
b. Underground mining			346.35							7,273.37

2. Oil and natural gas			766.52							16,096.83
a. Oil			49.25							1,034.16
b. Natural gas			698.49							14,668.34
c. Venting and flaring			18.78							394.33
2. Industrial process	**72,560.78**		**5.39**	**12.80**	**0.220**	**0.420**	**0.870**	**0.087**	**0.013**	**88,608.07**
A. Minerals	53,558.17									53,558.17
1. Cement production	44,056.00									44,056.00
2. Lime production	2,921.00									2,921.00
3. Limestone and dolomite use	5,961.68									5,961.68
4. Soda ash production and use	463.94									463.94
5. Glass	155.54									155.54
B. Chemicals	15,785.98		5.34	12.80						19,866.66
1. Ammonia production	11,067.30									11,067.30
2. Nitric acid production	0.00			11.75						3,643.83
3. Carbide production	102.72									102.72
4. Titanium dioxide production	43.75									43.75
5. Methanol production	229.84		0.79							246.41
6. Ethylene production	3,317.23		4.42							3,410.15
7. EDC and VCM production	233.23									233.23
8. Ethylene oxide production	51.29		0.11							53.53
9. Acrylonitrile production	26.98		0.0049							27.08
10.Carbon black production	713.64		0.02							713.98
11. Caprolactam				1.05						324.69
C. Metal production	2,522.5		0.05				0.870	0.087	0.01	9,229.62
1. Iron and steel production										
2. Ferro-alloys production	1,467.55		0.05							1,468.65
3. Aluminium production	1,025.31						0.87	0.09		7,480.38
4. Lead production	23.22									23.22
5. Zinc production	6.42									6.42
6. Magnesium production									0.01	250.95
D. Other production					0.220	0.420			0.0025	5,259.10
1. Production of halocarbons					0.220	0.42				5,199.35

2. Consumption of SF_6									0.0025	59.75
E. Non-energy product use	694.14									694.14
1. Lubricant	672.91									672.91
2. Paraffin wax	21.23									21.23
3. Agriculture			**14,088.30**	**192.73**						**355,600.19**
A. Enteric fermentation			10,068.07	0.00						211,429.43
B. Manure management			241.19	0.07						5,087.75
C. Rice cultivation			3,540.98	0.00						74,360.58
D. Agricultural soils				186.49						57,810.47
E. Field burning of agricultural residues			238.06	6.17						6,911.96
4. Land use, land-use change and forestry		**236,257.43**	**552.38**	**6.74**						**(222,567.43)**
A. Forest land		217,393.8	552.38	6.74						(203,704.42)
B. Cropland		15,327.31								(15,327.31)
C. Grassland		3,460.77								(3,460.77)
D. Settlement		75.55								(75.55)
E. Wetland										0.00
F. Other land										0.00
G. Fuelwood use										0.00
5. Waste			**2,307.19**	**13.23**						**52,552.29**
A. Solid waste disposal on land			488.19							10,251.99
1. Managed waste disposal on land			488.19							10,251.99
B. Waste water handling			1,819.00	13.23						42,300.30
1. Industrial waste water			1,103.00							23,163.00
2. Domestic and commercial waste water			716.00	13.23						19,137.30
Memo item										
International bunkers	3,467.12		0.05	0.10						3,498.86
Aviation	3,194.12		0.02	0.089						3,222.13
Marine	273.00		0.03	0.010						276.73
CO_2 from biomass	376,005.00									376,005.00

CO_2 – carbon dioxide; CH_4 – methane; N_2O – nitrous oxide; HFC – hydrofluorocarbon; CF_4 – tetrafluoromethane; C_2F_6 – hexafluoroethane; SF_6 – sulphur hexafluoride; EDC – ethylene dichloride; VCM – vinyl chloride monomer

References and Sources

Attri, S.D. and Tyagi, Ajit, 2010. Climate Profile of India, Met Monograph No. Environment Meterology-01/2010, 1-22

ADB (Asian Development Bank), 1998. *Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) India*. ADB, Manila

Andreae M. O. and Merlet P., 2001. *Emission of trace gases and aerosols from biomass burning*, Global Biogeochemical Cycles, 15, 955–966

Bandyopadhyay S.K., Pathak H., Kalra N., Aggarwal P.K., Kaur R., Joshi H.C., Choudhary R. and Roetter R.P. 2001. Yield estimation and agro-technical description of production systems. In Aggarwal P.K., Roetter R.P., Kalra N., Van Keulen H., Hoanh C.T., and Van Laar, H.H. (eds.) Land use analysis and planning for sustainable food security: with an illustration for the state of Haryana, India. New Delhi: Indian Agricultural Research Institute; Los Banos: International Rice Research Institute; Wagningen: Wagningen University and Research Center. pp. 61-89

Champion, H. G. and Seth, S. K. 1968. *A Revised Survey of the Forest Types of India*. Ministry of Environment and Forest, Government of India

Choudhary, A., Roy, J., Biswas, S., Chakraborty, C. C. and Sen, K., 2004. *Determination of carbon dioxide emission factors from coal combustion*. In Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.). Universities Press, Hyderabad

ESI (Economic Survey of India), 2008. *Economic Survey 2007–08*. Ministry of Finance, Government of India

Gadde B., Christoph M.C., and Wassmann R. 2009. Rice straw as a renewable energy source in India, Thailand, and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation, Biomass Bioenergy 33: 1532-1546

Gupta, P. K., Das S. N., Adya T. K., Pathak H., Ramesh R., Purkait N., Barua K. K., Venkataratnam L., Singh G., Iyer C. S. P., Gupta V., Sharma C., Sharma P., Pradhan V., Singh N., Koul S., Singh K., Johri P., Garg S. C. and Mitra A. P., 2004. *Reducing uncertainties in methane emissions from rice cultivation, 2004*. In Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.). Universities Press, Hyderabad

IPCC (Intergovernmental Panel on Climate Change), 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Task Force on National Greenhouse Gas Inventories, IPCC

IPCC (Intergovernmental Panel on Climate Change), 1996. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change, Paris

IPCC (Intergovernmental Panel on Climate Change), 1996. *Good Practice Guidance and Uncertainty Management in National Green House Gas Inventories*

IPCC (Intergovernmental Panel on Climate Change), 2009. *Emission Factor Database (EFDB)*. Available at http://www.ipcc-nggip.iges.or.jp/EFDB/main.php, last accessed on 11 February 2010

IPCC (Intergovernmental Panel on Climate Change), 2003. *Good Practice Guidance for Land Use, Land Use Change and Forestry*. Institute for Global Environmental Strategies (IGES)

Jha A. K., Sharma C., Singh N., Ramesh R., Purvaja R. and Gupta P. K., 2007. *Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: A case study of Chennai landfill sites*. Chemosphere 71 (2008), 750–758

Manjunath, K.R, Kundan Kumari, S. Panigrahy, J.S. Parihar, T.K.Adhya, V Beri, B.S.Sidhu, G S Saroa and K. V. Rao, Methane Emission Inventory from Indian Rice Ecosystem using Remote Sensing, GIS and Field observations, Scientific Report: SAC/AFEG/AMD/EIAA/SN/03/08.

Manjunath, K.R, Panigrahy, S., Adhya, T.K., Beri V., Rao, K.V. and Parihar, J.S. (2009). Rice-ecosystems of India in the context of methane emission,pp. 269-275. 'The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences' Vol. XXXVIII Part 8/W3 (eds. Sushma Panigrahy, Shibendu Shankar Ray and Jai Singh Parihar). ISPRS WG VIII/6 'Agriculture, Ecosystem and Biodiversity', GEO Task AG 07 03 'Global Agricultural Monitoring System of Systems' and ISRS Joint International Workshop on 'Impact of Climate Change on Agriculture' held during Dec 17-18, 2009 at SAC, Ahmedabad.

MoP (Ministry of Power), 2002. *Annual Report*, MoP, Government of India, New Delhi

MoS (Ministry of Iron and Steel), 2009/10. *Annual Report*, MoS, Government of India, New Delhi

NATCOM (National Communication), 2004. *India's Initial National Communication to the United Nations Framework Convention on Climate Change*. Ministry of Environment and Forests, Government of India, New Delhi

Panigrahy S., Murthy T V R, Singh, T S., and Patel J G, 2011, National Wetland Atlas, SAC/EPSA/ABHG/NWIA/ATLAS/34/2010, Space Applications Centre (ISRO), Ahmedabad, India, 306p. Also available in MoEF Website.

PAT, 2011. *PAT Consultation Document, 2010–11*. Bureau of Energy Efficiency, Ministry of Power, Government of India, New Delhi

Pathak, H., Bhatia, A., Prasad S., Jain, M. C., Kumar, S., Singh, S. and Kumar, U., 2002. *Emission of nitrous oxide from soil in rice-wheat systems of Indo-Gangetic plains of India*. Journal of Environmental Monitoring and Assessment 77 (2), 163–178

Planning Commission, 2002. *Tenth Five Year Plan: 2002–2007*. Planning Commission, Government of India, New Delhi

Quershi, M. S., Rao, P.V. and Devotta, S., 2003. *Uncertainty reduction in nitrous oxide emission coefficient from nitric acid production in India*. In: Proceedings of the Workshop on uncertainty Reduction in Greenhouse Gas Inventories, 4–5 March 2003, New Delhi

Rao, P. V., Qureshi, M. S. and Devotta, S., 2004. *GHG emission measurements in industrial processes*. In Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.). Universities Press, Hyderabad

Sharma, S., Bhattacharya, S., Garg, A. and Mitra, A. P., 2004. *Future perspectives in refinement and uncertainty reduction in GHG inventory estimates*. In: Climate change and India: Uncertainty reduction in greenhouse gas inventory estimates, Universities Press (Ed.)

Sharma, S., Bhattacharya, S. and Garg, A., 2006. *Greenhouse gas emissions from India*: A perspective. Current Science, 90 (3)

Singh, A. K. 2004, *Methane emission from coal mining and handling activities in India*. In Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.). Universities Press, Hyderabad

Shukla, P.R., Sharma, S., Garg, A. and Bhattacharya, S., 2004. *Inventory estimation and emerging issues*. In: Climate change and India: Uncertainty reduction in greenhouse gas inventory estimates, Universities Press (Ed.)

Streets D.G., Yarber K.F., Woo J.H., and Carmichael G.R. 2003 An inventory of gaseous and primary aerosol emissions in Asia in the year 2000. J. Geophys. Res. 108: 8809-8816

Sudha, P., Murthy, I. K., Sukanya, T. S. and Ravindranath N. H., 2003. *Uncertainty reduction, quality assurance and quality control procedure for GHG inventory in the LUCF sector.* In: Proceedings of the Workshop on Uncertainty Reduction in Greenhouse Gas Inventories, 4–5 March 2003, New Delhi

Swamy, M., Singhal, K. K., Gupta, P., Mohini, M., Jha, A. K. and Singh, N., 2006. *Reduction in uncertainties from livestock emissions*. In Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.). Universities Press, Hyderabad

Data References for Greenhouse Gas Inventory Estimation

Energy and Transformation

AAI (Airports Authority of India), 2001. *Review of Traffic at AAI Airports* 2000–01. AAI, Operational Offices, New Delhi

ASS (Annual Statistical Statements), 1996, 1998, 2000, 2002, 2004, 2006, 2008. *Indian Railways Annual Statistical Statements*. Railway Board, Ministry of Railways, Government of India, New Delhi

CEA (Central Electricity Authority), 1997/98–2007. *Public Electricity Supply, All India Statistics, General Review*. CEA, Ministry of Power, Government of India, New Delhi

CEA (Central Electricity Authority), 1994–2008. *Review of Performance of Thermal Power Stations*. CEA, Ministry of Power, Government of India, New Delhi

Chakraborty, N., Mukherjeea, I., Santra, A. K., Chowdhury, S., Chakraborty, S., Bhattacharya, S., Mitra, A. P. and Sharma, C., 2008. *Measurement of CO_2, CO, SO_2, and NO emissions from coal-based thermal power plants in India*. Atmospheric Environment, 42, 1073–1082

Chaudhuri, S., 2005. *Coal Resource Availability and Production Projections in India*. The Coal Summit 2005, Editors: Seam, M. M. and Gautam, N. N. Ushnak and Arvind, New Delhi, pp. 91–111

Choudhary, S., Chakraborty, S., Bhattacharya, S., Garg, A., Mitra, A.P., Mukherjee, I. and Chakraborty, N., 2003. *An estimation of greenhouse gas emission from thermal power plants in India during 2002–03*. In: Proceedings of the workshop on Uncertainty Reduction in Greenhouse Gas Inventories, 4–5 March 2003, New Delhi

CMIE (Centre for Monitoring Indian Economy), 1995, 2000, 2001, 2007, 2008. *Energy.* Economic Intelligence Service, CMIE, Mumbai, India

CRRI (Central Road Research Institute), 2002. *Urban Road Traffic and Air Pollution in Major Cities*. Report submitted to Expert Committee on Auto Fuel Policy. CRRI, New Delhi, India

CRRI (Central Road Research Institute), 1998. *Evaluation of Emission Characteristics and Compliance of Emission Standards for In-use Petrol-driven Vehicles and Critical Appraisal of the Efficacy of Existing Pollution Checking System in Delhi.* CRRI, New Delhi

DGCA (Directorate General of Civil Aviation), 1997, 1999, 2001, 2002, 2004, 2006, 2007. *India Air Transport Statistics*. DGCA, New Delhi

DGMS (Directorate General of Mines Safety), 1990–2007. *Statistics of Mines in India Vol. I (Coal).* DGMS, Ministry of Coal and Mines, Government of India, India

DGMS (Directorate General of Mines Safety), 1967. *The Coal Mines Regulations.* DGMS, Ministry of Coal and Mines. Government of India, Dhanbad

Garg, A., Bhattacharya, S., Shukla, P. R., Dadhwal, V. K., 2001. *Regional and sectoral assessment of greenhouse gas emissions in India.* Atmospheric Environment, 35, 2679–2695

GSI (Geological Survey of India), 2009. *Inventory of Coal Resources of India.* Coal wing, GSI, Kolkata, India

Kapoor, M., 2002. *Report on 'Vision 2020 Transport,* Prepared for Planning Commission, New Delhi. Task Force on Integrated Transport Policy, Planning Commission, Government of India, New Delhi, India

Mittal, M.L. and Sharma, C., 2003. *Anthropogenic emissions from energy activities in India: Generation and source characterization. Part I: emissions from thermal power generation in India.* Available at http://www.osc.edu/research/pcrm/emissions/India.pdf

MoC (Ministry of Coal and Mines), 1993. *Coal Atlas of India:* 2003. Central Mine Planning and Design Institute, MoC, Government of India, Ranchi

MoC (Ministry of Coal and Mines), 1994/95–2007/08. *Coal Directory of India*. Coal Controller's Organisation, MoC, Government of India

MoC (Ministry of Coal and Mines), 1999/2000. *Coal Statistics.* Coal Controller's Organisation, MoC, Government of India

MoPNG (Ministry of Petroleum and Natural Gas), 1994/95, 2000/01, 2002/03, 2003/04, 2006/07, 2007/08. *Indian Petroleum and Natural Gas Statistics.* MoPNG, Government of India, New Delhi

MoPNG (Ministry of Petroleum and Natural Gas), 1996–2008. *Indian Petroleum and Natural Gas Statistics.* Economics and Statistics Division, MoPNG, Government of India, New Delhi, India

MoSRTH (Ministry of Road Transport and Highways), 2000, 2002, 2007. *Motor Transport Statistics of India.* Transport Research Wing, MoSRTH, Government of India, New Delhi, India

NSSO (National Sample Survey Organisation), 1993–94. *50th Round, Energy used by Indian Household Survey (Report no. 410/2).* NSSO, Ministry of Statistics and Programme Implementation, Government of India

NSSO (National Sample Survey Organisation), 1999–2000. *55th Round, Energy used by Indian Household Survey (Report no. 464).* NSSO, Ministry of Statistics and Programme Implementation, Government of India

NSSO (National Sample Survey Organisation), 2004–05. *55th Round, Energy Sources of Indian Households for Cooking and Lighting in India Survey (Report no 511).* NSSO, Ministry of Statistics and Programme Implementation, Government of India

SIAM (Society of Indian Automobile Manufacturers), 2008. *The Indian Automobile Industry, Statistical Profile 2007–2008.* SIAM, New Delhi

Singh, A., Gangopadhyay, S., Nanda, P. K., Bhattacharya, S., Sharma, C. and Bhan, C., 2008. *Trends of greenhouse gas emissions from road transport sector in India.* Science of Total Environment, 390 (1), 124–131

Singh, A. and Sikdar, P.K., 2004. *Apportionment of direct and indirect GHG emissions for road transport sector.* Proceedings of the International Conference on Environment and Development, 4–8 February 2004, Kolkata, India

Singh, A., 1998. *GHG emissions from road transport.* In: ALGAS India Report, Asian Least-cost Greenhouse Abatement Strategy. Asian Development Bank, Philippines

TERI (The Energy and Resources Institute), 2000/01, 2001/02, 2002/03, 2004/05, 2005/06, 2006/07. *Energy Data Directory and Year Book.* TERI, New Delhi

Industrial Processes

CMA (Cement Manufacturers Association), 1995–2009. *Annual Report*. CMA, New Delhi

CMA (Cement Manufacturers Association), 1996–2008. *Basic Data – Indian Cement Industry: CMA Annual Publication.* CMA, New Delhi

CMA (Cement Manufacturers Association), 2002–2008. *Data Base on Benchmarking Exercise for Cement Plants.*

Annual Benchmarking Data for Energy Consumption Performance. CMA, New Delhi

CMA (Cement Manufacturers Association), 2004-05 and 2005-06. *Report to BEE on Cement Plant-wise Fuel and Power Consumption for the years 2004-05 and 2005-06 – Guidelines for Fixing Norm for Energy Consumption by Indian Cement Plants.* CMA, New Delhi

CMA (Cement Manufacturers Association), 2007. *Indian Cement Industry – Growth Trends and Future Perspective.* CMA Special Publication on Sustainable Development of Indian Cement Industry and Infrastructure – Challenges, Indian CMA, New Delhi

CMIE Prowess Database. Centre for Monitoring Indian Economy, Mumbai. Available at http://www.cmie.com

FAI (Fertilizer Association of India), 1998–99 to 2007–08. *Fertilizer Statistics*. FAI, New Delhi

IBM (Indian Bureau of Mines), 1999–2007. *Indian Mineral Year Book.* IBM, Ministry of Steel and Mines, Nagpur

IIP, 2006–07. Ministry of Statistics and Programme Implementation, Government of India

IISI (International Iron and Steel Institute), 2005–2008. International Iron and Steel Institute Yearbooks

MoCF (Ministry of Chemicals and Fertilizers), 2007–08. *Annual Report.* Department of Chemicals and Petrochemicals, MoCF, Government of India, New Delhi

MoCF (Ministry of Chemicals and Fertilizers), 2001 to 2007. *Performance of Chemical and Petrochemical Industry at a Glance, 2001–07.* Monitoring and Evaluation Division, Department of Chemicals and Petrochemicals, MoCF, Government of India, New Delhi

Planning Commission, 2003. *Report of the Working Group on Cement Industry – XI Five Year Plan, 2007-2012 Sub-Group-II – Productivity, Technology and Environmental Issues.* Planning Commission, Government of India, New Delhi

SAIL (Steel Authority of India Ltd), 1996, 1998, 2000, 2002, 2004, 2006. *Steel Authority of India Ltd.: Statistics for Iron & Steel Industry in India.* New Delhi

WMS (World Mineral Statistics), 1996–2008. WMS, British Geological Survey

Agriculture

Anon, 1999. *Basic Animal Husbandry Statistics, AHS Series 7.* Department of Animal Husbandry and Dairying, Ministry of Agriculture, Government of India, New Delhi

Chhabra, A., Manjunath, K.R., Panigrahy, S., and Parihar, J.S. (2009). *Spatial pattern of methane emissions from Indian livestock.* Current Science, 96(5): 683-689.

Chandramoni, 1997. *Studies on methane production in Muzaffarnagari sheep.* Ph.D. Thesis. Indian Veterinary Research Institute, Izatnagar, India

FAO (Food and Agricultural Organization), 2000. *Food and Agricultural Organization: Agricultural database.* Rome, Italy. Available at www.fao.org

Gupta, P K., Jha, A K, Koul, S., Sharma, P., Pradhan, V., Gupta, V., Sharma, C., Singh, N., 2007. *Methane and nitrous oxide emission from bovine manure management practices in India.* Environmental Pollution, 146 (1), 219–224

Haque, N. and Bhar, R., 2002. *Comparative methane production in oat and sorghum hay based diets in rams.* IVth Biennial Conference of Animal Nutrition Association of India, Kolkata, 20–22 November

Khan, M.Y., Murarilal, Biswas, J.C., Haque, N. and Girdhar, N., 1996. *Methane emission from Indian ruminants.* Proceedings of National Symposium on "Prospects of Livestock and Poultry Development in 21st Century" held at Central Avian Research Institute, Izatnagar, India

Mahadeswara, S. and Bhattacharya, S., 2006. *Budgeting anthropogenic GHG emission from Indian livestock using country-specific emission co-efficients.* Current Science, 91, (10), 1340– 1353

Mahadeswara, S. and Shashirekha, V., 2003. *Country Specific Emission Co-efficients for Estimation of Methane from Livestock Sector.* In: Proc. NATCOM Workshop on Uncertainty Reduction in GHG Inventory Estimates, March 4–5, New Delhi, pp 128 – 138

MoA (Ministry of Agriculture), 2004. *17th Livestock Census – 2004.* Commissioner and Director of Veterinary Services, MoA, Government of India, Chennai

MoA (Ministry of Agriculture), 1996–2005. *Agricultural Statistics at a glance 2006.* Directorate of Economics and Statistics, Department of Agriculture and Cooperation (DAC), MoA, Government of India

MoA (Ministry of Agriculture), 2006. *Basic Animal Husbandry Statistics, AHS Series – 10.* Department of Animal Husbandry, Dairying and Fisheries, MoA, Government of India, New Delhi

MoA (Ministry of Agriculture), 2006. *Livestock and Poultry Statistics.* Department of Animal Husbandry, Dairying and Fisheries. MoA, Government of India, New Delhi

MoA (Ministry of Agriculture), 2007. *Agricultural Statistics at a Glance:* 2007. India's Export of Agricultural Products during 2001–02 to 2006–07, MoA, Government of India

NIANP, 2007. *Livestock feed resources in different agro ecosystems of India: Availability, requirement and their management.* Bangalore, India

Ranjhan, S. K., Sen, K. C. and Ray, S. N., 1999. *Nutritive values of Indian cattle feeds and feeding of animals.* ICAR Publications, New Delhi

Singh, G.P. and Mohini, M. 1996. *Methane production by Indian ruminant livestock.* Current Science, 71 (7), 580

Singh, G.P., 1997. *Effect of greenhouse gases on climate change and Indian ruminant livestock.* Current Science, 72, 441–446

Singhal, K. K. and Mohini, M. 2002. *Report on uncertainty reduction in methane and nitrous oxide reduction from livestock in India.* National dairy Research Institute, Karnal

Land Use, Land-use Change and Forestry

Bhatia, A., Pathak, H. and Aggarwal, P.K., 2004. *Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential.* Current Science, 87, 317–324

Brown, S, 1993. *Estimating biomass and biomass change of tropical forests: A primer.* FAO Forestry Paper 134, FAO, Rome

Chhabra, A., Parila, S. and Dadhwal, V.K., 2002. *Growing stock based forest biomass:estimate of India.* Biomass and Bioenergy, 22, 187–194

FAO (Food and Agriculture Organization), 2006. *Global Forest Resource Assessment 2005,* FAO, United Nations

FSI (Forest Survey of India), 1996. *Volume Equations for Forests of India, Nepal and Bhutan.* FSI, Ministry of Environment and Forests, Dehradun

FSI (Forest Survey of India), 2010. *A manual for National Forest Inventory of India.* FSI, Ministry of Environment and Forests, New Delhi

Jha, M.N., Gupta, M.K., Saxena, A. and Kumar, R., 2003. *Soil organic carbon store in different forest of India.* Indian Forester, 129 (6), 714–724

MoEF (Ministry of Environment and Forests), 1987, 1995, 2005. *The State of Forest Report.* FSI. Ministry of Environment and Forests, Government of India, New Delhi

NBSSLUP (National Bureau of Soil Survey and Land Use Planning), 1998. *Benchmark Soils of India.* NBSSLUP, Nagpur, India

Parashar, D.C., Kulshreshtha, U.C. and Sharma, C, 1998. *Anthropogenic emissions of NO_x, NH_3 and N_2O in India. Nutrient Cycling in* Agroecosystems, 52, 255–259

Ramachandran, A., Jayakumar, S., Haroon, R. M., Bhaskaran, A. and Arockiasamy, D. I., 2007. *Carbon sequestration: Estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India.* Current Science, 92 (3): 323–331

Ravindranath, N.H., Somashekhar, B.S. and Gadgil, M, 1997. *Carbon flows in Indian forests.* Climatic Change, 35, 297–320

TIFAC (Technology Information Forecasting & Assessment Council), 1991. *Techno Market Survey on Utilization of Agricultural Residues (Farm and Processes).* TIFAC, Department of Science and Technology, New Delhi

Waste

CPCB (Central Pollution Control Board), 1999. *Status of Solid Waste Generation, Collection and Disposal in Metro Cities.* Central Urban Pollution Series: cups/46/1999/2000 in 1999-2000. CPCB, New Delhi.

Gurjar, B. R., J. A. Van, A., Lelieveld, J. and Mohan, M., 2004. *Emission estimates and trends (1990–2000) for megacity Delhi and implications.* Atmospheric Environment 38 (2004), 5663–5681

Jha A. K., Sharma C., Singh N, Ramesh R., Purvaja R. and Prabhat K. Gupta, 2008. *Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: A case study of Chennai Landfill sites.* Chemosphere, 71(4), 750–758

Kumar, S., Mondal A. N., Gaikwad, S. A., Devotta, S. and Singh R. N., 2004. *Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: A case study.* Atmospheric Environment 38, 4921–4929

Kumar, S., Gaikwad, S. A., Shekdar, A.V., Kshirsagar, P. S. and Singh, R. N., 2004. *Estimation method for national methane emission from solid waste landfills.* Atmospheric Environment 38, 3481–3487.

NEERI (National Environmental Engineering and Research Institute), 2005. *Assessment of Status of Municipal Solid Waste Management in Metro Cities, State Capitals, Class – I Cities and Class – II Towns.* NEERI, Nagpur

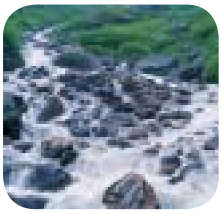
Rawat, M., Singh, U. K., Mishra, A. K. and Subramanian, V., 2008. *Methane emission and heavy metals quantification from selected landfill areas, India.* Environmental Monitoring and Assessment, 137, 67–74

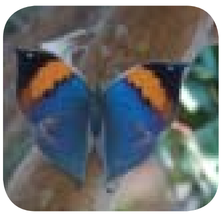
Rinne, J., Pihlatie, M., Lohila, A., Thum, T., Aurela, M., Tuovinen, J. P., Laurila, T. and Vesala, T., 2005. *Nitrous oxide emissions from a municipal landfill.* Environmental Science and Technology, 39 (20), 7790–7793

Talyan, V., Dahiya, R. P., Ananda, S. and Sreekrishnan, T. R., 2007. *Quantification of methane emission from municipal solid waste disposal in Delhi.* Resources, Conservation and Recycling, 50, 240–259

Chapter 3

Vulnerability Assessment and Adaptation






In this chapter, the vulnerability of natural ecosystems and socio-economic systems, and the impacts of climate change on them are presented. The sectors considered for the assessment of climate change impacts include water resources, agriculture, forest and natural ecosystems, coastal zones, health, energy, and infrastructure. First, the climate change projections for the Indian sub-continent are presented. Second, the impact and vulnerability of different sectors are assessed, which includes a brief introduction to the current status of the sector, impacts of climate change, and socio-economic implications of these impacts. Third, adaptation strategies are suggested. As planned for the Second National Communication (SNC), the analysis is based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A1B Scenario. This scenario has been the basis for analysis in the various sectors. In some sectors, some alternate scenarios have been considered; which are mentioned at appropriate places.

Contents

Chapter 3 Vulnerability Assessment and Adaptation

CHAPTER 3 Vulnerability Assessment and Adaptation

The assessment of climate change impacts, and vulnerability and adaptation to climate change require a wide range of physical, biological, and socio-economic models, methods, tools, and data. The methods for assessing the vulnerability, impacts, and adaptation are gradually improving and have significantly improved compared to India's Initial National Communication (INC). This improvement has facilitated a much deeper analysis of the impacts due to climate change on the various sectors. Consequently, during the process of the SNC, 36 institutions were involved in a range of scientific analysis on the aspects of identifying vulnerabilities, assessing impacts, and subsequently adopting adaptation strategies (Annexure 1 at the end of the chapter). This chapter contains details from these 36 assessments, spread across all natural and socio-economic systems of the country. Direction of research and analysis is consistent with the country's requirement of helping policy-makers formulate appropriate adaptation measures. However, due to uncertainties in regional climate projections, unpredictable response of natural and socio-economic systems and the inability to foresee the future technological developments do provide some limits to the exercise, but substantial progress has already been made to mitigate the uncertainties associated.

Climate change is not only a major global environmental problem, but is also an issue of great concern to a developing country like India. The earth's climate has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities. The changes observed in the regional climate have already affected many of the physical and biological systems, and there are indications that social and economic systems have also been affected. The recent assessment report (AR4) of the IPCC states that climate change has and would have significant impact on myriad economic sectors and ecosystems. Growing international and national studies have pointed towards the damage accrued to the environment due to anthropogenic emissions. The various manifestations being-increase in global average surface temperature, increase in global average sea level, and decrease in the Northern Hemisphere snow cover. These changes are likely to threaten food production, increase water stress and decrease its availability, result in sea-level rise, which could flood crop fields and coastal settlements, and increase the occurrence of diseases, such as malaria. Given the lack of resources and access to technology and finances, developing countries such as India have limited capacity to develop and adopt strategies to reduce their vulnerability to changes in climate.

Presently, there are observations that point towards the extent of changes taking place in the various physical systems (snow, ice, hydrology, and coastal processes) and biological systems (terrestrial, marine, and freshwater) along with the changes in the surface temperature profile of the different regions of the world; for example, ice cover has shrunk by 2.7% per decade since 1978 (affecting freshwater resources of the world), and there are also global changes in precipitation.

Assessment of the implementation of the current climate commitments has confirmed non-attainment of greenhouse gas (GHG) reduction targets, and therefore, adaptation has become inevitable. However, there are limits and barriers to adaptation as well. There is now an ever strong belief that enhancing of society's response capacity through the pursuit of sustainable development pathways is one of the most significant ways of mitigating the likely impacts due to climate change, and sustainable development paradigm emerges as a foundational tool in building our polices/programmes to mitigate the likely impacts due to climate change on various sectors. India is a large developing country with a population of over one billion, and its population is projected to grow in the coming decades. In India, a significant share of the population is rural, and its dependence on climate-sensitive natural resources is very high. The rural population also depends largely on agriculture, followed by forests and fisheries, for its livelihood. Indian agriculture is monsoon dependent, with over 60% of the crop area under rain-fed agriculture, which is highly vulnerable to climate variability and change.

An assessment of the impacts of projected climate change on natural and socio-economic systems is central to the whole issue of climate change. Climate change impact assessment involves the following:

- To identify, analyse, and evaluate the impacts of climate variability and changes on natural ecosystems, socio-economic systems, and human health.
- To assess the vulnerabilities of the affected communities and sectors, such as farmers, forest dwellers, and fishermen, and assess the potential adaptation responses.

Developing countries such as India have low adaptive capacity to withstand the adverse impacts of climate change due to the high dependence of a majority of the population on climate-sensitive sectors, coupled with poor infrastructure facilities, weak institutional mechanisms, and lack of financial resources. India is, therefore, seriously concerned with the possible impacts of climate change.

Current Observed Climate and Projected Changes in India

India is subject to a wide range of climatic conditions. These conditions range from the freezing Himalayan winters in the north to the tropical climate of the southern peninsula; from the damp, rainy climate in the North East to the arid climate in the north-western region; and from the marine climates of its coastline and islands to the dry climate in the interior of the country. However, the most significant feature in the meteorology of India is the Indian summer monsoon. This feature plays a significant role in sustaining the various economic, social, and environmental systems of the country.

Observed climate trends over India

Data sources: The monthly maximum and minimum temperature data from 121 stations distributed over the country, during the period 1901–2007, has been used. The data for the period 1901–90 is sourced from the monthly weather reports of India Meteorological Department (IMD) Pune, and the monthly data for the period 1901–2007 has been estimated from the daily data reported in the Indian Daily Weather Reports (IDWRs) of the IMD. These station normal values were objectively interpolated onto a 0.5° × 0.5° grid. Further, the global monthly air temperature 5° × 5° gridded data from the Climatic Research Unit (CRU), University of East Anglia, for the period 1961–90 have been used for evaluating the model skills in baseline simulations of the mean surface air temperature. High-resolution (1° × 1° latitude/longitude) daily gridded rainfall data available from 1803 stations distributed over India, prepared by the IMD and set for the Indian region for the period 1951–2007, has been used in this assessment. The century-long gridded rainfall data for the period 1901–2004 has also been used to examine the long-term trends over the region. This data has been collected from 1384 observation stations of the IMD. Analysis in this study for rainfall is restricted to the Indian summer monsoon season (June to September), since nearly 80% of the annual rainfall over the major parts of India occurs during this period.

Annual mean temperature trends

India's annual mean temperature showed significant warming trend of 0.56°C per 100 years during the period 1901–2007. Accelerated warming has been observed in the recent period (1971–2007), mainly due to intense warming in the recent decade (1998–2007). This warming is mainly contributed by the winter and post-monsoon seasons, which have increased by 0.70°C and 0.52°C, respectively in the last 100 years. The pre-monsoon and monsoon temperature also indicate a warming trend.

Mean temperature increased by about 0.2°C per decade (that is, 10 years) for the period 1971–2007, with a much steeper increase in minimum temperature than maximum temperature (Figure 3.1). In the most recent decade, maximum temperature was significantly higher compared to the long-term (1901–2007) mean, with a stagnated trend during this period, whereas minimum temperature showed an increasing trend, almost equal to that observed during 1971–2007. On a seasonal scale, pronounced warming trends in the mean temperature were observed in winter and monsoon seasons, and a significant influence of El Niño Southern Oscillation events on temperature anomalies during certain seasons across India was observed. Spatial analysis of changes in temperature between 1901 and 2007 reveals that most parts of India show a warming trend, except the north-western parts of the country, where a cooling trend is observed.

Annual trends in maximum temperature: The all India maximum temperature shows an increase in temperature by 1.02°C per 100 years (Figure 3.1 – middle panel). The trend in daily maximum temperature in India is observed to be increasing from January, attaining a peak in the month of May. Beyond May, the temperature starts decreasing up to December. During the pre-monsoon (March, April, and May) season, the Indian region is marked by clear skies, which, coupled with intense as well as increased solar radiation, results in high temperature. The occurrence of heat wave conditions is more frequent in May than in June, while very few heat waves occur in the months of March and April. During the pre-monsoon season, a large part of the country between 75°E to 85°E and 14°N to 25°N has uniform maximum temperature between 34°C and 40°C. Steep temperature gradient is found over the West Coast and East Coast of India. Monsoon season follows the pre-monsoon, and the seasonal temperature variation is considerably modified by the south-west monsoon. The temperature is nearly uniform over the Indian region except over north-west India, where the temperature is more than 34°C. Maximum temperature is almost uniform over the entire country in the post-monsoon season, and it decreases from west to east (72°E to 96°E), ranging between 28°C and 30°C. The highest annual mean maximum temperature is observed in the north-western and central parts of India.

Annual trends in minimum temperature: The all-India mean annual minimum temperature has significantly increased by 0.12°C per 100 years during the period 1901–2007 (Figure 3.1, lower panel). The spatial changes in minimum temperature are observed to be decreasing in most parts of Western Ghats and increasing in most

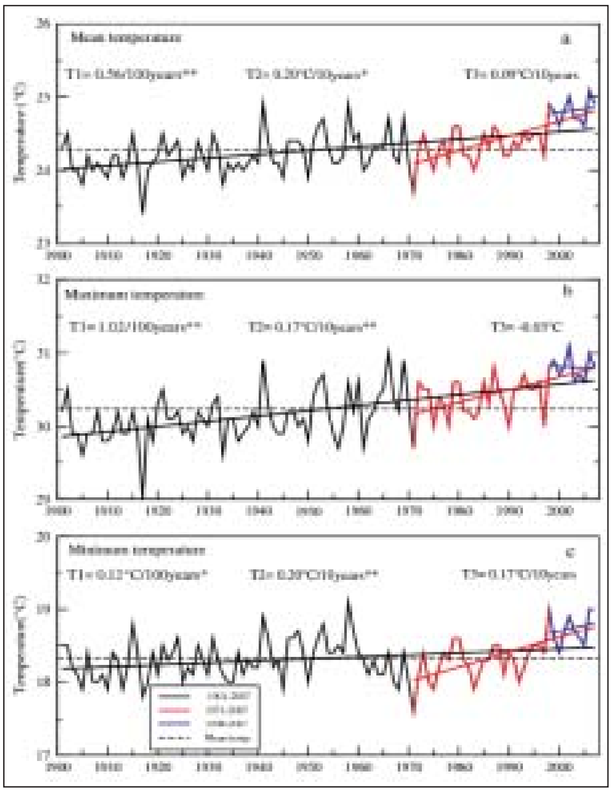


Figure 3.1: All-India annual mean, maximum, and minimum temperature variations during 1901–2007

parts of the Himalayan region and certain parts of the north-eastern region. The warming is mainly contributed by winter and post-monsoon temperatures. In the recent three-and-a-half decades, the all-India mean annual minimum temperature shows a significant warming trend of 0.20°C/10 years. Unlike maximum temperature, the trend in the minimum temperature during the latest decade is maintained at the rate observed for the most recent three-and-a-half decades. On the seasonal scale, all the seasons show significant warming trend, except post-monsoon, wherein the trend is positive but not significant.

Indian summer monsoon rainfall

The all-India monsoon rainfall series (based on 1871–2009 data) indicates that the mean rainfall is 848 mm, with a standard deviation of 83 mm. Inter-annual variability of Indian monsoon rainfall during this period is shown in Figure 3.2. The Indian monsoon shows well-defined epochal variability with each epoch of approximately three decades. Though it does not show any significant trend, when averaged over this period, a slight negative trend of 0.4 mm/year is observed.

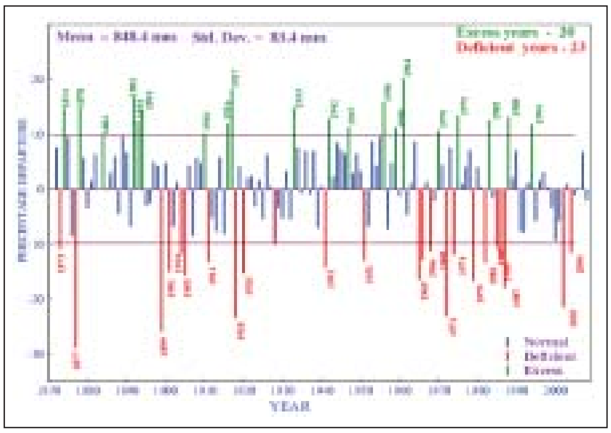


Figure 3.2: Inter-annual variability of Indian monsoon rainfall 1871–2009

Bars denote percentage departure from normal (blue) with excess (green) and deficient (red) years.

The rainfall is deficient or in excess if all-India monsoon rainfall for that year is less than or greater than mean standard deviation. With this definition, the deficient years are marked red, excess years are marked green, and the normal years are marked blue. It is seen that in this 139-year period, there are total 23 deficient years and 20 excess years; and the remaining are normal monsoon years. It is observed that the excess and deficit years are more frequent in above and below normal epochs, respectively.

Spatial trends of monsoon rainfall: All-India, north-west, West Coast, and peninsular India monsoon rainfall shows a slightly higher negative trend, though not significant, than for the total period. However, pockets of increasing/ decreasing trends in 36 meteorological sub-divisions across India are seen (Figure 3.3 a and b). North-west India, West Coast, and peninsular India show increasing trends, though not statistically significant. Central India depicts a decreasing trend. In all, 14 (22) sub-divisions show decreasing (increasing) trends. However, in recent decades (Figure 3.3a), 16 (20) sub-divisions show decreasing (increasing) long-term trends. East central India shows positive trends, which were decreasing based on the entire period 1871–2008.

Extreme precipitation trends: The highest rainfall pockets in India are generally those that receive orographically induced rainfall, caused by forced moist air ascent over the slopes during the active monsoon conditions. Western Ghats and North East India receive such types of heavy rainfall (Figure 3.4(a)). Trend analysis of one-day extreme rainfall series based on the period 1951–2007 indicates that this extreme rainfall is increasing at many places in India, as seen from Figure 3.4(b). Only the cases with the minimum rainfall of 10 cm/day are taken into account to give weightage to the high rainfall values. The rainfall of 10 cm/day may be an extreme for the north-west region, whereas it may not be a significant value for the north east region or the west coast of India during summer monsoon. Even during summer monsoon season, the west coast of India gets heavy rainfall spells in the first fortnight of June, while the northern part of the country is devoid of rainfall. Therefore, for this analysis, the magnitude of extreme point rainfall event (EPRE) has not been taken as a fixed threshold for all the stations, but it is different for each station and varies according to the month. Considering the climatological data, the magnitude of the extreme precipitation event at the station is defined as "its highest 24-hour rainfall reported in a particular month during the entire period of the data availability". Accordingly, it may increase for certain stations, if their previous EPRE are exceeded in the course of time. This definition is adopted in order to examine whether there was any change in the number and intensity of the EPRE in the recent decades, and if so, which parts of the region are affected the most.

The analysis shows that majority of the stations have reported their highest 24-hour rainfall during 1961–80, with an alarming rise in their intensity in the subsequent period from 1980 onwards till 2009. Of the 165 stations analysed, the majority (77.6%) have registered their EPRE during 1961–80. Thereafter, several stations have reported the rainfall events surpassing the intensity of their previous highest rainfall.

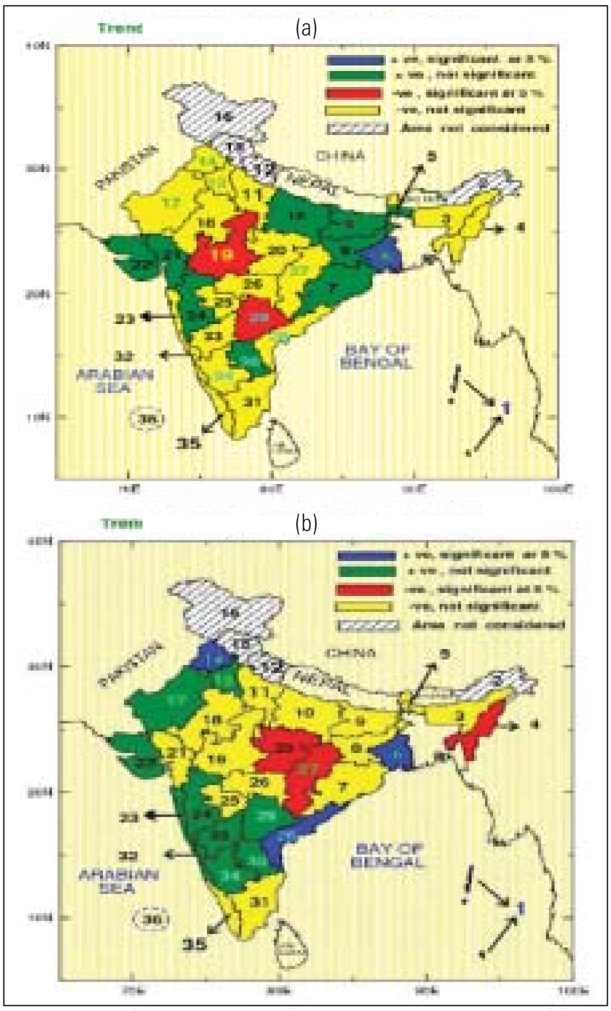


Figure 3.3: Trends in summer monsoon rainfall for 36 meteorological sub-divisions for the years (a) 1951-2008 and (b) 1871-2008.

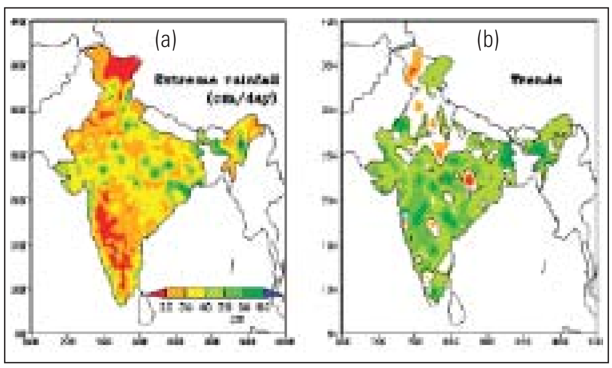


Figure 3.4: (a) Highest recorded rainfall (cm) during 1951–2007 and (b) trends in annual extreme rainfall

Dark green colour indicates a significant increasing trend

Climate Model Simulations of the Indian Climate

In order to narrow the gaps between the state of knowledge and the policy response to the effects of climate change, the most fundamental requirement is the availability of reliable estimates of future climatic patterns on the regional scale, which can be readily used by different impact assessment groups. This needs a systematic validation of the climate model simulations, development of suitable regional climate change scenarios, and estimations of the associated uncertainties.

With the availability of a hierarchy of coupled atmosphere–ocean–sea-ice–land-surface global climate models (AOGCMs), having a resolution of 250–300 km, it has been possible to project the climate change scenarios for different regions in the world. The global models, however, fail to simulate the finer regional features and the changes in the climate arising over sub-seasonal and smaller spatial scales. This is more relevant in the case of India due to its unique climate system dominated by the monsoon and the major physiographic features that drive this monsoon.

Climate change projections during Initial National Communication

For the INC, the high-resolution simulations for India were based on the second generation Hadley Centre Regional Climate Model (HadRM2). HadRM2 is a high-resolution climate model that covers a limited area of the globe, typically 5000 km × 5000 km. The typical horizontal resolution of HadRM2 is 50 km × 50 km. The regional model reproduces the large-scale features of the global climate model (GCM) climate and adds realistic local detail. For example, the rain-shadowing effect of the Western Ghats was found to be closer to the observations. The annual cycles of rainfall and surface air temperature were also remarkably close to the observed patterns, which demonstrate that the regional model is able to overcome the large biases of the GCM in portraying these features.

For assessing the nature of the likely future climate in India at an all-India level during the INC, eight AOGCMs (Box 3.1) were run using the IS92a and SRES A2 and B2 scenarios.

The simulated climate approximately represented the period spanning nominal time scale of 1860–2099, but the individual model-years did not correspond to any specific years or events in this period. Considering all the land-points in India according to the resolution of each AOGCM, the arithmetic averages of rainfall and temperature fields were worked out to generate all-India monthly data for the entire duration of model simulations and for different experiments. These monthly data values were then used to compute the seasonal totals/means of rainfall/temperature. Taking 1961–90 as the baseline period, the seasonal quantities were then converted into anomalies (percentage departures in the case of rainfall). The resulting time series were examined for their likely future changes into the 21st century.

The GHG simulations with IS92a scenarios showed marked increase in both rainfall and temperature by the end of the 21st century, relative to the baseline. There was a

Box 3.1: Coupled atmosphere-ocean general circulation models used for deriving climate change projections during Initial National Communication.

1. Canadian Center for Climate Modeling (CCC), Canada
2. Center for Climate System Research (CCSR), Japan
3. Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
4. Deutsches Kilma Rechen Zentrum (DKRZ), Germany
5. Geophysical Fluid Dynamics Laboratory (GFDL), USA
6. Hadley Center for Climate Prediction and Research (HadCM3), UK
7. Max-Planck Institute (MPI), Germany
8. National Center for Atmospheric Research (NCAR), USA

Box 3.2: A description of IPCC IS92a and A1B* SRES scenario

IS92a scenario: In this scenario, greenhouse gas (GHG) forcing is increased gradually to represent the observed changes in forcing due to all GHGs from 1860 to 1990; for future time period of 1990–2099, the forcing is increased at a compounded rate of 1% per year (relative to 1990 values).

A1B scenario: This scenario assumes significant innovations in energy technologies, which improve energy efficiency and reduce the cost of energy supply. Such improvements occur across the board and neither favour nor penalize the particular groups of technologies. A1B assumes, in particular, drastic reductions in power generation costs through the use of solar, wind, and other modern renewable energies, and significant progress in gas exploration, production, and transport. This results in a balanced mix of technologies and supply sources with technology improvements and resource assumptions such that no single source of energy is overly dominant.

Source: IPCC (2000)

considerable spread among the models in the magnitudes of both precipitation and temperature projections, but more conspicuously in the case of summer monsoon rainfall. The increase in rainfall from the baseline period (1961–90) to the end of 21st century ranged between 15% and 40% among the models. In case of mean annual temperature, the increase was found to be of the order of 3–6° C.

Climate change projections for Second National Communication

Considering the limitations of the global climate models during the INC, high-resolution simulations for India were carried out using the second generation Hadley Centre Regional Climate Model (HadRM2). It was envisaged; during the SNC to add new scenarios from the bouquet of emission scenarios available from the IPCC Special Report on Emission Scenarios (SRES). Subsequently, A1B scenario was chosen as the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies, following a sustainable growth trajectory (Box 3.2). Subsequently, new development in regional models has taken place. India now has access to PRECIS—the latest generation of regional model from the Hadley Centre. PRECIS is an atmospheric and land surface model having 50 km × 50 km horizontal resolution over the South Asian domain and is run by the Indian Institute of Tropical Meteorology (IITM), Pune. PRECIS is forced at its lateral boundaries by a high-resolution GCM (150 km) called HadAM3H in so-called "time slice" experiments. Following sections provide an overview of the observed climate trends in India since 1900 and projections of climate change over India using the latest A1B SRES scenarios. The model simulations have been carried out for three quantifying uncertainties in model projections (QUMP) for A1B scenario for the period 1961–90 (baseline simulation) and for three time slices-2020s (2011–40), 2050s (2041–70), and 2080s (2071–98). Some basic parameters like rainfall, surface air temperature, and mean sea level pressure are analysed to get climatic projections towards the end of the present century. Three PRECIS runs – Q0, Q1, and Q14 – are carried out for the period 1961–2098 and are utilized to generate an ensemble of future climate change scenarios for the Indian region.

Climate change projections: It appears that there may not be a significant decrease in the monsoon rainfall in future except in some parts of southern peninsula (Figure 3.5). Q0, Q1, and Q14 simulations project 16%, 15%, and 9% rise, respectively, in the monsoon rainfall towards the end of 21st century.

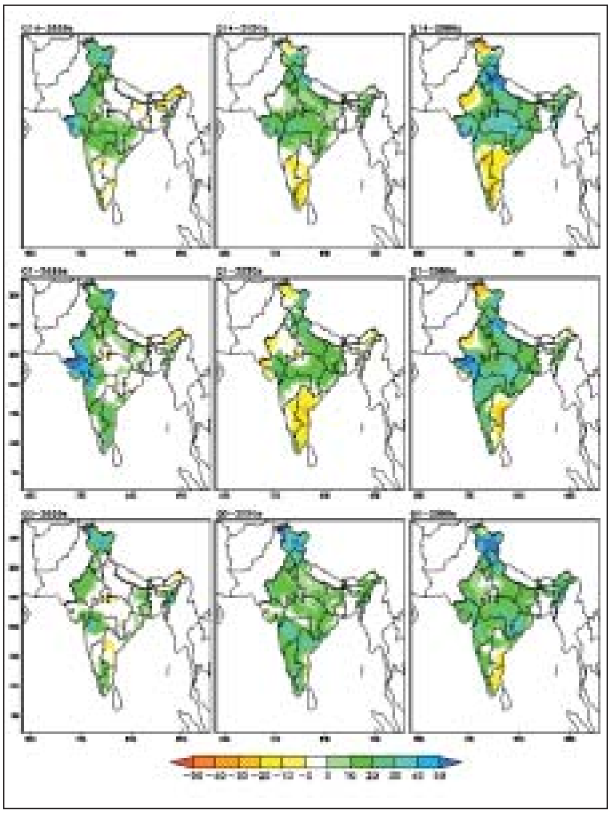


Figure 3.5: Simulated percentage change in mean monsoon precipitation in 2020s, 2050s, and 2080s with respect to baseline (1961–90)

PRECIS simulations for 2020, 2050, and 2080s indicate an all-round warming over the Indian sub-continent. Figure 3.6 shows the time series of mean annual surface air temperature from 1961 (first year of model simulation) to 2098 (last year of model projections), as simulated by PRECIS. The data indicates that Q14 simulations are warmer than the remaining two simulations. The annual mean surface air temperature rise by the end of the century ranges from 3.5°C to 4.3°C.

Figure 3.7 depicts the annual cycle of rainfall and surface air temperature for the three time slices. The model indicates positive change in rainfall in the future, especially during monsoon months. This increase is seen in all the three simulations except for the June rainfall simulated by Q1 simulation. The projected change of about 5°C towards 2080s is seen for nearly all months in all three simulations except for temperature during the monsoon months of Q1 simulation, which is nearly 3°C.

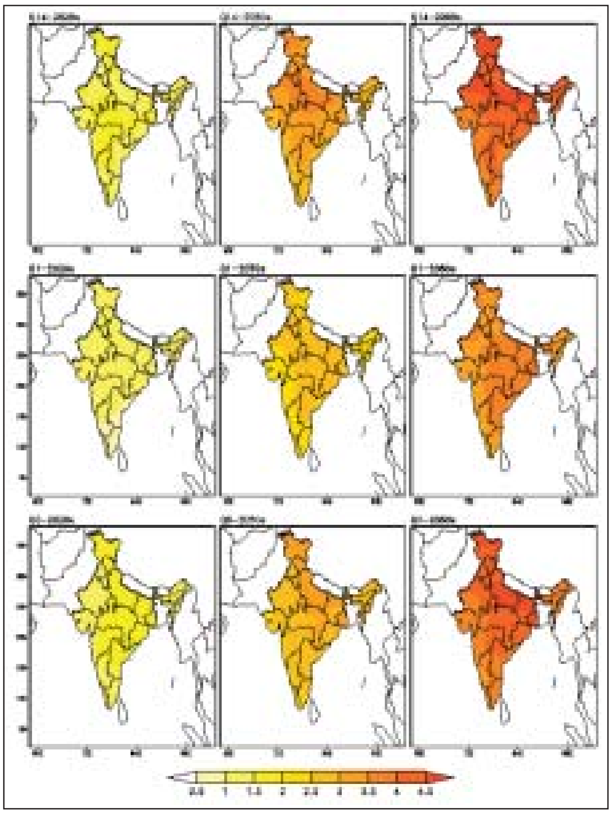


Figure 3.6: Simulated change in mean annual surface air temperature in 2020s, 2050s, and 2080s with respect to baseline (1961–90)

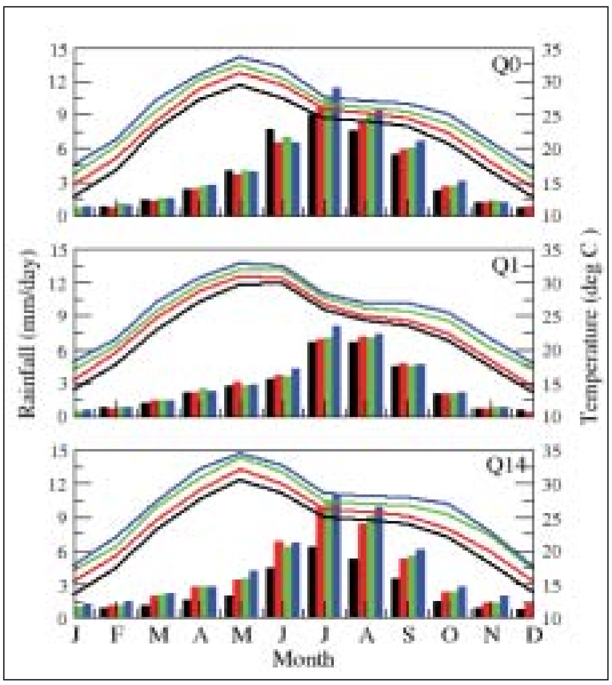


Figure 3.7: Annual cycle for all-India summer monsoon rainfall (bars) and surface air temperature (lines) simulated by PRECIS for 1970s (black), 2020s (red), 2050s (green), and 2080s (blue)

Changes in extreme precipitation event: The number of rainy days and the intensity of the rainy day may change in future. The rainy days in future appear to be less in number than the present, especially over north and central India and east peninsula, in two of the three simulations, namely, Q0 and Q1 (Figure 3.8), whereas Q1 and Q14 simulations indicate less rainy days in the future in north-west India.

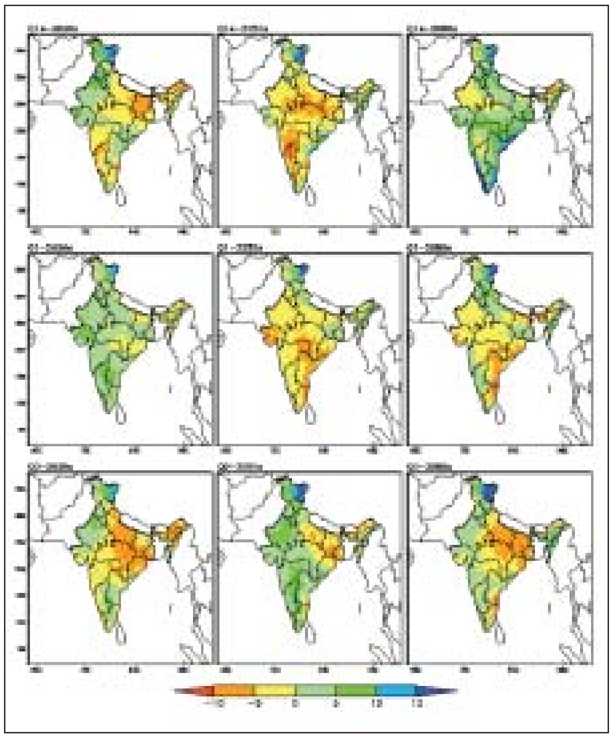


Figure 3.8: Projected change in rainy days in 2020s, 2050s, and 2080s with respect to baseline (1961–90) as simulated by three ensembles: Q0 (lower panel), Q1 (middle panel), and Q14 (upper panel)

On the other hand, all the three simulations indicate increase in the rainfall intensity in the 21st century over most of the regions. The rise in intensity may be more in central India (Figure 3.9). Marginal decrease in the intensity may be seen in the east peninsular region.

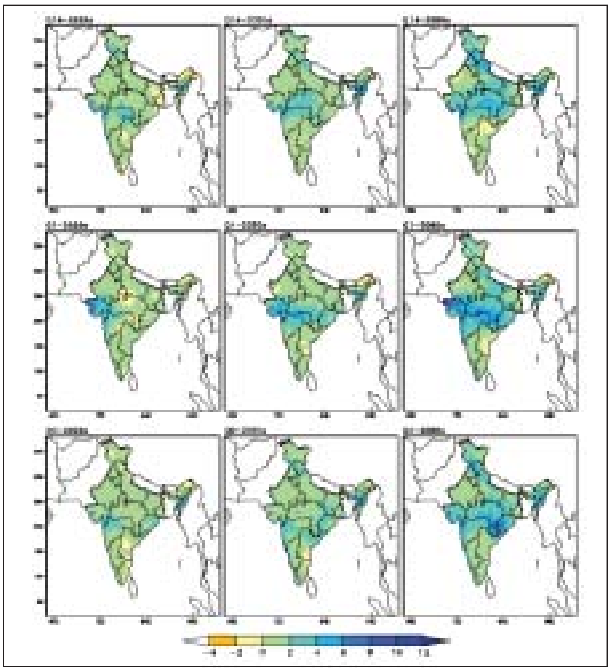


Figure 3.9: Projected change in the intensity of rainy days in 2020s, 2050s, and 2080s with respect to baseline (1961–90) as simulated by three ensembles: Q0 (lower panel), Q1 (middle panel), and Q14 (upper panel)

Changes in extreme temperature events: The analysis of the three model simulations indicates that both the daily extremes in surface air temperature may intensify in the future. The spatial pattern of the change in the highest maximum temperature (Figures 3.10a and 3.10b) suggests warming of 1–4°C towards 2050s, which may exceed even 4.5°C in most of the places towards the end of the present century.

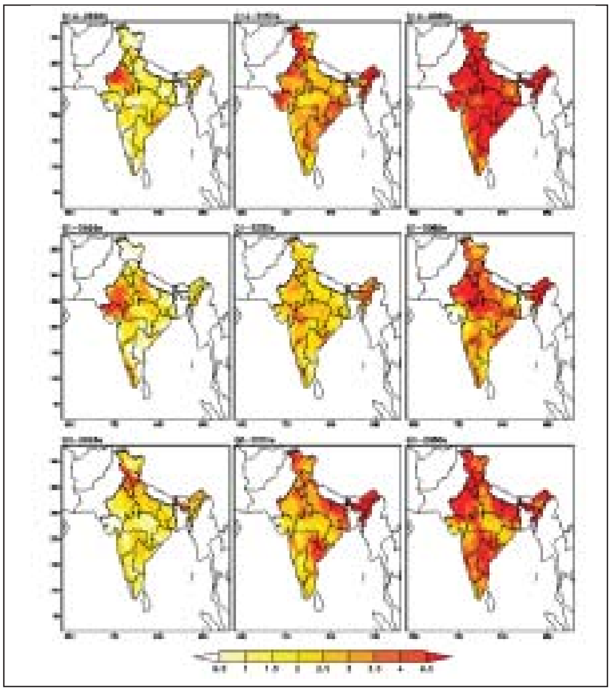


Figure 3.10a: Projected change in the highest maximum temperatures in 2020s, 2050s, and 2080s with respect to baseline (1961–90), as simulated by three ensembles: Q0 (lower panel), Q1 (middle panel), and Q14 (upper panel)

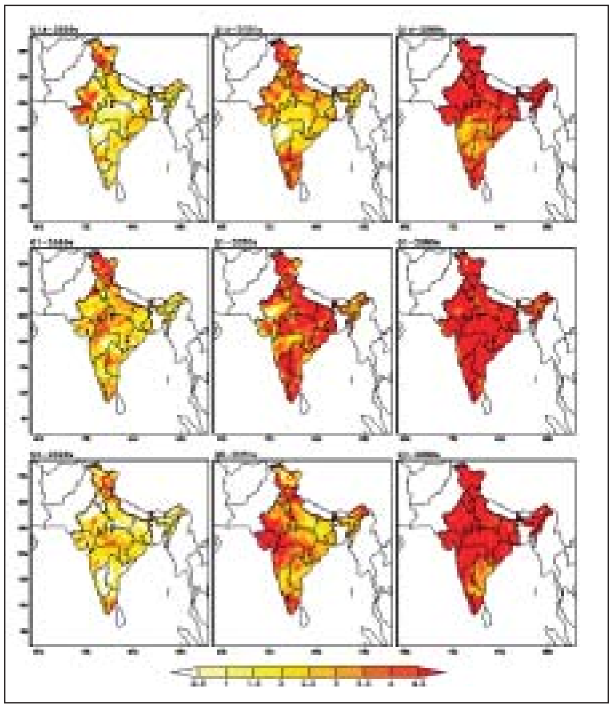


Figure 3.10b: Projected change in the lowest minimum temperatures in 2020s, 2050s, and 2080s with respect to baseline (1961–90), as simulated by three ensembles: Q0 (lower panel), Q1 (middle panel), and Q14 (upper panel)

Warming in night temperature (Figure 3.10b) is even more in all the three time slices as compared to the daytime warming. The rise of more than 4.5°C in night-time temperature may be seen throughout India, except in some small pockets in peninsular India.

Projected changes in cyclonic storms: Regional model simulations indicate decrease in the frequency of the cyclonic disturbances towards the end of the present century (Table 3.1). The number of cyclonic disturbances over the Arabian Sea may be less in the future as compared to the present simulations. However, the analysis indicates that it might be more intense in the future (last column in Table 3.1). The increase in the intensity of cyclonic storms is particularly seen in Q0 and Q1 simulations. There is, however, no change in the track of cyclonic disturbances in the future scenarios as compared to the baseline simulations.

Table 3.1: Frequency of monthly cyclonic disturbances in monsoon season simulated by PRECIS (maximum intensity in brackets (m/s))

Q0	June	July	August	September	JJAS
Obs	45 (27)	42 (23)	63 (24)	60(29)	210 (26)
1970s	30 (34.4)	42 (32.5)	31 (31.2)	37 (30.9)	140 (32.4)
2020s	6 (39.3)	39 (33.5)	33 (32.9)	55 (33.0)	133 (34.7)
2050s	10 (36.1)	37 (32.9)	20 (32.4)	29 (29.7)	96 (32.8)
2080s	12 (35.2)	32 (37.2)	19 (32.5)	37 (31.8)	100 (34.2)
Q1	**June**	**July**	**August**	**September**	**JJAS**
1970s	17 (33.1)	35 (32.9)	50 (30.4)	42 (29.3)	144 (31.4)
2020s	17 (36.3)	29 (31.8)	43 (30.3)	44 (31.8)	137 (32.5)
2050s	10 (41.3)	36 (33.6)	50 (31.0)	38 (33.3)	134 (34.8)
2080s	12 (40.1)	38 (34.0)	37 (32.0)	35 (32.6)	122 (34.7)
Q14	**June**	**July**	**August**	**September**	**JJAS**
1970s	18 (35.7)	27 (32.8)	23 (30.4)	27 (29.6)	95 (32.1)
2020s	20 (35.2)	30 (33.1)	23 (31.1)	30 (31.3)	103 (32.6)
2050s	8 (34.6)	36 (33.2)	25 (30.1)	18 (30.7)	87 (32.2)
2080s	12 (33.5)	28 (32.7)	24 (30.6)	22 (30.1)	86 (31.7)

JJAS: June, July, August, September

Climate change scenarios for 2030s

'Climate Change and India: A 4×4 Assessment: A sectoral and regional analysis for 2030s' was undertaken by the Indian Network for Climate Change Assessment (INCCA). It provided an assessment of the impact of climate change in 2030s on four key sectors of the Indian economy, namely, agriculture, water, natural ecosystems and biodiversity, and health in four climate-sensitive regions of India, namely, the Himalayan region, the Western Ghats, the Coastal area, and the North-East region. It is for the first time that such a comprehensive assessment has been undertaken based on rigorous scientific analysis. It is also for the first time that an assessment has been made for the 2030s (all previous assessments were for the 2070s and beyond). The climate change scenarios were derived from the regional climate change model PRECIS. Such a scientific analysis was a one-of-its-kind attempt to look at the climate change projections in the near to mid-term. This has contextual importance as most of climate change projections are made, keeping the long term viewpoint.

Projected changes in 2030s from the model

- The assessment projects about 10% increase in the Indian monsoon rainfall over central and peninsular India in the 2030s. The expected change in the rainfall is within the current monsoon variability, and there are large model-to-model differences, making these projected changes to be less confident.
- The assessment projects 1.5–2°C warming in the annual mean temperature over the Indian landmass, while winter (January–February) and Spring (March–April–May) seasons show higher warming.
- The projections of PRECIS in 2030s indicate 3–7% increase in all-India summer monsoon rainfall.
- The annual mean surface air temperature may rise from 1.7°C to 2°C by 2030s, as indicated by the simulations.
- The regional climate model simulations indicate that the cyclonic disturbances over Indian oceans during summer monsoon are likely to be more intense, and the systems may form slightly to the south of normal locations.
- The ensemble mean changes in the monsoon rainfall are in the range of 2%–12%, while the annual temperature changes are of the order of 1.4–1.9°C; however, the individual simulations show large differences.

Impacts of Climate Change and Vulnerability Assessment

Impact on water resources

There is a clear case for developing water resources and its conservation, owing to India's high share in the world population (According to UN Population database, India shares nearly 18% of the world's population in 2010), but it has only 4% of the total water resources. This clearly indicates the need for water resource development and conservation, and its optimum use. The irrigation sector (with 83% of use) is the main consumer of water. The main water sources of India consist of precipitation on the Indian territory, which is estimated to be around 4000 km^3/year (billion cubic metres), and transboundary flows. Precipitation over a large part of India is concentrated in the monsoon season during June to September/October. Out of the total precipitation (including snowfall), the availability from surface water and replenishable groundwater is estimated to be 1869 km^3. It has been estimated that only about 1123 km^3 (690 km^3 from surface water and 433 km^3 from groundwater resources) can be put to beneficial use. India has been planning to utilize this water by prolonging its stay on land by using engineering innovations such as dams and barrages.

Further, extreme conditions of flood followed by droughts are a common feature, affecting the availability of water for various purposes. It has been estimated that 40 million hectares (Mha) of area is flood-prone, and this constitutes 12% of the total geographical area of the country. Droughts are also experienced due to deficient rainfall. It has been found that 51 Mha of area is drought prone, and this constitutes 16% of the total geographical area. Added to this is the growing demand for water. The population of the country increased from 361 million in 1951 to 1.13 billion in July 2007. Accordingly, the per capita availability of water for the country as a whole decreased from 5177 m^3/year in 1951 to 1654 m^3/year in 2007. Due to spatial variation of rainfall, the per capita water availability also varies from basin to basin.

The major contribution to surface water source comes from the major and minor river basins. The river basin is considered as the basic hydrologic unit for the planning and development of water resources. There are 12 major river basins in India, with a catchment area of 20,000 km^2 and above. The major river basin is the Ganga–Brahmaputra–Meghna system, which is the largest with a catchment area of about 11.0 lakh km^2 (more than 43% of the catchment area of all the major rivers in the country). The other major river basins with a catchment area of more than one lakh km^2 are Indus, Mahanadi, Godavari, and Krishna. There are 46 medium river basins with a catchment area between 2000 km^2 and 20,000 km^2. The total catchment area of medium river basins is about 2.5 lakh km^2. All major river basins and many medium river basins are inter-state in nature, and cover about 81% of the geographical area of the country. The demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization, and economic development. At present, changes in the cropping pattern and land-use pattern, overexploitation of water storage, and changes in irrigation and drainage systems are modifying the hydrological cycle in many climatic regions and river basins of India. Table 3.2 summarizes the various elements, by basin, such as population, catchment area, and water availability (total and on per capita basis).

Table 3.2: Population and water resources of Indian river basins

River basin	Catchment area	Length of the river	Population			Total renewable water resources (TRWR)	Potentially utilizable water resources (PUWR)			Per capita water resources	
			Total	Density	Rural (% of total)		Surface	Ground water	Total	RWR/ pc	PUWR/ pc
	km^2	km^2	Million	No. people/ km^2	%	km	km^3	km^3	km^3	m	m
All basins	**3,190,819**		**932**	**282**	**73**	**1869**	**690**	**433**	**1123**	**2011**	**1130**
Indus	321,289	1114	48.8	140	71	73.3	46.00	14.30	60.3	1611	1325
Ganga	861,452	2525	370.2	449	75	525.0	250.0	136.5	386.5	1353	996
Brahmaputra	194,413	916	33.2	161	86	585.6	24.30	25.70	48	17,108	1529
Minor River Basins drainage to Bangladesh and Myanmar	41,723	-	10.0	160	82	31.0	1.70	8.50	10.2	7224	1522
Subarna rekha	29,196	395	15.0	347	76	12.4	6.80	1.70	8.5	1216	833
Sabarmati	21,674	371	6.0	521	54	3.8	1.90	2.90	4.8	239	302
Brahmani and Baitarani	51,822	1164	16.7	204	87	28.5	18.30	3.40	21.7	2689	2047

Mahanadi	141,589	851	27.2	202	80	66.9	50.00	13.60	63.6	2331	2216
Godavari	312,812	1465	76.7	186	85	110.5	76.30	33.50	109.8	1877	1865
Krishna	258,948	1401	68.9	253	68	78.1	58.00	19.90	77.9	1186	1183
Pennar	55,213	597	14.3	189	78	6.3	6.30	4.04	10.9	601	1040
Cauvery	81,155	800	32.6	389	70	21.4	19.00	8.80	27.8	676	878
Tapi	65,145	724	17.9	245	63	14.9	14.50	6.70	21.2	931	1325
Narmada	98,796	1312	17.9	160	79	45.6	34.50	9.40	43.9	2868	2761
Mahi	34,842	583	6.7	324	77	11.0	3.10	3.50	6.6	973	584
WFR of Kutch and Sau and Luni[a]	55,940	-	58.9	425	72	15.1	15.00	9.10	24.1	478	763
WFR South of Tapi[a]	378,028		51.9	166	57	200.9	36.20	15.60	51.8	3184	821
EFR bet, Mahanadi and Pennar[a]	86,643	-	19.2	293	74	22.5	13.10	12.80	25.9	946	1089
EFR bet, Pennar and Kanyakumari	100,139	-	39.0	484	60	16.5	16.70	12.70	29.4	340	605

a- West flowing rivers (WFR) includes rivers Kutch & Saurashtra including Luni; West flowing rivers includes rivers south of Tapi, East flowing rivers (EFR) includes rivers between Mahanadi and Pennar and East flowing rivers includes rivers between Pennar and Kanyakumari

Note

Source for total population (UN 1998).

Source for renewable and potentially utilizable water resources is CWC (2000).

Potentially utilizable ground water resources is the ground water replenished from normal natural recharge.

The length of Brahmani river itself is 799 km.

Source: CWC 1993. Reassessment of Water Resources Potential of River Basin ; CWC, Annual Report – 2003-04

Impact assessment of climate change on water resources

Changes in key climate variables, namely, temperature, precipitation, and humidity, may have significant long-term implications for the quality and quantity of water. The possible impacts of climate change on water resources of the river basins of India have been assessed using the hydrologic model SWAT[1] (soil and water assessment tool). The model requires information on terrain, soil profile, and land use of the area as input, which have been obtained from the global sources. These three elements are assumed to be static for future as well. The weather conditions (for model input) have been provided by the IITM, Pune (PRECIS outputs).

Simulated climate outputs from PRECIS regional climate model for present /baseline (1961–90, BL), near term (2021–50, MC), and long term (2071–98, EC) for A1B IPCC SRES socio-economic scenario have been used. Q14 QUMP ensemble has been used for simulation. The potential impacts of climate change on water yield and other hydrologic budget components are quantified by performing SWAT hydrological modelling with current and future climate scenarios for the regional systems. Impacts of climate change and climate variability on the water resources are likely to affect irrigated agriculture, installed power capacity, environmental flows in the dry season, and higher flows during the wet season, thereby causing severe droughts and flood problems in the urban and rural areas.

Detailed outputs have been analysed with respect to the two major water balance components of water yield and actual evapo-transpiration that are highly influenced by the weather conditions dictated by temperature and allied parameters. Majority of the river systems show increase in the precipitation at the basin level (Figure 3.11). Only Brahmaputra, Cauvery, and Pennar show marginal decrease in precipitation under MC. The decrease in water yield in the Pennar basin is more pronounced, which may be on account of changes in the distribution of precipitation under MC. The situation under EC improves, wherein all the river systems exhibit increase in precipitation. There is an associated increase in water yield for all the river systems

1. The Soil and Water Assessment Tool (SWAT) model is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as the man-made interventions on water and sediment yields in un-gauged catchments. The model (i) is physically based; (ii) uses readily available inputs; (iii) is computationally efficient to operate; and (iv) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on ungauged watersheds (in fact the usual situation).

under EC. The change in evapo-transpiration under the MC scenario exhibits appreciable increase (close to 10 %) for Brahmaputra, Indus, and Luni river basins. All other systems show marginal increase or decrease. For majority of the river systems, the evapo-transpiration has increased by more than 40%. The only two river basins that show some decrease in evapo-transpiration under the EC scenario are Cauvery and Krishna rivers. The major reason for such an increase in evapo-transpiration is on two accounts: one is the increase in the temperature and the second one is the increase in precipitation, which enhances evapo-transpiration.

One may observe that the change in precipitation is highly variable in most of the river basins (Figure 3.11). This is true for not only the big basins such as Ganga but also for smaller basins such as Cauvery and Pennar. It may also be observed from the lower left hand box in Figure 3.11 that the average change in precipitation (shown through the red cross bar) reflects increase in precipitation for majority of the river basins, although there are few sub-basins within specific river basins that may be showing decrease in precipitation under the MC scenario. The situation is further improved when we see the EC scenario, wherein there is increase in the average basin

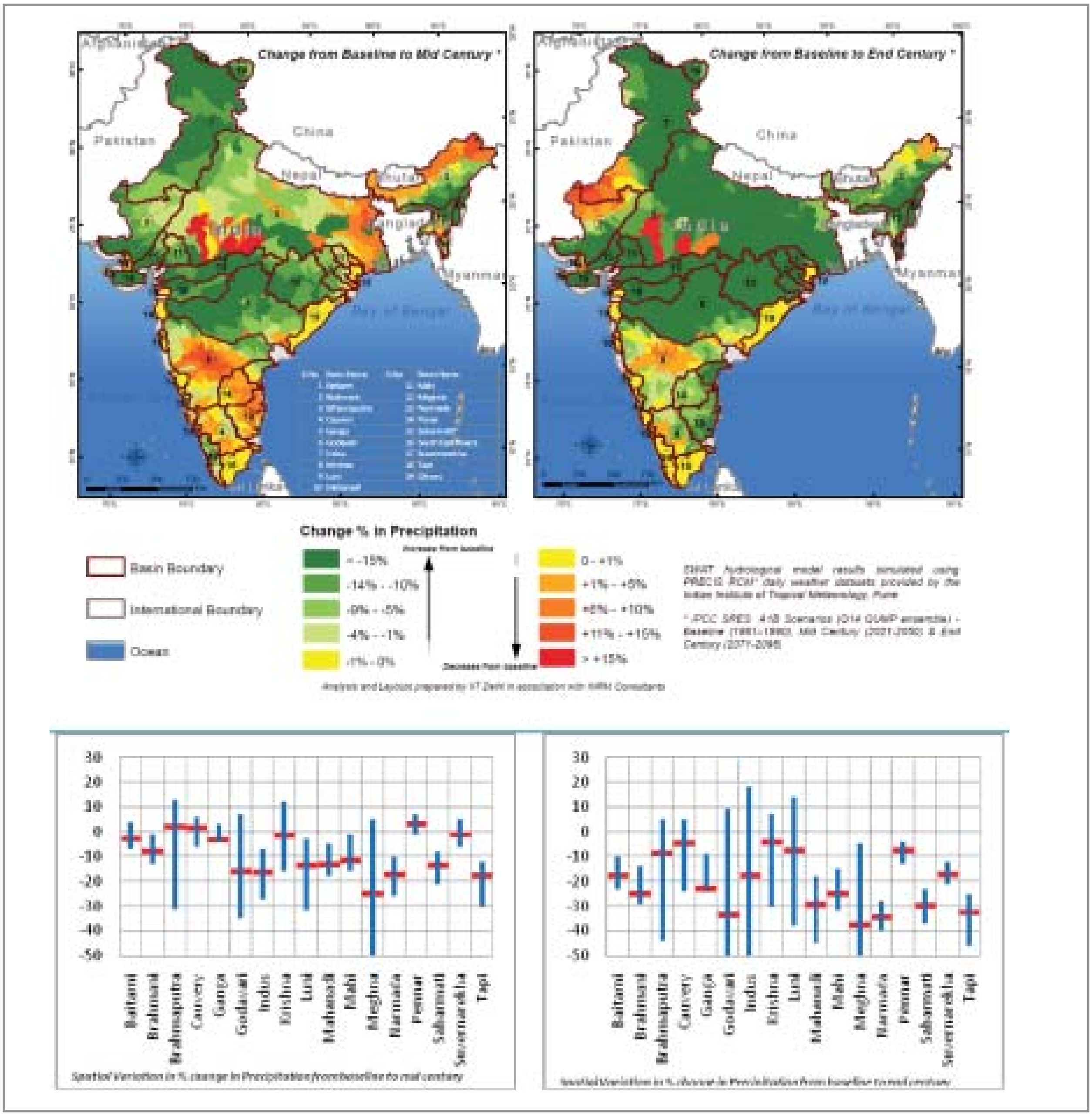


Figure 3.11: Change in precipitation towards 2030s and 2080s with respect to 1970s

precipitation as compared to the BL scenario (Figure 3.12). However; even in this scenario many river systems, such as Ganga, Indus, Luni, Godavari, and Krishna, have sub-basins that show decrease in precipitation.

Although changes in the core entities of precipitation, water yield, and evapo-transpiration have been provided, which give the average value of these changes over the entire river basin. Many of these basins are, however, very big and have considerable spatial variability.

The implications of changes in precipitation have also been quantified in the form of resulting water yields through the SWAT modelling exercise. The response of water yield is dependent on a combination of factors such as terrain, land use, soil type, and weather conditions. It is found that despite the increase in precipitation from MC to EC scenario, the Krishna river system is showing reduction in the water yield. This can be on account of higher evapo-transpiration (because of increased temperatures). It may

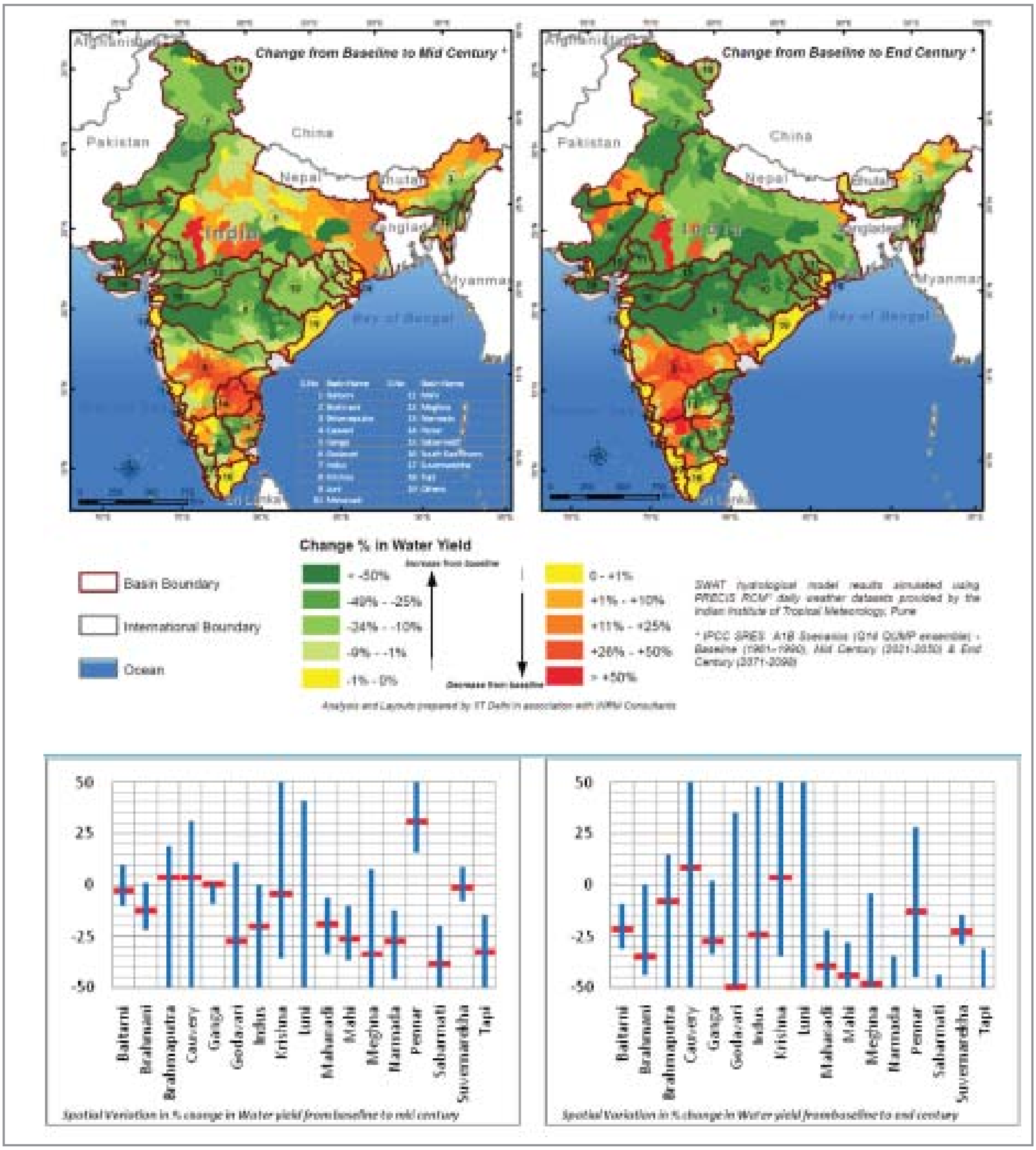


Figure 3.12: Change in Water Yield (water availability) towards 2030s and 2080s with respect to 1970s

also be observed that in the case of Cauvery river system, although there is an improvement in the average water yield from MC to EC scenario, there are some sub-basins that show reduction in water yield.

Evapo-transpiration is a very important component of water balance with respect to the biomass and agricultural activities. The potential evapo-transpiration is driven by the weather conditions, but the actual evapo-transpiration is also dependent on the moisture conditions prevalent under the weather conditions (assuming that the land-use and soil characteristics are not changing). The outcome of actual evapo-transpiration has been obtained after the continuous simulation on daily basis for all the sub-basins of various river systems by using SWAT model, and the changes in evapo-transpiration values in percentage are shown in Figure 3.13 for all the sub-basins under the MC and EC scenarios. In general, majority of the northern river systems show increase in evapo-transpiration under the MC scenario, whereas majority of the southern river systems show marginal reduction in evapo-transpiration despite increase in precipitation. One possible reason can be higher intensities of rainfall under the MC scenario, which has not allowed sufficient time for water to be stored in the soil through infiltration. The EC conditions

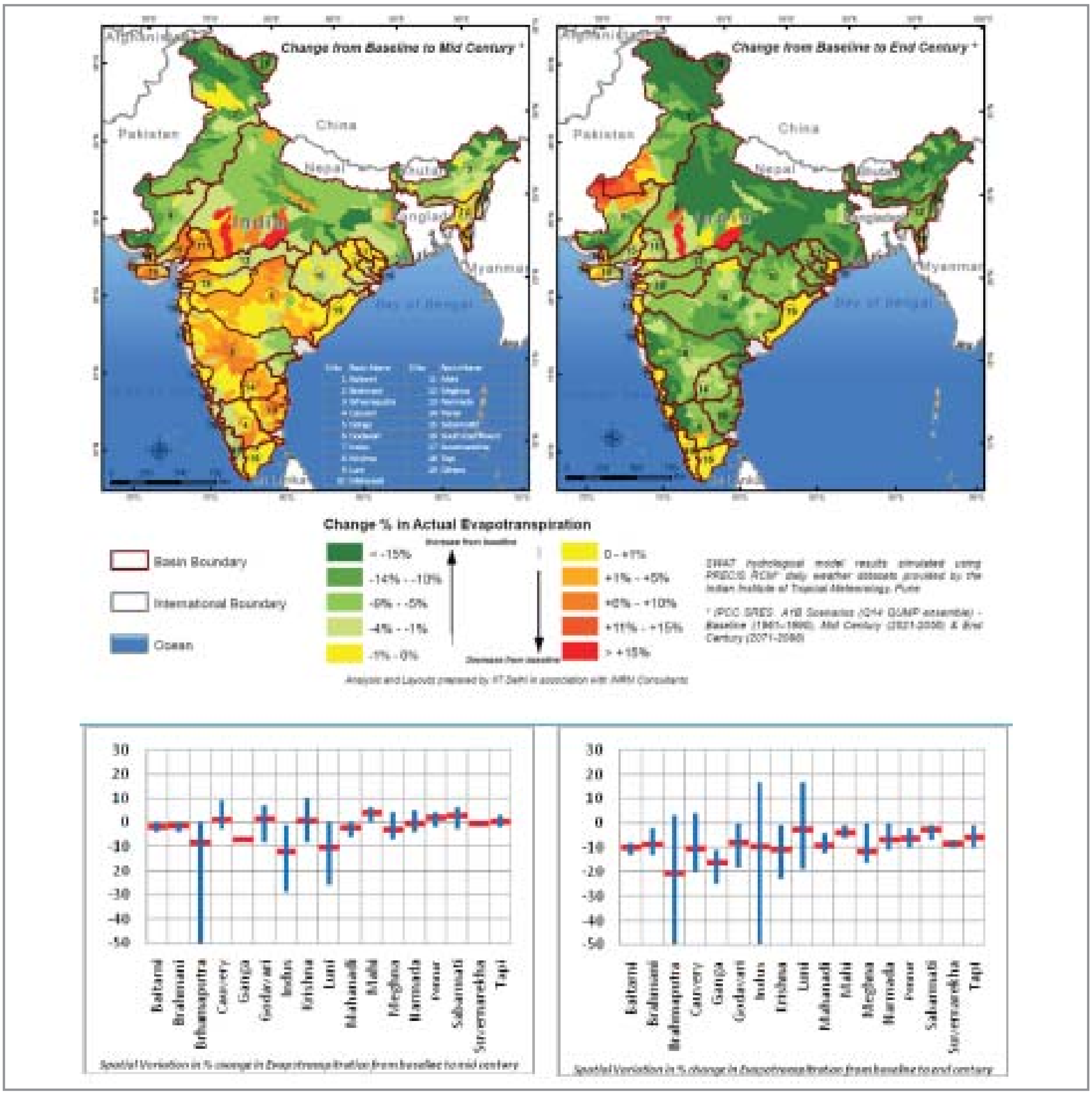


Figure 3.13: Change in Evapo-transpiration (crop water demand) towards 2030s and 2080s with respect to 1970s

are showing considerable improvement in evapo-transpiration, which has increased for majority of the river basins (guaranteeing better crop production and less of agricultural droughts), but Indus and Luni rivers show reduction in evapo-transpiration under the EC scenario.

Droughts and floods

Droughts: Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness affecting water-sensitive economies. In this analysis, Soil Moisture Index is developed to monitor drought severity using SWAT output to incorporate the spatial variability. The focus is on agricultural drought, wherein severity implies cumulative water deficiency. In the current context Scale 1 (Index between 0 and –1) represents the drought developing stage and Scale 2 (Index between –1 and –4) represents mild to moderate and extreme drought conditions. Soil Moisture Deficit Index (SMDI) was calculated for 30 years of simulated soil moisture data from baseline (1961–90), MC (2021–50), and EC (2071–98) climate change scenarios. Weeks when the soil moisture deficit may start drought development (drought index value between 0 and –1) as well as the areas that may fall under moderate to extreme drought conditions (drought index value between –1 and –4) have been assessed and are shown in Figure 3.14.

It may be seen that there is an increase in the moderate drought development (Scale 1) for Krishna, Narmada, Pennar, Cauvery, and Brahmini basins, which have either predicted decrease in precipitation or have enhanced level of evapo-transpiration for the MC scenario. It is also evident from the depiction that the moderate to extreme drought severity (Scale 2) has been pronounced for the Baitarni, Sabarmati, Mahi, and Ganga river systems, where the increase is ranging between 5% and 20% for many areas despite the overall increase in precipitation. The situation of moderate drought (Scale 1) is expected to improve under the EC scenario for almost all the river systems except Tapi river system, which shows about 5% increase in drought weeks. However, the situation for moderate to extreme droughts (Scale 2) does not appreciably improve much under the EC scenario despite the increase in precipitation. There is some improvement in Ganga, Godavari, and Cauvery basins.

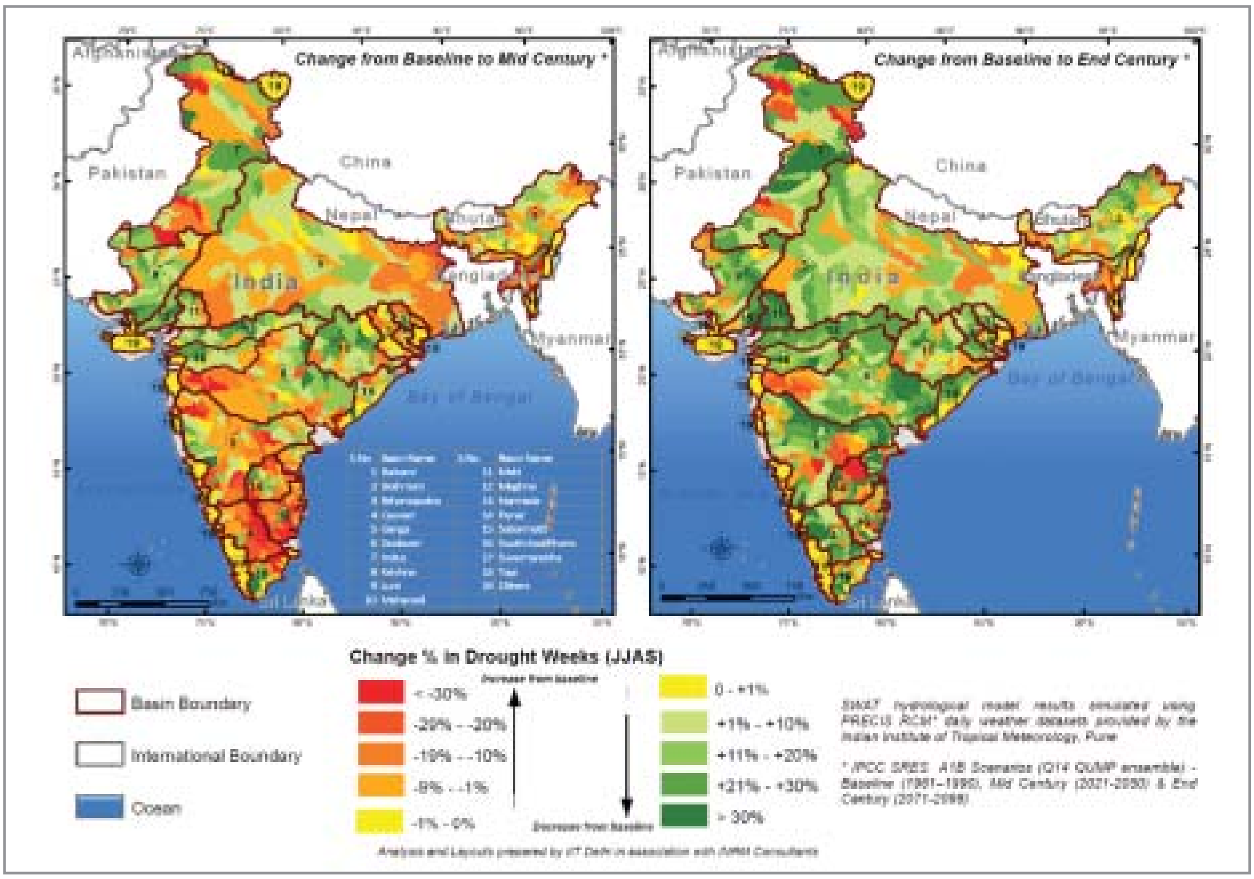


Figure 3.14: Change in monsoon drought weeks towards 2030s and 2080s with respect to 1970s

Floods: The vulnerability assessment with respect to the possible future floods has been carried out using the daily outflow discharge taken for each sub-basin from the SWAT output. These discharges have been analysed with respect to the maximum annual peaks. Maximum daily peak discharge has been identified for each year and for each sub-basin. Analysis has been performed to earmark the basins where flooding conditions may deteriorate under the future scenario. The analysis has been performed to ascertain the change in magnitude of flood peaks above 99th percentile flow under baseline (1961–90),

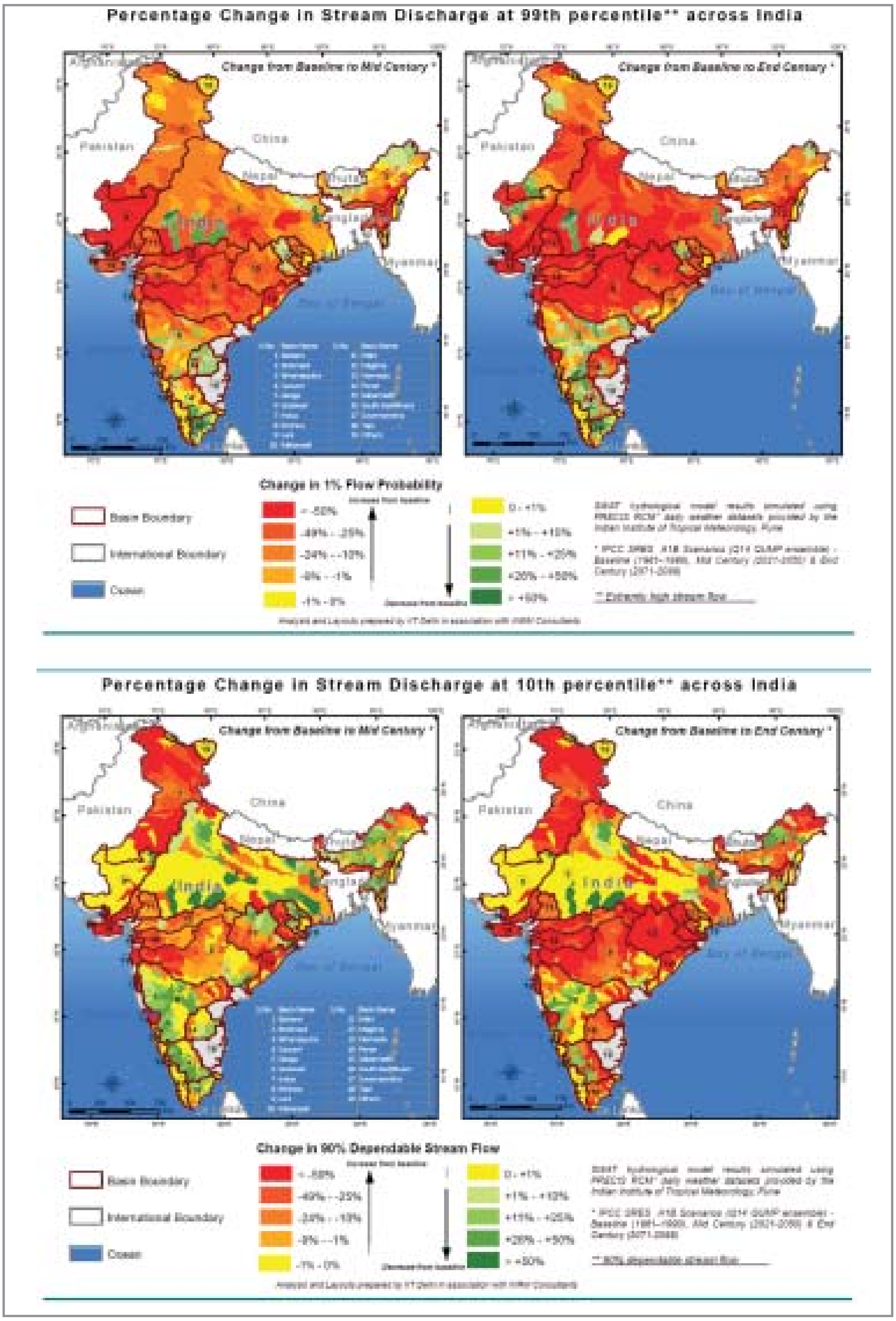


Figure 3.15: Change in stream flow towards 2030s and 2080s with respect to 1970s (stream discharge at 99th percentile – extremely high stream flow – and 10th percentile – 90 % dependable flow)

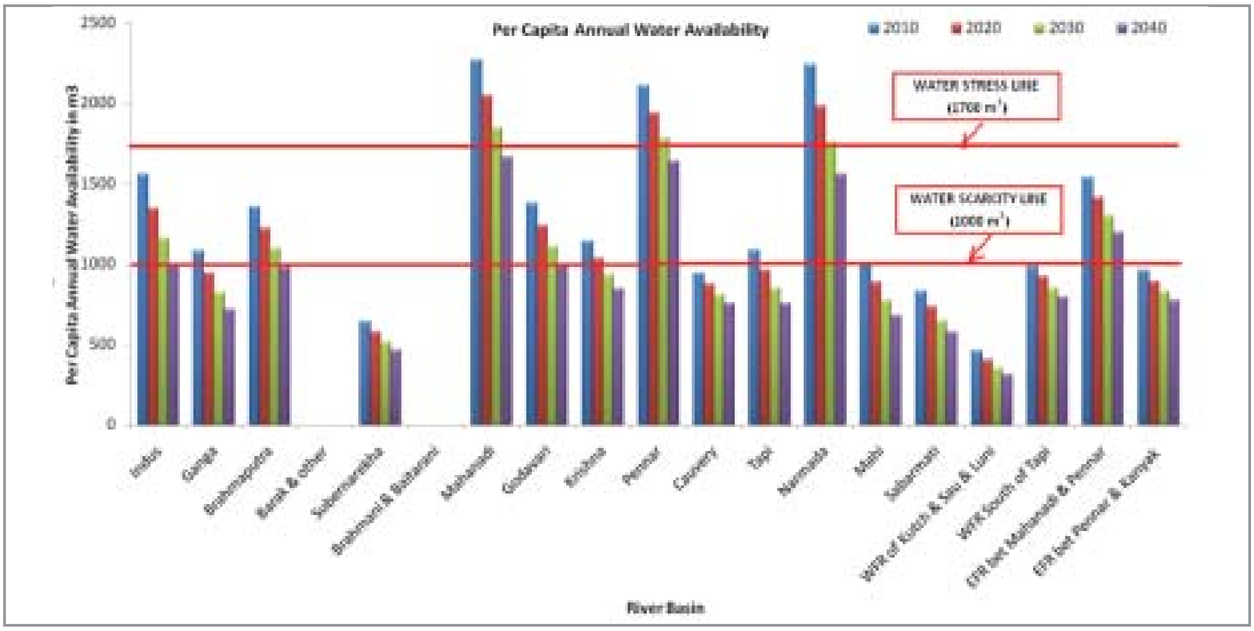


Figure 3.16: Per capita annual water availability

Impacts on water availability and demand

The impacts of climate change on water demand and the current water demand at national level for the irrigation, domestic, and industry sectors were also assessed. Projections of water demand for these sectors were made till 2040, under the present climate scenario, and taking into consideration the projected climate change scenario with respect to temperature and rainfall (using PRECIS output). Though available resource meets the present demand, in some river basins like Subarnarekha, Cauvery, Mahi, Sabarmati and west flowing rivers of Kuch, Sau, and Luni, water scarcity condition would be prevalent, which is also highlighted in Figure 3.16. Water scarcity line has been assessed at 1000 m^3 and the water stress line at 1700 m^3.

Climate data is essential to the design of water resource systems so as to take into account two aspects of hydrological processes: the extremes and the averages. The extremes, both floods and droughts, are the end results of climatic and hydrological causes. The results of an analysis for assessing vulnerability with respect to water availability across river basins were the basis for classifying various basins (Table 3.3). For example, Ganga downstream, Brahmaputra, and Surma Imphal showed high vulnerability towards climate change among all the river basins of East and North East India in A1B scenarios.

Table 3.3 : Vulnerability scale of water availability, by basin, in three different scenarios for the period of 2040, 2070, and 2100

Water availability	AIB scenario		
Year	2040	2070	2100
Ganga –Upstream	SV	V	V
Ganga Downstream	HV	HV	HV
Mahanadi	SV	V	SI
Brahmani	V	V	SI
Brahmaputra	HV	HV	HV
Surma Imphal	HV	HV	HV

V – Vulnerable, SV – Semi-Vulnerable, HV – Highly Vulnerable, SI- Semi-Invulnerable

Along with the assessments of water availability, it is also important to examine the impacts of climate change on water demand. A policy dialogue model PODIUM-Sim (details given in Box 3.3) has been used to compute the future sectoral water demand for households, irrigation, and industries for 2010, 2020, 2030, and 2040. The demand has been computed for different basins, which include 12 major basins (including Ganga, Indus, Narmada, Godavari) and seven minor basins. The projections of water demand have been made under present climate scenario as well as under projected climate change in India, factoring in the PRECIS data on temperature and rainfall (Table 3.4).

Box 3.3: About PODIUM -Sim

The PODIUM-Sim, a revised version of PODIUM (the cereal-based policy dialogue model), developed by the International Water Management Institute (www.iwmi.org) in 1999, is an interactive model studying the issues ranging from food demand and production to water supply and demand. It enables users to develop scenarios of water and food supply and demand with respect to various policy options at national level. It can generate scenarios at sub-national level, for example, at river basins or at administrative boundaries.

PODIUM-Sim consists of three main components: annual consumption–demand scenario development at the national level; seasonal production scenario development for irrigated and rain-fed agriculture at the sub-national level; and annual water supply scenario development at the sub-national level, seasonal water demand scenario development for the irrigation sector, and annual water demand scenarios for the domestic, industrial, and environmental sectors at the sub-national level.

Table 3.4: Water availability and demand (km^3)

	2010		2020		2030		2040	
	Total water availability	Total demand	Total water availability	Total demand	Total water availability	Total demand	Total water availability	Total demand
Indus	93.2	75.95	91.94	74.44	90.74	73.05	89.63	71.81
Ganga	492.26	257.41	491.67	261.50	491.45	266.69	492.59	275.97
Brahmaputra	53.52	9.19	53.85	9.79	54.22	10.48	54.66	11.31
Barak and other								
Subernarekha	11.58	6.41	11.7	6.80	11.85	7.24	12	7.73
Brahmani and Baitarani								
Mahanadi	72.33	19.38	72.47	20.08	72.62	20.85	72.8	21.69
Godavari	125.01	40.84	125.28	42.69	125.65	44.84	126.18	47.41
Krishna	91.45	40.98	91.46	42.16	91.5	43.40	91.55	44.70
Pennar	34.15	16.95	34.07	17.18	34	17.41	33.92	17.67
Cauvery	34.33	17.27	34.28	17.56	34.25	17.88	34.23	18.23
Tapi	23.55	8.80	23.61	9.29	23.67	9.82	23.77	10.39
Narmada	48.5	12.84	48.64	13.28	48.82	13.77	49.03	14.31
Mahi	8.26	5.44	8.27	5.53	8.27	5.62	8.3	5.73
Sabarmati	6.05	4.28	6.09	4.40	6.09	4.52	6.13	4.65
WFR of Kutch and Sau and Luni	33.33	41.38	33.87	42.47	33.87	43.67	34.32	45.01
WFR South of Tapi	57.64	15.30	58.2	16.26	58.2	17.30	58.54	18.42
EFR between Mahanadi and Pennar	33.57	17.86	33.44	18.27	33.44	18.72	33.36	19.19
EFR between Pennar and Kanyakumari	41.69	30.45	41.29	30.59	41.29	30.76	41.09	30.94

Water availability v/s water demand

A comparison of water availability with withdrawal for different years – 2010, 2020, 2030, and 2040 (Figure 3.17) – indicates that water availability exceeds total withdrawal for all basins except west flowing River of Kuch, Sau, and Luni. The maximum water withdrawal takes place from Ganga, Godavari, Indus, and Krishna river basins in all the years. Though at basin-level, the comparison between water availability and water demand indicates a comfortable position, but due to wide temporal and spatial variation in the availability of water, there exists a water crisis-like situation in most areas of the country. It is expected that due to climate change, water availability situation is likely to be aggravated.

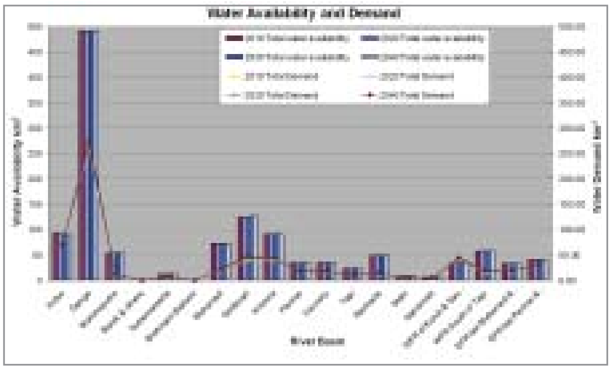


Figure 3.17: Water availability and demand

Impact of climate change on groundwater resources

An important source of water in India is groundwater. The estimation of groundwater resource is done mainly for dynamic groundwater potential (annually replenishment) by using data on precipitation and groundwater from other sources such as seepage from carrier channels and surface waterbodies, return seepage from irrigated fields during the monsoon and non-monsoon periods, and the draft component, mainly from different groundwater structures based on the minor irrigation statistics. The in-storage potential is computed, considering cumulative thickness of all the aquifer zones below the water level fluctuation, and this is considered as static storage. As per the present status, the dynamic groundwater potential of India is estimated as 433 BCM against which the groundwater development was only 115 BCM in 1995 but increased to 231 BCM in 2004. Thus, the groundwater development of the unconfined aquifer increased from 32% to 58%, but this has led to over-development (more than 100% of annual recharge) in some areas, totalling about 15% of the total country area. In addition to the dynamic groundwater resources available in the zone of fluctuation, which gets annually replenished from rainfall, there exists a sizable amount of groundwater below the zone of fluctuation in the unconfined aquifer as well as in the deeper confined aquifers. The in-storage potential computed up to a depth of 450 m in alluvial areas and 200 m in hard rock areas as a first approximation works out to the tune of 10,812 BCM, of which more than 90% lies in the alluvial aquifers of Ganga , Indus, and Brahmaputra basins.

A detailed groundwater recharge study of four water-stressed basins – Lower Indus, Sabarmati, Cauvery, and Godavari – indicates substantial increase in groundwater development over the past 10 years. Two of the river basins – Sabarmati and Indus – have recorded groundwater development of more than 100% of the annual replenishment in some areas. In such over-exploited areas, the water table shows continuous decline. Also, groundwater development in the coastal areas of Cauvery and Sabarmati basins will induce saline ingress; therefore, groundwater development in such critical areas would have to be regulated. Changes in rainfall pattern induced by climate change will influence the dynamic potential of some areas, leading to a change in the hydrodynamics of the unconfined aquifer system of different geological formations and may further affect the storage potential. Under the changed scenario, new groundwater management practices will need to be adopted, giving emphasis on utilizing monsoon run-off to create sub-surface storages wherever natural recharge has decreased.

Given that groundwater utilization is increasing at the rate of 2.5–4% throughout the country, it is pertinent to undertake detailed groundwater balance study and parameter estimation in terms of various inputs and outputs to quantify the impact of climate change under various scenarios. What has been studied thus far is a step towards the better understanding of the possible recharge potential during monsoon and non-monsoon period under different scenario of rainfall intensity and the hydrogeology of the area. The recharge from other sources can be added to the recharge potential calculated based on the same percentage between the monsoon and non-monsoon recharge and the recharge from other sources, based on the present groundwater assessment.

Vulnerability assessment and adaptation strategies: Studying the potential socio-economic impacts of climate change involves comparing two future scenarios: one with and the other without climate change. Uncertainties involved in such an assessment include (i) the timing, magnitude, and nature of climate change; (ii) the ability of the ecosystems to adapt either naturally or through managed intervention to the change; (iii) future increase in population and economic activities and their impacts on natural resources systems; and (iv) how society adapts through the normal responses of individuals, businesses, and policy changes. The uncertainties, long periods involved, and the potential for catastrophic and irreversible impacts on natural resources systems raise questions as to how to evaluate climate impacts and other policies that would affect or be affected by changes in the climate.

At present, few climate impact models explicitly consider how climate variability and change would affect groundwater recharge. Groundwater is poorly represented in the land-surface models (LSMs) incorporated in GCMs. Groundwater fluxes operating at a range of spatio-temporal scales require consideration. These fluxes include: (i) capillary flow from the water table to the root zone to sustain evapo-transpiration during dry periods, (ii) shallow groundwater discharge to local stream networks and other surface waterbodies (lakes and wetlands), (iii) deeper regional groundwater discharge to downstream river and wetlands, and (iv) submarine discharge in the coastal areas. Failure to consider groundwater fluxes as mentioned above can lead to errors in simulated river discharge and soil moisture in LSMs and offline hydrological models.

Fundamental constraints to both the representation of groundwater in climate models and the consideration of climate impact on groundwater includes limited groundwater observations in time and space as well as difficulty in accessing the data. There is therefore an urgent need to remove the above barriers through a concerted effort at the modelling levels, so as to enhance our understanding of the projected changes in ground water estimations.

Impacts of Climate Change on the Himalayan Glaciers

The Himalayas are often referred to as the “water towers of Asia” because they are the source of nine of the largest rivers. In the context of the evident challenge of growing water deficits, the impacts of climate change on the Himalayan glaciers have to be carefully assessed. There is a great degree of uncertainty about the extent to which the overall glacier melting is occurring. But the Himalayan glaciers are generally experiencing rapid and unprecedented rates of melting; retreating faster than nearly all other glacier regions around the world; and retreating at highly variable rates, depending on glacier size, orientation, and climate zone. Possible reasons for the melting of the glaciers include human-induced CO_2 emissions and growing levels of short-lived aerosols in the air, snow, and on glaciers. More conclusive scientific evidence is, however, required.

Glaciers in the eastern and central parts of the Himalayas are expected to be especially sensitive to present atmospheric warming, due to their summer accumulation type nature. New satellite LIDAR observations reveal for the first time that 3 km thick atmospheric brown cloud (ABC) surround the southern flank of the Himalayas, subjecting the air to intense solar heating. Coupled ocean–atmosphere GCMs with both GHG and ABC forcing suggest that the ABC solar heating amplifies the GHGs warming by a factor of 2 at elevated levels (3–6 km). Another area of concern is extremely limited water storage capacity. South Asia in general and countries like India store less than 250 m^3 of water per capita compared to more than 5000 m^3 per capita in countries like Australia and USA. The lack of water storage capacities leaves the already vulnerable populations at great risk of fluctuating water flows and changing monsoon patterns. There is a huge potential in the south Asian countries to build constructed and sustain natural storage capacities. The melting of the Himalayan glaciers is a phenomenon that clearly deserves greater study and closer monitoring, but the existing reality of deglaciation is already having downstream impacts. The first and most obvious concern with regard to deglaciation is the threat of diminishing water flows to the hundreds of millions of the people in the downstream regions of India and the neighbouring countries. The regional and micro-climate changes are manifesting themselves not only in the melting of glaciers and diminished sources of water to the major river systems, but also in changes in monsoon patterns, variations in overall precipitation levels, and increased occurrence of extreme weather events.

Considering various aspects of flow regimes of the Himalayan rivers and the different views, it can definitely be mentioned that the reduction in river discharge is almost certain under the future warming scenarios, which may either be due to the reduction in contribution from glaciers or due to reduction in monsoonal precipitation. However, the studies do not cover all the micro-climatic zones and different river basins of the Himalayas, and a detailed study is required to estimate future water flow patterns in the Himalayan rivers.

A study "**Himalayan Glaciers: A State-of-Art Review of Glacial Studies, Glacial Retreat and Climate Change**" was conducted to assess the state of glaciers in the Indian context. This study was carried out by an eminent expert in the field of glacial studies. Key findings of the study are as follows.

1. All the glaciers under observation, during the last three decades of the 20th century, have shown cumulative negative mass balance.

2. Degeneration of the glacier mass has been the highest in Jammu and Kashmir (single glacier, 10-year record), relatively lower in Himachal Pradesh (three glaciers, 10-year record), even lower in Uttarakhand (one glacier, 10-year record), and the lowest in Sikkim (one glacier, 10-year record), thus clearly showing a declining trend from north-west to north-east.

3. Irrespective of the latitudinal differences, glacier melt contributes to about 25–30% of the total discharge of glacier ice. Maximum discharge takes place from mid-July to mid-August. On an average, the sediment load producing capacity of the glacier ice in the Himalayas has been found to be of the order of 30 tonnes of ice per day per square km^2 during the melt season in a granite/gneissic terrain.

4. Glaciers in the Himalayas, over a period of the last 100 years, behave in contrasting ways. As an example, Sonapani glacier has retreated by about 500 m during the last 100 years. On the other hand, Kangriz glacier has practically not retreated even an inch in the same period. Siachen glacier is believed to have shown an advance of about 700 m between 1862 and 1909, followed by an equally rapid retreat of about 400 m between 1929 and 1958, and hardly any retreat during the last 50 years. Gangotri glacier, which had hitherto been showing a rather rapid retreat along its glacier front, at an average of about 20 m per year up to 2000, has since slowed down considerably, and between September 2007 and June 2009 is practically at a standstill.

MoEF and ISRO have jointly carried out a study to monitor more than 2000 glaciers well distributed throughout the Himalayas, for their advance/retreat over a period of 15 years. The study is based on satellite data analysis and field expeditions. This study indicates that 76% of glaciers have shown a retreat in area, 7% have advanced, while 17% are static. This study does not indicate conclusively any uniform response of the Himalayan glaciers to climate change.

The major conclusion from these studies was that it was premature to make a statement that glaciers in the Himalayas are retreating abnormally because of global warming. A glacier is affected by a range of physical features and a complex interplay of climatic factors. These findings warrant a more detailed study related to glaciers.

Impacts of Climate Change on Forests and Biodiversity

The impacts of climate change on forests in India are assessed based on the changes in area under different forest types, shifts in boundary of forest types, and net primary productivity (NPP). The present assessment was based on (i) spatial distribution of current climatic variables, (ii) future climate projected by relatively high-resolution regional climate models for two different periods for the A1B climate change scenario, and (iii) vegetation types, NPP, and carbon stocks as simulated by the dynamic model IBIS v.2, or Integrated Biosphere Simulator.

The IBIS model is designed around a hierarchical, modular structure, which is based on four modules, namely, (i) the land surface module, (ii) vegetation phenology module, (iii) carbon balance module, and (iv) vegetation dynamics module. These modules, though operating at different time steps, are integrated into a single physically consistent model. The state description of the model allows trees and grasses to experience different light and water regimes, and competition for sunlight and soil moisture determines the geographic distribution of plant functional types and the relative dominance of trees and grasses, evergreen and deciduous phenologies, broadleaf and conifer leaf forms, and C3 and C4 photosynthetic pathways.

Scenarios of climate change: SRES scenario A1B is considered for two future time-frames: (i) timeframe of 2021–50 (atmospheric CO_2 concentration reaches 490 ppm), which is labelled as "2035" and (ii) timeframe of 2071–2100 (atmospheric CO_2 concentration reaches 680 ppm), which is labelled as "2085". Observed climatology for the period 1961–91 was treated as the baseline for the simulations.

Changes in the distribution of forests

The vegetation distribution simulated by IBIS for baseline and A1B scenario in the simulation grids (as shown in Figure 3.18) illustrates an expansion of tropical evergreen

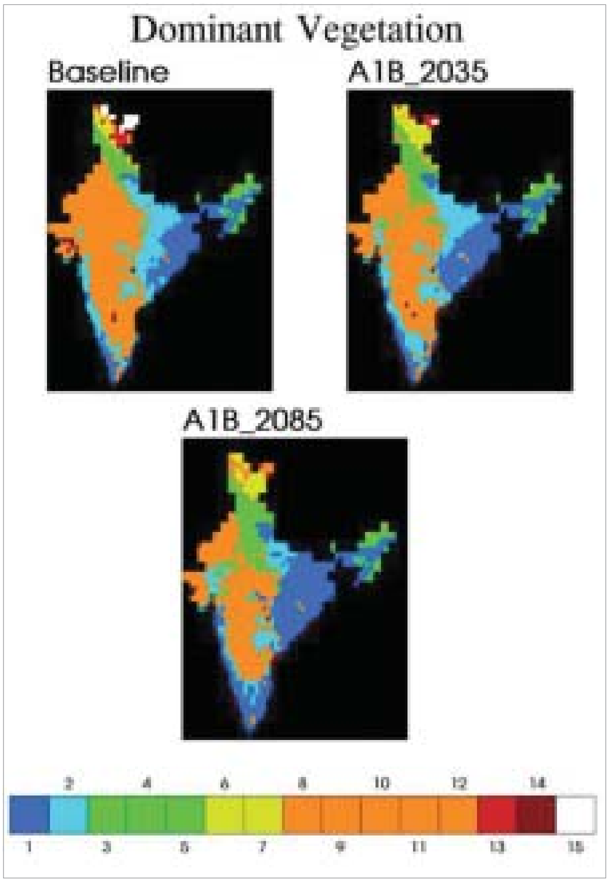


Figure 3.18: Forest type distribution and extent simulated by IBIS for the baseline case and A1B (2035 and 2085) scenarios (VT – refers to vegetation types. The numbers refer to the following vegetation types. 1: tropical evergreen forest/woodland, 2: tropical deciduous forest/ woodland, 3: temperate evergreen broadleaf forest /woodland, 4: temperate evergreen conifer forest/woodland, 5: temperate deciduous forest/woodland, 6: boreal evergreen forest/woodland, 7: boreal deciduous forest/woodland, 8: mixed forest/woodland, 9: savanna, 10: grassland/steppe, 11: dense shrubland, 12: open shrubland, 13: tundra, 14: desert, 15: polar desert/rock/ice)

forests (IBIS vegetation type 1) in the eastern India plateau in the A1B scenario. Similar trend is observed in the Western Ghats. It is interesting to note that there is almost no change in the vegetation type in the North East. Further, there is a slight expansion of forests into the western part of central India.

Impact on net primary productivity (NPP) and soil organic carbon (SOC)

The NPP tends to increase over India for the A1B scenario (Figure 3.19). It increases by an average of 30.3% by 2035, and by 56.2% by 2085 for A1B scenario. Notably, the increase is higher in the north-eastern part of India due to warmer and wetter climate predicated there.

A trend similar to NPP distribution is simulated for soil organic carbon (SOC), which is to be expected as increased NPP is the primary driver of higher litter input to the soil. However, the quantum of increase compared to baseline in this case is lower. This increase is less due to the inertia of the SOC pool and increased soil respiration. The estimates for both NPP and SOC increase should be viewed with caution as IBIS, compared with other dynamic vegetation models, tends to simulate a fairly strong CO_2 fertilization effect. This can partly be explained by the fact that the nitrogen cycle and acclimation of soil microbiology to the higher temperatures are not explicitly taken into account in IBIS. It also does not simulate forest fires dynamically, which are very common especially in dry deciduous forests of India. IBIS does not simulate changed pest attack dynamics, and thus, the impact of increased or decreased pest attack in a changed climate is not included.

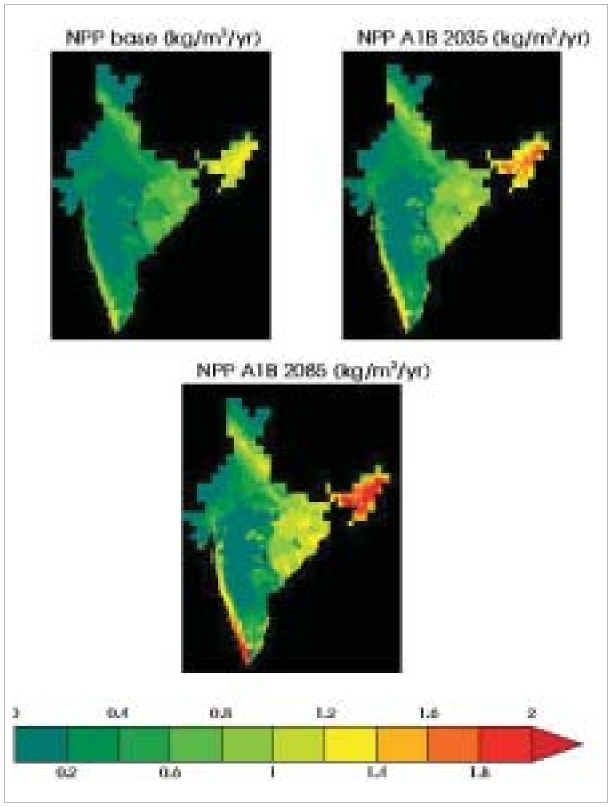


Figure 3.19: Net primary productivity distribution (kgC/m2/year) simulated by IBIS for baseline and A1B scenarios

Implications of climate change for biodiversity

Climate change is expected to increase species losses. Changes in phenology are expected to occur in many species. The general impact of climate change is that the habitats of many species will move poleward. Species that make up a community are unlikely to shift together. Ecosystems dominated by long-lived species will be slow

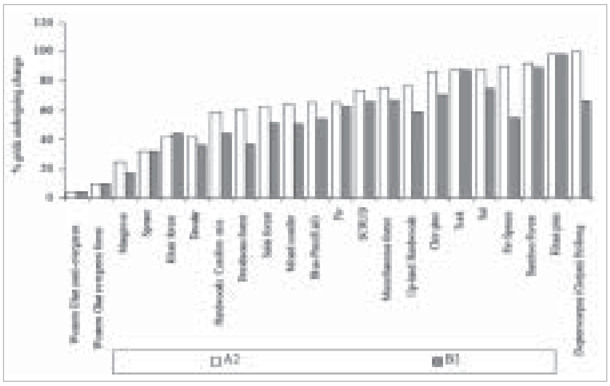


Figure 3.20: 82 % of the forest grids in sal and teak forests show shift in forest type (in both A2 and B2 scenarios)

to show evidence of change and slow to recover from the climate-related stress.

Climate change and modelling studies on tree species like sal *(Shorea robusta)*, teak *(Tectona grandis)*, eucalyptus, and pine (Pinus spp.) have been undertaken for A2 and B2 climate change scenario. Test run studies on teak and sal trees, highly characteristic of central India, have indicated that there would be a net increase in primary productivity with increase in temperature and rainfall, but this would also lead to a die-back with the induced stress to nutrient availability (Figure 3.20). Enhanced levels of CO_2 are expected to lead to an increase in the NPP of forest ecosystems, with more than 75% of the grids showing an increase in NPP. Even in a relatively short span of about 50 years, most of the forest biomes in India seem to be highly vulnerable to the projected change in climate. Further, it is projected that by 2085, 77% and 68% of the forest grids in India are likely to experience shift in forest types under A2 and B2 scenarios, respectively (Figure 3.21). Indications point towards a shift to wetter forest types in the north-eastern region and drier forest types in the central and north-western region, in the absence of human influence. Increasing atmospheric CO_2 concentration and climate warming could also result in the doubling of NPP under the A2 scenario and nearly 70% increase under the B2 scenario.

Vulnerability of Indian forests

Forests in India are already subjected to multiple stresses, including over-extraction, insect outbreaks, livestock grazing, forest fires, and other anthropogenic pressures. Climate change will be an additional stress. Forests are likely to be more vulnerable to climate change. Thus, vulnerability map is developed to assess the vulnerability of different forest types and regions. A grid is marked vulnerable if there is a change in vegetation, as simulated between the baseline and the future (both 2035 and 2085, and A1B SRES scenario, in this case) vegetation. This means that the future climate may not be optimal to the present vegetation in those grids. The distribution of this vulnerability in the country is shown in Figure 3.22.

Left panel in the figure is for timeframe of 2021–50. Here, 326 (30.6%) grids, out of a total number of 1064 grids, are projected to be vulnerable. The right panel is for the timeframe of 2071–2100. In this case, 489 (45.9%) grids

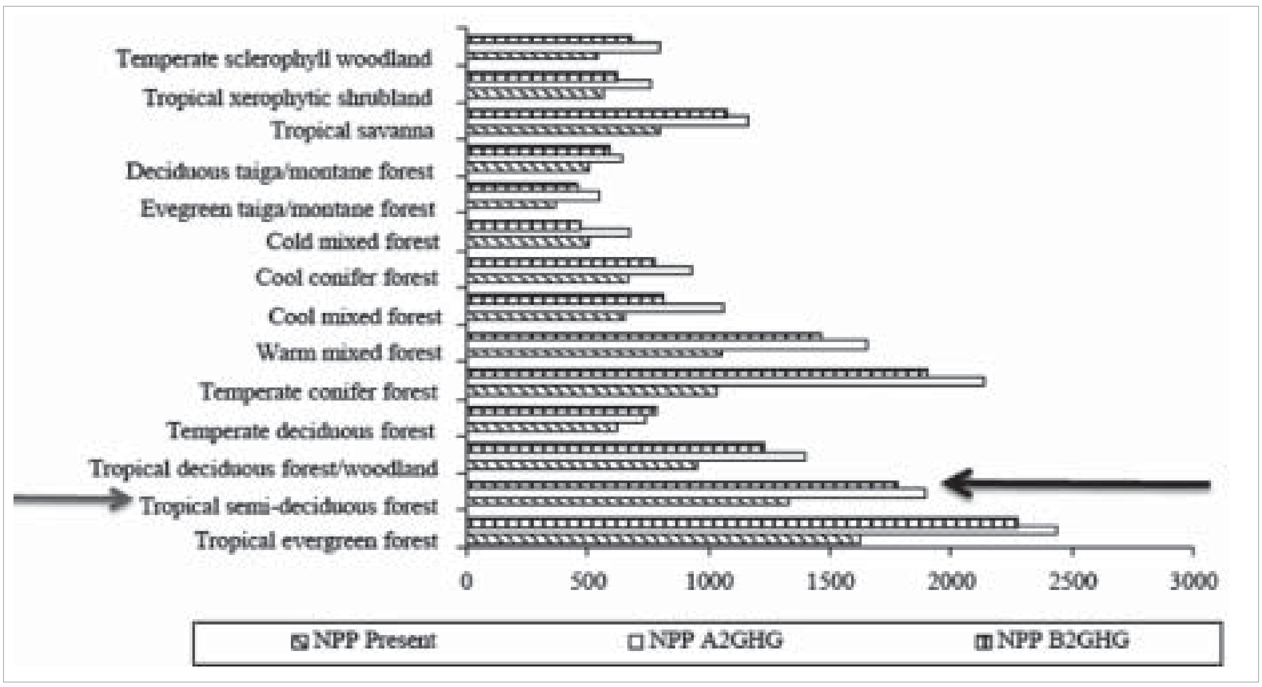


Figure 3.21: Net primary productivity of sal and teak forests likely to rise (in A2 and B2 scenarios)

are projected to be vulnerable. In turn, all forest areas in such vulnerable grids are projected to be vulnerable to climate change. A digital forest map of India was used to determine the spatial location of all the forested areas. This map was based on a high-resolution mapping (2.5’ × 2.5’), wherein the entire area of India was divided into over 165,000 grids. Out of these, 35,899 grids were marked as forested grids (along with the forest density and the forest type). The projected change in vegetation information was combined with the spatial location of the Forest Survey of India (FSI) grids (Figures 3.23 and 3.24).

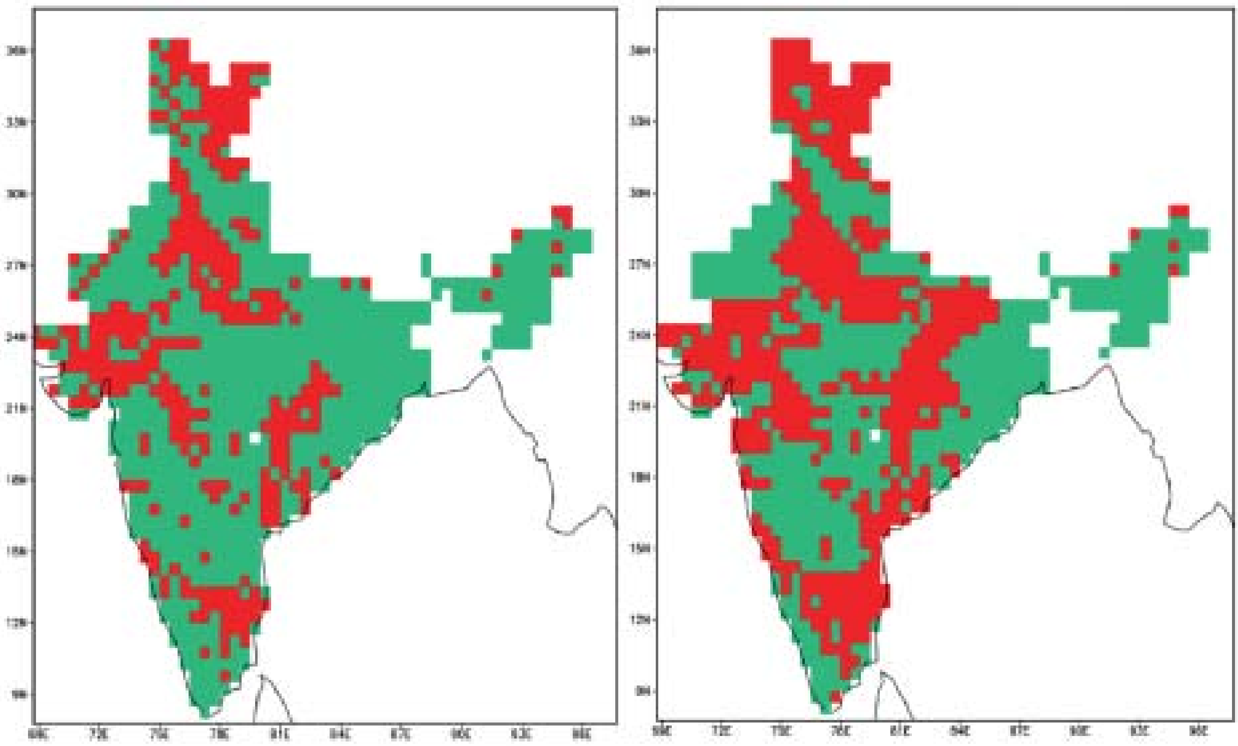


Figure 3.22: Vulnerable grids (marked red) in the A1B scenario

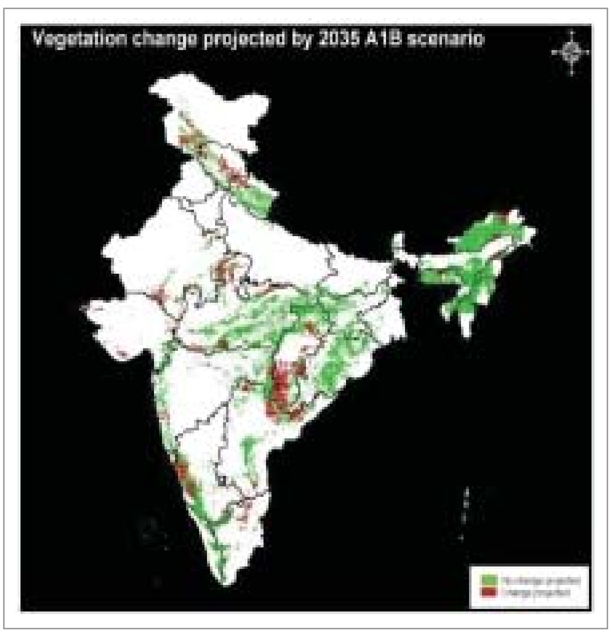


Figure 3.23: All forested grids in India (as per FSI, 2001) are shown in colour (red or green): red indicates that a change in vegetation is projected at that grid in the time period of 2021–50, and green indicates that no change in vegetation is projected by that period.

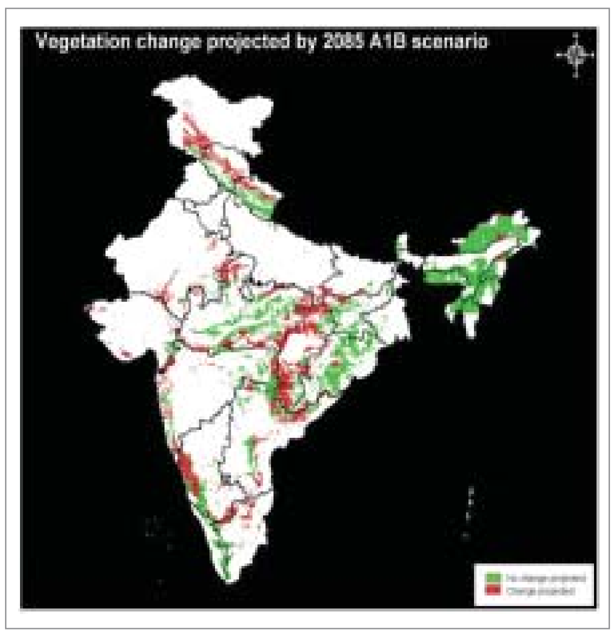


Figure 3.24: All forested grids in India (as per FSI, 2001) are depicted in colour (red or green): red indicates that a change in vegetation is projected at that grid in the time period of 2071–2100, and green indicates that no change in vegetation is projected by that period.

Implication of climate impact assessment

The assessment of climate impacts showed that at the national level, about 45% of the forested grids are likely to undergo change. Vulnerability assessment showed that the vulnerable forested grids are spread across India. However, their concentration is higher in the upper Himalayan stretches, parts of central India, northern Western Ghats, and Eastern Ghats. In contrast, north-eastern forests, southern Western Ghats, and the forested regions of eastern India are estimated to be least vulnerable. Currently, within the forested area of 69 Mha, only 8.35 Mha is categorized as very dense forest. More than 20 Mha of forest is monoculture, and more than 28.8 Mha of forests are fragmented (open forest) and have low tree density. Low tree density, low biodiversity status as well as higher levels of fragmentation contribute to the vulnerability of these forests. Western Ghats, though a biodiversity hotspot, has fragmented forests in its northern parts. This makes these forests additionally vulnerable to climate change as well as to increased risk of fire and pest attack. Similarly, forests in parts of western as well as central India are fragmented and have low biodiversity. At the same time, these are the regions that are likely to witness a high increase in temperature and either decline or marginal increase in rainfall. Most of the mountainous forests (sub-alpine and alpine forest, the Himalayan dry temperate forest, and the Himalayan moist temperate forests) are susceptible to the adverse effects of climate change. There is a need to explore win-win adaptation practices in such regions such as anticipatory plantations, sanitary harvest, and pest and fire management. Forests are likely to benefit to a large extent (in terms of NPP) in the northern parts of the Western Ghats and the eastern parts of India, while they are relatively adversely affected in the western and central India. This means that afforestation, reforestation, and forest management in the northern Western Ghats and eastern India may experience carbon sequestration benefits. Hence, in these regions, a species-mix that maximizes carbon sequestration should be planted. On the other hand, in the forests of the western and central India, hardy species, which are resilient to increased temperature and drought risk, should be planted, and care should be taken to further increase forest resilience.

Adaptation measures

Forest conservation and enhancement are the stated objectives of the national policy. Various policy initiatives have resulted in the increase in the forest cover and a reduction in the per capita deforestation rate. The National Forests Policy envisages peoples' participation in the development of degraded forests to meet their fuel, fodder, and timber needs, as well as to develop the forests for improving the environment through Joint Forest Management. India has implemented a large number of progressive policies, programmes, and measures to conserve and develop forests, wildlife, mangroves, and coral reefs, examples being the Forest Conservation Act, 1980, the National Forest Policy, 1988, the Wildlife Act, Joint Forest Management, Social Forestry, banning of timber extraction in reserve forests, improved cook-stove programme, and use of biogas to conserve fuelwood. Similarly, there are conservation programmes for mangroves, coral reefs, and lake ecosystems. The FSI monitors changes in the forest area. All these measures have led to some stabilization of the forest area, a reduction in deforestation, and afforestation, significantly contributing to the conservation of the forest carbon sink. All these preparations will act as a buffer for the forest-dependent communities against the challenges posed by climate change. The Ministry of Environment and Forests (MoEF) notified the constitution of Compensatory Afforestation Fund Management and Planning Authority (CAMPA) on 23rd April 2004 for management and use of the fund generated by levying cost of compensatory afforestation in equivalent forest lands offered by the user agencies or in degraded land whenever there is a diversion of forest lands for non-forestry purposes, under the Forest (Conservation) Act, 1980.

Adaptation strategies

There is a need for developing and implementing adaptation measures to enable forest ecosystems to cope with climate risks. Many "win-win" or "no-regret" adaptation practices could be considered for implementation. A few pilot adaptation projects could be launched, incorporating the "win-win" adaptation practices, particularly in the most vulnerable regions identified in this assessment. A few examples of adaptation practices include: (i) Modifying the forest working plan preparation process and incorporating the projected climate change and likely impacts, (ii) Initiating research on adaptation practices, covering both conservation and forest regeneration practices, (iii) Linking Protected Areas and forest fragments, (iv) Anticipatory planting of species along the altitudinal and latitudinal gradient, (v) *In situ* conservation, (vi) Adopting mixed species forestry in all afforestation programmes, (vii) Incorporating fire protection and management practices and implementing advance fire warning systems.

Impacts of Climate Change on Agriculture

The agriculture sector, including crop, animal husbandry, fisheries, and agro-processing, is vital for the food and nutritional security of the nation. The contribution of the agriculture sector to the national gross domestic product (GDP) has declined from 19% in 2004/05 to 14.2% in 2010/11, while overall GDP has grown by an average of 8.62% during 2004/05 to 2010/11. This rapid decline is essentially due to high growth experienced in the industry and services sector, in a fast growing and structurally changing economy of India. However, this sector provides the underpinning for the food and livelihood security and support for the economic growth and social transformation of the country. Nearly two-third of country's population depends directly or indirectly on the agriculture sector for their livelihood.

With about 60% of the cultivated area as rain-fed, the agricultural production is strongly influenced by the movement of south-west monsoon. In the recent past, out of 526 meteorological districts, 215 districts (41%) received excess/normal rainfall and the remaining 311 districts (59%) received deficient/scanty rainfall during the season, which reflected adversely on the overall production of kharif crops, especially, rice and the coarse grains.

The livestock and fisheries sector contributed over 4.07% to the total GDP during 2008/09 and about 29.7% to the value of output from total agricultural and allied activities. In 2009/10, this sector produced 112.5 million tonnes of milk, 59.8 billion eggs, 43.2 million kg wool, and 4.0 million tonnes of meat. India continues to be the largest producer of milk in the world, with its production increasing from 17 million tonnes in 1950/51 to about 112.5 million tonnes in 2009/10. The per capita availability of milk has also increased from 112 grams per day in 1968/69 to 263 grams per day in 2009/10. It is, however, still low compared to the world average of 279.4 grams per day (as per the Food and Agriculture Organization Statistical Database (FAOSTAT) 2009 database). Poultry development in the country has shown a steady progress over the years. India ranks third in egg production in the world as per the FAOSTAT data for 2008. Egg production increased from 21 billion in 1990/91 to 56 billion in 2008/09. India is the third largest producer of fish and the second largest producer of freshwater fish in the world. Fish production has increased from 41.57 lakh tonnes (24.47 lakh tonnes for marine and 17.10 lakh tonnes for inland fisheries) in 1991/92 to 76.08 lakh tonnes (29.72 lakh tonnes for marine and 46.36 lakh tonnes for inland fisheries) in 2008/09.

Growth in the production of agricultural crops depends upon acreage and yield. Given the limitations in the expansion of acreage, the main source of long-term output growth is improvement in yields. The food and nutritional security of India currently depends, to a great extent, on the production of wheat and rice, which together constitute 78% of the total food grain production (in 2009/10), whereas production of coarse cereals such as jowar, bajra, maize, ragi, millets, and barley constituted only 15% in the same year. The growth, yield, and production of rice and wheat suggest that the yield levels have plateaued, and there is a need for renewed research to boost production and productivity. The area under coarse cereals has shown a decline over the years, whereas the yield has shown significant improvement despite decrease in area in all the major coarse cereals except maize. The nutritional value of coarse cereals is also gradually being realized. It is necessary to promote the production of these crops and promote their cultivation, particularly in rain-fed areas.

Decreasing crop diversity

Diversity in agricultural crops is an important measure of the society's ability to face the changes in the natural environment. In a bid to maximize profits, there is now a tendency among farmers to specialize in a few crops, usually commercial crops. As a result, crop diversity has reduced. Today, more than 50% of food requirements are derived form just three crops (maize, rice, and wheat) and 95% of energy requirements from less than 30 crop species.

Crop diversity is important for many reasons. It can be used to combat risks that farmers face from pests, diseases, and variations in climate. Specialization in just one crop increases the risk of huge losses due to crop failure. The mono cultivation of any one crop results in the depletion of organic content and micronutrients in the soil, calling for higher consumption of fertilizers and chemicals. The loss of crop diversity has been associated with greater dominance of high yielding varieties of rice and wheat, which are also more water-intensive and also energy-intensive. Another impact of crop diversity is on nutrition. The diversity in diets can only be ensured by having greater diversity of crops in the fields.

The net availability of food at any given time depends on a number of local, regional, national, and international factors. Climate change associated variables such as

CO_2 and temperature can influence food availability through their direct effect on growth processes and yield of crops. In addition, it may also impact crop production through indirect effects caused by, for example, change in rainfall-induced irrigation availability, soil organic matter transformation, soil erosion, changes in pest profiles, and decline in arable areas due to the submergence of coastal lands. Equally important determinants of food supply are socio-economic environment, including government policies, capital availability, prices and returns, infrastructure, land reforms, and intra- and international trade, which might be affected by climatic change.

Vulnerability of agriculture

As already mentioned, crop diversity is an important indicator of agricultural vulnerability. However, climate is a primary determinant of agricultural productivity, as crop yields are influenced by many environmental factors like temperature and precipitation, which may act either synergistically or antagonistically with other factors in determining yields. Changes in climate are expected to affect hydrological balances, input supplies, livestock production, and other components of agricultural systems. However, the nature of these impacts and the responses of human beings to them are uncertain and complex. The complexity and uncertainty are governed, on the one hand, by the impact of changes in climatic parameters (such as temperature, CO_2, and precipitation) and the frequency of extreme events like drought, flood, and wind storms, which directly affect the crop and livestock yields and, on the other hand, by the kind of adaptation responses to the climate changes. These changes even may also change the type, frequencies, and intensities of various crop and livestock, pests, the availability and timing of irrigation water supplies, and the severity of soil erosion. While the degree of vulnerability is a function of the magnitude and the rate of variation in climate exposure, agricultural systems with a stronger adaptive capacity are likely to be less vulnerable to climate change. Agricultural systems are considered to be dynamic because producers and consumers are incessantly responding to changes in crop and livestock yields, input prices, food prices, market demand, resource availability, and technological changes. Humans may respond to these changes either by changing the production or consumption pattern of agricultural commodities, diversifying the cropping system, adopting indigenous technologies or trying some innovations for adaptation to climate change.

PRECIS outputs on future climate scenarios – A1B-2030 and A1B-2080 – indicated a significant increase in temperature and changes in rainfall, which will have large spatial and temporal variations (Table 3.5). Overall, the temperature increases are likely to be much higher in winter (rabi) season than in rainy season (kharif). Precipitation is likely to increase in all time slices in all months, except during December–February when it is likely to decrease. Eastern parts of India are likely to receive more rains, while southern plateau and Rajasthan are projected to receive less rains. It is projected that by the end of the 21st century, rainfall over India will increase by 10–12%, and the mean annual temperature will increase by 3–5°C. The warming is more pronounced over land areas, with the maximum increase over northern India.

These changes are likely to increase the pressure on Indian agriculture, in addition to the ongoing stresses of yield stagnation, land use, competition for land, water, and other resources, and globalization. It is estimated that by 2020, food grain requirement would be almost 30–50% more than the current demand. This will have to be produced from same or even shrinking land resource due to increasing competition for land and other resources by non-agricultural sector. Any perturbation in agriculture can considerably affect the food systems and thus increase the vulnerability of a large fraction of the resource-poor population. Adaptation strategies, if practised, have the potential of nullifying this loss completely in short term

Table 3.5: Changes in temperature and rainfall for PRECIS A1B-2030, A1B-2080 scenarios

Scenarios	A1B-2030	A1B-2080	A1B-2030	A1B-2080
Crop growing season	Kharif		Rabi	
Increase in minimum temperature (°C)	1.36–3.28	3–6.6	1.85–3.07	4.13–6.17
Increase in maximum temperature(°C)	0.79–2.82	2.35–6.31	0.85–2.96	2.74–6.1
Rainfall (% change)	–22 to 60%	–46 to >60%	–60 to 36%	–21 to 60%

(2020) but later these are less effective. Thus, there should be a comprehensive plan for adaptation to climate change.

Impact of climate change on Indian agriculture (including livestock): methods and models

A combination of field studies and simulation models with comprehensive input data sets has been used to assess possible impacts of climatic variability and climate change on Indian agriculture. This has been supplemented with statistical tools and available historical data and analysis.

Field experimentations using controlled environments such as open top chamber (OTC) or free atmospheric carbon dioxide enrichment (FACE) and free atmospheric temperature elevation (FATE) facilities, temperature gradient tunnels (TGTs), phytotron, and greenhouses are increasingly being used to understand the impact of temperature, humidity, and CO_2 on crop growth and productivity. The interactive effects of CO_2, rainfall, and temperature can be best studied through the use of crop growth simulation models. These models simulate the effect of daily changes on weather (including those caused by climatic change), for any location, on growth and yield of a crop through the understanding of crop physiology and soil processes. Several crop models have also been used in India for impact assessment of climatic variability and climate change. Crop growth simulation models, which share a common input data and format, have been developed and embedded in a software package called Decision Support System for Agro-technology Transfer (DSSAT). The DSSAT Cropping System Model simulates growth and development of a crop over time, as well as the soil water, carbon, and nitrogen processes and management practices. For rice, the ORYZA series of models have been effectively used. Indian models, such as the Wheat Grown Simulator (WTGROWS) for wheat, have been the basis of a large number of studies.

The simulation analysis using InfoCrop models were carried out with inputs of the gridded weather data (IMD), soil data , climate change scenario data (PRECIS), crop management and genetic coefficients for respective crop varieties, wherever applicable. For plantation crops, the research information from studies in controlled environments was used to fine-tune data in the simulation models and develop regression models for studying the climate change impacts on its productivity. InfoCrop is a generic dynamic crop simulation model designed to simulate the effects of weather, soil, agronomic management, and major pests on crop yield and the associated environmental impacts. The model is particularly designed for integrated assessment of the effects of variety of elements, pests, soil, weather, and management practices on crop yield; water, nitrogen, and carbon dynamics; and GHG emission in aerobic as well as anaerobic conditions, especially for tropical regions.

In the case of livestock, Temperature Humidity Index (THI) has been used to represent thermal stress due to the combined effects of air temperature and humidity on livestock. THI > 75 affects milk production of high producing European, cross-breds, and buffaloes. THI > 80 severely impacts livestock health and productivity. THI for different locations of India has been calculated using average THI.

Impact assessment

Impact of climate change on crop: A rise in atmospheric CO_2 to 550 ppm under controlled environment conditions (FACE and OTC) enhanced the yields of wheat, chick pea, green gram, pigeon pea, soybean, tomato, and potato between 14% and 27% (Figure 3.25). These enhancements were largely due to the increase in the number of storage organs. In most of the crops, this was accompanied by a small reduction (2–10%) in the protein content. In plantation crops like coconut, arecanut and cocoa, increased CO_2 led to higher biomass.

In the case of rice hydrid and its parental lines, elevated CO_2 affected positively in few grain quality traits such as head recovery, test weight, proportion of high density grains, and germination characteristics but adversely affected traits like aroma, gelatinization temperature (measurement of cooking quality), and protein and micronutrient contents. Sunflower hybrids grown under elevated CO_2 conditions inside open top chambers showed a significant increase in biomass (61–68%) and grain yield (36–70%) but adversely affected the quality of the produce in terms of protein and micro-nutrient contents.

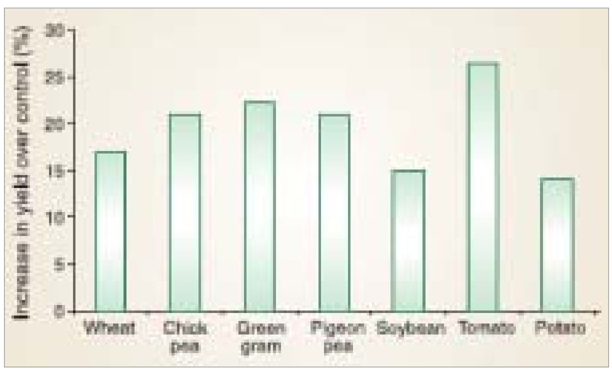


Figure 3.25: Increase in yield of different crops as CO_2 concentration was enhanced to 550 ppm

Magnitude of the impact of climate change on wheat production in India assesed through simulation studies indicated that an increase in 1°C in mean temperature, associated with CO_2 increase, would not cause any significant loss to wheat production in India, if simple adaptation strategies such as change in planting date and varieties are used. Such strategies can reduce the extent of loss caused by high temperature. The benefits of such simple adaptation strategies, however, gradually decrease as temperature increases to 5°C. In the absence of adaptation and CO_2 fertilization benefits, a 1°C increase in temperature alone could lead to a decrease of 6 million tonnes of wheat production. This loss is likely to increase to 27.5 million tonnes at 5°C increase in mean temperature. Increase in CO_2 to 450 ppm is likely to reduce these losses by 4–5 million tonnes at all temperatures.

Increase in temperature during grain development phase of rice and wheat affects their grain quality. High temperature reduced 1000-grain weight and amylose content and adversely affected important quality traits such as grain elongation and aroma in basmati cultivars. Increase in temperature from 23°C to 31°C resulted in a sharp decline in amylose content due to change in starch composition, which ultimately will result in stickiness in the cooked rice. In wheat, high temperature reduced both 1000-grain weight and hecto-litre weight, and increased grain protein content. The impact was more pronounced on bread wheat than durum wheat cultivars.

Field experiments in TGTs and by varying dates of sowing were done to quantify the effects of increase in temperature on growth and yield of rice, wheat, potato, green gram, soybean, and chickpea (Figure 3.26). An increase of temperature from 1ºC to 4ºC reduced the grain yield of rice (0–49%), potato (5–40%), green gram (13–30%), and soybean (11–36%). The linear decrease per degree Centigrade temperature increase was 14%, 9.5%, 8.8%, 7.3%, and 7.2% in rice, potato, soybean, wheat, and green gram, respectively. Chickpea, however, registered a 7–25% increase in seed yield by an increase in temperature up to 3°C, but yield was reduced by 13% at 4°C increase in temperature. Rice showed no significant change in yield upto an increase of 1°C temperature.

InfoCrop-maize coupled with holometabolous population dynamics model, used to simulate population dynamics of maize stem borer, *Chilo partellus*, as well as crop-pest interactions showed that as the larval population increased, the crop yield decreased. Simulation of pest dynamics and crop yield for many years showed decline in maize productivity as well as in larval population of maize stem borer. Yield of healthy crop consistently declined from 5156 kg/ha at present to 3172 kg/ha with

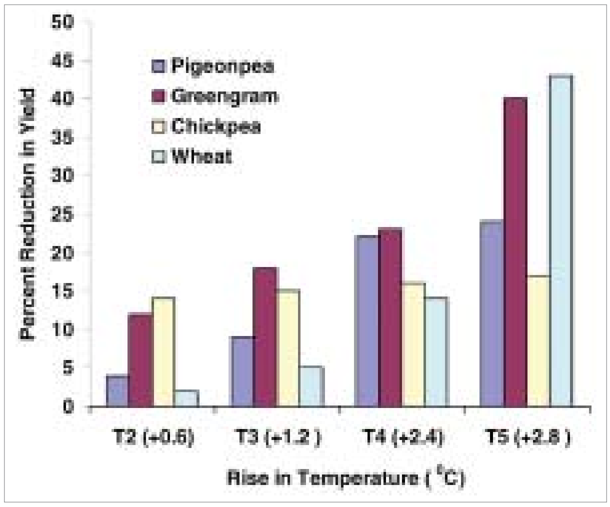


Figure 3.26: Effect of rise in temperature on different crops grown in temperature gradient tunnels

3°C rise in daily mean temperature. Likewise, the yield of pest-stressed crop continuously decreased from 4773 kg/ha to 2701 kg/ha with 3°C rise in daily mean temperature. Larval population of maize stem borer also depicted consistent decline with rise in temperature. The pest population declined by 13.7–43.1% with a rise of 0.5–3°C in temperature over the current daily mean temperature. In accordance with the decline in pest population, stem borer-induced yield losses also decreased. Although the severity of maize stem borer may decline with increase in temperature, concomitantly, net productivity of maize will also be reduced.

Legumes are major rain-fed agro-ecosystems of the country. In the simulation studies conducted using InfoCrop models for soybean and groundnut, and DSSAT CROPGRO model for chickpea with projected changes in temperature, CO_2, and rainfall, the current (baseline, 1961-90), A1B (2021–50), and A1B (2071–2100) scenarios indicated a positive impact of future climate (combined change in temperature, rainfall, and CO_2 levels) on their productivity. Average simulated rain-fed yields under current (baseline) scenario were 2144 kg/ha, 2473 kg/ha, and 1948 kg/ha for soybean, groundnut, and chickpea, respectively. As compared to current yields of soybean, 10%, and 8% increase in yield was observed in A1B (2021–50) and A1B (2071–2100), respectively (Figure 3.27). In case of groundnut, except for A1B (2071–2100), which showed a decline of 5% in yield, rest of the scenarios showed 4–7% increase in rain-fed yield as compared to the

Box 3.4: Assessment of the impacts of climate change on rice and wheat in Punjab

The geographical area of Punjab is only 1.53 % of the country, yet it contributes nearly 70% of wheat and 55% of rice to the central pool of food grains. It is, therefore, important to study agricultural vulnerability to climate change in this Indian state. A climate variability study was carried out in Punjab by analysing historical data of maximum and minimum temperature and rainfall for five locations in three agro-climatic zones of the state, namely, Ballowal Saunkhri, Amritsar, Ludhiana, Patiala, and Bathinda.

On the basis of climatic variability trends observed in the state, anticipated synthetic scenarios of increase or decrease from normal temperature, interactions of maximum and minimum temperatures, solar radiation, and CO_2 levels were generated for the simulation study for wheat and rice crops. The effects of intra-seasonal temperature change were also generated for the simulation study for wheat crop. One variable at a time was modified and its effect on crop growth and yield was simulated while taking all the other climate variables to be normal.

The findings for rice are as follows:

- The growth and yield of rice reduced with increase in temperature, but increased with decrease in temperature from normal.
- In general, increase in solar radiation favoured the growth and yield, whereas the decrease in solar radiation led to reduction in growth and yield of rice.
- The maximum leaf area index (LAI), biomass yield, and grain yield were adversely affected by increasing the minimum temperature from normal. However, these adverse effects were partially counteracted by decreasing maximum temperature from normal.
- The interactive effects of increasing temperature and decreasing radiation revealed a cumulative adverse effect on the growth and yield of rice crop.
- The results of the simulation study revealed that increasing CO_2 levels were able to counteract the adverse effects of temperature increase on growth and yield to some extent.

For wheat, the findings are as follows:

- The growth and yield of wheat reduced with increase in temperature, but increased with decrease in temperature from normal. Increase in solar radiation favoured growth and yield, whereas the decrease in solar radiation led to reduction in growth and yield of wheat.
- Generally, the maximum LAI, biomass yield, and grain yield were adversely affected by increasing the minimum temperature from normal. However, these adverse effects were partially counteracted by decreasing maximum temperature from normal.
- The interactive effects of increasing temperature and decreasing radiation revealed a cumulative adverse effect on the growth and yield of wheat crop.

In addition, wheat being a major winter cereal crop in northern India, any abrupt changes in weather parameters, especially an increase in maximum/minimum temperature from normal, at any growth stage of crop.,adversely affect the growth and ultimately the potential yield of wheat. A simulation study conducted using CERES-Wheat model revealed that in general, an increase in temperature from mid-February to mid-March severely affected the grain yield of early, normal, and late sown wheat.

current yield (Figure 3.27). Chickpea showed an increase in yield to the tune of 23% and 52% in A1B (2021–50) and A1B (2071–2100) scenarios, respectively (Figure 3.27). Across the locations, the rain-fed yield of soybean and groundnut showed significant positive association with crop season rainfall, while association with temperature was poor/non-significant, which indicated that under rain-fed conditions, the availability of water will remain a major limiting factor for the yields realized by the farmers. However, for chickpea, which is a post-rainy winter season crop, the simulated rain-fed yield showed a significant positive association with crop season temperature, while with crop season rainfall (which is received in very meager amount), no significant association was observed. The greater positive impact of future climate on chickpea was associated with both increase in temperature and CO_2

levels, as the optimum temperature for chickpea growth and yield is between 22°C and 28°C, which is much above the prevailing current crop season mean air temperatures across major chickpea growing regions in India.

Cotton in India is an important cash crop which is mostly grown under rain-fed conditions, making it more vulnerable to precipitation. At present, more than 80% of the cotton is under transgenic Bt cotton hybrids in India. The model results indicate that climate change and the consequent increased temperature and altered pattern of precipitation might decrease the cotton yield of North India to a greater extent than the southern region. The impact of climate change on rain-fed cotton, which covers more than 65–

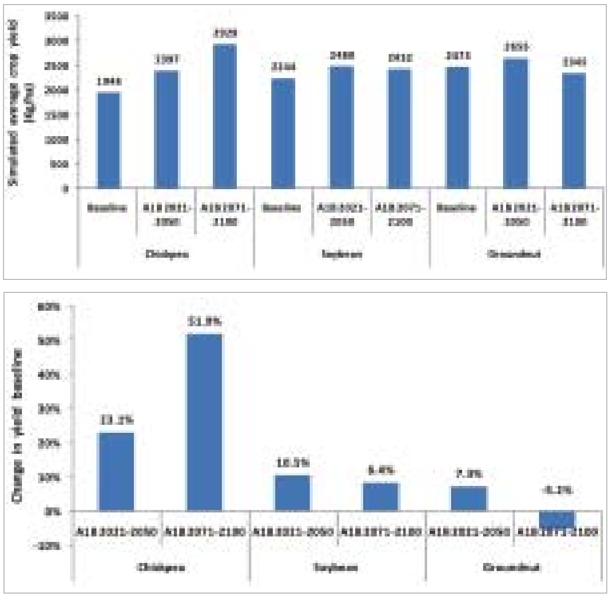


Figure 3.27: Average simulated rain-fed crop yields (chickpea, soybean, and groundnut) under current (baseline) and future climate scenarios (upper panel), and projected average change in simulated rain-fed crop yields under future climate scenarios as compared to baseline (lower panel)

70% of area and depends on monsoon rains, is likely to be minimum, possibly because of marginal increase in rain. Moreover, the stimulating effect of CO_2 could offset the negative effect of climate on cotton production. Thus, at the national level, cotton production is unlikely to change with climate change. Adaptive measures such as changing planting time may further boost cotton production.

Potato, a tuber, is widely consumed in India, and it was found that without adaptation, the total potato production in India under the impact of climate change may decline by 2.61% and 15.32% in 2020 and 2050, respectively. The impacts on productivity and production varied among different agro-ecological zones. The north-western plains, comprising the states of Punjab, Haryana and areas of western UP and northern Rajasthan, are least vulnerable with possible increases of 3.46–7.11% in productivity, and with simple adaptation measures like change in planting time and proper selection of cultivars, the potato production may be sustained at current levels. The eastern and southern states appeared more vulnerable to tuber yield losses of 4–19% in future climate scenarios because simple adaptation measures were not found to be effective. The potato crop in Orissa and plateau regions of Gujarat, Karnataka, Maharashtra, and other areas in south India would be most vulnerable due to warming and associated drought conditions, with yield loss ranging from 6.58% to 46.51%. West Bengal, Orissa, and plateau regions would require technological interventions and adaptation through breeding heat- and drought-tolerant cultivars to arrest the impending decline in potato productivity and production in the future climate scenarios. Intensification of potato cultivation in the least to moderately vulnerable regions, with simple adaptation measures of proper selection of cultivars and adjustment in planting time, offers opportunity to offset the decline in production in other regions.

Plantation crops: Using validated coconut simulation model, the impact of elevated temperature and CO_2 on coconut yields was simulated for different agro-climatic zones. Overall results indicate that the coconut yields are likely to be positively influenced by increase in CO_2 and increase in temperature of up to 2–3°C.

Under the A1B scenario, coconut productivity on all India basis is likely to go up by up to 4% during 2020, up to 10% in 2050, and up to 20% in 2080 over current yields due to climate change. In the West Coast, yields are projected to increase by up to 10% in 2020, up to 16% in 2050, and up to 39% by 2080, while in the East Coast, yields are projected to decline by up to 2% in 2020, 8% in 2050, and 31% in 2080 scenario over the

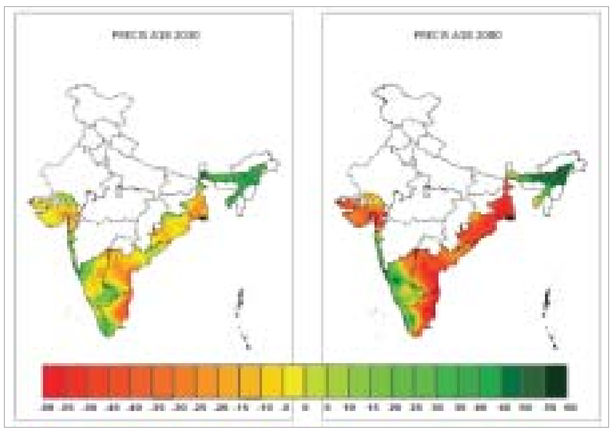


Figure 3.28: Impact of climate change on coconut production in India in PRECIS A1B-2030 and -2080 scenarios (percentage change from current yields)

current yields Thus, on all-India basis, climate change is projected to increase coconut production by 4.3 % in A1B-2030 scenario. Production may remain stagnant or may slightly go up by ~2% in A1B 2080 scenario (Figure 3.28). Climate change is likely to have positive impacts on coconut yields in Kerala and parts of Tamil Nadu, Karnataka, and Maharashtra (provided current level of water and management is made available in future scenario as well), while negative impacts are projected for Andhra Pradesh (particularly Godavari districts, the major production zone in Andhra Pradesh), Orissa, West Bengal, Gujarat, and parts of Karnataka and Tamil Nadu. On all-India basis, coconut yield is projected to go up even with the current management. In places where positive impacts are projected, current poor management will become a limiting factor in reaping the benefits of CO_2 fertilization. While in adverse impact regions, adaptation strategies can reduce the negative impacts. Hence, better irrigation and fertilizer management will further increase the yields.

Another plantation crop arecanut is mainly an irrigated plantation and is sensitive to water stress, and temperature and rainfall play a major role in its productivity. Regression analysis indicated that increase in temperature even by 1°C will reduce productivity in Karnataka. The reduction will be more in the plains of Karnataka as compared to the Western Ghat portions of Karnataka. On the other hand, arecanut productivity in central Kerala is likely to be benefitted due to increase in temperature of up to 1°C. On the other hand, a 10% reduction in rainfall during July and August will improve the arecanut yields significantly. Since the favourable climate for growth can be taken as a surrogate for productivity, current analysis indicates that future production of arecanut in India is likely to reduce in 2030 scenario due to climate change.

Cocoa, another plantation crop, is grown as an intercrop under arecanut or under coconut. Cocoa, being a shade-crop, is being influenced only indirectly by the increase in atmospheric temperature. The crop is maintained in irrigated conditions, and presently, the area under cocoa is confined to limited pockets of Karnataka and Kerala. Analysis indicated that a rise in temperature by 1°C will be beneficial for crop productivity. The improvement is likely to be about 100 kg of dry beans/ha. This benefit will be more in cocoa growing areas of Karnataka as most of the area falls in the foothills of the Western Ghats, as compared to that in central Kerala. However, crop management and irrigation supply should be maintained or improved to exploit this benefit. Further, an increase in temperature beyond 3°C is likely to reduce cocoa yields.

Vegetables and fruits

Significant effect of increased climatic variability on short season crops such as vegetables, if changes occur during critical periods in growth, is observed. Such crops will have limited time to adapt to adverse environments. Among the vegetable crops, onion and tomato are important commercial crops grown across the country. However, the productivity levels are very low compared to major producing countries. This problem of lower productivity would further be compounded under climate change scenarios as the major onion and tomato growing regions are under tropical conditions and prevailing temperature conditions are already high. Onion and tomato are sensitive to environmental extremes. Periodic high temperature and soil moisture stress conditions cause drastic reduction in yields. InfoCrop model simulations for onion show that in Nasik region of Maharashtra state, the A1B-2080 scenario would be having a greater impact on onion production. Junagadh region in Gujarat state indicates that in A1B-2030 and A1B-2080 scenarios, the yield reduction would be to the tune of 27.34% and 52.41%, respectively. Another onion growing area, Bhavnagar in Gujarat, would be facing lower impacts compared to Junagadh region under all the scenarios. In Karnataka state, in Dharwad region, under A1B-2030 scenario, the yield reduction would be to the tune of 14.79% and 9.06% in kharif and rabi, respectively, while in Gadag region, under A1B-2030 scenario, the yield reductions are likely to be 22.53% and 22.99% in kharif and rabi, respectively. The impacts would be much greater in A1B-2080 scenarios in both the regions, but in Gadag region, the yield reductions would be much more. Production is often limited during rainy season due to excessive moisture as both tomato and onion are susceptible to flooding, and higher incidence of fungal disease during bulb initiation stage can halve the bulb size of onion. Examination of adaptation strategies show that raised bed cultivation may be adopted for onion in flood-prone areas. In the case of tomato, while yield increase is seen with elevated CO_2 levels, flooding can affect the yield adversely. Raised bed is seen as beneficial for tomatoes in the event of flooding.

Grape is one of the important commercial fruit crops in India, with productivity of 23.5 tonnes/ha. Grape has been adapted to tropical conditions by employing the practice of pruning twice a year. The impact of climate change on grapes would be determined by the impact of rainfall during the months of February to April, when the berries mature. In severe conditions, rainfall during the month of October would increase the incidence of Downey mildew disease on leaves and flower clusters. The increase in minimum temperature during fruit maturation plays an important role in anthocyanin, total phenol, total flavanoids, and total acidity content of the berries, which ultimately affect the quality.

Another fruit, the productivity of which is heavily linked with climatic variations, is the apple. Analysis of current and future climatic scenarios using HADRM3 model has revealed that Himalayan ecosystems will suffer from reduced winter precipitation (January–June) in sub-tropical zone, high temperature during winters and summers as well as change in seasonal rainfall patterns besides significant reduction in snowfall. Specifically, it is seen that while the average increase in mean minimum and mean maximum temperature in winters during mid period (2021–50) in Scenario A1B will be 2.43°C and 1.74°C, respectively, in the subtropical sub-temperate region (districts Solan, Sirmaur, Una, and Mandi), corresponding temperature changes in sub-temperate and temperate regions (districts of Shimla, Kulu, Lahaul-Spiti, Kinnaur, and Chamba) will be 2.77°C and 2.17°C, respectively. Cumulative chill units of coldest months have declined by 9.1–19.0 units per year in the last two decades in different districts of Himachal Pradesh. The rise in temperature will reduce the chilling-hours accumulation, which could be a limiting factor in more tropical areas, especially for cultivars with medium to high chilling requirement. The temperature change will benefit apple cultivation in high altitudinal regions (> 2300 m above sea level), especially Kinnaur and Lahaul-Spiti districts, due to availability of enhanced growing period and reduced extreme cold weather conditions.

Adaptation strategies

Agriculture is a critical component of Indian sustainable developmental policies, since more than 650 million people depend on agriculture. The Green Revolution during the 1970s made India self-sufficient in food production through increased agricultural output based on high- yielding seeds, irrigation, and fertilizers. Now, Indian agriculture is more intensive with regard to the use of inputs per hectare of land.

Several measures/strategies have evolved during the Eleventh Plan period to address various issues pertaining to the agriculture sector. In the medium term, the focus has been on improving yields with the existing available technology, timely availability of water through expansion of the irrigation system, and also improvement of existing irrigation systems.

Any disturbance in agriculture can considerably affect the food systems and thus increase the vulnerability of the large fraction of the resource-poor population. We need to understand the possible coping strategies by different sections and different categories of producers to global climatic change. Such adaptation strategies would need to simultaneously consider the background of changing demand due to globalization, population increase, and income growth, as well as the socio-economic and environmental consequences of possible adaptation options. Developing adaptation strategies exclusively for minimizing the negative impacts of climatic change may be risky in view of large uncertainties associated with its spatial and temporal magnitude. We need to identify "no-regrets" adaptation strategies that may be needed for the sustainable development of agriculture. These adaptations can be at the level of the individual farmer, society, farm, village, watershed, or at the national level. Some of the possible adaptation options are discussed below. It should be noted that many of the measures mentioned below are already a part of the national programmes, either at the state level or the country level. Some of the adaptation strategies for coping with the impacts of climate change on various agricultural crops are described below. While some are specific to certain crops, other strategies are more widely applicable.

1. **Agronomic adaptation/ crop management:** Small changes in climatic parameters can often be managed reasonably well by altering the dates of planting, spacing, and input management. Alternate crops or cultivars more adapted to the changed environment can further ease the pressure. For example, in the case of wheat, early planting or the use of longer duration cultivars may offset most of the losses associated with increased temperatures. Available germplasm of various crops needs to be evaluated for heat and drought tolerance. In case of perennial crops, crop management is an important aspect of adaptation. Drought in the current year not only affects the yield of the current year but also that of the subsequent years. In coconut, the drought impact is worst in the third and fourth year to follow. Apart from this, recovery will take three to four years, thus causing a perennial loss in farm income. Multi-location trials on soil moisture conservation practices

indicate very significant improvement in yield due to the conservation of soil moisture. The low-cost measures include basin mulching with husk/leaves/other farm biomass, burial of composted coir pith, and hush burial, which act as the moisture storage and retention mechanisms in palm/plant basin. This helps in the reduction of the amount and frequency of irrigation. The growing of tomato and onion on raised beds during the periods of likely flooding is a specific example of the adaptation strategy to cope with extreme events as a result of climate change. Modifying techniques of fertilizer application could prove to be an extremely effective option in enhancing crop yield.

2. **Crop diversification/socio-economic adaptation:** Extensive surveys conducted in the drought-affected areas in Tamil Nadu and Karnataka indicate that the in the event of severe consecutive drought years situation, the coconut plantation crops are replaced with seasonal annual crops such as pulses, maize, and sorghum. Apart from this, farmers who adapted soil moisture conservation practices and drip irrigation could save their plantations from drought. In situations where severity of drought was less and limited water was available, farmers even opted for groundnut or flower culture as intercrop of plantation. It is important to realize that the standing plantation crops cannot be replaced easily with tolerant varieties due to the long gestation period for flowering and first harvest; thus crop management becomes crucial.

3. **Genetic adaptation:** Growing of the "Local Tall" coconut cultivars, for example, WCT and LCT (for West Coast), "Tiptur Tall" (for Karnataka), "SakhiGopal Tall" (for Orissa), "ECT" (for Andhra Pradesh) is undertaken in the areas prone to water scarcity. The hybrids like "WCT × COD" may be grown only in areas with the availability of water for at least 8–12 irrigations during January to June. In arecanut, initial results from OTC experiments indicated that Sumangala and Sreemangala have better capability to adapt to climate change conditions. In case of cocoa, I-56 and II-67XNC-29/66 exhibited better adaptation to climate change conditions. Growing of these cultivars/hybrids provides advantage in climate change scenarios. Utilization of identified *in situ* drought-tolerant coconut palms in population improvement programme is very important for making the crop more resilient to climate change conditions.

   Though the grape vines are grown under irrigated conditions, due to the limited availability of groundwater they experience water shortage during summer months. As an adaptation strategy, use of rootstocks was introduced and many farmers have adopted the rootstocks to overcome the adverse effects of limited moisture stress. The rootstocks have helped the farmers to a great extent in withstanding the intermittent water stress. Dogridge rootstock is mainly used, and the use of rootstocks needs to be further emphasized and popularized.

   Grafting has been used primarily to control soil-borne diseases in tomato, eggplant (brinjal), and cucurbits, and there are reports to show their utility in soil-related environmental stresses, such as drought, salinity, low soil temperature, and flooding if appropriate tolerant rootstocks are used. Development of varieties/hybrids is the most cost-effective option. The tolerant varieties must be able to match the yields of conventional, non-heat tolerant varieties under non-stress conditions. In tomato, it is reported that the fruit set in CL5915 ranges from 15–30%, while there is complete absence of fruit set in heat-sensitive lines at mean field temperatures of 35ºC. Such tolerant varieties could be the options under higher temperature conditions.

4. **Water harvesting and recycling:** Water harvesting ponds, recycling of the harvested water, and *in situ* water harvesting form important strategies to effectively utilize the excess rainwater (in climatic variability extreme events). Irrigation at crucial stages of crop growth is very important.

   Drip irrigation not only helps in saving precious irrigation water but also enhances the productivity of crops. Switching over to drip irrigation results in water savings to the tune of 40–50% due to its high water application efficiency and reduced evaporative and percolation losses. The salts in the soil remain at the manageable depth due to the frequency of irrigation. This method is very effective for growing shallow rooted vegetable crops, onion, and tomato. Soil moisture conservation is critical, and this may be done by using organic and plastic mulches. Drip irrigation along with soil moisture conservation practices is one of the important water management strategies in climate change scenarios. By adopting this strategy and by providing higher nutrients, one can not only reduce the adverse impacts of climate change but also maximize the positive impacts of climate change.

5. **Awareness creation among farmers:** Even though farmers realize change in rainfall amount and pattern, and rise in temperatures over a period of time, it is essential to provide awareness regarding climate change impacts and also the possible adaptation strategies to reduce the adverse impacts of climate change or maximize the potential benefits due to climate change. For example, even though the climate change is projected to improve the coconut yield in Kerala, it is essential to inform farmers that they need to provide adequate irrigation and nutrients in order to reap the projected benefits. In case of arecanut, above- mentioned crop management practices will reduce the adverse impacts of climate change.
6. **Area expansion in positive impact zones:** An example is to consider expanding the area under coconut in positive impact zones like North East region. Scientific management of plantations in Lakshadweep Islands, and Andaman and Nicobar Islands can add to improved production.
7. **Development of resource conserving technologies:** Recent research has shown that surface seeding or zero-tillage establishment of upland crops after rice gives similar yields as when planted under normal conventional tillage over a diverse set of soil conditions. This reduces the costs of production, allows earlier planting, thus, resulting in higher yields, less weed growth, reduced use of natural resources such as fuel and steel for tractor parts, and improvements in efficiency of water and fertilizers. In addition, such resource conserving technologies restrict the release of soil carbon, thus mitigating the increase of CO_2 in the atmosphere. It is estimated that zero tillage saves at least 30 litres of diesel as compared to the conventional tillage. This leads to 80 kg/ha/year reduction in CO_2 production. If these savings could be translated even partially to large arable areas, substantial CO_2 emissions to the atmosphere could be reduced.
8. **Augmenting production and its sustainability:** The climatic factors allow very high yield potential of many crops in India. For example, the potential yields of rice and wheat are calculated to be more than 6 tonnes/ha, whereas their average yields range between 2 tonnes/ha and 3 tonnes/ha. Such yield gaps are very large in eastern India and, hence, this region can be a future source of food security for the whole country, under the scenario of adverse climatic impacts. Institutional support in the form of improved extension services, markets, and infrastructure needs to be provided in such regions to increase stability and bridge yield gaps.
9. **Increasing income from agricultural enterprises:** Rising unit costs of production and stagnating yield levels are adversely affecting the incomes of farmers. Global environmental changes, including climatic variability, may further increase the costs of production of crops due to the associated increases in nutrient losses, evapo-transpiration, and crop–weed interactions. Suitable actions such as accelerated evolution of location-specific fertilizer practices, improvement in extension services, fertilizer supply and distribution, and development of physical and institutional infrastructure can improve efficiency of fertilizer use.
10. **Improved land use and natural resource management policies and institutions:** Adaptation to environmental change could be in the form of social cover such as crop insurance, subsidies, and pricing policies related to water and energy. Necessary provisions need to be included in the development plans to address these issues of attaining the twin objectives of containing environmental changes and improving resource use productivity. Rational pricing of surface water and groundwater, for example, can arrest their excessive and injudicious use. The availability of assured prices and infrastructure could create a situation of better utilization of groundwater in eastern India. Policies such as financial compensation/incentive for green manuring should be evolved, which would encourage farmers to enrich organic matter in the soil and, thus, improve soil health.
11. **Improved risk management through early warning system and crop insurance:** The increasing probability of floods and droughts and other uncertainties in climate may seriously increase the vulnerability of eastern India and of resource-poor farmers to global climate change. Policies that encourage crop insurance can provide protection to farmers in the event their farm production is reduced due to natural calamities. In view of these climatic changes and the uncertainties in future agricultural

technologies and trade scenarios, it will be very useful to have an early warning system of environmental changes and their spatial and temporal magnitudes. Such a system could help in determining the potential food insecure areas and communities, given the type of risk. Modern tools of information technology could greatly facilitate this.

12. **Recycling waste water and solid wastes in agriculture:** Since freshwater supplies are limited and have competing uses, a vigorous evaluation of using industrial and sewage waste water in agriculture should be undertaken. Such effluents, once properly treated, can also be a source of nutrients for crops. Since water serves multiple uses and users, effective inter-departmental coordination within the government is needed to develop the location-specific framework of sustainable water management and optimum recycling of water.

13. **Special focus on vulnerable ecosystems:** While the vulnerability of Indian agriculture to climate change is well-recognized, it needs to be highlighted that some ecosystems such as the Himalayan mountains are more vulnerable. In this regard, it is important to enhance, maintain, and conserve soil and plant carbon pools on highly vulnerable mountain slopes; adopt tree-based/mixed farming systems to conserve biodiversity; increase climate resilience of mountain farming systems; and adopt an appropriate framework for use of barren and unproductive land in hilly areas. Focus on recording of meteorological and hydrological data in the inaccessible regions of the north-western Himalayas is also needed.

14. **Reducing dependence on agriculture:** The share of agriculture has declined to 24% of the GDP, but 64% of the population continues to remain dependent on agriculture for its livelihood. Such trends have resulted in the fragmentation and decline in the size of land holdings, leading to inefficiency in agriculture and rise in unemployment, underemployment, low volume of marketable surplus and, therefore, increased vulnerability to global change. Institutional arrangements, such as cooperatives and contract farming, which can bring small and marginal farmers together for increasing production and marketing efficiencies, are needed.

Impact of climate change on livestock productivity

Milk is an important component of food, which is significantly increasing in demand. Increased heat stress associated with global climate change may, however, cause distress to dairy animals and possibly impact milk production. Temperature Humidity Index (THI) was used to relate animal stress with the productivity of milk of buffaloes, cross-bred, and local cows. The THI analysis indicated that the congenial THI for production is 0.70 and is achieved during the months of January to February at most places in India (Figure 3.29). There is an all round increase in THI in all the regions, which may impact the economic viability of livestock production systems. Only about 10–15% places have optimum THI for livestock productivity during summer and hot humid season. Majority of places in India have THI > 75, and more than 85% places in India experience moderate to high heat stress during April, May, and June, when the value of THI is in the range 75–85 at 2.00 pm when the heat is at its peak. At about 25% places in India, during May and June, the THI exceeds 85, that is, severe stress levels are experienced. The night temperature remains high and there is no relief from heat stress, and morning THI is high. On an average, THI exceeds 75 at 75–80% places in India throughout the year.

It is estimated that India loses 1.8 million tonnes of milk production at present due to climatic stresses in different parts of the country. Global warming will further negatively impact milk production by 1.6 million tonnes by 2020 and

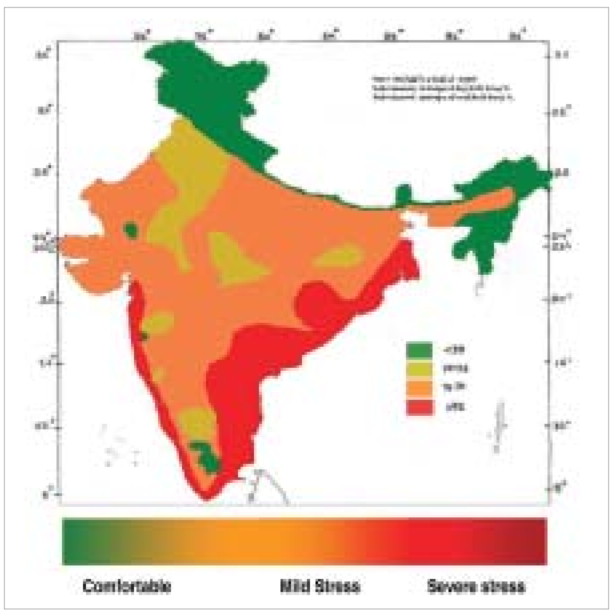


Figure 3.29: Temperature and Humidity Index map of India

more than 15 million tones by 2050, as per one study by scientific institutions. High producing cross-bred cows and buffaloes will be impacted more than the indigenous cattle. Northern India is likely to experience greater impact of warming on milk production of both cattle and buffaloes in future. A rise of 2–6°C due to warming will negatively impact growth, puberty, and maturity of cross-breds and buffaloes. Time required for attaining puberty of crossbreds and buffaloes will increase by 1 to 2 weeks due to their higher sensitivity to temperature than indigenous cattle. It will negatively impact oestrus expression, duration, and conception of buffaloes.

Impact of climate change on fisheries

Inland fisheries: Recent hydrological changes in the flow pattern of river Ganga related to changes in the climatic patterns have been a major factor resulting in erratic breeding and decline in fish spawn availability. The average fish landing in the Ganga river system has declined from 85.2 tonnes during 1959 to 62.5 tonnes during 2004. There is also a perceptible shift in geographic distribution of fish Ganga. The warm water fish species such as *Glossogobius giuris, Puntius ticto, Xenentodon cancila, Mystus vittatus,* earlier available only in the middle stretch of the River Ganga, are now available in the colder stretch of the river around Haridwar due to increase in river water temperature in recent periods. In the middle and lower Ganga, 60 genera of phytoplanktons were recorded during 1959, which declined to 44 by 1996. The zooplankton number during the same period diminished from 38 to 26. In recent years, the phenomenon of maturing and spawning of Indian major carps has been observed as early as March in West Bengal. Its breeding season has also extended from 110 days to 120 days (pre-1980–85) to 160 days to 170 days (2000–05). As a result, it has been possible to breed these fishes biannually at an interval ranging from 30–60 days. A prime factor influencing this trend is elevated temperature, which stimulates the endocrine glands of fish and helps in the maturation of the gonads.

Coastal fisheries: Sea surface temperature in the Indian seas may increase by about 3°C by 2100. This is likely to affect fish breeding, migration, and harvests. The relationship of oil sardine distribution, a coastal, pelagic schooling fish, forming massive fisheries in India, with sea surface temperature was examined using the data of annual oil sardine catch along each maritime state for 1961–2005. Considering the catch as a surrogate of distribution, it was found that the oil sardine has extended with time its northern and eastern boundaries of distribution. Oil sardine fishery did not exist before 1976 in the northern latitudes and along the East Coast. With a gradual slow warming of sea surface, the oil sardine was able to find temperature of its preference in the waters of northern latitudes and eastern longitudes, thereby extending its distributional boundaries. It is expected that the distribution may extend further to Gujarat and West Bengal coasts in the coming years, assuming that other fishery-related physical and biological parameters will not vary considerably. However, if the sea surface temperature in the southern latitudes increases beyond the physiological optimum of the fish, it is possible that the population may be driven away from the southern latitudes, which will reduce the catches along the south-west and south-east coasts in the future.

The threadfin breams – *Nemipterus japonicus* and *N. mesoprion* – are distributed along the entire Indian coast at depths ranging from 10 m to 100 m. Data on the spawning season of these fishes off the Chennai coast from 1981 to 2004 showed a good correlation between sea surface temperature and spawning activity. The occurrence of spawners linearly decreased with increasing temperature between April and September and increased positively from October to March. It appears that sea surface temperature between 28°C and 29°C may be the optimum, and when this is exceeded, the fishes adapt to shift the spawning activity to seasons when the temperature is around the preferred optima.

Climate Change and India: A "4x4" Assessment: A Sectoral and Regional Analysis for 2030s

The MoEF, Government of India, has launched a network-based scientific programme, that is, the Indian Network of Climate Change Assessment (INCCA), which has conducted an assessment to review the impacts of climate variability in the four major climate-sensitive regions in India, namely, the Himalayan region, the north-eastern region, the Western Ghats, and the coastal region. Further, it presents an assessment of the impacts of climate change in the 2030s on four key sectors of the economy that are climate dependent, namely, agriculture, water, natural ecosystems and biodiversity, and human health. The key results of assessments made at such short time lines are useful, as they can be used to develop adaptation strategies for a foreseeable future. This attempt was a remarkable step towards a proactive approach by the Government of India so as to design, develop, and implement policies that help in mitigating the impacts of climate change in the most sensitive regions and in the most sensitive sectors. The key findings of the assessment are listed below.

Impacts on agriculture

Western Ghats

Rice: The productivity of irrigated rice is likely to reduce by 4% in most of the areas in this region. However, irrigated rice in parts of southern Karnataka and northern-most districts of Kerala is likely to gain. In case of rain-fed rice, all areas in the region are likely to lose yields by up to 10%. The results thus indicate that irrigated rice is able to benefit due to CO_2 fertilization effect as compared to the rain-fed rice, which is supplied with less amount of fertilizers.

Maize and sorghum: Climate change is likely to reduce the yields of maize and sorghum by up to 50%, depending upon the area in this region. These crops have C_4 photosynthetic systems and hence do not have relative advantage at higher CO_2 concentrations.

Coconut: Coconut yields are projected to increase by as much as 30% in the majority of the region by the 2030s. Increase in coconut yield may be mainly attributed to the projected increase in rainfall (~10%) and relatively less increase in temperature, apart from CO_2 fertilization benefits. However, some areas like south-west Karnataka, parts of Tamil Nadu, and parts of Maharashtra may show reduction in yields by up to 24%.

Livestock productivity: The THI is likely to remain under highly stressful conditions in the 2030s. The heat-stress days per annum are likely to increase with THI above 80 in the 2030s in the Western Ghats, leading to severe thermal discomfort of the livestock, and hence, negative impact on livestock productivity is expected.

Coastal region

Rice: The yields of irrigated rice are projected to decrease by about 10% to 20% in this region. However, in some coastal districts of Maharashtra, northern Andhra Pradesh, and Orissa, irrigated rice yields are projected to marginally increase by 5% with respect to the 1970s. On the other hand, rain-fed rice yields are projected to increase up to 15% in many districts in the East Coast but reduce by up to 20% in the West Coast.

Maize and sorghum: Impacts of climate change on irrigated maize in coastal districts are projected to be much higher with projected yield loss between 15% and 50%, whereas in the case of rain-fed maize, the projected yield loss is up to 35%. In some districts of coastal Andhra Pradesh, rain-fed maize yields are likely to increase by 10%. Projected increase in seasonal maximum temperature in these areas is less than 1°C in the 2030 scenario.

Coconut: Yields of coconut are projected to increase in the West Coast of India by up to 30% (provided current level of water is made available in the future as well), while in the East Coast, yields may increase by about 10% in the north coastal districts of Andhra Pradesh. All other coastal districts in eastern coast and those in the Gujarat coast are projected to lose coconut yields up to 40%.

Livestock productivity: The livestock in the coastal regions are likely to be highly vulnerable with consequent adverse impacts on their productivity throughout the year in the 2030 scenario with THI above 80.

Fisheries: (i) An increase in recruitment and catches of oil sardine during the post-south-west monsoon season along the coastal region, especially along the Kerala coast, is expected in the future due to warming, elevated sea surface temperature, favourable wind (and perhaps current), and increasing Coastal Upwelling Index (CUI), inducing higher chlorophyll-a concentration during the south-west monsoon; (ii) the Indian mackerel is able to take advantage of the increase in temperatures of sub-surface sea water. Therefore, with increase in global temperatures and sea surface temperatures, it is likely to move northwards and deeper into the seas surrounding it; (iii) the threadfin bream spawns optimally in sea surface temperature between 27.5°C and 28.0°C, and when the sea surface temperature exceeds 28.0°C, the fish shifts the spawning activity to seasons when the temperature is around the preferred optimum. Therefore, in the climate change context, in the 2030s, if the sea surface temperature exceeds 28°C during April to September, an increase in catch might take place in the comparatively cooler months of October to March.

North-eastern region

Rice: Irrigated rice yields in this region may range between –10% and 5%, with respect to the 1970s, while the rain-fed rice yield may vary between –35% and 5% with respect to 1970s.

Maize: Maize crop yields are projected to reduce by about 40%.

Livestock productivity: In this region, the THI is likely to increase during April–October months (with THI > 80).

Himalayan region

Apples: Apple production in the Himachal Pradesh region has decreased between 1982 and 2005 as the increase in maximum temperature has led to a reduction in total chilling hours in the region—a decline of more than 9.1 units per year in last 23 years has taken place. This reduction was more during the months of November and February. With increasing temperature, it is anticipated that there may be an all-round decrease in apple production in the Himalayan region, and the line of production may shift to higher altitudes.

Livestock productivity: THI is projected to rise in many parts of the Himalayan region during March–September with a maximum rise during April–July in 2030s with respect to 1970s.

Impacts of Climate Change on Energy

There is a two-way relationship between environment and economic activities. Not only do economic activities, especially the energy-related activities, contribute towards climate change and other environmental pollution, there is a reverse link too, whereby the impacts of climate change are felt on the energy systems. Limited studies on the impacts of climate change on the energy sector in Asia suggest that this sector will be affected by climate change. An increase in the energy consumption by the industry, residential, and transport sectors could be significant as population, urbanization, and industrialization rise.

Sectoral and regional variability of impacts

The structure of energy supply and demand in the country influences the impact on the net energy demand due to climate change impacts. Significant regional variability exists in the energy production and consumption in India. This is more so with energy production since that depends on the resource endowments of the different regions. The energy consumption is, however, more evenly distributed than production since it is linked to population and income distribution, level of economic activities, and development patterns across the country. The imbalances in production and consumption centres also require a formidable energy evacuation and transportation network.

The heating and cooling requirements in the residential and commercial sectors would vary depending on region and season. Air conditioning and refrigeration load is closely related to ambient air temperature and thus will have a direct relation to temperature increase. Temperature increase in the northern mountainous region, where space heating in winter is required, might reduce the need for heating energy, to some extent. However, the increased energy requirements for space cooling in the plains might compensate for this reduction. Besides, the growing income levels, especially in urban areas, could also lead to increase in the demand for air conditioning and other electrical products. Higher temperatures (and rising income levels) could also lead to greater need for air conditioning systems in passenger and freight vehicles, thereby increasing fuel consumption by the transport sector. Seasonal variation in total demand is also important since it would influence the transmission potential of the grid.

Climate impacts on space heating and cooling: Climate change will require a modification in the safety limits and permissible design levels for the type of climatic effects in the infrastructure design codes. Potential changes in humidity and climate may cause a variety of problems. There can be adverse effects of storms, heat, and humidity on walls and insulation, which will affect infrastructure durability and energy usage.

Climate change impacts on energy demand and consumption: The impact analysis for energy and environment indicates that a rise in average temperature increases cooling space requirement for the residential, services, and transport sectors. This results in an increased electricity requirement, thus, requiring higher power capacity build-up.

Climate change impacts on energy production and supply: The need for a more deeper understanding on the nature and structure of energy production and supply is to be undertaken with regards to shift to cleaner sources of energy. Renewable energy and bioenergy offers a sustainable option but concerns regarding the pace of technology development, land availability and transfer of new technologies still exist and need to be mitigated.

Methodology to study the impacts of climate change on energy

An integrated approach, which adopts a bottom-up methodology, would examine in detail the economic and environmental implications of different energy policies and vice-versa, was used for studying the implications of climate change on energy system (Figure 3.30). The

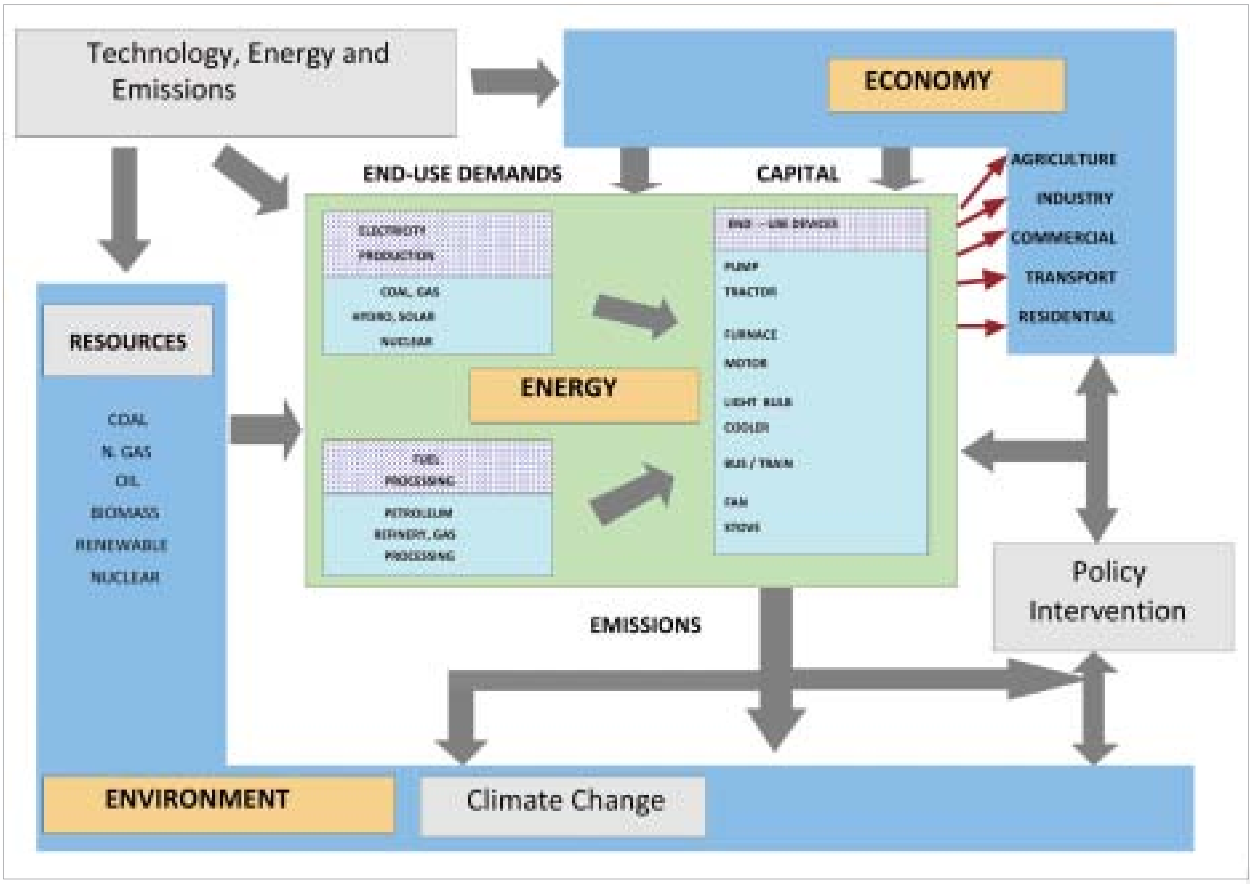


Figure 3.30: Soft linked integrated modelling framework

integration requires sectoral study of energy demand and supply projections, environmental implications of various technologies, detailed assessment of technological progress, and energy transitions in future.

The integrated modelling system (Figure 3.31) for the overall analysis include the following models: (i) ANSWER-MARKAL, which is an energy system optimization model, (ii) a demand model, which projects demand for each of the end-use services, and (iii) AIM/Trend, which a top-down model that estimates energy and environment trends for the long run and its results are soft-linked to ANSWER-MARKAL. The top-down AIM/Trend model provides GDP projections that are useful for projecting exogenous inputs like demand. The bottom-up models provide future energy balance output and sectoral level emission projections.

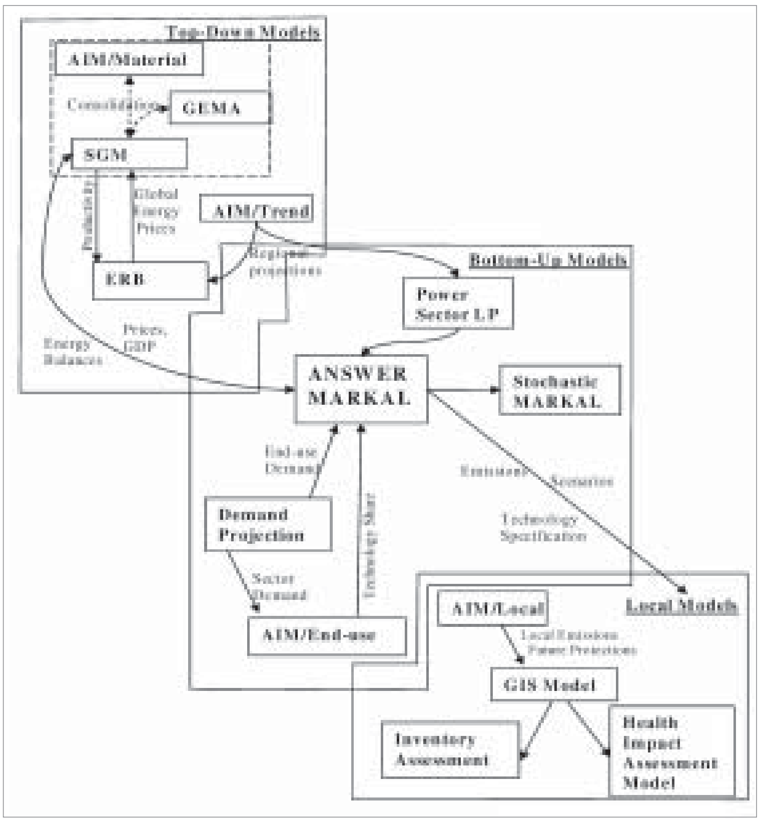


Figure 3.31: Bottom-up energy modelling framework

Current projections of climate change linked to energy systems

The climatic gridded projections for temperature and humidity have been extracted from A1B projections. These have been used to find out the business-as-usual (BAU) and projected number of days when temperature would be above 40°C, or relative humidity would be above 80% and temperature above 30°C. These would indicate requirements of air conditioning systems and would have impacts on energy system demand.

Energy supply projections: In the BAU scenario, the Indian power generation capacity increases about nine times from 135 GW to 3500 GW between 2000 and 2100. The share of coal in total generation capacity drops from a little over 65% in 2000 to about 52% by the end of the century but remains the mainstay of power generation. A notable feature of technology trajectory is substantial increase in gas- and nuclear-based capacities, which reach about 1316 GW and 633 GW, respectively, in 2100. The growing attractiveness for natural gas is due to its relatively low investment costs as compared to coal, high operating efficiencies, and suitability for meeting peak load. Nuclear capacity shows enhanced penetration because of the ease of import of uranium post Indo-US nuclear deal. Hydro capacity increases to about 232 GW in 2100, but its share decreases from about 25% in 2000 to 7% of the total installed capacity by 2100. The slow growth in capacity is due to barriers of high investment requirements and long gestation periods. A number of socio-environmental issues are related to dam construction, flooding of areas, damages to the ecology, and resettlement and rehabilitation of the population. The share of renewables excluding biomass increases to about 3% by the end of the century. Biomass share also steadily increases to 2.5% by the end of the century. The total renewables-based generation capacity reaches 98 GW, while that of biomass touches 87 GW in 2100.

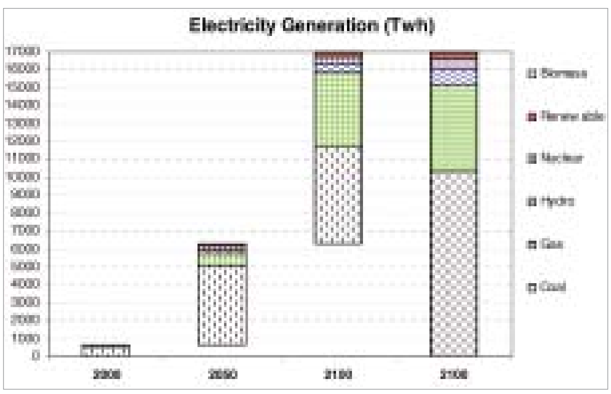


Figure 3.32: Projections of electricity generation of India

The total electricity generation increases from 651 TWh in 2000 to 17,000 TWh in 2100 (Figure 3.32). Though the domination by coal-based generation continues, its share decreases from 75% in 2000 to 61% in 2100.

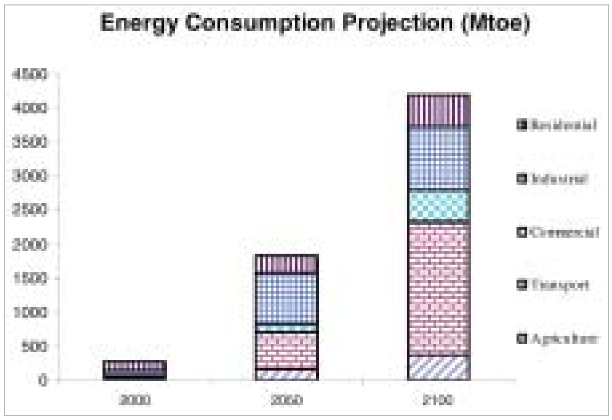


Figure 3.33: Projection of energy consumption within various sectors

Energy consumption projection (Figure 3.33) for various sectors shows that the total primary energy, including non-commercial biomass, increases from closer to 300 Mtoe in 2000 to 4200 Mtoe in 2100. Overall, energy consumption growth for transport and commercial sectors show a compounded annual growth rate (CAGR) of 4%, followed by agriculture and industrial with 3%, and finally, residential showing a CAGR of 1%. The primary energy mix diversifies from being highly dependent on coal, oil, and traditional biomass to one, which has significant share of natural gas, other renewable, nuclear, and commercial biomass. Further, decoupling of GDP and energy takes place as a result of changes in the structure of economy and efficiency improvements.

Impacts of Climate Change on Human Health

Climate plays a key role in the propagation of majority of the diseases either impacting directly or indirectly through interaction with the ecological systems. The direct health impacts can be in the form of heat strokes, and indirect impacts include diarrhoeal risk from water contamination via flooding, or higher risk of mortality from the impact of large-scale loss of livelihoods. Other indirect health impacts can be in terms of deterioration in nutritional health arising due to crop failure caused by droughts and especially from high night temperatures, reducing cereal yields.

Changes in climate may alter the distribution of important vector species (for example, mosquitoes) and may increase the spread of disease to new areas that lack a strong public health infrastructure. High altitude populations that fall outside the areas of stable endemic malaria transmission may be particularly vulnerable to increases in malaria, due to climate warming. The seasonal transmission and distribution of many other diseases transmitted by mosquitoes (dengue, yellow fever) and by ticks (Lyme disease, tick-borne encephalitis) may also be affected by climate change.

Though India's overall population health has improved greatly, with its life expectancy doubling from 32 years in 1947 to 66 years in 2004, many threats to health and life expectancy remain. However, climate change can increase the burden of disease, especially amongst the set of population that may have a lower capacity to combat the impacts with particular reference to their access to medical facilities. Projections of the extent and direction of potential impacts of climate variability and change on health are extremely difficult to make with confidence because of the many confounding and poorly understood factors associated with potential health outcomes. These factors include the sensitivity of human health to elements of weather and climate, differing vulnerability of various demographic and geographic segments of the population, the movement of disease vectors, and how effectively prospective problems can be dealt with. In addition to uncertainties about health outcomes, it is very difficult to anticipate what future adaptive measures (for example, vaccines and the improved use of weather forecasting to further reduce exposure to severe conditions) might be taken to reduce the risks of adverse health outcomes. Therefore, in this scenario, carrying out improvements in environmental practices, preparing disaster management plans, and improving the public health infrastructure in India, including disease surveillance and emergency response capabilities, will go a long way in coping with the impacts of climate change on human health.

Malaria and dengue are two of the important climate-change related diseases that have been extensively studied for understanding the relationship between climate parameters and disease incidence, and their future spread in the climate change context. The seasonal transmission and distribution of many other diseases transmitted by mosquitoes (dengue, yellow fever) and ticks may also be affected by climate change.

Malaria scenario under climate change

Vector-borne diseases, especially malaria, is climate sensitive as the development of the parasite (extrinsic incubation period) is sensitive to climatic conditions such as temperature, rainfall, relative humidity, and wind velocity. With the projected increase in surface temperature, increase in frequency and intensity of extreme events such as increase in night temperature, increase in number of warm days, and extreme heat and heavy precipitation in the future due to anthropogenic causes, the human health impacts are likely to escalate with respect to their virulence and spread to areas where they have not manifested so far. For example, with increase in average surface temperature it is apprehended that the window of transmission for vector-borne diseases will be available in areas where they have not been seen before. There is evidence of increasing malaria prevalence in some foci in India, which is thought to stem partially from economic development, which changes vector dynamics and human migration patterns, and partially from climate change, wherein recent models predict the spread of malaria into new regions in the 2050s and 2080s.

The distribution map of India reveals that highest endemicity is confined to Orissa, north-eastern states, Jharkhand, and Chhattisgarh, while it is lowest in Rajasthan, Uttar Pradesh, Himachal Pradesh, and Uttarakhand. The reason for the highest and lowest endemicity is linked to malaria stability or instability. In stable malaria, transmission continues almost throughout the year as the temperature, rainfall, and resultant relative humidity are favourable for almost all the 12 months. The states having unstable malaria, experience winters during which transmission does not take place. Areas with unstable malaria are epidemic prone, depending on the favourable conditions provided by unusually high rains at the threshold of the transmission season.

Methodology of analysis

PRECIS data of temperature and relative humidity for baseline and A1B scenarios was received from IITM Pune, while meteorological data was provided by the Indian Meteorological Department, Pune. Epidemiological data for malaria and dengue was received from various sources such as the Directorate of National Vector Borne Disease Control Programme (NVBDCP), state programme officers of various states/district malaria officers of districts concerned, and Medical Health Officer of MCD, Delhi.

Transmission windows (TWs) of malaria are determined keeping in view the lower cut-off as 18°C and upper cut-off as 32°C and relative humidity from >55%. The TW for malaria transmission at each grid (0.44° × 0.44° pixel, roughly 50 × 50 km) were prepared covering India for the baseline scenario. Monthly maps of TWs generated had two classes: open TW and closed TW. Keeping in view the climatic suitability for the number of months during which transmission is open, TWs/pixels were grouped into five classes and were categorized as follows—Category I: not a single month is open; Category II: 1–3 months open; Category III: 4–6 months open; Category IV: 7–9 months open; and Category V: 10–12 months are open continuously for malaria transmission. TW has been determined based on the temperature alone as well as in combination with temperature and relative humidity and for baseline (1960–90) and for the projection years 2030s, 2071, 2081, 2091, and 2100.

TWs for dengue were determined, based on the occurrence of dengue fever cases in Delhi and published literature. The lowest cut off of temperature was taken as 20°C and upper cut off as 32°C.

Malaria under A1B scenario: Determination of transmission windows of malaria, based on temperature

Based on the baseline temperature, from 1961–90, three tiers of TWs are visible (Figure 3.34). In northern states of India, there are 148 pixels with no transmission suitability. TW category of 1–3 months is seen in districts under Uttarakhand, Himachal Pradesh, parts of Jammu and Kashmir, Sikkim, and Arunachal Pradesh. Windows of transmission increase as we progress downwards towards southern states. In Rajasthan, central India, Jharkhand, Chhattisgarh, Orissa, West Bengal, and most parts of north-eastern states, 7–9 months category of TW exists. In southern states, most of the districts have 10–12 months open for transmission.

Projections for 2030 indicate opening of some months of TWs in the northern states like Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, which were closed in baseline (Figure 3.34). There is a progression of 7–9 months category of TWs towards northern districts. In

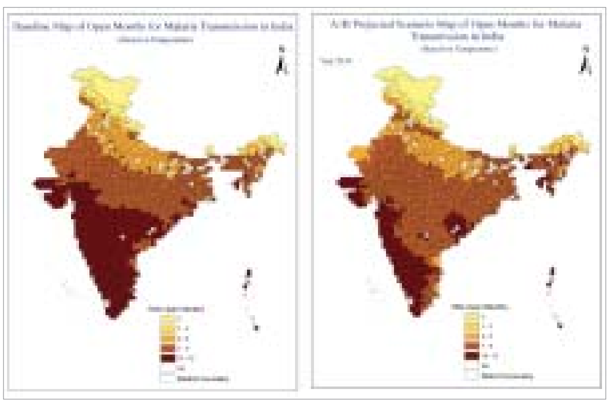


Figure 3.34: (a)Baseline and (b) projection of open transmission windows of malaria by 2030

north-eastern states like Tripura, parts of Assam, and Mizoram, there is increase from 7–9 months to 10–12 months open category of TWs. In parts of Gujarat and southern states (particularly towards East Coast), there is a closure of some months of TWs, that is, 10–12 months category turning into 7–9 months. In Orissa, which is highly endemic for malaria, increase in the months of TWs

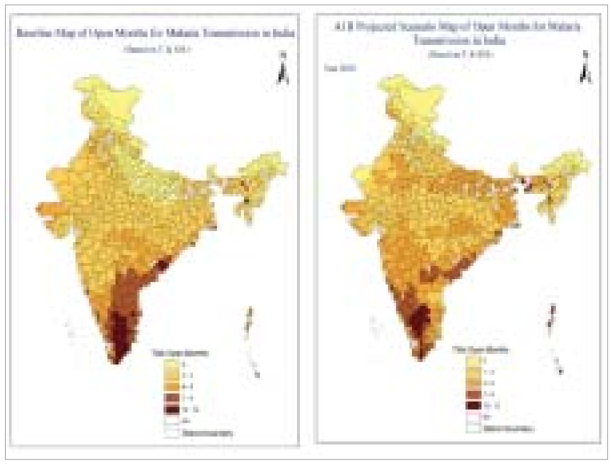


Figure 3.35: (a)Baseline and (b) projection of open Months for Malaria by 2030 (based on T. & RH; A1B scenario)

in some districts is seen by 2030. Andaman and Nicobar Islands remain unaffected.

TWs based on temperature and relative humidity: TWs of malaria were also determined based on suitable range of temperature and relative humidity required (Figure 3.35). In general, in almost all the regions, the number of open months for malaria transmission is less than those based on temperature alone. In north-eastern states, there are very few districts showing transmission for 7–9 months. When the TWs were compared with monthly epidemiological data of the respective area, there was no match, that is, cases occurred in more months as determined by TWs. The TWs determined based on temperature and relative humidity were found to be less realistic as compared to the TWs determined based on temperature alone (in Rajasthan and parts of Gujarat and Western Ghats). It provides a clue that the resting places of mosquitoes have different micro-niche, particularly for relative humidity as compared to outside temperatures. Major parts of India show 1–3 and 4–6 months open category of TWs. Some districts on the eastern side of India from Tamil Nadu, parts of Karnataka, and Andhra Pradesh show TWs open for 7–9 and 10–12 months. Projections by the year 2030 (Figure 3.35) indicate increase in 2nd and 4th categories of TWs towards northern states of India. Increase in 3rd category of TW towards south-western districts in Karnataka is noticed.

Transmission of malaria (Figure 3.35) is open for 1–3 or 4–6 months in the states like Rajasthan, Jharkhand, Chhattisgarh, and parts of Gujarat and Karnataka, while the monthly epidemiological data shows transmission for more months. TWs determined using both temperature and RH are closer to the reported distribution of malaria in India as compared to TWs based on temperature alone particularly in eastern part of India.

Future projection of dengue in India

A1B scenario based on temperature: In A1B scenario, 154 pixels in India are without a single month suitable for dengue transmission. These pixels are confined in the northern part (Figure 3.36). Under the projected scenario, there is a slight opening of TWs, while there is increase in all categories of TWs except 10–12 months, which show reduction. The determined TWs match with monthly incidence of dengue in Delhi, for example (Figure 3.37).

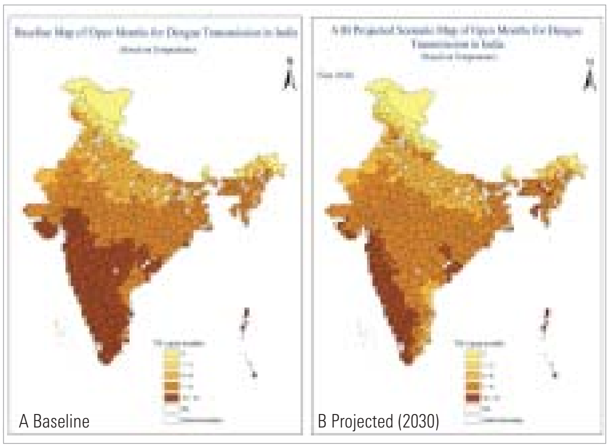


Figure 3.36: Transmission windows of dengue, based on temperature by 2030 (A1B scenario)

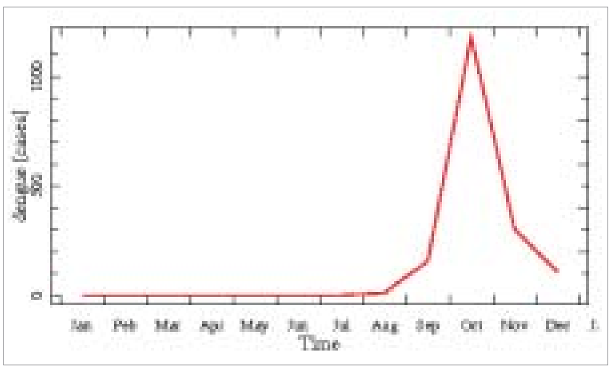


Figure 3.37: Monthly fluctuations in dengue fever cases in Delhi (average of 10 years)

A1B scenario based on temperature and relative humidity: With combined TWs of dengue based on temperature and relative humidity, fewer windows are open for transmission in baseline as well as under projected scenario (Figure 3.38). The intensity of transmission for more than 7–9 and 10–12 months is reduced, while there is increase in Categories II and III of TWs.

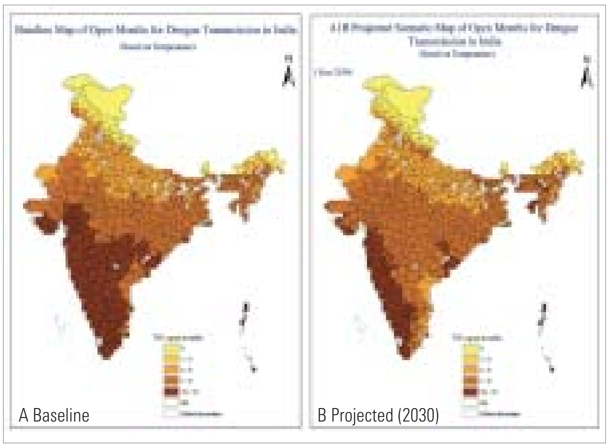


Figure 3.38: Transmission windows of dengue, based on temperature and relative humidity (A1B scenario)

There is a need to understand the various uncertainties and limitations of the model and data used for estimation of health impacts and its projections into the future (highlighted below) and simultaneously, some of the knowledge and research gaps are also highlighted; which would require future attention in the context of the changing climate.

Uncertainties and limitations of PRECIS model and data

- The data on temperature and RH provided by the model are at the resolution of 48 km × 48 km, which cannot delineate differences in hills and valleys in the Himalayas and some parts of the northeastern region and even in the plains.
- Analyses have been done using mean temperature, studies are warranted using diurnal temperature17.
- Mitigation measures can change the scenarios.
- The projections made for transmission windows may be affected drastically by intervention measures, ecological changes and socio-economics of the communities.

Knowledge and research gaps

- In some geographic areas, TWs show suitability for less number of months while the occurrence of cases reflects transmission for longer periods. This suggests the presence of a micro-niche, which needs to be studied in detail, particularly in areas like Gujarat and Rajasthan.

- Based on the outputs of open months for malaria transmission, validation is needed at the district level to determine cut-off limits of transmission for temperature, RH and rainfall.
- The study should be expanded to other Vector Borne Diseases in India.
- The outcome of projections is based on only climatic parameters alone, which if integrated with intervention measures, socio-economics and immunity of the population would provide a holistic projection.

Heat waves and human health

Heat waves are normally associated with the high average temperature and the number of consecutive hot days. Heat exhaustion is the most common response to prolonged exposure to high outdoor temperature; it is characterized by intense thirst, heavy sweating, dizziness, fatigue, fainting, nausea or vomiting, and headache. If unrecognized and untreated, heat exhaustion can progress to heatstroke, a severe illness with a rapid onset that can result in delirium, convulsions, coma, and death. Heatstroke has a high fatality rate. Non-fatal heatstroke can lead to long-term illness. In India, 18 heat waves have been reported during the period between 1980 and 1998, with a heat wave in 1988 affecting 10 states and causing 1300 deaths. Heat waves in Orissa in 1998, 1999, and 2000 caused an estimated 2000, 91, and 29 deaths, respectively, and heat waves in 2003 in Andhra Pradesh caused more than 3000 deaths. In South Asia, heat waves are associated with high mortality in rural populations, and among the elderly and outdoor workers. In India, the frequency of hot days and multiple-day heat waves has increased in India in the past century (IPCC's AR4). In particular, El Niño years are more prone to get frequent heat waves, whereas heat wave occurrences are fewer during La Niña years.

Methodology

In India, generally the average temperatures are high during the summer months of March to June, and any further increase in average temperatures during these months causes severe human distress due to heat waves. As per the IMD, a heat wave is occurs when the maximum temperature goes up by 7°C or more above its long-term normal values recorded by the station having average maximum temperature < 40°C or remains more above by 5°C of its long-term normal value recorded by the station having average maximum temperature >40°C.

The PRECIS model's future climate scenarios received from the IITM for A1B scenarios have been used to determine the future occurrences of heat waves in seven Indian states, namely, Andhra Pradesh, Bihar, Gujarat, Orissa, Rajasthan, Uttar Pradesh, and West Bengal. In order to identify heat wave conditions, the long-term average of monthly mean maximum temperatures of the capital cities of these states (Table 3.6) is used as a benchmark for respective states. It is evident that the long-term average of all these capital cities ranges from about 37°C to 40°C, based on the meteorological records of last 50 to 100 years.

Using these values as benchmarks, the values of maximum monthly temperatures of the targeted seven states, by

Table 3.6: Monthly mean maximum temperatures of capital cities of seven target states of India for the months of March, April, and May

State	City	Monthly mean maximum temperature (°C)			Period
		March	April	May	
Andhra Pradesh	Hyderabad	37.9	39	37.5	1951–2000
Bihar	Patna	37.4	38.4	36.7	1951–2000
Gujarat	Ahmedabad	39.5	41.4	38.5	1901–2000
Orissa	Bhubaneswar	37.2	37.5	35.2	1951–2000
Rajasthan	Jaipur	37	40.3	39.5	1951–2000
Uttar Pradesh	Lucknow	38	40.3	38.6	1951–2000
West Bengal	Kolkata	35.7	35.5	33.7	1901–2000

district, have been extracted from the PRECIS model outputs for the A1B scenario for the months of April, May, and June of 2030, 2050, and 2080. These values are then analysed for identifying the likely heat stress vulnerability of districts of identified seven Indian states by filtering the occurrences of future maximum temperatures in the range of 45–50°C for three days continuously, which is assumed to be heat wave conditions in that area in the present study. In order to identify the areas of highest vulnerability due to heat stress, districts with more than 15 days of heat wave conditions (that is, at least five events of three consecutive days of high maximum temperature occurrences in the range of 45–50°C) in a month under future climate scenarios have been identified.

Future projection of vulnerable areas in India: The heat wave occurrences under future climate change scenarios under A1B scenario for the months of April, May, and June of 2030, 2050, and 2080 from the PRECIS model, identified using the methodology described in the previous portion, also showed large temporal and spatial differences among the different districts of Andhra Pradesh, Bihar, Gujarat, Orissa, Rajasthan, Uttar Pradesh, and West Bengal. The number of three consecutive days of high maximum temperature occurrence in the range of 45–50°C in a month for the months of April, May, and June of the years of 2030, 2050, and 2080 in the districts of above mentioned Indian states were projected.

Impact and Vulnerability of Climate Change on Human Settlements

With increasing urbanization, the understanding of the impacts of climate change on the urban environment has become even more important. The climate change presents unique challenges for urban areas and their growing populations. These impacts are a result of the climatic changes such as warmer and more frequent hot days and nights over most land areas; fewer cold days and nights in many parts of the world; increase in the frequency of warm spells/heat waves over most land areas; increase in the frequency of heavy precipitation events over most areas; increase in areas affected by drought; increases in intense tropical cyclone activity; and increase in the incidence of extreme high sea levels in some parts of the world.

Beyond the physical risks posed by the climatic changes, some cities will face difficulties in providing basic services to their inhabitants. These changes will affect water supply, physical infrastructure, transport, ecosystem goods and services, energy provision, and industrial production. Local economies will be disrupted and populations will be stripped of their assets and livelihoods. The impacts of climate change will be particularly severe in low-elevation coastal zones, where many of India's largest cities are located.

Climate change causes vulnerability of human settlements, which is mainly related to extreme weather events, and such gradual changes in the climate exceed the adaptive capacity of human systems. Climate change adds to the existing stress on the sustainability of human settlements and society.

The concentration of urban development in a few large cities has led to tremendous pressure on civic infrastructure systems like water supply, sewerage and drainage, solid waste management, parks and open spaces, and transport. It has also led to the deterioration in the quality of city environment. In several cities, the problem of traffic congestion, pollution, poverty, slums, crime, and social unrest are assuming alarming proportions. Climate change is likely to exacerbate the existing stresses that these settlements already face. It may also impact the measures that are being undertaken for sustainable development of these areas. Climate change impacts are felt locally—in cities, towns, and other human settlements. Due to rapid urbanization, cities are more at risk, given the existing environmental, economic and social problems. The cities with large concentration of population, property, and crucial economic assets and infrastructure are highly vulnerable.

Climate change could affect water supply systems in a number of ways. It can affect the water demand for drinking and cooling systems. Where climate change leads to the failure of small local water sources such as wells, it could lead to greater demand for regional water supplies. Changes in precipitation patterns could lead to reduction in water availability and fall in water tables. In coastal areas, it could lead to saline intrusions in rivers and groundwater. Loss of melt water could reduce river flows during critical times. A change in water availability and supply also affects sanitation and drainage systems. When water supplies reduce, sewerage systems also become vulnerable. Further, sewage treatment plants are vulnerable to floods or sea level rise, as these are often located near rivers or seas. Where the sewer outfalls are in the sea, sea level rise will affect the functioning of such systems. Storm water drainage systems could become frequently overloaded and cause flooding, and heavy storms become more frequent due to climate change. The impact of inadequate drainage systems in cities like Mumbai is already being felt, leading to flooding and huge economic losses. More frequent floods could also present a significant threat if these lead to contamination of flood water with faecal material. Climate change may impact the transport and other infrastructure due to extreme local climatic experience, leading to significant economic losses. Rising sea levels in the coastal area would increase the risk of flooding and increase the vulnerability of communities residing in these areas, especially the poor. The urban heat island effects could get exacerbated due to increase in baseline temperatures, affecting climatic comfort of the urban population and may consequently lead to additional costs in climate control.

The vulnerability of human populations varies with economic, social, and institutional conditions. Approximately one person in six worldwide lives in slums. The poor and the marginalized have little capacity to adapt to changes in climate by adopting such mechanisms as air conditioning or heating. The traditional coping mechanisms of these vulnerable communities may be overstretched due to additional stresses related to climate change. Climate change threatens the homes, livelihoods, and health of the urban poor. When disaster strikes, their homes may be damaged or destroyed and they may be unable to travel to work, causing loss in money for food and other basic needs. Drought, floods, and storms in the rural areas have increased migration to cities. Poor people often live in informal settlements on land, which is susceptible to climate change—floodplains, coastal lowlands or unstable hill sides. Drain and culverts are frequently blocked with rubbish. Slum dwellers often lack secure tenure, proper shelter, water, sanitation, electricity, and other services. Most have no insurance. Climate change may add to their problems.

River and inland flooding and extreme rainfall events: Climate change is also expected to increase the severity of flooding in many Indian river basins, especially in the Godavari and Mahanadi along the eastern coast. Floods are expected to increase in north-western India adjoining Pakistan and in most coastal plains, in spite of existing upstream dams and "multi-purpose" projects. An extreme precipitation is expected to show a substantial increase in some parts of the country. Sanitation infrastructure is the main determinant of the contamination of urban flood water with faecal material presenting a substantial threat of enteric diseases. In addition to flood hazards, more extreme rainfall events associated with climate change will also cause hazards from landslides in many urban centres in the hilly regions. Dealing with likely increase in risks associated with storm water will require a significant revision of urban planning practices across cities in the flood-affected regions. Flood and climate change migration and adaptation measures will have to be integrated into day-to-day urban development and service delivery systems. Due to higher precipitation in more intense events, there is a need to increase the margin of design safety to enhance the hydraulic capacity of the sections. This will result in additional investments.

Cyclonic storms, storm surges, and coastal flooding: Yet another important climate change induced risk is that of cyclonic storms, storm surges, and accompanying coastal inundation. The high concentration of population, especially on the eastern coast, has led to extremely high vulnerability in this region, leading to devastating loss of life and property. The 1999 Orissa super cyclone killed over 10,000 people and devastated buildings, lifeline infrastructure, and economic assets across 10 coastal and six inland districts, which included a number of towns and cities, due to mix of devastating storm surges, cyclonic winds, and coastal flooding.

Cyclones and storm surges could have a devastating impact on large urban centres, including the mega cities of Mumbai and Chennai, the million plus cities of Vishakhapatnam and Surat as well as other cities like Bharuch, Bhavnagar, and Jamnagar apart from leading to critical bottlenecks in important ports such as Kandla. Increased migration to the coast, powered by huge investments in coastal infrastructure, settlements and enterprises, could lead to a substantial rise in losses.

Sea level rise: It is estimated that sea level rise by 3.5 to 34.6 inches between 1990 and 2100 would result in saline coastal groundwater, endangering wetlands and inundating valuable land and coastal communities. The most vulnerable stretches along the western Indian coast are Khambat and Kutch in Gujarat, Mumbai, and parts of the Konkan coast and south Kerala. The deltas of the Ganga, Krishna, Godavari, Cauvery, and Mahanadi on the East Coast may be threatened, along with irrigated land and a number of urban and other settlements that are situated in them. The loss of these important economic and cultural regions could have a considerable impact in some states.

Climate Change and Integrated Assessment

Integrated assessment studies interactions between natural and socio-economic systems, for understanding the cause–effect chains, including feedback loops across many dimensions, for the purpose of policy-making and implementation. The integration here relates to sectoral, spatial, temporal, process, policy, and implementation, and finally mitigation, vulnerability, impact, and adaptation. They represent interactive complexity of climate impact phenomena. The integration analyses the key interactions within and between sectors of a particular exposure unit and between this unit and outside world. It generates a comprehensive assessment of the totality of impacts rather than the separate sectoral impacts. The second purpose of the integrated assessments is to enable policy-makers to place climate change impacts in a broader context such as natural resources management, sustainability of ecosystems, economic development, and associated broader questions.

Integration provides opportunity for linking wide scientific knowledge and interests to distinctly differing socio-economic and political interests and opinions. These assessments are very much needed not only to provide a platform for the scientists to link their own area of research with other scientific disciplines but also to apprise the policy-makers about the likely impacts of climate change and the ranges of adaptation strategies available. Therefore, in the final analysis, integrated assessments are essential for facilitating the optimal development of institutional and research linkages, projects, and policy recommendations as they enable the best available synthesis of current scientific, technical, economic, and socio-political knowledge.

Methodology for integrated assessment ranges from simple to extremely complex representation of systems. Simple models are better at representing uncertainty, whereas scenarios and projections from complex models will be more precise if not more accurate. An example of an integrated assessment framework for estimating impacts of climate change on rural resources, products, and services, on the one hand, and strengthening their resilience to withstand these impacts in a sustainable manner over a period of time through various interventions for the enhancement of natural resources, infrastructure, and livelihoods, on the other hand, is indicated in Figure 3.39.

Integrated assessment would require consistent and holistic understanding of diverse resources, sectors, and socio-economic systems within a region to assess synergies and trade-offs possible due to climate change. This would require capacity creation, enhancement, and sustenance for modelling, database creation, and policy formulation and implementation. India has initiated modest steps in this direction through this national communication

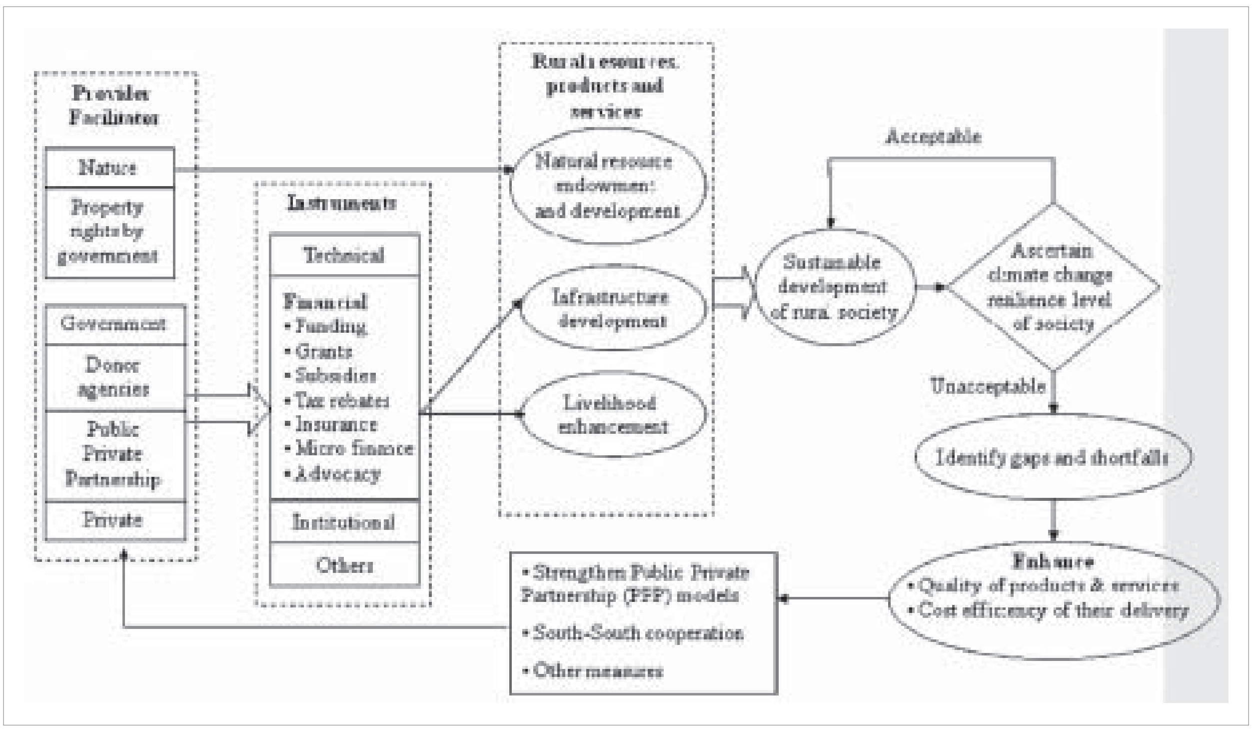


Figure 3.39: Sectoral integration for impact assessment

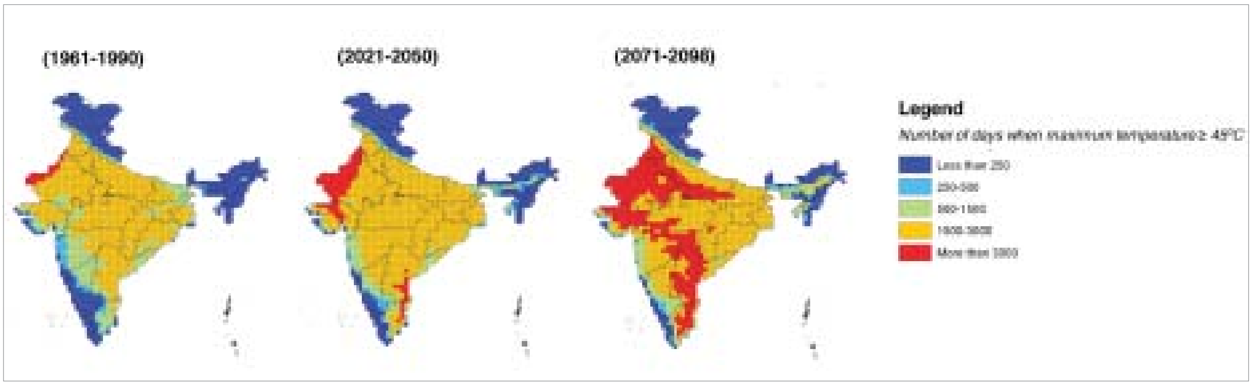


Figure 3.40: Projected maximum temperature duration profile under A1B scenario for India

process which requires strengthening on all fronts. Some of these assessments are presented here.

Impact of climate change on energy systems

Energy is a key driving force for the development of all economic activities. Integrated assessment would require integrating supply of energy resources (commercial and traditional) and energy demand, keeping in mind constraints posed by key drivers such as population projections, living standards, environmental consciousness, developmental goals and targets, water availability, and land resources. Spatial variability in endowment, and supply and demand of energy also needs to be captured over the entire period of assessment.

Climate change is projected to impact both energy supply and demand. On the supply side, the main effects would be on electricity generation, although oil and gas production would also be affected indirectly due to changes in relative economics of fuels under a climate change regime. Hydropower generation is the energy source that is most likely to be impacted because it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting). Reduced flows in rivers and higher temperatures reduce the capabilities of electric generation; high temperatures also reduce transmission capabilities. Increased cloudiness can reduce solar energy production despite the availability of generation capacity. Wind energy production would be reduced if wind speeds increase above or fall below the acceptable operating range of the technology. Changes in photosynthesis and growing conditions could affect the production of biomass-based energy. Energy demand side would also be similarly affected in sectors, specifically, residential, commercial, and transport. Changes in space cooling and heating requirements, and water pumping needs would be the main drivers of energy demand changes.

The Indian energy system is characterized by the predominance of coal use due to huge domestic reserves of coal, but limited gas and oil reserves. Most carbon emissions arise from the use of coal in electric power and industry sectors, which is a major contributor towards global warming. Rising particulate and SO_2 emissions due to coal combustion is a concern among policy-makers. Integrated macro-economic energy and environment paths need to address issues related to investment requirements and their availability, energy supply (indigenous availability vis-à-vis imports), technology R&D and transfer issues, local and global environmental implications, institutional requirements, and capacity building measures.

Impact on and of built environment

Developments in Indian economy have triggered the growth of real estate in the country. Huge investments are being committed in real estate due to increased demand and increasing capacity to invest. Buildings account for more than 60% of all energy use in most high- and middle-income countries of the world, and an increasing proportion in low-income regions. Studies have indicated that both the functionality of the existing built environment and the design of future buildings may need to be altered to cope with the climate change impacts. This would

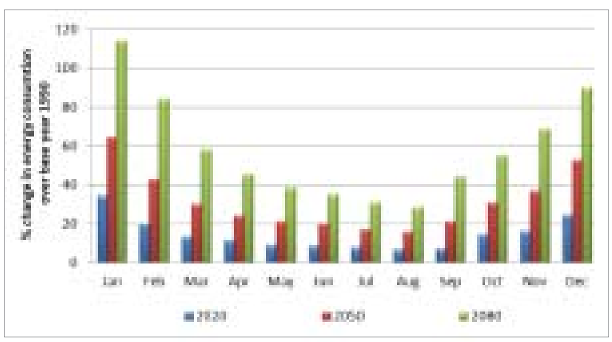


Figure 3.41: Change in space cooling energy for a 1:2 rectangular building

include heat island effects created due to more use of conventional space cooling technologies in future when mean and maximum temperatures rise. Figure 3.40 projects the number of days above 45°C under A1B scenario for India.

The required alterations and adaptation strategies shall vary according to the building designs, materials used, technology employed, and most importantly the location. India exhibits wide variations in climate, topology, and geography and also has wide economic, social, ethnic, religious, and cultural differences amongst its inhabitants. This heterogeneity accounts for differences in habits, attitudes, and lifestyles and also manifests itself in varying levels and patterns of energy use throughout the country.

Temperature has significant effect on electricity or energy consumption. The characteristics of electricity consumption in India show that it changes with seasonal fluctuation and has a rising trend. This relationship between the temperature variation and electricity consumption has been demonstrated in the study for Madhya Pradesh, which is a state where electricity demand-supply gap is very wide and results in planned and unplanned outages. Bhopal being the state capital, planned outages are minimal and efforts are made to provide uninterrupted power supply. The observations in the study for future show that warm dry season in 2020, 2050, and 2080 would have the maximum average electricity demand, whereas cool dry season would have the minimum average electricity demand. In the warm humid season, the electricity demand would be slightly less than the warm dry season for the same periods. The higher increase during warmer seasons indicates that the increase in temperature during hot summer days is expected to force the already high electricity demand, whereas the moderate increase during winter indicates that though some warmer days will experience increased cooling load, most of the days will continue to be in comfortable range of temperature. Analysing the simulation study results, it can be observed that the rising temperatures during cooler seasons in future years result in cooling demand during winter months. This is indicated by the higher percent increase during November to February compared to energy consumption growth percentage for space cooling in summer months for future years (Figure 3.41), as presently there is almost no space cooling required during winter months.

The building sector requires special attention as the diversity of this sector with distinct uses and extended life cycle of buildings poses greater challenge. It gets further complicated as energy consumption behaviour of individuals involved depends on their gender, age, and socio-demographic and economic conditions apart from variations in climate, topology, geography, and level of development. Since vulnerability and impacts for built environment are location-specific, similar studies need be carried out for different representative locations in India before any kind of generalized inferences are drawn. A wide range of adaptation measures need to be implemented in response to both observed and anticipated climate change. These include possibilities of reducing energy consumption at building design and construction stages such as going for green and sustainable building design, and use of low energy foot-print materials such as sand, aggregate, fly ash, volcanic ash, and soil (0.2–0.5 MJ/kg) as compared to aluminium, plastics, copper, stainless steel (50–250 MJ/kg). Efficient interiors and energy-efficient lighting and air-conditioning appliances would ensure lower energy consumption and thus lower GHG emissions through the active life of a building. Building users need also to be sensitized about making some lifestyle changes.

Climate change impact assessment on livelihoods

Assessment of the impacts of climate change on livelihood of people spread across vast and variable geography of India is a challenging task. Livelihoods depend upon endowment and conservation of natural resources, as well as infrastructure assets and man-made systems and institutions available in a region. Climate change impacts on river flows, natural resources, connected ecosystems, and thus on people and their livelihoods can be dramatic, although not the same in rate, intensity, or direction in all parts of India. Moreover, the impacts of climate change are superimposed on a variety of other environmental and social stresses. Integrated assessment of these impacts, therefore, is a challenging task. The relative sea level rise also depends upon the geological stability of the coastal regions and extreme events such as cyclones, with their attached uncertainty on intensity and frequency. Vulnerability of any area due to sea level rise and climate change depends on the resources present in that area and the adaptive capacity. As resource and adaptive capacity are dynamic features, predicting vulnerability for future is a complex process. Indian coast has been rising at the rate of about 1.3 mm/year on an average as per the latest assessments.

In a study on vulnerability assessment in coastal area in Orissa, agriculture was found to be adversely affected due to sea level rise, causing changes in hydro-geological dynamics of the area. The rise in sea level has direct impact on the mangroves and on the relatively lower elevation (mostly along river/channels etc) and on the agricultural land surrounding drainage channel carrying high tide water inside the village.

On the other hand, hydrological imbalances observed in case of Himalayas are mainly linked to the loss of vegetation cover. Further the influence of geo-morphological forces in geologically active belts exacerbates the process of landslides and erosion. These phenomena, apart from directly deteriorating the local environment, have significant implications for the adjoining regions too. Nearly 40 million people inhabit the Himalayan region (3.8% of the total population of the country). The complex environmental and development problems create tremendous constraint on the sustainability and conservation of water resources. For instance, Uttarakhand state in the northern part of India has 917 glaciers, spread over 735 km^2, providing perennial supply of water to the people of the state and downstream riparian states. The state provides to lower riparian states roughly 35 BCM of water annually with nearly half of its rainfall going directly as downstream run-off. It has annual replenishable groundwater resources of 2.27 BCM, being the main source of water for agricultural and household uses. Nearly 51% of habitations are fully covered by drinking water schemes. Climate change could also result in significant changes in the variables that affect the quality of water. These impacts originate from a variety of alterations to the hydrology of waterbodies, their physico-chemical and biological attributes, and changes in anthropogenic pressures.

There is increasing evidence of poverty in mountain communities because the natural resource bases of forests, soil, water, plants, and animal life, on which the people depend for their continued survival, are decreasing at an alarming rate. These could result in reduced production of agriculture, livestock, and hydropower, resulting in income losses to poor local communities, revenue loss to local state government, and economic loss to the rest of the Indian economy. Further for example, agriculture is practised in the river valleys of Uttarakhand on only 10–15% of the total land area. Over hundreds of years, many of the slopes have been cut into field terraces, a common characteristic of mountain agriculture. Out of the total population of 84.89 lakh (census 2001) in the state, 74% lives in villages where agriculture is the mainstay of the economy. Majority of the worker population is actually engaged in agriculture. The area under food crops and fruits has shifted to off-season vegetable cultivation. Decline in area under apple and other fruit was comparatively higher in marginal and small farms. Productivity of apple has recorded a decrease of about 2–3% over the past years, and a maximum decrease of about 4% has been noticed in marginal farms. The total farm income, on an average, has shown a marginal reduction of about 4% in the present period. In sub-tropical environment, the decrease in potential wheat yields ranged from 1.5% to 5.8%. From 2002/03–2006/07, there was a fall in the area under crops by 98,233 hectares. The percentage cropped area of Uttarakhand in the year 2006/07 declined by 8.01% as compared to year 2002/03 (Table 3.7).

Changing cropping patterns and environmental hazards, such as landslides, forest fires, and floods in Uttarakhand, attributed to anthropogenic activity and climate factors, have direct adverse implications on livelihood challenges for people in these regions. However, the resilience and adaptation of people in Uttarakhand have acquired important dimension in the light of climate change conditions. The livelihood systems are adapted through the promotion of high value mountain niche products such as value-added wild edible like sea buckthorn berries, rhododendron flowers, bamboo culms, berries fruits, handicrafts articles, and services rendered by the vulnerable local people.

Table 3.7: Changing cropping pattern in Uttarakhand during 2002/03 to 2006/07

Crops	2002/03		2006/07		Marginal Increment over 2002–06 (hectares)	Changes in Percentage over 2002–06
	Area in hectares	% of total cropped area	Area in hectares	% of total cropped area		
Cereals	993,379	81.06	923,842	81.95	-69,537	-7.00
Pulses	50,948	4.16	51,949	4.61	1001	1.96
Oil Seeds	28,504	2.33	28,030	2.49	-474	-1.66
Other Crops	152,682	12.46	123,469	10.95	-29,213	-19.13
Total	**1,225,513**	**100**	**1,127,290**	**100**	**-98,223**	**- 8.01**

On the other end of the Himalayan range, in the north-eastern part of India, occasional floods in the low land region and early flowering of certain vegetable species such as brinjal and brassica have been observed. Another impact that North East has experienced is the high rainfall in 2008, resulting in lower production of potato and pumpkin. In the case of wheat, the yields are projected to reduce by up to 20%. Potato yields are likely to be marginally benefitted up to 5% in the upper parts of North East region due to climate change influence, but in the central part, the yields are projected to reduce by about 4%, while in the southern parts of the North East region, the negative impacts will be much higher. Forest is another sector that provides a multitude of benefits that are crucial to the environment as well as the economy. Economically, apart from supplying timber, forests support the livelihoods of people living within the forests and their marginal lands; forests provide fuelwood, food, and fodder, which are the basic means of survival for poor families. Forests are one of the possible sources of livelihood for the poor. Non-timber forest produce (NTFP) sold in the market is a source of income for many.

Another integrated assessment-based case study was conducted to assess the impacts of enhanced tidal storm surges on agriculture productivity in coastal regions of Orissa state. Agriculture contributes nearly 17.1% of Indian GDP currently. It is estimated that by 2020, food grain requirement will be almost 30–50% higher than the present demand. Droughts, flood, tropical cyclones, heavy precipitation events, and hot extremes and heat waves are known to negatively impact agricultural production and farmers' livelihood. The effect of climate on agriculture is related to variability in local climates rather than in global climate patterns. Projections indicate the possibility of loss of 4–5 million tonnes in wheat production with every rise of 10°C temperature throughout the growing period with current land use. The case study of Brahamani–Baitarani estuary region in the state of Orissa shows that enhanced tidal storm surge along with intensified cyclonic wind due to climate change will adversely affect the agriculture, and there could be several impacts of storm surge on agriculture. First of all, fertile agriculture land will be inundated by the saline water, which may hinder the crop production for several future years. Erosion of agricultural land shall also badly influence the agriculture options and crop yield. Almost all the agricultural activities (sowing to harvesting) are climate sensitive. About 211.8 ha of agriculture area and 3130.9 ha of forest area are under very high vulnerable category, whereas 11.1% of total agricultural area in the Brahamani–Baitarani estuary, that is, 4447.2 ha and 4965.9 ha of forest area, is under high vulnerable category.

In another integrated case study on change in cropping patterns due to climate change and its impacts on livelihoods of farmers has been carried out in southern Indian state of Tamil Nadu. Cultivation of major stable crop paddy has declined compared to commercial crops such as sugar cane and cotton. About 87% of the farmers who raised paddy five years ago continue to raise the same crop. Remaining 13% of the rice cultivating farmers shifted to other commercial crops such as sugar cane and cotton. The percentage of commercial crop growers such as cotton and sugar cane increased from 11% and 2.22% to 14% and 7.22%, respectively. The majority of the remaining 3.33% of the farmers and those who were raising other crops have switched over to maize and sorghum, which demand less water. The percentage of groundnut cultivating farmers has increased from 0.56% to 1.11% and coconut cultivation remains the same (1.11%). The adverse impacts of climate change depend on the adaptation and mitigation potential of the farmers. Apart from this, there is also lack of information on many specific local regions, which includes the uncertainties on magnitude of climate change, the effects of technological changes on productivity, and the numerous possibilities of adaptation. This makes the process more complex to accurately estimate the impact of climate change on agriculture. The predicted change in the resource base would adversely impact the communities that are directly dependent on forest resources for their daily subsistence and livelihoods. Therefore, the communities will have to deal with the changing resource base and their livelihood.

Integrating water and gender issues under climate change

Many regions in India are characterized by water scarcity, especially during summers. Even urban areas are not spared from water stresses, where municipal water rationing is a regular phenomenon. This is affecting the well-being of millions of the poorest people since rich can afford to buy water at higher prices. Rapidly growing populations, urbanization, agricultural intensification, and climate change all contribute to greater competition and scarcity of water resources. Despite enhanced provision of water facilities over the past few decades and the development of low-cost, sustainable technical solutions to many aspects of water provision, millions still suffer from water-related diseases and the physical, social, and economic burdens associated with scarcity.

Indian women, especially in rural areas, bear the responsibility and disproportionately higher burden of fetching water for households. In India as well as many other developing countries, 20% households still do not have provision of adequate water for domestic use. This has resulted in a significant loss of time and effort, especially on the part of women, who most often have to bear the burden of water collection. The female children have to share the temporal and physical burden of carrying water, often leading to very large gender gaps in school attendance in many countries. Translating the losses borne by girls and women in terms of man (woman) hours and economics shows a loss of human capital and reduction in the ability of the household to capitalize fully on its other resources.

In the Indian policy statements and recent initiatives, a focus on women has been seen as critical to improving the management or governance of water within an overall context of poverty alleviation. Climatic change, associated with increasing population, urbanization and industrialization, is projected to reduce per capita water availability in many parts of India. The per capita availability of water was 5177 m^3/capita/year in 1951. This value has drastically reduced to 1654 m^3/capita/year in 2007 and is likely to further go down to below 1140 m^3/year by 2050. While the per capita availability of water is decreasing, the gross demand for water is likely to rise due to growing population and affluence. The total water consumption in India is expected to rise by 20–40% in the next 20 years. Crop-mix and intensification of cropping would add their bit to enhanced water demand. An integrated assessment would require a holistic view of projections of land use change, crop mix and crop intensity, water irrigation facilities, and adoption of water conservation systems and practices such as micro irrigation systems, urban settlement, and water conservation systems. Such studies have to be conducted in subsequent national communications in a scientific manner and with a broader regional coverage.

In a case study of mountain ecosystem in Uttarakhand, it was observed that women remain largely absent at all levels of policy formulation and decision-making in natural resource and environmental management and conservation. They also lack the ownership rights over productive resources, restrictions on decision-making outside of the household economic constraints, and

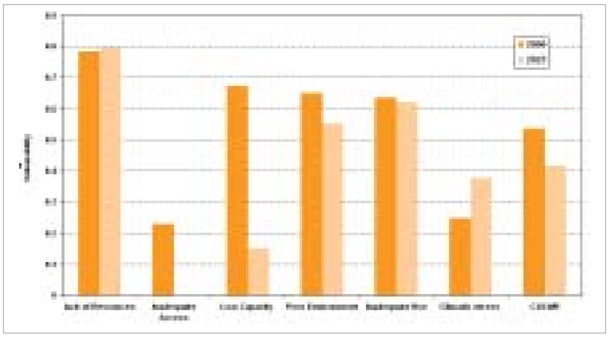


Figure 3.42: Comparison of components of climatic vulnerability of India for water at the household level in 2000 and 2025 (A1B scenario)

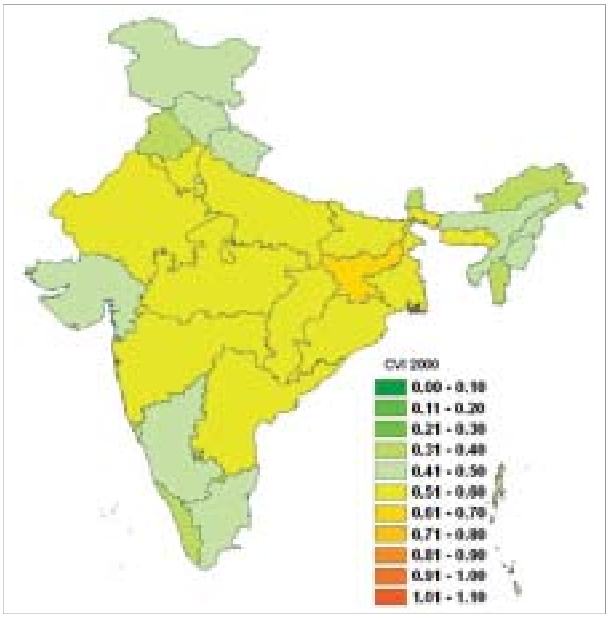


Figure 3.43a: Climate Vulnerability Index for water at household level (2000)

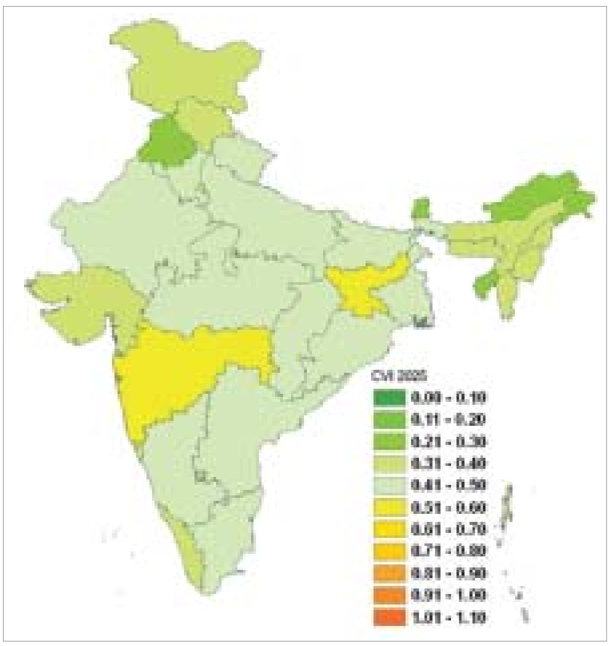


Figure 3.43b: Projected Climate Vulnerability Index for water at household level (2025)

educational barriers and constraints on accesses to information, informal and unorganized nature of women's enterprises. It is also observed that given the lack of resources and access to technology and finances, women have limited capacity to develop and adopt strategies to reduce their vulnerability to adverse impacts of climate change.

Besides carrying out the majority of the tasks related to agriculture, women in some of the tribal areas especially in the central part of India still remain largely confined to their homestead. Community affairs are invariably run by men unless there has been an external initiative that has promoted inclusion of women in the public domain. Within the household women do most of the labour, but have limited control over decision-making and resources. Female-headed households face multiple vulnerabilities as they often lack access to land and vital social networks in the community, which are predominantly based on male kinship relations. The subjugation of women also results in fewer opportunities to access health facilities and education. This manifests in the form of a high level of vulnerability among women as compared to men.

In an analysis on Climate Vulnerability Index for 2025, it was shown that in most states, there was huge decrease in vulnerability of people in the capacity component because of projected increase in literacy rate, life expectancy, incomes, and decrease in infant mortality, leading to increased abilities of people to lobby for water and other resources (Figure 3.42). There was substantial decrease in vulnerability of states in "Access" and "Environment" components, since a significantly higher percentage of families had access to safe source of water as well better sanitation facilities in terms of safe toilets.

However, there was a marginal increase in vulnerability in a large majority of the states in the "Resources" component because of the growth in population, leading to reduced per capita availability of water resources. The vulnerability of states increased in almost 50% of the states in terms of "Use" component because of high growth of population and lower per capita use of water for different purposes despite increased withdrawals of groundwater. Finally in the "Climate" component, the vulnerability of all the states increased owing to the projected increase in mean temperatures during 2020–30 (Figure 3.43a and b).

Overall for India, the climatic vulnerability to water at the household level is projected to decrease from 0.54 in the year 2000 to 0.42 in the year 2025 (Figure 3.44). In terms of various components of vulnerability, inadequate access is likely to be completely wiped out by 2025, and there is likely to be tremendous growth in various components of human development, reducing the vulnerability of people to "Low Capacity". There will be a moderate reduction in vulnerability in the "Use" component accompanied by a slight reduction in vulnerability in the "Environment" component. On the other hand, in India, the vulnerability is likely to increase marginally in "Resources" because of population growth and lower per capita availability, but it will increase substantially in the "Climatic stress" component. As a result of the interaction between the six components defining vulnerability of people to climatic and water-related stresses at the household level, there is likely to be overall reduction in vulnerability of India in 2025 as compared to vulnerability in the year 2000. However, India will remain moderately vulnerable to climatic and water-related stresses despite development efforts in different sectors.

Since independence, there has been a gender gap in literacy in India of the order of 20–25 percentage points. However, there is regional variation in male:female literacy rate among states in India. The analysis revealed that the states with high gender gaps in education of the order of 25–30 percentage points, such as Bihar, Uttar Pradesh, and Madhya Pradesh, were among the most vulnerable states to climate- and water-related stresses. By comparison, Kerala had the least gender differential in literacy of a little more than 6 percentage points and was among the least vulnerable states. The data clearly showed that the more a state invests in education of girls and women, the more the likelihood of reduced vulnerability of people to climatic and water-related stresses because of higher adaptive capacities.

Climate change impact assessment on human health and livelihoods

Global warming poses serious challenge to the health sector and hence warrants emergency health preparedness and response. Heat stresses, vector-borne diseases, and water contamination are some of the main health impacts projected due to climate change. Warmer temperature, shifting rainfall patterns, and increasing humidity affect the transmission of diseases by vectors like mosquitoes. They are quite sensitive to changes in temperature and rainfall and are among the first organisms to extend their range when environmental conditions become favourable. Health is very closely linked to access to sufficient nutrition, health care, safe water, and sanitation, and is determined by a number of

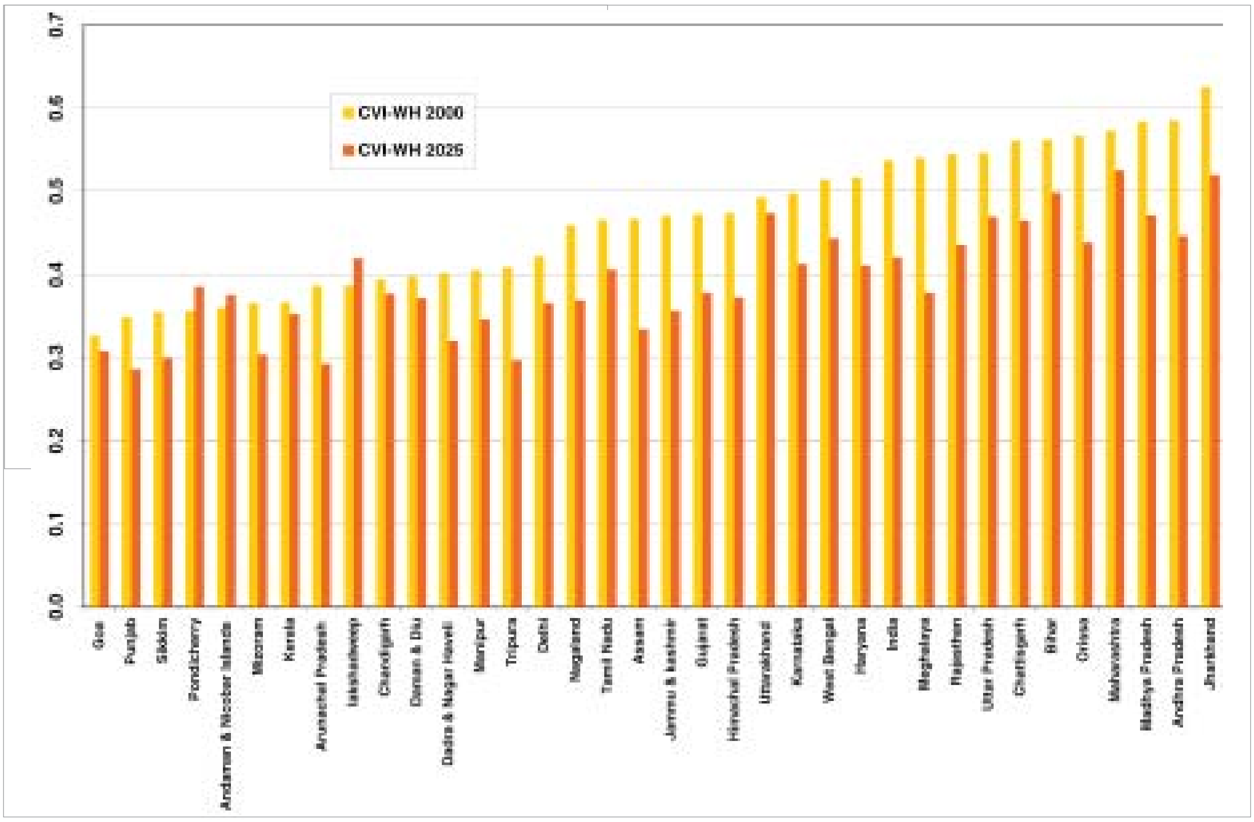


Figure 3.44: Comparison of CVI-WH (Climate Vulnerability Index for Water at Household level) values in different states in India in 2000 and 2025 (A1B scenario)

socio-economic factors characterizing the community. Overall, for India, as compared to other components of status, "Health" was one component in which there were minimum differences between female and male index scores (Figure 3.45a and b).

The health index for both female and male shows that Manipur and Kerala had low female infant mortality rates of 13 and 15, respectively, representing good ante- and post-natal care as well as hygiene and sanitation. By contrast, Madhya Pradesh and Orissa performed very poorly with female infant mortality rates as high as 79 and 77, respectively. The composite index of health of women showed that Madhya Pradesh and Orissa were the worst performers since they had a low value of life expectancy and a high value of infant mortality rate.

Access to safe toilet facilities has a positive impact on the health status of population, therefore, this is a positive indicator and the study across India shows that the highest availability of safe toilets (82.9%) was in Lakshadweep, which scored the index value of 1 (Table 3.8). This study was aimed at estimating the integrity of the environment through measuring identified variables such as access to safe toilets, use of pesticides etc. Lakshdweep was followed by Mizoram with a value of 81.7% and a consequent index value of 0.98. In states such as Kerala, Tripura and Manipur also, more than 70% of the households had access to safe toilet facilities. Conversely, only 11.3% of people in Chhattisgarh had access to safe toilet facilities, followed by Jharkhand and Bihar (14%). Chattisgarh, therefore, scored an index value of 0, whereas Bihar scored as low as 0.04. In case of Punjab and Haryana, 44.7% and 33.2% families had provision of safe toilet facilities, translating into index values of 0.47 and 0.31, respectively.

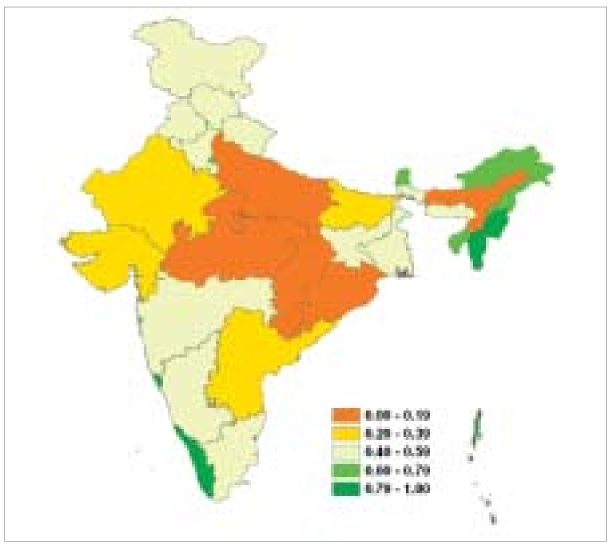


Figure 3.45a: Index of health status of males

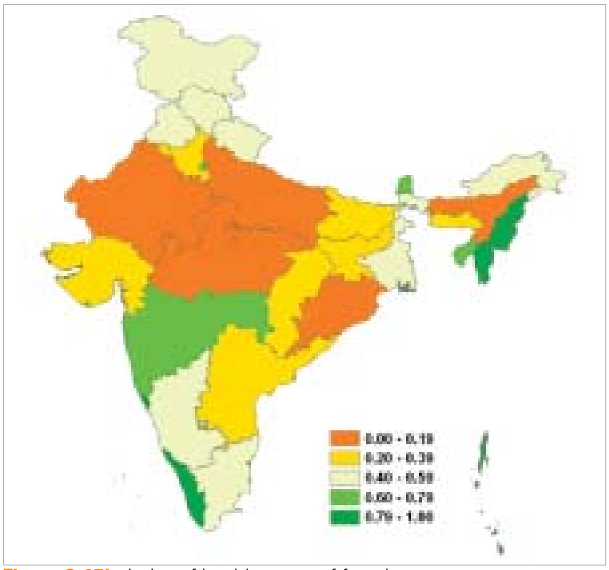


Figure 3.45b: Index of health status of females

At the all-India level, only a little above 29% households had access to safe toilet facilities. A large section of the population in slums and in rural areas continues to use open areas for defecation, leading to the contamination of soil and waterbodies, impacting human health negatively. This shows lack of knowledge and awareness in people about the increase in productivity of people as a result of better sanitation.

Due to urbanization and industrialization, large numbers of people are migrating towards urban areas, thus leading to the formation of slums with very poor access to basic services such as safe water supply and sanitation. Trends of urbanization in India show that the growth of urban population in India is faster than the rest of the world. By 2030, more than 40% population in India will come to reside in cities. A major chunk of this population will come to reside in slums and slum-like settlements. The urban poor – already a vulnerable population – are the most susceptible to extreme heat. This could further decrease access to the basic needs of the people, and poor sanitation in the slums would enhance water-related infections, which can transmit in the following ways: through ingestion from drinking supplies, through lack of good water for hygiene, and via aquatic pathogens and insect vectors that are hydrophilic. Slum conditions promote the spread of disease through all of these means. Rise in temperature affects the quantity and quality of water on one hand and also human productivity on the other. The change in weather has not only impacted human health but livestock also. This was evident with the rainfall pattern (1960–2003) of Rajasthan; the cattle population showed a decreasing trend, whereas the buffalo and goat population showed an increasing trend, and sheep population showed a fluctuating trend. With regards to the total milk production during 1985–2005, the buffalo and goat milk production showed an increasing trend, whereas in cow milk production, a significant impact has been observed. During the year 1960–2003, the average maximum temperature increased by 0.8°C. The total livestock population increased simultaneously similar to the increase of buffalo and goat population, whereas the cattle population slightly decreased. There are slight upward variations in sheep population in comparison with other animals. Although the methods for assessing the vulnerability, impact, and adaptation are gradually improving, they are still inadequate to help policy-makers formulate appropriate adaptation measures. Climate change poses new challenges to natural resource management and livelihood. The poor are most vulnerable to climate change, which will make pro-poor growth more difficult.

Climate change and sea level rise

Impacts of climate change at the coast are caused mainly by mean sea level rise and occurrence of extreme sea level events. Mean sea level rise is a gradual and slow process; however, severe impacts at the coast occur through extreme sea level events. An important concern of the consequences of global warming is the possible changes in the frequency and intensity of tropical cyclones. As far as the coastline of India is concerned, the East Coast is particularly vulnerable to the occurrence of storm surges generated by tropical cyclones in the Bay of Bengal.

In order to make detailed impact studies at select locations along the coast, some vulnerable areas were considered. As a first case Nagapattinam along the Tamil Nadu coast was chosen, which is known for its vulnerability to storm surges and also for the 2004 tsunami. For different projected sea level rise scenarios, inundation maps were prepared and area of inundation estimated through GIS techniques. Later, two more areas were considered, one surrounding Kochi and another surrounding Paradip for estimating the area of inundation for different scenarios of projected sea level rise. Along the Indian coast, records at four stations, namely, Mumbai, Kochi, Visahkhapatnam, and Diamond Harbour (Kolkata), were considered. These records are found to be long (more than 50 years duration), and the estimated trends are found to be statistically significant. These estimates were corrected for vertical land movements, caused by glacial iso-static adjustment (GIA).

Table 3.8: State level variation in various sub-components used for estimation of integrity of the "Environment" of the region

Name of the state	Percent households having safe toilets	Percent households having bathrooms	Plant nutrients (kg/ha)	Percent forest cover	Pesticides in kg/ha.	Percent slum population	Percent of sewerage treated	Index value of "Environment"
Andaman and Nicobar	41.9	47.9	9.6	84.42	0.18	14.00	0.00	0.62
Andhra Pradesh	26.6	39.8	158.1	16.15	0.37	24.90	4.98	0.36
Arunachal Pradesh	36.8	22.5	2	81.22	0.09	0.00	0.00	0.63
Assam	59.8	14.4	30.8	35.48	0.06	2.40	0.00	0.57
Bihar	14.4	9.6	97.7	5.9	0.18	6.10	15.69	0.40
Chandigarh	69.9	76.7	57.5	13.16	0.50	13.20	40.67	0.64
Chattisgarh	11.3	12.4	47	41.42	0.07	19.50	22.25	0.41
Dadra and Nagar Haveli	31.9	31.6	41.5	45.82	0.22	0.00	0.00	0.56
Daman and Diu	41.8	64.5	74	7.45	0.50	0.00	0.00	0.56
Delhi	61.9	71	435.7	11.47	2.22	15.70	79.05	0.46
Goa	48.6	66.5	44.1	58.24	0.04	2.20	0.00	0.68
Gujarat	39.8	50.6	87.8	7.62	0.47	9.90	43.97	0.54
Haryana	33.2	51.6	148.5	3.43	1.42	23.20	54.52	0.40
Himachal Pradesh	26	35.4	39.4	25.78	0.70	0.00	99.85	0.64
Jammu and Kashmir	26.2	45.7	55.1	9.57	0.13	10.70	0.00	0.46
Jharkhand	14	15.1	67	28.5	0.02	5.00	0.00	0.44
Karnataka	32	58.9	103.4	19	0.27	7.80	2.98	0.52
Kerala	77.6	62.1	70.6	40.08	0.41	0.80	0.00	0.68
Lakshadweep	82.9	82.2	0	71.88	0.67	0.00	0.00	0.80
Madhya Pradesh	18.4	24.3	47.2	24.79	0.07	15.10	15.43	0.44
Maharashtra	29.9	61.1	88.9	15.23	0.21	27.30	7.47	0.42
Manipur	75.6	10.4	92	77.12	0.09	0.00	0.00	0.66
Meghalaya	42.8	33.7	16.5	75.08	0.03	19.00	0.00	0.56
Mizoram	81.7	51.2	17.4	87.42	0.15	0.00	0.00	0.78
Nagaland	54.6	37.4	2.8	82.09	0.02	0.00	0.00	0.70
Orissa	12.8	10.5	44.4	31.06	0.23	11.40	10.66	0.41
Pondicherry	47.5	55	529.8	8.33	2.71	11.30	0.00	0.25
Punjab	44.7	69.5	184.6	3.14	1.69	14.00	0.00	0.40
Rajasthan	22.4	32.4	39.5	4.62	0.18	9.80	2.30	0.43
Sikkim	58.4	36.3	3.2	45.97	0.03	0.00	0.00	0.65
Tamil Nadu	30.5	39.9	164.9	17.41	0.71	10.40	16.87	0.44
Tripura	73.8	11.2	19.6	77.18	0.31	5.50	0.00	0.63
Uttar Pradesh	18.3	28.7	125.4	5.86	0.40	12.70	27.61	0.40
Uttarakhand	34.1	38.8	111	45.74	0.16	9.00	15.16	0.54
West Bengal	38.4	23.6	136	13.91	0.54	18.40	21.75	0.40
India	**29.20**	**36.13**	**95.60**	**20.64**	**0.35**	**15.00**	**23.11**	**0.46**

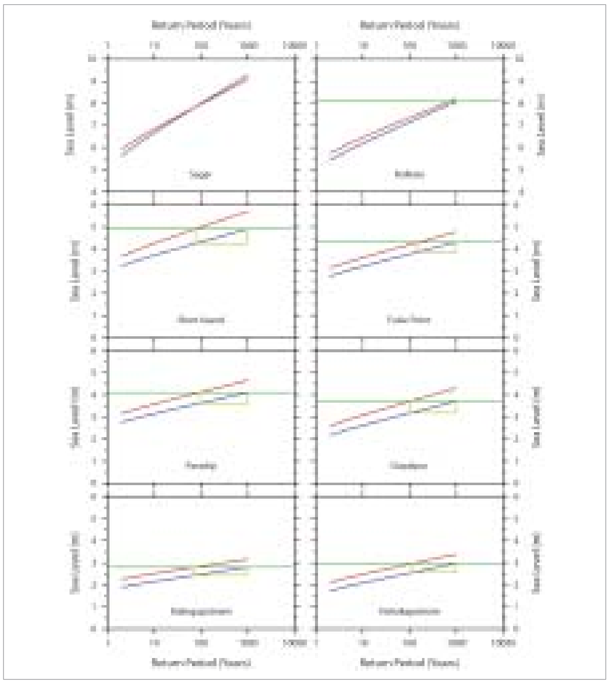


Figure 3.46: Estimated return levels from 30-year storm surge model runs

Blue indicates the B1 scenario (1961–90) and red indicates the A2 scenario (2071–2100). Mean sea level rise of 4mm/year is added from the 1990 levels for the model runs for A2 (2071–2100) scenario

Till accurate regional projections become available, global projections are used for regional impact assessment. The projected trends of mean sea level rise for the current century vary depending on the scenario, but are about 4 mm/year on an average. Storm surges that are generated by the cyclones in the Bay of Bengal cause tremendous destruction along the East Coast of India. The frequency distribution of the tropical cyclones in the Bay of Bengal during the past 50 years and different causative factors for the genesis of cyclones in the Bay were studied. For future projections, simulations of a regional climate model (PRECIS) were analysed to study the occurrence of cyclones in the Bay during a baseline climate scenario (1961–90) and a future scenario (2071–2100).

It was found that for all stations north of Visahkhapatnam, the increase in 100-year return levels (Figure 3.46) is about 15–20% in the future scenario, when compared to those in baseline scenario. However, for the two stations considered in the head Bay, namely, Sagar and Kolkata, increase in 100-year return levels for the future scenario was found to be less than 5%. Figure 3.46 also indicates a reduction in 1000-year return periods at different stations. In the future scenario with increased sea level, 1000-year return period reduces to about 100-year period. It means that an extreme event occurring presently once in 1000 years will occur once in 100 years in future. However, in regions of very large tidal ranges, as in the case of Sagar and Kolkata, the difference in return levels due to sea level rise is relatively small.

Impacts and vulnerability at the coast depend on many other factors such as land topography, density of population. IRS P6 LISS III satellite image, and Shuttle Radar Topography Mission (SRTM). Digital elevation model data (90 m resolution) was used with the help of topographic sheets of the Survey of India for finding out the probable inundation areas for the different sea level projections. Digital image processing and GIS software were used for determining the area of inundation.

The study showed that estimated inundation areas are 4.2 km^2 and 42.5 km^2 to a sea level rise of 1.0 m and 2.0 m, respectively, in the region surrounding Nagapattinam. But for the same sea level conditions, 169 km^2 and 599 km^2 will be inundated in the coastal region surrounding Kochi. Kochi region is directly connected to the backwaters; a lot of inland areas far from the coast, but adjacent to the tidal creeks, backwaters, and lakes will be inundated. This causes considerable increase in the total area of inundation. In Paradip, the variations in topography are not smooth and low-lying areas are large, which are connected by tidal creeks and river inlets. This area seems to be the most vulnerable, as about 1128 km^2 falls under inundation zones for a 2 m rise in sea level. Also, 478 km^2 may be inundated in Paradip coastal region for a 1 m sea level rise. All the creeks, estuaries, and low lands adjacent to the shoreline increase the risk of inundation. The extent of probable inundation zone goes upto approximately 40 km landward. In a similar way, Kochi region is also vulnerable even in the interior land areas. The study also showed that all the three regions considered for impact studies are highly vulnerable to sea level rise. The methodology used in the present study can be improved by using high resolution DEM, and accurate area of inundation can be determined. Different land use classes, which get affected by the inundation, also can be estimated, which will be very much helpful for the planners and decision makers to devise contingency plans for combating sea level rise problems along the coast of India. Validation with ground data is also important. Sea level rise will modify the configuration of the Indian coastline and create a lot of environmental and societal problems. Impact assessment will provide useful information for different sectors such as ports and infrastructure development near the coast. It is useful for planners and policy-makers to develop long-term adaptation measures. Environmentalists and coastal zone managers need to work out the plans for managing coastlines and its environment affected by sea-level rise and natural disasters.

References and Sources

CWC (Central Water Commission), 1993. *Reassessment of Water Resources Potential of River Basin.* CWC, Ministry of Water Resources, Government of India

CWC (Central Water Commission), 2000. *Renewable and Potentially Utilizable Water Resources.* CWC, Ministry of Water Resources, Government of India

Garg, N. K. and Hassan, Q., 2007. *Water Plan Update 2005, Public Review Draft, Vol. 3. Alarming scarcity of water in India.* Current Science, 93, 932–941

Gupta, S. K.and Deshpande, R. D., 2004. *Water for India in 2050: First order assessment of available options.* Current Science, 86,1216–1224

IPCC (Intergovernmental Panel on Climate Change), 2007a. *Summary for Policymakers.* In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. (eds). Cambridge University Press, Cambridge, UK, pp. 7–22

IPCC (Intergovernmental Panel on Climate Change), 2007b. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. (eds). Cambridge University Press, Cambridge, UK, 976 pp.

IWMI, 2003. *Country Policy Support Studies program (CPSP) of the International Commission for Irrigation and Drainage.* International Water Management Institute

MoA (Ministry of Agriculture), 2009. *Agriculture Statistics at a glance: 2009.* Directorate of Economic and Statistics, Department of Agriculture and Cooperation, MoA, Government of India

MoEF (Ministry of Environment and Forests), 2010. *Climate Change and India: A 4x4 assessment: A Sectoral and Regional Analysis for 2030s.* MoEF, Government of India, New Delhi

MoWR (Ministry of Water Resources), 2008. *Preliminary Consolidated Report on Effect of Climate Change on Water Resources.* MoWR, Government of India, New Delhi

Nakicenovic, N. and Swart, R. (eds), 2000. *IPCC Special Report on Emissions Scenarios.* Cambridge University Press, Cambridge, 599 pp.

NCIWRD, 1999a. *Report of the Working group on Water Availability for Use.* Ministry of Water Resources, Government of India, New Delhi

NCIWRD, 1999b. *Report of the Working Group on Perspective of Water Requirements.* Ministry of Water Resources, Government of India, New Delhi

Planning Commission, 2007a. *Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007–12).* Planning Commission, Government of India, New Delhi

Planning Commission, 2007b. *Eleventh Five Year Plan: 2007–2012, Vol I–III.* Planning Commission, Government of India. Oxford University Press, New Delhi

Planning Commission, 2007c. *Report of the Expert Group on Ground Water Management and Ownership.* Planning Commission, Government of India, New Delhi

Shukla, P. R., Sharma, S. K., Ravindranath, N. H., Garg, A. and Bhattacharya, S. (eds), 2003. *Climate Change and India: Vulnerability Assessment and Adaptation.* Universities Press, Hyderabad

UNPD (United Nations Population Division), 1998. *Population Projections.* UNPD, United Nations

Annexure 1: List of institutions and projects/activities undertaken under V&A (Impacts, Vulnerability Assessment and Adaptation) assessment		
Sl. No.	**Institute**	**Activities**
1	Indian Institute of Tropical Meteorology, Pune	Development of future climate change scenarios for India
2	Institute of Economic Growth	Developing the future socio-economic scenarios for India in the context of climate change
3	Indian Institute of Technology, Delhi	Improved river run-off estimates using SWAT for all the Indian river basins
4	Jadavpur University, Kolkata	Assessment of river run-off in the flood-prone river systems of the eastern and north-eastern regions using HEC-HMS model and compare with drought prone river basins
5	National Environmental Engineering Research Institute (NEERI)	Assess the impacts of climate change on water demand at national level for the short, medium to long term time line
6	Arete Glacier and Water Consultants Pvt. Ltd	Effects of climate change on the Himalayan glaciers and livelihood: a review of Indian studies
7	Global hydrogeological solution	Impact of climate change on groundwater resources – future scenario
8	Indian Agricultural Research Institute, New Delhi	Impact assessment of climate change on major crops and integrated vulnerability assessment of agriculture in India
9	Tamil Nadu Agriculture University -Geetha lakshmi	Assessment of impacts of climate change on major irrigated and rain-fed crops in India and hence food security issues with special focus on regional crops in Tamil Nadu
10	Punjab Agricultural University	Assessment of impacts of climate change on rice/wheat and other crops
11	Dr. Y.S. Parmar University of Horticulture and Forestry	Assessment of impacts of climate change on apple and horticulture
12	Indian Institute of Horticulture Research	Assessment of impacts of climate change on vegetables and fruits
13	National Research Centre for Soybean, Indore	Assessment of impacts of climate change on major legume crops
14	Central Plantation Crop Research Institute, Kerala	Assessment of impacts of climate change on plantations
15	Central Potato Research Institute, Jalandhar	Assessment of impacts of climate change on potato
16	Indian Institute of Soil Science, Bhopal	Assessment of impacts of climate change on cotton
17	Indian Institute of Science, Bangalore	Assessment of the impacts and vulnerability of Indian forests and adaptation framework
18	Andaman & Nicobar Islands Forest & Plantation Corporation Limited	Assessment of changes in the status of mangroves and coral reefs in India with particular reference to Andaman & Nicobar Islands
19	Indian Institute of Technology, Bombay	Assessment of the impacts and vulnerability of the present climate and climate change on the three most vulnerable coastal districts in India identified in INC and formulate a framework for adaptation
20	National Institute of Oceanography, Goa	Impacts and vulnerability studies along the coast of India to projected sea level rise and changes in extreme sea level
21	National Institute of Malaria Research	Assessment of impacts of climate change on malaria and dengue at national scale and adaptation strategies for short, medium to long term time scales
22	National Physical Laboratory, New Delhi	Assessment of impacts of heat stress on human health and adaptation strategies
23	Indian Institute of Management, Ahmedabad -Energy	Assessment of reverse impacts of climate change on Indian energy systems
24	Tamil Nadu Agriculture University	Case study in Tamil Nadu: vulnerability assessment of climate, water resources, agriculture productivity and development of an adaptation framework
25	M.S. Swaminathan Research Foundation	An integrated case study to assess the vulnerability of selected East Coast stretch of Tamil Nadu to climate change and develop adaptation framework with a focus on coastal ecosystems, food security and livelihood issues
26	Institute of Home Economics, Delhi	Gender specific impacts of climate change on household water poverty
27	Action For Food Production (AFPRO), Udaipur	Assessment of vulnerability of the livestock, associated livelihoods due to climate change and adaptation strategies
28	Jadavpur University, Kolkata, Joyashree Roy	Extreme events, water resources, status of human health, livelihood: an adaptation framework for Kolkata urban agglomeration
29	Winrock International India, New Delhi	An integrated assessment of impacts and vulnerabilities on forest and associated livelihoods in the central Indian region and development of an adaptation framework

30	Integrated Research and Action for Development (IRADe)	Climate change impacts and vulnerability of mountain ecosystems and livelihoods
31	Institute of Minerals & Materials Technology, Bhubaneswar	An integrated assessment of vulnerability of agriculture to climate change and sea level rise in Brahmani–Baitarani estuaries in Orissa
32	The Energy and Resources Institute, New Delhi	An integrated case study to assess impacts and vulnerabilities in the north-eastern region
33	Indian Institute of Management, Ahmedabad -Infrastructure	Integrated impact assessment and adaptation policy response study for a multipurpose hydroelectric project in the Himalayan region
34	Maulana Azad National Institute of Technology, Bhopal	Climate change vulnerability assessment and adaptation strategies for built environment.
35	INRM	Development of user-friendly data conversion tool for PRECIS outputs
36	IIT Bombay	Occurrence and impacts of climate-related natural hazards

Chapter 4

Programmes Related to Sustainable Development

This chapter describes, in accordance with Article 12, paragraph 1(b) of the United Nations Framework Convention on Climate Change (UNFCCC), the steps taken or envisaged by India to implement the Convention, taking into account the specific national and regional development priorities, objectives, and circumstances. This chapter details information on various programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change. The chapter also details, in the light of India's social and economic conditions, information on activities related to the transfer of, and access to, environmentally sound technologies and know-how, the development and enhancement of endogenous capacities, technologies, and know-how, and measures related to enhancing the enabling environment for development and transfer of technologies. The chapter outlines India's commitment to address the challenges of climate change through its National Action Plan on Climate Change (NAPCC), with the underlying framework of sustainable development. It further establishes the link between sustainable development and climate change in the Indian context and concludes by highlighting a range of climate-friendly measures initiated by India.

Contents

Chapter 4 Programmes Related to Sustainable Development

CHAPTER 4

Programmes Related to Sustainable Development

India faces challenges in economic development, which have to be met with the limited resources available, with minimal externalities and in the presence of large uncertainties with respect to climate. One of the growing and accepted approaches to overcome this development paradox is adoption of a sustainable development paradigm, which entails development that meets the needs of the present without compromising the ability of the future generations to meet their own needs (WCED, 1987). The relationship between climate change and sustainable development was recognized in "Delhi Declaration" during Conference of Parties (COP)-8 in 2002. In fact, it has been argued that exclusive climate centric vision shall prove very expensive and might create large mitigation and adaptation "burden", whereas the sustainable development pathway results in lower mitigation cost besides creating opportunities to realize co-benefits without having to sacrifice the original objective of enhancing economic and social development.

On 30th June 2008, India announced and launched its National Action Plan on Climate Change (NAPCC). The NAPCC, guided by the principles of sustainable development, aligns the environmental and economic objectives. Broadly, the NAPCC is based on the following principles: protecting the poor and vulnerable sections of society through sustainable development strategies that are sensitive to climate change; achieving national growth targets through means that enhance ecological sustainability; devising an efficient and cost-effective strategy for demand-side management; deploying appropriate mitigation and adaptation technologies extensively and at an accelerated pace; promoting sustainable development through innovative and new forms of market and regulatory and voluntary mechanisms; effecting implementation through unique linkages with civil society, local governments, and public–private partnerships (PPPs); and finally, welcoming international cooperation for research, development, sharing, and transfer of technologies driven by external funding and facilitating global intellectual property rights (IPR) regime for such a technology transfer under the UNFCCC.

National Action Plan on Climate Change

The NAPCC identifies measures that promote our development objectives while also resulting in co-benefits in terms of addressing climate change. There are eight National Missions, which form the core of the NAPCC, representing a "*multi-pronged, long-term, and integrated strategies for achieving key goals in the context of climate change*". This underscores the fact that several of the programmes enumerated under the NAPCC are already being undertaken under various schemes/programmes of the Government of India, but in the present context, it would require a change in "*direction, enhancement of scope, and accelerated implementation*". It is understood that the implementation of the NAPCC would require appropriate institutional mechanisms and the focus would, therefore, be on the formation and evolution of such arrangements. Broadly, the Plan envisages promoting the understanding of climate change with emphasis on issues related to adaptation and mitigation, energy efficiency, and natural resource conservation.

Missions of the Action Plan

National Solar Mission (renamed as Jawaharlal Nehru National Solar Mission): Under the brand name "Solar India", this Mission was launched to significantly increase the share of solar energy in the total energy mix. This Mission would promote the use of solar energy for power generation and other applications. The objective of the Mission is to establish India as a global leader in solar energy by creating enabling policies for its quick diffusion across the country. The immediate aim of the Mission is to set up a conducive environment for solar technology penetration in the country, both at the centralized and decentralized levels. The first phase (till 2013) will capture all the options in solar thermal and vigorously promote off-grid decentralized options and at the same time ensure modest capacity additions in the grid-based systems. In the second phase (2013–2022 and after gaining substantial experience), solar energy capacity is planned to be aggressively ramped up. The ultimate objective of the Mission is to develop a solar capacity in India that is capable of delivering solar energy competitively against fossil options in the next 20–25 years. Through this Mission, the Government of India has aggressively pursued a policy that makes a distinct shift towards clean energy options and at the same time enhances the energy security position of the country. This is a strong policy choice towards making the energy profile of the country ecologically sustainable.

JNNSM - National Solar Mission envisions significant capacity addition in the solar energy sector

In January 2010, the Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM). The Mission aims to enable 20 GW of grid-connected solar energy being deployed in India by 2022 and 1 GW by 2013 itself. The Mission is not merely an effort at deploying solar technologies, it has additional major objectives (as highlighted in the paragraph above): a) to encourage R&D and support innovation tehereby facilitating grid-parity in the cost of solar power and b) to establish India as the global hub for solar manufacturing. In the one year since the launch of the Mission, 37 projects of 620 MW capacity have already been allotted. In addition, exisiting 30 MW solar projects have also been included under the Solar Mission. Besides, over 75 small projects of 1-2 MW each have been allotted for installation at the tail ends of the grid. By November 2011, bidding process for 350 MW under second batch of projects of first phase of National Solar Mission has been completed. By October 2011, around 125 MW capacity solar power projects have been installed in the country. It is expected that by March 2012, the installed capacity would reach to 400 MW.

National Mission for Enhanced Energy Efficiency (NMEEE): This Mission focuses on enhancing energy efficiency measures in the country [in addition to the already existing programmes pursued by Ministry of Power (MoP) and Bureau of Energy Efficiency (BEE)] through four new initiatives. These initiatives are: a market-based mechanism to enhance cost-effectiveness of energy efficiency improvements in energy-intensive large industries through the certification of energy savings that could be traded (perform, achieve, and trade), accelerating the shift towards energy-efficient appliances in identified sectors (market transformation), creating a financing mechanism for facilitating demand side management (DSM) programmes (energy efficiency financing platform), and developing fiscal instruments that promote energy efficiency (framework for energy efficient economic development). The Mission seeks to enhance efforts to unlock the energy efficiency market on a purchasing power parity basis to result in a total avoided capacity addition of 19,598 MW by 2017.

National Mission on Sustainable Habitat: This Mission has been launched with three main components: promoting energy efficiency in the residential and commercial sector, managing municipal solid waste, and promoting urban public transport. The main objectives of the Mission are to exploit the potential for mitigation of climate change through reduction in energy demand from the residential and commercial sectors through measures focusing on energy efficiency improvements and resource conservation and to adopt a comprehensive approach in the management of water, municipal solid waste, and waste water so as to realize their potential in terms of energy generation, recycling, reuse, and composting, mitigating climate change by taking appropriate measures in the transport sector (evolving integrated land use and transportation plans, effecting modal shift from private to public transport, encouraging greater use of non-motorized transport, improving fuel efficiency, and using alternative fuels). It is estimated, on an average, that the implementation of energy efficiency measures would help in achieving about 30% of energy savings in new residential buildings and 40% in new commercial buildings. In the case of existing buildings, these estimates are about 20% and 30%, respectively. Among the various plans for the implementation of this Mission, it is identified that the Bachat Lamp Yojana (BLY) model is an effective mechanism to promote energy efficiency through promoting replacement of incandescent bulbs in households by compact fluorescent lamps (CFLs). It is also identified that a comprehensive implementation of this plan could translate into a demand reduction of 10,000 MW. As a broader strategy, it is envisaged to promote various energy service companies (ESCOs) as vehicles to deliver energy efficiency targets.

National Water Mission: The main objective of the Mission is "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management". The main identified goals of the Mission are: development of a water database in the public domain, particularly regarding the assessment of the impact of climate change on water resources; promoting water conservation, augmentation, and preservation; focusing attention on over-exploited areas from water use perspective, increasing water use efficiency by 20%; and promoting basin level integrated water resource management. The Mission has identified certain key strategies to achieve the above-mentioned goals, such as: reviewing the National Water Policy, promoting and facilitating research on all aspects of the impact of climate change on water, fast-tracking implementation of various new and old water resource projects, promoting traditional systems of water conservation, an intensive programme of groundwater recharge in over-exploited areas, incentivizing recycling of water, including waste water, promoting planning on the principles of integrated water resources development and management, ensuring convergence among the various water resource programmes, intensive stakeholder capacity building and awareness through measures such as sensitizing elected representatives regarding over-exploited areas; and re-orienting public investment under various government programmes towards water conservation.

National Mission on Green India: The Mission aims at addressing climate change by enhancing carbon sinks in sustainably managed forests and ecosystems, enhancing the resilience and ability of vulnerable species/ecosystems to adapt to the changing climate and enabling adaptation of forest dependent local communities in the face of climatic variability. There are three main objectives of the Mission: doubling the area under afforestation/eco-restoration in India in the next 10 years (total area to be afforested/eco-restored to 20 million ha), increasing the GHG removal by India's forests to 6.35% of India's annual total GHG emissions by the year 2020, and enhancing the resilience of forests/ecosystems under the Mission.

National Mission for Sustaining the Himalayan Ecosystem: This Mission identifies the importance of continuity and enhancement in the monitoring of the Himalayan ecosystem, in particular, the state of glaciers and the impact of changes in the glacial mass and its subsequent impact on river flows. It envisages an appropriate form of scientific collaboration and exchange of information among South Asian region so as to enhance the understanding of ecosystem changes and their effects. It is also identified, under the Mission, to empower local communities through Panchayati Raj institutions (PRIs), so as to assume greater responsibility for the management of natural resources. These measures are over and above the specific measures/strategies identified in the National Environmental Policy (2006).

National Mission for Sustainable Agriculture (NMSA): The Mission seeks to transform Indian agriculture into a climate resilient production system through suitable adaptation and mitigation measures in the domain of crops and animal husbandry. These interventions would be embedded in research and development activities, absorption of improved technology and best practices, creation of physical and financial infrastructure and institutional framework, facilitating access to information and promoting capacity building. While promotion of dryland agriculture would receive prime importance by way of developing suitable drought and pest-resistant crop varieties and ensuring adequacy of institutional support, NMSA would also expand its coverage to rain-fed areas for integrating farming systems with management of livestock and fisheries, so that agricultural production continues to grow in a sustainable manner.

National Mission on Strategic Knowledge for Climate Change: This Mission envisions a broad-based approach, to include the following: conducting research in the key domains of climate science, improving the global and regional climate models for the specificity and quality of climate change projections over the Indian sub-continent, strengthening of observational networks and data gathering and assimilation, and creating an essential research infrastructure. The Indian Network for Climate Change Assessment (INCCA) was launched on 14 October 2009 and is a step in the direction of implementing the objectives of the Mission.

State Action Plans on Climate Change

As a second step, after the NAPCC was announced, all states have been asked to prepare a state-level action plan to deal with the challenges of climate change. Broadly, the state-level action plans are envisioned to be an extension of the NAPCC at various levels of governance, aligned with the eight National Missions.

Other Steps Envisaged to Implement the Convention

National Action Plan on Climate Change – Climate-friendly initiatives

The NAPCC (Table 4.1), apart from the eight Missions, has laid emphasis on numerous other climate-friendly measures. Specific to the power sector, the Government of India has laid down numerous initiatives to be taken up aggressively. These initiatives are vigorous R&D in the area of ultra-super-critical boilers for coal-based thermal plants, use of integrated gasification combined-cycle (IGCC) technology to make coal-based power generation more efficient, setting up of more combined cycle natural gas plants, promotion of nuclear energy through adoption of fast breeder and thorium-based thermal reactor technology, adoption of high-voltage AC and DC transmission to reduce technical losses during transmission and distribution, setting up of small and large hydropower projects as a source of clean energy (apart from adaptation related benefits), promotion of renewable energy technologies such as biomass combustion and gasification-based power generation, enhancement in the regulatory/tariff regimes to help mainstream renewable based sources in the national power system, and promotion of renewable energy technologies for transportation (biofuels) and industrial fuels.

National Action Plan on Climate Change – Adaptation aspects

Additionally, specific to the adaptation aspects of climate change, the Action Plan envisages an effective disaster management strategy that includes mainstreaming disaster risk reduction into infrastructure project design, strengthening communication networks and disaster management facilities at all levels, protecting coastal areas, providing enhanced public health care services, and assessing increased burden of disease due to climate change. All these measures, as a part of the NAPCC, highlight the priority accorded by the Government of India in mitigating the likely impacts due to climate change. The Action Plan also highlights the role of various levels of government in providing suitable local adaptation measures. Such local measures are envisioned to be delivered on the broad principles of fairness and equity. It is also envisioned that India's NAPCC will continuously evolve on the basis of new scientific and technical knowledge (the National Mission on Strategic Knowledge for Climate Change), and also, in response to the continuous evolution of the multi-lateral climate change regime, including arrangements for international cooperation.

Recent initiatives with regard to climate change

At the COP-15 to the UNFCCC in Copenhagen, Denmark, during 7–18 December 2009, India pledged to continue a constructive role in international climate diplomacy while emphasizing the need for implementing a comprehensive domestic response to reduce the emissions intensity of gross domestic product (GDP) by 20–25% by 2020, on 2005 levels (emissions from the agriculture sector not included). Some specific actions taken by the Government of India with regard to climate change are as follows.

- India's Twelfth Five-year Plan (2012–17), to be launched on 1st April 2012, will have, as one of its key pillars, a low-carbon growth strategy. Detailed work in this regard, through research and other findings, has been initiated by the Government of India at all levels.
- A "carbon tax" on coal to fund clean energy (at the rate of US $1 per tonne to both domestically produced and imported coal) was announced. The money collected would go into the National Clean Energy Fund, to be used for funding research and innovative projects on clean energy technologies and

Table 4.1: National Missions under the National Action Plan on Climate Change (NAPCC) – Objectives and targets

Sl. No.	National Mission	Objectives	Goals and targets
1	National Solar Mission	Promoting ecologically sustainable growth while meeting energy security challenges	Enabling environment to deliver 20 GW of solar power by 2022 Grid-connected solar power capacity of 1 GW by 2013 Additional 3 GW through mandatory purchases backed with preferential tariff by 2017 Favourable conditions for solar manufacturing capabilities Off-grid applications: 1 GW by 2017, 2 GW by 2022 15 million m^2 solar thermal collector area by 2017 and 20 million m^2 by 2022 20 million solar lighting systems for rural areas by 2022

2	National Mission on Sustainable Habitat	Extension of Energy Conservation Building Code (optimization of energy demand) Urban planning/shift to public transport: long-term transport plans for small/medium cities Recycling of material and urban waste management: power from waste	Increasing energy efficiency in buildings: building bye laws and standards, energy performance monitoring, national standards for construction and recycling of construction waste Urban transport: norms integrating congestion charges, parking, etc., norms for pedestrian and cycling, integrating transport planning with spatial planning Water supply: mandatory rainwater harvesting, water and energy audits
3	National Mission on Green India	Double area under afforestation/ eco-restoration in the next 10 years Increase greenhouse gas (GHG) removals by forests to 6.35% of India's annual GHG emissions by 2020 (increase of 1.5% over baseline) Enhance forests/eco-systems resilience	2 Mha of moderately dense forests 4 Mha of degraded forests regenerated/afforested 0.10 Mha of mangroves restored, 0.1 Mha wetlands conservation 0.20 Mha urban/peri-urban forests, 1.50 Mha degraded land under agro-forestry
4	National Mission for Sustaining the Himalayan Ecosystem	Strengthening institutional capacity Standardization of field and space observations Prediction/projection of future trends and assessment of possible impacts Governance for Sustaining Himalayan Ecosystem (G-SHE)	Continuous monitoring of Himalayan ecosystems Identification of desirable adaptation and development policies (sustainable urbanization, water security: rejuvenation of springs, infrastructure development: green roads)
5	National Mission on Enhanced Energy Efficiency	Market-based approaches Cumulative avoided electricity capacity addition of 19,000 MW	Specific energy consumption (SEC) reduction targets for energy-intensive units Incentivizing action through Energy Savings Certificates (ESCerts) – traded and used for compliance National energy efficiency Clean development Mechanism (CDM) roadmap National energy efficiency financing platform Creating markets for energy efficient products and services
6	National Water Mission	Conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management	Comprehensive water database in public domain and assessment of impact of climate change on water resources Promotion of citizen and state action for water conservation, augmentation and preservation Focused attention to vulnerable areas including over -exploited areas Increasing water use efficiency by 20% Promotion of basin level integrated water resources management
7	National Mission for Sustainable Agriculture	Use of bio technology Dryland (rain-fed) agriculture Risk management Access to information	Use of genetic engineering to produce carbon responsive crops Low input sustainable agriculture: enhanced water use efficiency Micro-irrigation for efficient use of water Water conservation in rain-fed areas
8	National Mission on Strategic Knowledge on Climate Change	Network of institutions Promotion of climate science research Data sharing policy: from various arms of government Building human and institutional capacity: filling knowledge gaps in modelling and technology	Climate change research and fellowship programme Climate Change Professor Chairs National Research Chairs Climate Research Institute Network of climate change research institutes and scientists

Source: NAPCC (2008)

environmentally remedial programmes. The expected earnings from the cess is about US $500 million for the year 2010–11.

- India has pursued aggressive strategies on forestry and coastal management, recognizing their ecological as well as livelihood significance. A major coastal zone management programme has been launched to address the adaptation challenges facing over 300 million vulnerable inhabitants in these regions.
- On 10th May 2010, India released its GHG emissions inventory for 2007 with the aim of informed decision making and ensuring transparency. Before this, the only official estimates were available for the year 1994. Thus, India became the only non-Annex I country to publish such updated numbers. It is aimed to follow a two-year cycle for the same.

Bachat Lamp Yojana - programme has been developed to promote energy efficient lighting

- Promoting regional and international cooperation has been one of the key achievements of the Government of India regarding climate change. South Asian Association for Regional Cooperation (SAARC) adopted the Thimpu Statement on Climate Change on 29th April 2010. This statement, among other things, calls for an Inter-governmental Expert Group on Climate Change to develop a clear policy direction for regional cooperation on climate change. Sharing of knowledge among the SAARC countries would help in better assessment on all areas related to climate change.
- The Bachat Lamp Yojana conceived as Clean Development Mechanism (CDM) Programme of Activity (PoA) for mass distribution of CFLs in India has been registered successfully by the CDM Executive Board. The Programme has been developed to promote energy-efficient lighting.

Sustainable Development and National Planning

The singlemost important feature of our post-colonial experience is that the people of India have conclusively demonstrated their ability to forge a united nation despite its diversity, and to pursue development within the framework of a functioning, vibrant, and pluralistic democracy. In this process, the democratic institutions have put down firm roots, which continue to gain strength and spread.

A planned approach to development has been the central process of the Indian democracy, as reflected in the national five-year plans, departmental annual plans, and perspective plans of various ministries of the central and state governments. For more than six decades, the guiding objectives of the Indian planning process have been sustained economic growth, poverty alleviation, food, health, education, and shelter for all, containing population growth, employment generation, self-reliance, people's participation in planning and programme implementation, and infrastructure development. In the present context of climate change, development has focused on enhancing the adaptive and mitigative capacity of the economy, and thereby, the Government of India has initiated policies, programmes, and missions aimed in that direction. Infrastructure emerged to be a key sector during the Eleventh Plan period (2007–12), with its role as a backbone through which the economy flourishes, and therefore, the Government of India initiated new policy measures to ensure infrastructure growth in line with the economic growth. A key feature of the vigorous infrastructure growth policy has been the adoption of a sustainable development path, wherein infrastructure choices were made keeping in mind the longer-term perspective of ensuring lesser impacts due to likely climate change and avoiding critical lock-ins. Thus, measures like developing the renewable energy sector, shifting towards public transport, enhancing rural and urban infrastructure, and others were aimed at enhancing the adaptive and mitigative capacities of the economic systems.

Eleventh Five-year Plan and sustainable development

India is presently implementing its Eleventh Five-year Plan (2007–12) and is in the process of preparing the Twelfth Five-year Plan (2012–17), having achieved considerable progress during the previous ten five-year plans and three annual plans. The planning process in India aims to increase wealth and human welfare, while simultaneously conserving the environment. The national planning process lays emphasis on the promotion of people's participatory institutions and social mobilization, particularly through the empowerment of women, to ensure the environmental sustainability of the development process.

India has entered the Eleventh Plan period with an impressive record of economic growth. After a lackluster performance in the Ninth Plan (1997–2002), when GDP grew at only 5.5% per annum, the economy accelerated in the Tenth Plan period (2002–07) to record an average growth of 7.7%. A major weakness in the economy during the Tenth Plan was that the growth was not perceived as being sufficiently inclusive for many groups. Gender inequality was considered to be a persistent problem. The Eleventh Plan seeks to remedy these deficiencies by seeking to accelerate the pace of growth while also making it more inclusive. The objective of inclusiveness is reflected in the adoption of 26 monitorable targets at the national level pertaining to income and poverty, education, health, women and children, infrastructure, and environment.

Poverty alleviation

India's poverty alleviation programmes over the years have focused on a variety of approaches. In the initial years of developmental planning, poverty was considered as essentially a rural problem, and the strategies adopted focused on agricultural development and providing employment to the poor in rural areas. Poverty alleviation is a key determinant in building resilience in the vulnerable population and, otherwise, provides livelihood security. Such a focus has a multiplier effect in terms of building human capabilities such as enhancing health status and improving the quality of life. The persistence of poverty on the scale at which it still exists is not acceptable. A decisive reduction in poverty and an expansion in economic opportunities for all sections of the population are, therefore, crucial elements of the vision for the Eleventh Plan. Rapid growth of the economy is an essential requirement to achieve this outcome since it is an instrument for achieving a steady increase in employment and incomes for large number of our people. Growth in the Eleventh Plan is planned in such a manner so as to rapidly create jobs in the industrial and services sectors. This is accompanied by efforts to improve the income-earning opportunities of those who remain in agriculture by raising land productivity. This rapid growth is supplemented by targeted livelihood support programmes aimed at increasing productivity and incomes of the poor in several low income occupations, which is considered to continue as important sources of employment for quite some time.

Skill development: Skill development has been the major thrust area during the Eleventh Plan, thereby building human capabilities so as to reduce chronic vulnerabilities. A three-tier structure for coordinated action on skill development has been set up. The three-tier structure consists of (i) the Prime Minister's National Council on Skill Development, (ii) the National Skill Development Coordination Board (NSDCB), and (iii) the National Skill Development Corporation (NSDC). The Prime Minister's National Council has outlined the core operating principles that advocate the need for co-created solutions for skill development based on partnerships between the state, civil society, and community leaders. The emphasis is on making skills bankable for all sections of society, including the poorest of the poor. By end December 2010, 28 states and five union territories had set up Skill Development Missions. As a next step, all these states/ union territories will assess the skill gaps in the major sectors and formulate action plans for bridging them. The NSDC, set up on 31st July 2008 as a non-profit PPP in skill development for co-coordinating/stimulating private sector initiatives, has been mandated to achieve the target of creation of skilled workforce of 150 million persons by 2022 under the National Skill Development Policy.

Employment generation programmes: Targeted employment programmes of the Government of India such as Swarnjayanti Gram Swarojgar Yojana (SGSY) and Swarna Jayanti Shahari Rozgar Yojana (SJSRY) have also gone a long way in building resilience and decreasing vulnerabilities by providing livelihood security to millions, thereby supporting poverty alleviation. The SGSY is a major ongoing scheme launched in April 1999 to help poor rural families cross the poverty line by assisting them to take up income-generating economic activities through a mix of bank credit and government subsidy. The scheme involves, primarily, the organization of the poor into self-help groups (SHGs) and building their capacities through training and skill development. A new initiative has also been taken up for setting up a Rural Self Employment Training Institute (RSETI) in each district of the country for basic and skill development training of rural below poverty line (BPL) youth to enable them to undertake micro-enterprises and wage employment. The SJSRY launched by the Government of India in December 1997 has been revamped with effect from April 2009. The scheme provides gainful employment to the urban unemployed and underemployed through encouraging the setting up of self-employment ventures or provision of wage employment.

Social safety initiatives: In order to provide an adequate social safety net for the vulnerable and disadvantaged, several schemes have been launched by the Government of India. Aam Admi Bima Yojana (AABY), launched on 2nd October 2007, provides insurance against natural as well as accidental and partial/permanent disability of the head of the family of rural landless households in the country. Rashtriya Swasthya Bima Yojana (RSBY) was launched on 1st October 2007 to provide smart card-based cashless health insurance cover of INR 30,000 per family per annum to BPL families (a unit of five) in the unorganized sector, and the Unorganized Workers' Social Security Act (2008) came into force from 16th May 2009, with the objective of providing social security to unorganized workers.

Table 4.1a: Rural Households provided with employment under MNREGA

S.No.	Financial Year	No. of households provided with employment (in crores)	No. of person days of employment (in crores)
1	2006-07	2.10	90.51
2	2007-08	3.39	143.68
3	2008-09	4.51	216.33
4	2009-10	5.25	283.59
5	2010-11	5.49	257.15
6	2011-12 (till 30th October 2011)	2.84	76.17

Rural Employment Guarantee Scheme: The Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) was notified under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) on 7th September 2005. The objective of the Act is to enhance livelihood security in rural areas by providing at least 100 days of guaranteed wage employment in a financial year to every household, the adult members of which volunteer to do unskilled manual work. The Act was notified in 200 districts in the first phase with effect from 2nd February 2006 and then extended to additional 130 districts in the financial year 2007/08. The remaining districts have been notified under the MGNREGA with effect from 1st April 2008. Thus, MGNREGA covers the entire country with the exception of districts that have a 100% urban population. The broad goals of the Act are providing a strong social safety net for vulnerable groups by providing wage employment and acting as a growth driver for sustainable development of an agricultural economy (providing employment on works that addresses causes of poverty such as drought, soil erosion). The number of rural households that have been provided employment since the beginning of the scheme are given in Table 4.1a.

The focus of the scheme, in order of priority, is on water conservation and water harvesting, drought proofing (including afforestation and tree plantation), irrigation canals, provision of irrigation facility, horticulture and land development facilities to lands owned by SC/ST or BPL

Table 4.1b : Work taken up under MNREGA (Figures in lakhs)

S.No.	Year	Water conservation and water harvesting	Drought proofing	Micro irrigation works	Individual beneficiary works	Renovation of traditional water bodies
1	2008-09	5.88	1.97	1.45	5.66	2.54
2	2009-10	10.98	3.64	2.99	7.73	3.96
3	2010-11	10.33	4.56	3.45	9.15	4.0
4	2011-12 (till 30th October 2011)	16.12	5.59	3.48	6.91	3.53

Bharat Nirman- Catalysing rural infrastructure development and dovetailing the Rural Employment Guarantee Scheme

families or IAY beneficiaries or small and marginal farmers or beneficiaries of Forest Rights Act and renovation of traditional water bodies. The creation of durable assets and strengthening the livelihood resource base of the rural poor is an important objective of the scheme. The number of aforesaid works taken up in last four years is given in Table 4.1b.

The MGNREGA scheme, by undertaking myriad works focusing on water conservation and afforestation, helps in combating the adverse impacts of climate change. The scheme also cushions economically and socially disadvantageous groups against the impact of climate change. Further, it creates conditions for inclusive growth and at the same time helps in addressing sustainable development issues by remedying them through focused interventions.

Rural infrastructure development – *Bharat Nirman*

Another major initiative during the Eleventh Plan has been *Bharat Nirman*, which is a time-bound plan for the development of rural infrastructure by the Government of India in partnership with the state governments and PRIs. The main goals of the programme during 2005–09 were: every village to be provided with electricity, every habitation with 1000 population and above (500 in hilly and tribal areas) to be provided with an all-weather road, every habitation to have a safe source of drinking water, every village to be connected by telephone, 10 million hectares of additional irrigation capacity to be created by 2009, and 60 lakh houses to be constructed for the rural poor by 2009. The programme has been extended beyond 2009, with expanded goals. These new goals include: providing safe drinking water to all uncovered habitations by 2012, achieving 40% rural tele-density by 2014, connecting all villages that have a population of 1000 (or 500 in hilly/ tribal area) with an all-weather road by 2012, enabling the reach of electricity to all villages and offering electricity connection to 1.75 crore poor households by 2012, and bringing additional 1 crore hectare of land under assured irrigation by 2012. The main thrust of the programme has been to build rural infrastructure that helps in reducing

Table 4.2: Policies/programmes promoting sustainable development in agriculture sector

Policy/programme	Features
National Policy on Agriculture	Attain output growth rate in excess of 4% per annum based on efficient use of resources
Integrated Watershed Management Programme	Restore ecological balance by harnessing, conserving, and developing degraded natural resources such as soil, vegetative cover, and water
National WatershedDevelopment Project for Rainfed Areas	Sustainable management of natural resources, enhancement of agricultural production, restoration of ecological balance in the degraded and fragile rain-fed ecosystems, reduction in regional disparity between irrigated and rain-fed areas, and creation of sustained employment opportunities for the rural community including the landless
Rashtriya Krishi Vikas Yojana	Assist states in the development and implementation of district-level agricultural plans (based on local agro-climatic conditions) and bring about quantifiable changes in the production and productivity of various components of agriculture and allied sectors
National Food Security Mission	Aims at increasing production of rice, wheat, and pulses through area expansion and productivity enhancement in a sustainable manner; restoring soil fertility and productivity at the individual farm level
National Project on Organic Farming	Aims to promote production, promotion, and market development of organic farming in the country
Micro Irrigation Scheme	Increase the area under efficient methods of irrigation like drip and sprinkler irrigation
Weather Based Crop Insurance Scheme	Aims to mitigate against the likelihood of financial loss on account of anticipated crop loss resulting from incidence of adverse conditions
National Horticulture Mission	To provide holistic growth of horticulture sector through regionally differentiated strategies
National Project on Management of Soil Health and Fertility	Facilitate and promote Integrated Nutrient Management (INM)through judicious use of chemical fertilizers in conjunction with organic manures and bio-fertilizers

vulnerabilities of the local population, build resilience within the habitats, and create infrastructural facilities that help in providing livelihood, health, and education security to the masses. The assets created would also help in improving the agriculture sector, thereby assisting in realizing the growth targets of the economy.

Agriculture and sustainable development

Agriculture is a critical component of Indian sustainable developmental policies, since more than 650 million people depend on agriculture. The Green Revolution during the 1970s made India self-sufficient in food production through increased agricultural output based on high- yielding seeds, irrigation, and fertilizers. Now, Indian agriculture is more intensive with regard to the use of inputs per hectare of land. The National Agricultural Policy (2000) is targeted to achieve an output growth in excess of 4% per year in a manner that is technologically, environmentally, and economically sustainable. During the Eleventh Plan, agriculture is considered to be a key area for addressing multiple aspects of the economy such as food security, economic growth, rural livelihood, and rural resilience. One of the most disappointing features of the Ninth Plan was the deceleration in agricultural growth, which set in after the mid-1990s with GDP in agriculture growing at only about 2% per annum after growing at 3.6% per annum between 1980 and 1996. Reversing this deceleration to achieve a growth target of 4% in agricultural GDP is a key element of the Eleventh Plan strategy for inclusive growth. Therefore, public expenditure on agriculture research is increased from 0.7% to 1% of GDP by end 2012. There is a programme to evolve suitable strategies on agro-climatic zone to reduce yield gap (Rashtriya Krishi Vikas Yojana [RKVY]) and public investment in developing irrigation has been increased (includes modernization to improve efficiency and launching of water shed programmes for dryland areas). There has been a provision for increasing private investments (provision of credit for farmers) to develop land, buy pump sets, and install drip irrigation systems. There is also a programme for the revival of the cooperative banking system. Restructuring of fertilizer subsidy on nutrient basis and creating awareness about soil health, increasing the supply of certified seeds and achieving credibility in the quality of seeds, making a strong effort in expanding food grain production (National Food Security Mission), incorporating diversification on the lines of technical appropriateness, forging assured market and logistics linkages, and improving market linkages through development of rural infrastructure (Pradhan Mantri Grameen Sadak Yojana and Rajiv Gandhi Grameen Vidyutikaran Yojana [RGGVY]) have been some of the thrust areas during the Eleventh Plan to boost the agriculture sector, within the broader principles of achieving a growth that is sustainable.

Several measures/strategies have evolved during the Eleventh Plan period to address various issues pertaining to the agriculture sector. In the medium term, the focus has been on improving yields with the existing available technology, timely availability of water through expansion of the irrigation system, and also improvement of existing irrigation systems. Development of watersheds, implementing rainwater harvesting in farm ponds and tanks, and improved methods of groundwater recharge are other coping strategies under implementation to achieve planned growth in agriculture. A major expansion in the Accelerated Irrigation Benefit Programme (AIBP) has been undertaken during the Eleventh Plan. The National Rainfed Area Authority is mandated to help converge different programmes in the rain-fed areas to achieve better water management and improve agricultural productivity.

On the output side, various measures have been undertaken to enhance food security, while there have been focused interventions aimed at diversifying into non-food grain crops and promoting animal husbandry and fishing. The new National Food Security Mission aims at increasing cereal and pulses production by 20 million tonnes by concentrating on those areas that have the greatest potential for increase in yields with the given technology. The National Horticulture Mission has also been expanded. Rashtriya Krishi Vikas Yojana (RKVY) is a focused programme that provides additional financial resource to the state governments to finance agriculture development programmes. The strategy is also aided by the NREG Act, by implementing projects that help in the larger objectives of enhancing agricultural productivity because the first priority is being given to projects aimed at water conservation. Table 4.2 gives a snapshot of the various policies/programmes of the Government of India and their key features, aimed at promoting sustainable development.

Rural electrification

The Government of India launched the RGGVY in April 2005 to provide electricity access to all rural households and extend free connections to all BPL households by 2009. The physical targets included electrification of 125,000 un-electrified villages by creating rural electricity distribution backbone and village electrification infrastructure and last mile service connectivity to 10% households. This programme has been critical, in terms of building a vibrant rural economy and also in terms of helping to enhance the quality of life of the rural population—enhanced medical devices in primary health centres and electricity in households for children to study at night. The Rural Electrification component under *Bharat Nirman* Programme is a sub-set of RGGVY. The time frame for these two programmes coincides. Expansion of the programme has helped farmers in those areas where the water table is high to use pump-based irrigation. This programme has also helped in supporting the National Food Security Mission by expanding groundwater irrigation through increased yields (particularly in the North East and eastern parts of the country).

Environmental governance

The National Conservation Strategy and Policy Statement on Environment and Development (1992) provides the basis for the integration of environmental considerations in the policies of the various sectors. It aims at achieving sustainable lifestyles and proper management and conservation of resources. The Policy Statement for Abatement of Pollution (1992) stresses the prevention of pollution at the source, based on the "polluter pays" principle. It encourages the use of the best available technical solutions, particularly for the protection of heavily polluted areas and river stretches. The Forest Policy (1988) highlights environmental protection through preservation and restoration of the ecological balance. The policy seeks to substantially increase the forest cover in the country through afforestation programmes. This environmental framework aims at taking cognizance of the longer-term environmental perspective related to industrialization, power generation, transportation, mining, agriculture, irrigation, and other such economic activities, as well as addressing parallel concerns related to public health and safety.

Economic development without environmental considerations can cause serious environmental damage, in turn impairing the quality of life of the present and future generations. Such environmental degradation imposes a cost on the society and needs to be explicitly factored into economic planning, with the incorporation of necessary remedial measures. The National Environment Policy (2006) has attempted to mainstream environmental concerns in all our developmental activities. It underlines that "while conservation of environmental resources is necessary to secure livelihoods and well being of all, the most secure basis for conservation is to ensure that people dependant on particular resources obtain better livelihoods from the fact of conservation, than from degradation of the resource". The strong sustainable development agenda followed by India incorporates rigorous environmental safeguards for infrastructure projects, strengthening of the environmental governance system, revitalizing of regulatory institutions, focusing on river conservation, and making efforts for improvements in air and water quality, on a continuous basis.

In this regard, the Ministry of Environment and Forests (MoEF) has notified the Wetlands (Conservation and Management) Rules (2010) in order to ensure that there is no further degradation of wetlands. The rules specify activities that are harmful to wetlands such as industrialization, construction, dumping of untreated waste, and reclamation, and prohibit these activities in the wetlands. Other activities such as harvesting and dredging may be allowed but only with prior permission from the concerned authorities. The National Green Tribunal

Table 4.3: Snapshot of the various Acts/policies/ programmes in the forestry sector

Policy/programme	Features
Forest (Conservation) Act (1980)	To check further deforestation, the Forest (Conservation) Act was enacted by the Government of India.
National Forest Policy	National Forest Policy acknowledges the importance and primacy of local communities and provides for a sustainable management approach with maintenance of environmental stability as the prime objective.
Participatory Forest Management/Joint ForestManagement Programme (JFM)	Initiated on 1st June 1990, JFM has emerged as an important intervention in the management of forest resources in India. The JFM approach optimizes the returns, minimizes conflicts, and links the forestry development works with the overall development of land based resources. It also aims at building technical and managerial capability at the grassroots level.
National Afforestation Programme (NAP)	The NAP Scheme was initiated by scaling-up the Samnavit Gram Vanikaran Samridhi Yojana (SGVSY) project experience and converging all afforestation schemes of the Ninth Plan period. The overall objective of the scheme is to develop the forest resources with people's participation, with focus on improvement in livelihoods of the forest fringe communities, especially the poor
National Watershed Development Project forRainfed Areas (NWDPRA)	The NWDPRA programme was initiated in 1990/91 with the twin objectives of improving agricultural production in rain-fed areas and restoring ecological balance.

(NGT) Act (2010) came into force on 18th October 2010. As per the provisions of the NGT Act (2010) the National Environment Appellate Authority (NEAA), established under the NEAA Act (1997) stands dissolved, and the cases pending before NEAA stand transferred to the NGT. The Act provides for the establishment of an NGT for the effective and expeditious disposal of cases relating to environmental protection and conservation of forests and other natural resources, including enforcement of any legal right relating to environment and giving relief and compensation for damages to persons and property and for matters connected with or incidental. Coastal ecosystems are a critical reservoir of our biodiversity and provide protection from natural disasters such as floods and tsunamis and are a source of livelihood to hundreds of millions of families. Hence, as a major national initiative in this direction, the Coastal Regulation Zone Notification has been published in the Gazette of India on 6th January 2011.

Other statutory frameworks for the environment include the Indian Forest Act (1927) the Water (Prevention & Control of Pollution) Act (1974), the Air (Prevention & Control of Pollution) Act (1981), the Forest (Conservation) Act, (1980), and the Environment (Protection) Act (1986). The courts have also elaborated on the concepts relating to sustainable development, and the "polluter pays" and "precautionary" principles. In India, matters of public interest, particularly pertaining to the environment, are articulated effectively through a vigilant media, an active NGO community, and, very importantly, through the judicial process that has recognized the citizen's right to clean environment.

Forests and sustainable development

Forest conservation and enhancement are the stated objectives of the national policy. Various policy initiatives have resulted in the increase in forest cover and a reduction in the per capita deforestation rate. The National Forests Policy envisages peoples' participation in the development of degraded forests to meet their fuel, fodder, and timber needs, as well as to develop the forests for improving the environment through Joint Forest Management. India has implemented a large number of progressive policies, programmes, and measures to conserve and develop forests, wildlife, mangroves, and coral-reefs, such as: the Forest Conservation Act (1980) the National Forest Policy (1988), the Wildlife Act, Joint Forest Management, Social Forestry, banning of timber extraction in reserve forests, improved cook-stove programme, and biogas to conserve fuelwood. Similarly, there are conservation programmes for mangroves, coral reefs, and lake ecosystems. The National Wasteland Development Board is responsible for regenerating degraded non-forest and private lands. The National Afforestation and Eco-development Board is responsible for regenerating degraded forest lands, the land adjoining forest areas, as well as ecologically fragile areas. The Forest Survey of India monitors changes in the forest area. All these measures have led to some stabilization of the forest area, a reduction in deforestation, and afforestation, significantly contributing to the conservation of the forest carbon sink. All these preparations will act as a buffer for the forest-dependent communities against the challenges posed by climate change. The MoEF notified the constitution of Compensatory Afforestation Fund Management and Planning Authority (CAMPA) on 23rd April 2004 for the management and use of the fund generated by levying cost of compensatory afforestation in equivalent forest lands offered by the user agencies or in degraded land whenever there is a diversion of forest lands for non-forestry purposes under the Forest (Conservation) Act (1980). The apex court of the country had observed that this fund was being appropriated to the implementing authorities. As a consequence of this observation, the MoEF issued guidelines for State CAMPA on 2nd July 2009, with the objective of putting in place a funding mechanism for enhancing forest and tree cover and conservation and management of wildlife by utilizing the funds currently available with the ad-hoc CAMPA. Table 4.3 gives a summary snapshot of sustainable development initiatives in the forestry sector.

Infrastructure development

Poor quality of infrastructure could seriously limit India's growth potential as infrastructure forms the backbone of any economy. The Eleventh Plan has outlined a

Urban Infrastructure- JNNURM programme of the government has catalysed massive development in urban infrastructure

Table 4.4: Acts/policies/programmes in the energy sector	
Act/policy/programme	**Features**
Integrated Energy Policy (2006)	Aims at reliably meeting the demand for energy services of all sectors, including the energy needs of vulnerable households with safe, clean, and convenient energy at the least-cost. This must be done in a technically efficient, economically viable, and environmentally sustainable manner.
Energy Conservation Act (2001)	A legal framework towards efficient use of energy and its conservation. The ultimate objective of the Act is energy security through conservation and efficient use of energy.
Electricity Act (2003)	Legal framework across various components of the electricity sector.
Village Energy Security Programme	Provide energy security in villages by meeting energy needs for cooking, electricity, and motive power through various forms of biomass material based on available biomass conversion technologies and other renewable energy technologies, where necessary.
National Draft Policy Statement on New and Renewable Energy	An exclusive and comprehensive policy on renewable energy, aiming to raise renewable capacity to 100,000 MW by 2050.
National Policy on Bio-fuels	Mainstreaming of biofuels and, therefore, envisioning a central role for it in the energy and transportation sectors of the country in coming decades.
Development of Solar Cities	To promote the use of renewable energy in urban areas by providing support to the municipal corporations for preparation and implementation of a roadmap to develop their cities as solar cities.
Energy Conservation Building Code	To provide minimum requirements for the energy-efficient designand construction of buildings. This aims at reducing the baseline energy consumption by supporting adoption and implementation of efficiency saving and saving in greenhouse gas emission.
Ministry of New and Renewable Energy (MNRE) Scheme on Green Buildings	Based on the climatic conditions, and in particular the construction of non-air-conditioned buildings, a national rating system – GRIHA – has been developed, which is suitable for all types of buildings in different climatic zones of the country(one of the criteria under GRIHA is to meet 1% of total connected load for interior lighting and space conditioning through solar photovoltaics).
Tariff Policy (2006)	The legal framework, which states that a minimum percentage of the energy, as specified by the regulatory commission, is to be purchased from renewable energy sources.
Programme on Biomass Energy and Co-generation (non-bagasse) inIndustry	The installation of biomass co-generation projects (excluding bagasse co-generation) is to be promoted in industry, with at least 50% of power for captive use, and a provision for the surplus power to be exported to the grid.
National Electricity Policy (2005)	Stipulates that progressively the share of electricity from non-conventional sources would need to be increased. It also envisages appropriate preferential pricing to promote non-conventional technologies before they can compete with the conventional sources in terms of cost.
Scheme on Biogas Based Distributed/Grid Power Generation Programme	To promote biogas-based power generation, especially in the small capacity range, based on the availability of large quantity of animal wastes and wastes from forestry, rural based industries.
Remote Village Electrification Programme (RVE)	To provide access to electricity through renewable energy to households in remote villages, which are not likely to get covered through grid extension.
Rajeev Gandhi Grameen Vidyutikaran Yojana	Aims at providing electricity to 100% rural households. It has theprovision of decentralized distribution and generation (DDG)Through use of renewable energy sources.

comprehensive strategy for the development of both rural and urban infrastructure (includes electric power, roads, railways, ports, airports, telecommunications, irrigation, drinking water, sanitation, storage, and warehousing). The total investment in these areas was around 5% of GDP in 2006/07, and the Eleventh Plan has targeted to increase this to about 9% of GDP by the terminal year of the plan period, that is, 2011/12. Since various social sector and livelihood support programmes for the poor will have the first charge on public resources, the strategy for infrastructure development has been designed to rely as much as possible on private sector investment through various forms of PPPs. The Plan also recognizes that the scope for private participation in infrastructure development in several areas is limited, and the infrastructure requirement of these areas, therefore, has to be met through public investment simultaneously. Both the centre and the states have seen varying degrees of success in attracting private investment in areas such as power generation, telecommunications, roads, railways, airports, and ports, though much more needs to be done. Special attention is being paid to the *Bharat Nirman* programme as a key driver for creating rural infrastructure in this regard.

The rate of urbanization in India has been relatively slow so far, but faster growth is likely to change this in future, leading to a faster pace of urbanization in the years ahead. Urbanization is a natural outcome of the process of development, and the Government of India has recognized the need to gear up to the challenge by meeting the infrastructure needs of the cities. It is also recognized that there will be an urgent need to simultaneously upgrade the quality of infrastructure in existing cities and also

Box 4.1: Indian developmental targets

Twenty-seven targets at the national level fall under six major categories. These six categories are: (i) income and poverty; (ii) education; (iii) health; (iv) women and children; (v) infrastructure; and (vi) environment. The targets in each of these categories are given below.

(i) Income and poverty

- Average gross domestic product (GDP) growth rate of 9% per year in the Eleventh Plan period.
- Agricultural GDP growth rate at 4% per year on the average.
- Generation of 58 million new work opportunities.
- Reduction of unemployment among the educated to less than 5%.
- 20% rise in the real wage rate of unskilled workers.
- Reduction in the head-count ratio of consumption poverty by 10 percentage points.

(ii) Education

- Reducing the drop-out rates of children at the elementary level from 52.2% in 2003/04 to 20% by 2011/12.
- Developing minimum standards of educational attainment in elementary schools, to ensure quality education.
- Increasing the literacy rate for persons of age 7 years or more to 85% by 2011/12.
- Reducing the gender gap in literacy to 10 percentage points by 2011/12.
- Increasing the percentage of each cohort going to higher education from the present 10% to 15% by 2011/12.

(iii) Health

- Infant mortality rate (IMR) to be reduced to 28 and maternal mortality ratio (MMR) to 1 per 1000 live births by the end of the Eleventh Plan.
- Total fertility rate to be reduced to 2.1 by the end of the Eleventh Plan.
- Clean drinking water to be available for all by 2009, ensuring that there are no slip-backs by the end of the Eleventh Plan.
- Malnutrition among children of age group 0–3 to be reduced to half its present level by the end of the Eleventh Plan.
- Anaemia among women and girls to be reduced to half its present level by the end of the Eleventh Plan.

(iv) Women and children

- Raising the sex ratio for age group 0–6 to 935 by 2011/12 and to 950 by 2016/17.
- Ensuring that at least 33% of the direct and indirect beneficiaries of all government schemes are women and girl children.
- Ensuring that all children enjoy a safe childhood, without any compulsion to work.

(v) Infrastructure

- To ensure electricity connection to all villages and below poverty line (BPL) households by 2009 and reliable power by the end of the Plan.
- To ensure all-weather road connection to all habitations with population 1000 and above (500 and above in hilly and tribal areas) by 2009, and all significant habitations by 2015.
- To connect every village by telephone and provide broadband connectivity to all villages by 2012.
- To provide homestead sites to all by 2012 and step up the pace of house construction for rural poor to cover all the poor by 2016/17.

(vi) Environment

- To increase forest and tree cover by 5 percentage points.
- To attain WHO standards of air quality in all major cities by 2011/12.
- To treat all urban waste water by 2011/12 to clean river waters.
- To increase energy efficiency by 20% by 2016/17.

Source: Eleventh Plan Document, Planning Commission (2007)

Box 4.2: Strategy for Eleventh Plan – Inclusive growth

The strategy for achieving faster growth with greater inclusiveness involves several interrelated components. These are as follows.

- Continuation of the policies of economic reform, which have created a buoyant and competitive private sector capable of benefiting from the opportunities provided by greater integration with the world.
- A revival in agricultural growth, which is the most important single factor affecting rural prosperity.
- Improved access to essential services in health and education (including skill development), especially for the poor, which is essential to ensure inclusiveness and also support rapid growth.
- Special thrust on infrastructure development, which is a critical area for accelerating growth.
- Environmental sustainability, which is becoming increasingly important.
- Special attention to the needs of the disadvantaged groups.
- Good governance at all levels – Central, State, and Local.

Source: Eleventh Plan Document, Planning Commission (2007) to develop new cities and suburban townships in the vicinity of existing cities as satellites/counter magnets to redistribute the influx of population.

Urban infrastructure is expensive to construct, and the financial condition of most of the cities is such that they are unable to finance the scale of investment for quite some time. Accordingly, the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was launched by the Government of India, which seeks to provide central assistance for urban infrastructure development (in a sustainable manner) linked to a process of reforms at the city and urban local body (ULB) level (making these bodies more financially viable and ultimately capable of financing the investment needs in urban areas).

National Urban Renewal Mission

JNNURM was launched by the prime minister on 3rd December 2005. The main aim was to encourage reforms and fast-track planned development of identified cities. The main focus of the Mission is on improving efficiency in urban infrastructure and service delivery mechanisms, community participation, and accountability of ULBs/para-statal agencies towards citizens. The main objectives of the Mission are: focused attention to integrated development of infrastructure services in cities, establishment of linkages between asset-creation and asset-management through reforms for long-term sustainability, ensuring adequate funds to meet the deficiencies in urban infrastructural services, planned development of identified cities including peri-urban areas, outgrowths and urban corridors leading to dispersed urbanization, scaling-up delivery of civic amenities and provision of utilities with emphasis on universal access to the urban poor, special focus on urban renewal programme for the old city areas to reduce congestion, and provision of basic services to the urban poor, including security of tenure at affordable prices, improved housing, water supply and sanitation, and ensuring delivery of other existing universal services of the government for education, health, and social security.

The Mission comprises two sub-missions: urban infrastructure and governance (the main thrust being on infrastructure projects related to water supply and sanitation, sewerage, solid waste management, road network, urban transport, and redevelopment of old city areas with a view to upgrading infrastructure) and basic services to the urban poor (the main thrust of this on integrated development of slums through projects for providing shelter, basic services, and other related civic amenities with a view to providing utilities to the urban poor). The underlying principle of the Mission is enhancement of the quality of life within the sustainability principles.

Eleventh Plan and energy sector

As in other developing countries, our ability to sustain rapid growth will depend critically on the availability or affordability of energy. The Eleventh Plan faces special challenges in this area since the start of the Plan coincided with a period of sharp increase in the world prices of petroleum products and a growing concern about the need to increase energy efficiency, both to economize on costs and also to reduce carbon emissions, as much as possible. It is necessary to evolve appropriate policies for the major energy producing sectors – electricity, coal, oil and gas, and various forms of renewable energy – which are consistent with optimal use of all these energy sources. The Eleventh Plan outlined a broad approach based on the Integrated Energy Policy (IEP 2006) formulated by the Planning Commission. The compulsions of moving to a rational energy policy are underlined by the emerging threat of climate change, which presents special challenges over the longer term. The various measures taken by the Government of India in the energy sector, within the overall objectives of sustaining economic growth and concern for the environment, are enumerated in Table 4.4.

Disaster management

India often faces natural calamities like floods, cyclones, and droughts, which occur fairly frequently in different parts of the country. Sometimes, the same area is subjected to both floods and droughts in successive seasons or years. About 85% of the country's total area is vulnerable to one or more disasters, and about 57% of the area lies in high seismic zones, including the national capital. While not all natural calamities can be predicted and prevented, a state of preparedness and the ability to respond quickly to a natural calamity can considerably mitigate loss of life and property and restore normalcy at the earliest. Therefore, the Government of India has formulated a plan of action to deal with contingencies that arise in the wake of natural calamities, which is periodically updated. Detailed plans are formulated up to the district level.

India's development plan – vision and targets

The last decade of the 20th century has seen a visible shift in the focus of development planning—from the mere expansion of production of goods and services, and the

Table 4.5: Millennium Development Goals and related Indian plan targets

Millennium Development Goals and global targets	**India's Eleventh Plan (2007–12) and beyond targets**
Goal 1: Eradicate extreme poverty and hunger **Target 1:** Halve, between 1990 and 2015, the proportion of people whose income is less than US $1/day **Target 2:** Halve, between 1990 and 2015, the proportion of people who suffer from hunger	Average GDP growth rate of 9% *[Between 1990 and 2005, 34.3% of population earning US $1/day, while 80.4% earning US $2/day]* Agricultural GDP growth rate on average of 4% 20% rise in real wage rate of unskilled workers *[Youth literacy rate of 76.4% (for ages 15–24)]* Reduction in head-count ratio of consumption poverty by 10 percentage points Total fertility rate to be reduced to 2.1 by the end of the Eleventh Plan *[Total fertility rate (births per woman) at 5.3 for 1970–75 and 3.1 for 2000–2005; Annual growth rate of population (1975–2005, 2%) and 2005–2015, 1.4%)]*
Goal 2: Achieve universal primary education **Target 3:** Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling	Reduction in drop-out rates of children at elementary level from 52.2% in 2003/04 to 20% by 2011/12 *[Combined gross enrollment ratio for primary, secondary, and tertiary education was 63.8% in 2005]* Develop minimum standards of education at elementary level, to ensure quality· Increase the literacy rate for persons 7 years or more to 85% by 2011/12 *[61% adult literacy rate between 1995 and 2005]* Reduce the gender gap in literacy to 10 percentage points by 2011/12 Increasing the percentage of each cohort going to higher education from the present 10% to 15% by 2011/12
Goal 3: Promote gender equality and empower women **Target 4:** Eliminate gender disparity in primary and secondary education, preferably by 2005 and in all levels of education no later than 2015	Sex-ratio for age-group 0–6 to be raised to 935 by 2011/12 and 950 by 2016/17 Ensuring that at least 33% of the beneficiaries of government schemes are women and girl children Ensuring that all children have a safe childhood, without any compulsion to work *Ratio of adult literacy (female rate to male rate) is 0.65 between 1995 and 2005*
Goal 4: Reduce child mortality **Target 5:** Reduce by two-thirds, between 1990 and 2015, the under five mortality rate	Infant mortality rate (IMR) to be reduced to 28 by the end of the Eleventh Plan Malnutrition among children of age group 0-3 to be reduced to half its present level by the end of the Eleventh Plan *[47% (under age 5) children underweight (1996–2005); 75% one-year-olds fully immunized against TB, 58% against measles; between 2002 and 2004, 20% of the population was undernourished and 30% (1998–2005) of the infants were with low birth weight]*
Goal 5: Improve maternal health **Target 6:** Reduce by three-fourths, between 1990 and 2015, the maternal mortality ratio (MMR)	MMR to be reduced to 1 per 1000 live births by the end of the Eleventh Plan Anaemia among women and girls to be reduced to half its present value by the end of the Eleventh Plan *[IMR improved from 127 in 1970 to 56 in 2005, while under five mortality rate improved from 202 to 74 (for the same period). MMR stands at 450 (per 100,000 live births) in 2005]*
Goal 6: Combat HIV/AIDS, malaria, and other diseases **Target 7:** Halted by 2015 and begin to reverse the spread of HIV/AIDS **Target 8:** Have halted by 2015 and begin to reverse the incidence of malaria and other major diseases	Malaria mortality reduction: 50% by 2010 and additional 10% by 2012 Kala-azar mortality reduction – 100% by 2010 and sustaining elimination by 2012 Filaria/microfilaria reduction – 70% by 2010, 80% by 2012, and elimination by 2015 Dengue mortality reduction – 50% by 2010 and sustaining at that level by 2012 Reduce new infections of HIV/AIDS by 60% in high prevalence states so as to obtain reversal of epidemic and 40% in highly vulnerable states to stabilize the epidemic
Goal 7: Ensure environmental sustainability **Target 9:** Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources **Target 10:** Halve by 2015 the proportion of people without sustainable access to safe drinking water **Target 11:** Achieve by 2020 a significant improvement in the lives of at least 100 million slum dwellers	Capacity addition of 16,553 MW hydro, 3380 MW nuclear (out of the total of 78,577 MW capacity addition) Increase forest and tree cover by 5 percentage points *[22.8% of forest cover of the total land area with an annual change of 0.4% between 1990 and 2005]* To attain WHO quality of air standards in all major cities by 2011/12 To treat all urban waste waters to clean rivers by 2011/12 Increase energy efficiency by 20% by 2016/17 Clean drinking water to be available to all by 2009 *[14% population not using improved water source (2004)]* Ensuring electricity connection to all villages and BPL households by 2009 and reliable power by the end of the plan *[56% electrification rate (2000–05), 487.2 million population without electricity(2005)]* Ensure all-weather road connection to all habitations with population 1000 and above (500 and above in hilly and tribal areas) by 2009, and all significant habitations by 2015 Connect every village by telephone and broadband connectivity by 2012 *[Telephone mainlines increased from 6 to 45 (per 1000 people, 1990–2005), cellular subscribers from 0 to 82, Internet users from 0 to 55 for the same period]* Provide homestead sites to all by 2012 and step up the pace of house construction for rural poor to cover all the poor by 2016/17*[Share of TPES; coal (38.7%), oil (23.9%), natural gas (5.4%), hydro, solar, wind, geothermal (1.7%), biomass and waste (29.4%), and others (including nuclear) is 0.8%. for 2005]*

Goal 8: Develop a global partnership for development **Target 12:** Develop further an open, rule-based, predictable, non-discriminatory trading and financial system (includes a commitment to good governance, development, and poverty reduction – both nationally and internationally) **Target 13:** In cooperation with developing countries, develop and implement strategies for decent and productive work for youth **Target 14:** In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries **Target 15:** In cooperation with the private sector, make available the benefits of new technologies, especially information and communication technologies	58 million new work opportunities *[Unemployment rate of 4.3% of labour force (1996–2005) with 67% employed in agriculture, 13% in industry, and 20% in services]* Reduction of unemployment among the uneducated to less than 5% 13 of the 27 monitorable targets have been disaggregated into appropriate state-level targets
Data in Italics from UNDP (2007)	
Source: Planning Commission (2007); UNDP (2007)	

consequent growth of per capita income, to planning for enhancement of human well being, more specifically to ensure that the basic material requirements of all sections of the population are met and that they have access to basic social services such as health and education. A specific focus on these dimensions of social development is necessary because experience shows that economic prosperity, measured in terms of per capita income alone, does not always ensure enrichment in the quality of life, as reflected, for instance, in the social indicators on health, longevity, literacy, and environmental sustainability. The latter must be valued as outcomes that are socially desirable within themselves and, hence, made direct objectives of any development process. They are also valuable inputs to sustain the development process in the long run. In line with the above objectives, as in the Tenth Plan, the Eleventh Plan has developed various developmental targets for the country (Box 4.1).

In order to ensure the balanced development of all states, the Eleventh Plan includes a break-up of the broad developmental targets, by state, including targets for growth rates and social development, which are consistent with the above national targets. These state-specific targets take into account the needs, potentialities, and constraints present in each state and the scope for improvement in their performance, given these constraints. Overall, the vision of development during the Eleventh Plan period is outlined in Box 4.2, consistent with the broad principles of sustainable development and inclusiveness.

The Eleventh Plan provides an opportunity to build upon the gains of the past and also to address the weaknesses that have emerged. The establishment of appropriate institutional frameworks to implement various development programmes has been an important component of development policies throughout India's planning effort

Table 4.6: A chronology of the Government of India's response to environment and climate change across various plan periods

Plan period	Achievements
Eighth Plan (1992–97)	(1) Eco Mark Scheme 1991 (2) National Conservation Strategy and Policy Statement on Environment and Development (1992) (3) Expert Group constituted by the Planning Commission to formulate a National Policy for the integrated development of the Himalayas in 1992 (4) Ministry of Non-conventional Energy Sources (now known as Ministry of New and Renewable Energy [MNRE]) created in 1992 (5) National Disaster Mitigation Programme (NDMP) (1993/94) (6) National River Conservation Plan (1995) (7) Environmental Impact Assessment Notification (EIA) (8) Rural Infrastructure Development Fund (RIDF)

Ninth Plan (1997–2002)	(1) Recycled Plastic Use Rules (1998) (2) National Committee on the Conservation and Management of Mangroves and Coral Reefs, set up in September 1998 (3) Hydro Policy (1998) (4) Biological Diversity Act (2002) (5) National Agriculture Insurance Scheme (1999–2000) (6) Municipal Solid Waste Management and Handling Rules (2000) (7) National Lake Conservation Plan initiated in 2001 (8) Exploration and exploitation of coal bed methane (9) Broad-based Energy security strategies in the Ninth Plan included energy conservation, energy efficiency standards, energy labelling programme, and energy audit to be made mandatory in energy-intensive units (10) Concern for climate change impacts highlighted (11) Lead in Gasoline phased out since 2000 (12) National Policy for hydropower development (13) National Action Programme (NAP) to combat desertification, 2001 (14) National Land Use and Conservation Board (NLCB) reconstituted (15) Pradhan Mantri Gram Sadak Yojana launched on 25th December 2000 (16) Energy Conservation Act (2001) (17) Remote Village Electrification (RVE) Programme (2001/02)
Tenth Plan (2002–07)	(1) National Environment Policy (2006) (2) National Agriculture Policy (2000) (3) *Bharat Nirman* (to build rural infrastructure) launched by the Government of India in 2005 (4) National Rural Health Mission (2005–12) (5) First National Communication to UNFCCC in 2004 (6) National Rural Employment Guarantee Act (NREGA) (2005) (7) JNNURM (Jawaharlal Nehru National Urban Renewal Mission) (2005) (8) Disaster Management Act (2005) (9) Energy Conservation Building Code (ECBC) (2006) (10) Rural Electrification Policy (2006) (11) Integrated Watershed Development Programme (2008) (12) National Rainfed Area Authority (NRAA) (2006)
Eleventh Plan (2007–12)	(1) Inclusive approach for development (2) National Action Plan on Climate Change launched in 2008 (3) Development of "Solar Cities" started in February 2008 (4) Environment protection considered as one of the monitorable target (5) India's greenhouse gas (GHG) emission report launched (6) National Hydro Energy Policy (7) Introduction of Rashtriya Krishi Vikas Yojana (RKVY) (8) Increase in forest cover by 5% of total geographical area (9) Reduction in energy intensity by 20% from the period of 2007/08 to 2016/17 (10) Contribution of renewable energy to increase by 2–3% in the plan period (11) Removal by India's forests to 6.35% of India's annual total GHG emissions by the year 2020 (12) National Green Tribunal Act

Source: Planning Commission (1992–97, 1997–2002, 2002–07, 2007–12)

since independence. These provide platforms to implement adaptation strategies for dispersed and informal sectors like watershed management, agriculture, rural health, and forestry.

The vision for the Eleventh Plan includes an important component in terms of an improvement in governance. Over the years, the governments at the centre and the states have launched a large number of initiatives at substantial public expense to achieve the objectives of growth with poverty alleviation and inclusiveness. Experience suggests that many of these initiatives have floundered because of poor design, insufficient accountability, and also corruption at various levels. Increasingly, there is a demand for effective implementation, without which expanded government intervention will not yield desired results. The strategy for the Eleventh Plan aims at bringing about major improvements in governance, which would make government-funded programmes in critical areas more effective and efficient. It is considered that the best possible way of achieving this objective is by involving communities in both the design and implementation of such programmes, although such involvement may vary from sector to sector. Experience shows that Civil Society Organizations (CSOs) can work with PRIs to improve the effectiveness of these programmes. For achieving the vision of the Eleventh Plan, it is extremely important to experiment with programme design to give more flexibility to decision making at the local level.

It is especially important to improve evaluation of the effectiveness of how government programmes work and to inject a commitment to change their designs in the light of the experience gained. Evaluation must be based on proper benchmarks and be scientifically designed to generate evidence-based assessment of different aspects of programme design. Along with greater transparency and feedback from community participation, this is particularly important in the case of programmes delivering services directly to the poor. Accountability and transparency are critical elements of good governance. The Right to Information Act (RTI) enacted in 2005 empowers people to get information and constitutes a big step towards transparency and accountability.

Constitutional provisions and legal requirements have been used to achieve various standards and norms that are needed for development programmes. The 42nd Amendment of the Constitution (1977) enjoined both the state and the citizens to protect and improve the environment and safeguard forests and wildlife. The 73rd Amendment (1992) made the panchayats responsible for soil conservation, watershed development, social and farm forestry, drinking water, fuel and fodder, non-conventional energy sources, and maintenance of community assets. Various national policies such as the National Forest Policy (1988) and the National Water Policy (1987 and 2002) are all important moves towards ensuring the sustainability of natural resources. India is also a signatory to many of the international multi-lateral treaties in matters relating to environment, health, investment, trade, and finance. The government has also incorporated the spirit of Agenda-21 in the form of two policy statements: the Abatement of Pollution and the National Conservation Strategy.

National Planning and Climate Change

The Eleventh Five-year Plan reflects the Government of India's commitment to the United Nations Millennium Development Goals (MDGs) (2002). The UN goals include halving extreme poverty, halving the proportion of people without sustainable access to safe drinking water, halting the spread of HIV/AIDS, and enrolling all boys and girls everywhere in primary schools by 2015. Many of the Indian national targets have been more ambitious than the UN MDGs like: doubling the national per capita income by 2012, all villages to have sustained access to potable drinking water by 2007, halting HIV/AIDS spread by 2007, and all children in schools by 2003 (Table 4.5). They reflect the commitment of the Government of India to the UNFCCC, the Rio Declaration (1992) on Agenda-21 at the UN Conference on Environment and Development, the Millennium Declaration at the UN Millennium Summit, the Johannesburg Declaration at the World Summit on Sustainable Development (2002), and the Delhi Declaration (2002) at the COP-8 to the UNFCCC; among other declarations to which India has been a party. India has been consistently responding positively and in a constructive manner (through its domestic programmes, policies, and measures) in order to respond to the environmental challenges, including climate change. Table 4.6 gives a summary of the various responses of the Government of India in addressing those challenges.

The specific planning targets of India's development plans address many climate change concerns. For example, reduced poverty and hunger would enhance the adaptive capacity of the population. Reduced decadal population growth rates would lower GHG emissions, reduce pressure on land, resources, and ecosystems, and provide higher access to social infrastructure. Increased reliance on hydro and renewable energy resources would reduce GHG and local pollutant emissions, enhance energy security and result in consequent economic benefits from lower fossil fuel imports, and provide access to water resources from additional hydro projects. The cleaning of major polluted rivers would result in enhanced adaptive capacity due to improved water, health, and food security.

India's development priority during the Eleventh Plan is hinged on an inclusive growth strategy so as to ensure that the growth in GDP should not be treated as an end in itself, but only a means to an end. This is achieved by translating developmental goals into monitorable targets, which would reflect the multi-dimensional economic and social objectives of inclusive growth, which envisages doubling the per capita income by 2012, reducing the

Table 4.7: National Action Plan on Climate Change (NAPCC) and development goals

Sl. No.	National Mission	Objectives	Links with development goals
1	National Solar Mission	Promoting ecologically sustainable growth, while meeting energy security challenges	Capacity addition of 16,553 MW hydro, 3380 MW nuclear (out of the total of 78,577 MW capacity addition) Ensuring electricity connection to all villages and below poverty line (BPL) households by 2009 and reliable power by the end of the plan *[56% electrification rate (2000–05), 487.2 million population without electricity (2005)}* 20% rise in real wage rate of unskilled workers *[Youth literacy rate of 76.4% (for ages 15–24)]* Reduction in head-count ratio of consumption poverty by 10 percentage points
2	National Mission on Sustainable Habitat	Extension of Energy Conservation Building Code (Optimization of energy demand) Urban planning/shift to public transport: long-term transport plans for small/medium cities Recycling of material and urban waste management: power from waste	Develop minimum standards of education at elementary level, to ensure quality To attain WHO quality of air standards in all major cities by 2011/12 Provide homestead sites to all by 2012 and step up the pace of house construction for rural poor to cover all the poor by 2016/17
3	National Mission on Green India	Double area under afforestation/ eco-restoration in the next 10 years Increase greenhouse gas (GHG) removals by forests to 6.35% of India's annual GHG emissions by 2020 (increase of 1.5% over baseline) Enhance forests/ecosystems resilience	Increase forest and tree cover by 5 percentage points *[22.8% of forest cover of the total land area with an annual change of 0.4% between 1990 and 2005]*
4	National Mission for Sustaining the Himalayan Ecosystem	Strengthening institutional capacity Standardization of field and space observations Prediction/projection of future trends and assessment of possible impacts Governance for Sustaining Himalayan Ecosystem (G-SHE)	Ensure all- weather road connection to all habitations with population 1000 and above (500 and above in hilly and tribal areas) by 2009, and all significant habitations by 2015
5	National Mission on Enhanced Energy Efficiency	Market-based approaches Cumulative avoided electricity capacity addition of 19,000 MW	Increase energy efficiency by 20% by 2016/17
6	National Water Mission	Conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management	Ensuring water security and food security (MDG 1: Eradicate extreme poverty and hunger) through efficient use of water and adaptation to climate change Ensure integrated water resources management (MDG 7: Ensure environ-mental sustainability)
7	National Mission for Sustainable Agriculture	Use of bio technology Dryland (rain-fed) agriculture Risk management Access to information	Average GDP growth rate of 9% *[between 1990 and 2005, 34.3% of population earning US $1/day, while 80.4% earning US $2/day]* Agricultural GDP growth rate on average of 4%

Data in Italics from UNDP (2007)

Source: Planning Commission; UNDP (2007); NAPCC (2008) poverty level by 10%, providing gainful employment to all, and ensuring food, energy, and economic security for the country. To achieve these development priorities, substantial additional energy consumption will be necessary, and coal, being the abundant domestic energy resource, would continue to play a dominant role. There are considerable costs associated with meeting the various goals and development targets, requiring the commitment of additional resources from various sources as well as by realigning new investments.

Market-oriented economic reforms initiated in the past decade have expanded the choice of policy instruments, technologies, and resources. In the energy and electricity sectors, this has led to the amelioration of fuel quality, technology stocks, infrastructure, and operating practices. The concerns about rising energy, electricity, and carbon intensity of the Indian economy inspired the Indian government to initiate targeted programmes and institutions to promote energy efficiency, energy conservation, and introduce renewable energy technologies. The thrust areas include improving energy efficiency in all sectors of the economy, promoting hydro and renewable electricity, power sector reforms, including national grid formulation and clean coal technologies for power generation, developing energy infrastructure, coal washing, promoting cleaner and less carbon-intensive transport fuel, and managing environmental quality. The resultant decline in energy and carbon intensity of the GDP signifies the beginning of the decoupling of economic growth from energy and carbon, which historically happened at a higher per capita income in the industrialized nations.

Therefore, it is clear that Indian planning process and global climate change concerns are intricately linked, and addressing the objectives would also respond to climate change concerns.

Climate Change and Development

India faces major development challenges—access to the basic amenities like drinking water, electricity, sanitation, and clean cooking energy still remains a luxury for both urban and rural dwellers alike. Groundwater, which has been the key source for meeting the irrigation and consumption needs of urban and rural population, is under tremendous pressure because of haphazard urban planning and climate change. Environmental degradation in future will have huge economic impacts on an agrarian and land-starved country like India. Developing countries would require building adaptive capacity for facing climate risks with increasing evidence of climate change.

Climate change interfaces with diverse societal and natural processes and, consequently, with the development processes. Conventionally, climate change has been considered as an impediment to development and, conversely, development is viewed as a threat to the climate. The development and climate paradigm sees development as the tool to address the challenges posed by climate change and the key to overcoming our vulnerability and enhancing our capabilities for adaptation to its adverse impacts. In this paradigm, the development itself –building capacities, institutions, and human capital in developing countries – emerges as the key factor for enhancing adaptive and mitigative capacities. However, in the current context of the impacts due to climate change, climate-centric actions have become a proactive policy tool to build adaptive and mitigative capacities within the broader principles of sustainable development. Such measures are not in isolation of the development targets of India but emerge as a targeted co-benefit out of social and economic development and in some cases, a "leading" policy statement like building of a vibrant renewable energy sector in India.

The term "development", in general, refers to broader social goals, in addition to economic growth. In recent years, the national development policy perspective has taken a more inclusive view of the scope, content, and the nature of national development. The conventional paradigm of economic development, which was woven around optimal resource allocation, is now extended to include participative processes, local initiatives, and global interfaces. The development approach views welfare as the raison d'etre of development. Under the emerging development perspective, while efficient resource allocation is best addressed by market mechanisms, the institutions are also considered as a key component for the optimal utilization of a nation's resources. Thus, the institutions and policies play a vital role in welfare development. The development approach duly recognizes the strong links between government policies, organizational capacity, and the results of social development. It also perceives the provision of resources for social services and the creation of new partnerships for the delivery of services as essential; it also accords primacy to the implementation of the vision within a framework of policies and institutions, which provide mechanisms for efficiency and accountability.

Many initiatives for adaptation and mitigation have been integrated with and added to the already existing economic development projects. The financing for projects involves ensuring that the risks and expected returns are commensurate with the requirements of the financial markets, matching investors who have available funds with projects and seeking funding is by no means easy in developing countries. The success of linking investors with projects, via appropriate sets of institutional and financial intermediaries, partly depends on the degree of development of the financial markets and the financial services sector in the country where the project will be implemented.

The cascading effects of sustainable development and proactive climate-centric policies would help reduce emissions and moderate the adverse impacts of climate change and thereby alleviate the resulting loss in welfares. In line with this approach, the Government of India announced the National Missions on Climate Change in 2008. These eight missions have various actions built into the individual missions. These actions range from a variety of goals: from promoting ecologically sustainable growth (National Solar Mission) to energy demand management (Mission on Energy Efficiency) to promoting measures that aim at sustainable development (Mission on Sustainable Habitat). These specific missions have enumerated goals and targets (Table 4.7), which help in making an accelerated progress towards achieving various developmental goals. These missions have targeted a much larger goal, which goes beyond the developmental targets of the Government of India. These goals have larger ramifications in terms of creating an enabling framework of institutions, policies, and programmes that help in simultaneously achieving developmental and climate goals. Thus, due to the growing national and international concern vis-à-vis climate change, there is a broad consensus among nations regarding immediate proactive actions pertaining to the mitigation of GHG and also towards adaptation to climate-induced impacts. The Government of India responded to these new challenges by rolling out its NAPCC, which not only helps in achieving the national development goals but also makes a distinct attempt at mitigating GHG emissions.

Climate-Friendly Initiatives

India ranks fifth in aggregate GHG emissions in the world, behind USA, China, EU, and Russia, in 2007. The emissions of USA and China are almost four times that of India, in 2007. It is also noteworthy that the emissions intensity of India's GDP declined by more than 30% during the period 1994–2007, due to efforts and policies that are proactively being put in place. India's total CO_2 emissions are about 4% of total global CO_2 emissions, and the energy intensity of India's output has been falling with improvements in energy efficiency, autonomous technological changes, and economical use of energy. On the energy efficiency front, India has been aggressively reducing the energy intensity of its GDP—from 0.3 kgoe per dollar GDP in PPP terms in 1980 to 0.16 kgoe per dollar GDP in PPP terms in 2007. India's energy efficiency is comparable to Germany, and only Japan, UK, Brazil, and Denmark have lower energy intensities.

Although India ranks in the top five countries in terms of absolute GHG emissions, the per capita emissions are much lower compared to those of the developed countries, even if the historical emissions are excluded. Its high level of emissions is due to its large population, geographical size, and a large economy. The most recent data available for India is based on the assessment carried out by the INCCA in May 2010. India's per capita CO_2 eq. emissions, including land use, land-use change and forestry (LULUCF) was 1.5 tonnes per capita in 2007.

To achieve the national developmental targets (Box 4.1), India endeavours to pursue a sustainable pathway with reduced population growth rates, an open market-based economy, and a sophisticated science and technology sector. It has also undertaken several response measures that contribute to the objectives of the UNFCCC.

Fossil energy

India is both a major energy producer and a consumer. It currently ranks as the world's seventh largest energy producer, accounting for about 2.49% of the world's total annual energy production. It is also the world's fifth largest energy consumer, accounting for about 3.45% of the world's total annual energy consumption in 2004. Since independence, the country has seen significant expansion in the total energy use, with a shift from non-commercial to commercial sources. The share of commercial energy in total primary energy consumption rose from 59.7% in 1980/81 to 72.6% in 2006/07 (Planning Commission, 2007).

The main challenge before the energy sector for fuelling the growth in the Eleventh Plan is to enhance energy supply in cost-effective ways. The persistent shortages of electricity, both for peak power and energy, indicate the magnitude of the problem. Average peak shortages were estimated to be 12% in 2006/07 (Planning Commission, 2007). The very high load factor of 76.8% for the system

Box 4.3: Key recent highlights of the energy sector

Additional sources of energy such as coal bed methane (CBM) to be exploited.
To reduce the energy intensity per unit of greenhouse gas (GHG) by 20% from the period 2007/08 to 2016/17 and initiate action to increase our access to cleaner and renewable energy sources.
Renewable energy contribution to increase by 2%–3% by the end of the Eleventh Plan.
Content of ethanol in petrol to increase up to 10% and depending upon the bio-diesel production and availability, the entire country may be progressively covered with sale of 5% bio-diesel-blended diesel.
Euro-IV equivalent norms in identified cities and Euro-III equivalent norms in the entire country introduced w.e.f. 1 April 2010.
Setting up of a National Energy Fund (NEF) for supporting R&D in the energy sector.
Encouragement through suitable fiscal concessions to be provided for manufacturing and assembly of fuel-efficient and hybrid vehicles and for use of alternative fuels.
10% increase of installed capacity in renewables (wind, small-hydro and biomass) during successive plans.
Achieve 10,000 MW of avoided capacity by 2012 through standards and labelling of appliances, building energy efficiency, efficient lighting, municipal and agriculture demand side management (DSM).

Source: Planning Commission (2007)

indicates that the system is operating under strain or has limited reserve. At the same time, for want of natural gas, some gas-based power plants are kept idle. Nuclear plants are also operated at lower load factors for want of adequate uranium. Power shortages are an indication of insufficient generating capacity and inadequate transmission and distribution (T&D) networks. To a great extent, this is the outcome of poor financial health of the state electricity utilities having high levels of aggregate technical and commercial (AT&C) losses.

It is evident from the discussions above that India is short of energy resources, and the focus of the Government of India has been to expand energy resources through exploration, energy efficiency, using renewables, and R&D. The environmental impact of various energy options is also a growing concern owing to the widespread use of energy.

The focus, therefore, has been to ensure that the available fossil energy resources are optimally exploited, using enhanced recovery techniques. Additional sources of energy, such as coal bed methane, are also being explored, and fossil fuel reserves are being advanced through more intensive exploration. Though the renewable energy sources such as wind energy, biomass, and biofuels account for a small percentage in the total energy, their contribution is planned to increase by 2%–3% in the Eleventh Plan. Accordingly, a roadmap with detailed policy initiatives is necessary in all the sub-sectors of the energy sector for achieving the desired growth. The Government of India has moved towards a more transparent policy framework that treats different sources of energy in a similar fashion. Such a framework, at its core, has introduced competition for minimizing distortions across sectors and maximizing efficiency gains.

The Government of India has also focused intensively on ensuring the availability of clean, modern fuel to all households by removing various kinds of barriers such as a mix of optimum fiscal structure. A robust and credible regulatory regime has ensured effective implementation of the policy framework.

Institutions for promoting the pace of energy conservation and improvement in energy efficiency have been strengthened. Restructuring incentives and support by shifting from supply-driven programmes to demand-driven programmes and technologies has assisted development and use of new and renewable energy sources. The subsidies and support have been linked to the outcomes in terms of renewable energy generated rather than to capital investments.

The need for a robust energy R&D system for developing relevant technology and energy sources that enhance energy security and lead to energy independence in a cost-effective way in the long run has been explicitly identified by the Government of India. A number of technology missions covering areas such as *in situ* gasification, integrated gasification combined cycle (IGCC), solar energy, and energy storage are in the proposal stage.

With regard to fossil-based energy use, several initiatives have been taken by the Government of India (Box 4.3 – Recent Highlights in the Energy Sector) . On the usage of coal, there have been guidelines, policies, and programmes that rationalize the use of coal and promote private sector participation to encourage efficiency improvements through competition, pricing reforms, and encouraging use of improved technologies such as coal-washing, combustion technology, and recovery of coal-bed methane. With regard to oil, the main thrust has been on promoting fuel efficiency and conservation. Among other initiatives, the thrust area has been reduction of gas-flaring, installation of waste-heat recovery systems, upgradation of equipment, encouragement of fuel switch from diesel to natural gas, and establishment of the Petroleum Conservation Research Association (PCRA) to increase awareness and develop fuel-efficient equipment. Numerous initiatives in promoting gas as a fuel source have also been undertaken (as a principal fuel for switching from coal and oil) such as in the residential sector (replacing coal and kerosene replacement with gas, encouraging compressed natural gas [CNG] as an alternate to petrol and diesel in transport, and enabling major investment in gas pipelines and related infrastructure). Petroleum and Natural Gas Regulatory Board (2006) was constituted in 2007. The provisions of the Board have been brought into force on 1st October 2007. The Board regulates refining, processing, storage, transportation, distribution, marketing, and sales of petroleum products and natural gas, excluding production of crude oil and natural gas.

In line with the promotion of improved technologies in the power sector, National Thermal Power Corporation (NTPC) has adopted the supercritical technology, thereby contributing to improvements in thermal efficiency and reduced emission of GHGs. This technology is being implemented in Barh-II and further being implemented in 11 units (in Mauda, Sholapur, Meja, Nabinagar and Raghunathpur plant) from 2008.

Further, NTPC has completed the feasibility study of IGCC technology with high ash Indian coal in 2010. Further efforts are on to take ahead the work already done to implement IGCC technology demonstration plant of about 100 MW capacity. Study of CO_2 capture technology has also been initiated by NTPC with various research institutions and organizations (IIT Guwahati, IIT Kharagpur, IIT Mumbai, IIP Dehradun, NEERI Nagpur, CSMRI Bhavnagar) (NTPC, 2010).

Renewable energy

In this sector, the Government of India has taken many initiatives (Table 4.8).

Background: India intends to provide a reliable energy supply through a diverse and sustainable fuel-mix that addresses major national drivers. These include energy security concerns, commercial exploitation of renewable power potential, eradication of energy poverty, ensuring availability and affordability of energy supply and preparing the nation for imminent energy transition. Accordingly, renewable energy has been an important component of India's energy planning process. The country has an estimated renewable energy potential of around 85,000 MW from commercially exploitable sources of wind, small hydro and biomass. In addition, India has the potential to generate around 50 MW per square km using solar photovoltaic and solar thermal energy. The potential is under reassessment and is likely to increase substantially. In addition, there is an estimated potential for around 140 million square metre solar thermal collector area and also 12 million household biogas plants. By March 2011, renewable power; excluding hydro above 25 MW, installed capacity has reached over 20 GW, contributing around 11% of the country's electric installed capacity. This has grown from 3% in 2003 at a time when the growth of conventional power has also been the fastest. At present, the share of renewable power in the electricity mix is around 6% and the National Action Plan on Climate Change mandates increasing share of renewable power

Table 4.8: Programmes and their features for the promotion of renewable energy in India

Programme	Features
National Biogas and Manure Management Programme(NBMMP)	To provide clean biogas fuel for reducing use of liquefied petroleum gas (LPG) and other conventional fuels; mitigation of climate change by preventing black carbon and methane emissions
Accelerated Programme onEnergy Recovery from Urban Wastes – Sanction for the Year 2005/06	To accelerate the promotion of setting up of projects for recovery of energy from urban wastes; to create an enabling environment to develop, demonstrate, and disseminate utilization of wastes for recovery of energy; to harness the available potential of municipal solid waste (MSW)-to-energy by the year 2017
Scheme on Biogas Based Distributed/Grid Power Generation Programme	To promote biogas-based power generation, especially in the small capacity range (based on the availability of large quantity of animal wastes and wastes from forestry, rural based industries, kitchen wastes)
Programme on Recovery of Energy from Industrial Wastes	Central financial assistance in the form of capital subsidy and grants-in-aid in respect of the following activities.(i) Industrial waste to biogas(ii) Power generation from biogas(iii)Power generation from solid industrial waste (iv) Promotional activities (v) R&D, resource assessment and technology upgradation

Source: MNRE (2010)

Solar Energy has begun to significantly penetrate into Rural India

in the electricity mix to 15% by the year 2020. The wind power programme constitutes around 70% of the total renewable power capacity and is the fastest growing programme with the investment almost entirely coming from the private sector. The Ministry has ambitious plans to have an installed capacity of about 72 GW, including 20 GW for solar by 2022.

The Government has been promoting private investment in setting up of projects for power generation from renewable energy sources through an attractive mix of fiscal and financial incentives, in addition to the preferential tariffs being provided at the State level. These include capital/interest subsidy, accelerated depreciation and nil/concessional excise and customs duties. In addition, generation-based incentives have also been introduced recently for wind power to attract private investment by Independent Power Producers not availing Accelerated Depreciation benefit and feed-in tariff for solar power.

Decentralized and stand alone renewable electricity systems: Amongst the major priorities of the Indian renewable energy programme are off-grid and distributed solutions including providing energy access to large rural populations including those in inaccessible areas and meeting unmet demands in many other areas. These also replace/reduce fossil fuel consumption. For instance, solar rural lighting replaces kerosene, a biogas plant or solar cooking systems replace cooking gas, solar PV replaces diesel or furnace oil in various areas. Renewable energy competitively meets the process heat as well as power requirements of large number of small and medium enterprises as well as some other areas, which use a lot of diesel for power generation. A new policy framework has been put into place for rapid up-scaling of off-grid programmes in an inclusive mode. The programmes are now being implemented through multiple channel partners including renewable energy service providing companies, financial institutions including microfinance institutions, financial integrators, system integrators, and industry and programme administrators. In order to sustain satisfactory performance and generation of output in the envisaged energy forms, a flexible funding approach has been adopted with a bouquet of instruments including support in the form of capital subsidy, interest subsidy, viability gap funding etc. This apart, the ministry provides full financial support for undertaking pilot and demonstration projects through manufacturers and other organizations for demonstrating new and innovative applications of renewable energy systems. An extension of off-grid relates to rural electrification. Over 40% of the country's population currently do not have energy access. Over 8000 remote and inaccessible villages and hamlets have been provided with basic electricity services through distributed renewable power systems. These include about 150 villages covered through mini grid by rice husk-based gasification systems in Bihar. In addition, over 570 MW capacity distributed off-grid in the capacity range of 5-100 kW are in use for small-scale industrial applications and electrification purposes. Further, over 1.6 million solar home lighting systems, including lanterns and streetlights have been set up in different parts of the country. To meet unmet demands, the Ministry aims to cover about 10,000 villages withbiomass-based systems and over 1000 villages with solar power by 2022.

The greatest potential area of off-grid relates to solar technologies. These include solar water heating systems, home lighting systems which include solar lanterns, solar cooking systems, and process heat using solar concentrators, biomass gasification for thermal application, solar pumps and small power generating systems. Under the National Solar Mission, it has been proposed to cover 2000 MW equivalent by 2022 which includes all the above, except solar water heating systems for which there is a separate target of 20 million sqm. Within the off-grid component, there is a separate target of covering 20 million rural households with solar lights. This includes coverage under the Remote Village Electrification Programme where largely solar lighting is provided to villages where grid is unlikely to go and which is almost entirely funded by Central grants. In addition, in other areas where grid is available but power supply is of erratic nature, solar lighting is financed through loans given through rural banks. There are areas where solar power is somewhat competitive with some government support. These include solar-powering of telecom towers, large scale use by industrial establishments in the manufacturing sector where diesel generating sets have been installed for partly mitigating daytime use of diesel, increased coverage in areas like Ladakh where diesel is the prime source of energy generation, solarisation of diesel-run electric pump sets etc. It is estimated that installation of 1000 domestic solar water heaters, can result in peak load saving of 1 MW. Mandatory provisions, therefore, are being made to make solar water heating mandatory in buildings and sectors where hot water demand is met by electricity or other sources. Large-scale deployment of this nature of renewable energy technology thus not only allows avoided utility cost but would also result in substantial saving of electricity and fossil fuels. Use of solar thermal systems has started gaining momentum, with a solar collector area of 4.8 million sqm already installed to meet these needs. However, regulations by municipal authorities have so far been sporadic and adoption by industry is less than desirable.

Heat energy for cooking purposes: Since the 1970s, around 4.8 million family-type biogas plants have been set up to provide a clean cooking energy option in rural areas. The present deployment is about 0.15 million plants annually. The aim is to reach an additional 2 million households by 2022. The biogas programme has had a favourable impact on the environment through supply of clean gaseous fuel. In addition to savings on fuel, the biogas technology has multiple benefits including provision of energy in a clean and unpolluted form; making available enriched organic fertilizer as a by-product for supplementing and optimizing the use of chemical fertilizers. Rural women walking for miles to collect fuel wood and sweating it out in smoky kitchens is a thing of the past in a large number of rural households in India. The concept has gradually caught up and it is no longer just the family type biogas plants that are promoted. Toilet-linked biogas plants are also coming up. Medium size and large size biogas plants are being installed for power generation from urban and industrial wastes and animal manure. Technology demonstration projects are also promoted to produce CNG-like gas for its use where CNG is being used.

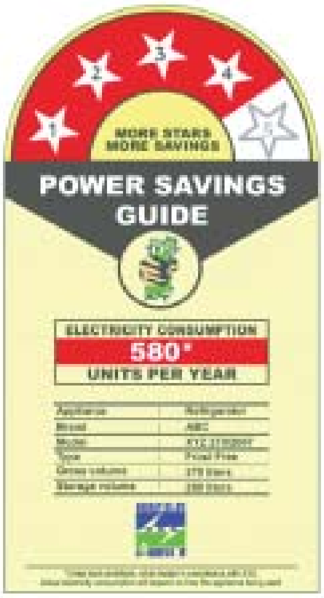
As far as cook-stove is concerned, the biggest problem relates to inefficient combustion of biomass and the inability of large number of people to spend money on processed fuels for improved cook-stoves because traditionally available biomass is used free of cost. A large number of community size cook-stoves currently use substantial amount of firewood. A pilot project has been launched to test the efficiency and marketability of improved community size cook-stoves, so that the consumption of firewood is reduced. This project covers governmental institutions like 'Anganwadi Centres', schools for mid-day meals and tribal hostels apart from private dhabas (roadside eateries). Simultaneously a pilot project is being contemplated to test sustainable delivery models for household improved cook-stoves. The Ministry has also started the process of upgrading biomass cook-stove test centres as well as developing modified standards for various improved cook-stoves. The world's largest system for cooking in community kitchens has been installed at Shirdi in Maharashtra to cook food for 20,000 people per day and is saving around 60,000 kg of LPG every year. All institutions including large institutions with hostels, hospitals/medical colleges, military/para-military establishments, industrial organizations, academies; wherever large number of meals is cooked, are the targets.

Policy Framework: India has been pursuing a three-fold strategy for the promotion of renewable energy:

- Providing budgetary support for research, development and demonstration of technologies
- Facilitating institutional finance from various financial institutions
- Promoting private investment through fiscal incentives, tax holidays, depreciation allowance and remunerative returns for power fed into the grid

India's renewable energy programme is primarily private sector driven and offers significant investment and business opportunities. A domestic manufacturing base has been established in the country for renewable energy systems and products. The annual turnover of the renewable energy industry, including the power generating technologies for wind and other sources, has reached a level of over USD 10 billion. Companies investing in these technologies are eligible for fiscal incentives, tax holidays, depreciation allowance and remunerative returns for power fed into the grid. Further, the Government is encouraging foreign investors to set up renewable power projects on a 'build-own and operate' basis with 100% foreign direct investment.

There continue to be barriers for speedy deployment of renewable energy in the country. These include creation of transmission infrastructure for evacuation of renewable power from remote locations, availability of low cost funds particularly for off-grid applications, sustainable business models for decentralised renewable energy projects and also absence of rural entrepreneurship and distributed service companies.



Bureau of Energy Efficiency- Equipment/Appliances labeling for informed consumer choice

Possibilities for Cooperation: India's experience in dissemination of renewable energy could be of much use to other developing countries, particularly in Asia and Africa . The cooperation activities could be:

- ❖ Exchange of officials/technologists for participation in the training programmes, on different aspects of renewable energy.
- ❖ Company-to-company cooperation through joint ventures.
- ❖ Technology transfer.

There are tremendous possibilities for scaling up clean and environment friendly renewable energy, which; because of their plentiful indigenous availability and suitability in meeting various diffused and decentralized needs and having low gestation periods, have the potential to provide both a framework for inclusive growth and an alternative low emission energy development pathway for the country.

Energy efficiency and conservation

India recognizes the importance of improving the efficiency of energy usage and conservation measures. Bureau of Energy Efficiency (BEE) has been set up to put into operation, conservation measures such as energy standards, labelling of equipment/appliances, building energy codes, and energy audits. Energy conservation has been approached in a multi-faceted manner with targeted interventions on the supply side, demand side, and also T&D system. In India, DSM has been identified to play a key role in eliminating power shortages to a considerable extent.

In the Eleventh Five-year Plan, the BEE has been strengthened as a nodal organization at the national level and has been empowered to provide direction to the energy conservation programmes in the states. An "Energy Conservation Information Centre" has been set up within BEE to collate energy use data and analyse energy consumption trends and monitor energy conservation achievements in the country. Supporting organizational set-up has been strengthened as the state designated agencies (SDAs) in various states and union territories. In the Eleventh Five-year Plan, BEE has been focusing on energy conservation programmes in various targeted sectors. Some such measures include developing 15 industry-specific energy efficiency manuals/guides, follow-up activities to be taken up by the state SDAs, and dissemination of the manuals to all the concerned units in the industries. BEE has prepared building-specific energy efficiency manuals covering specific energy consumption norms, energy-efficient technologies, and best practices. BEE has also been planned to assist SDAs in the establishment and promulgation of Energy Conservation Building Codes (ECBC) in the states, and facilitate SDAs to adapt ECBC. In alignment with the priorities of the National Action Plan on Climate Change (NAPCC), BEE is considering making ECBC mandatory by 2012. At present, the Indian Green Building Council (IGBC) reports a total of 857 million sq.ft. of LEED green buildings including airports, hospitals and factories. In addition, a rating system: 'Green Rating for Integrated Habitat Assessment (GRIHA)' has also been developed by TERI. BEE will enhance its ongoing energy labelling programme to include 10 other appliances, namely, air conditioners, ceiling fans, agricultural pump-sets, electric motors (general purpose), compact fluorescent lamps, fluorescent tube light (FTL)–61 cm, television sets, microwave ovens, set-top boxes, DVD players, and desktop monitors. To facilitate all the activities, generating consumer awareness has been taken up on a war-footing nationwide. It is planned that during the Eleventh Plan period, in order to promote energy efficiency in municipal areas, SDAs in association with state utilities will initiate pilot energy conservation projects in selected municipal water pumping systems and street lighting to provide basis for designing state-level programmes. In the Eleventh Plan, SDAs will also disseminate information on successful projects implemented in some states, launch awareness campaigns in all regional languages in print and electronic media, and initiate development of state-level programmes along with utilities.

It has been targeted that 5% of the anticipated energy consumption level in the beginning of the Eleventh Plan is to be saved by the end of the Eleventh Plan. Financial provision for the same has been made in the outlay of the power sector.

Transport

A major initiative has been the upgradation of vehicular emission norms. A norm called the "Bharat 2000", similar to Euro-I norms, was implemented throughout the country on 1st April 2000 for all categories of vehicles manufactured in India. Emission standards (Bharat Stage II) for motor cars and passenger vehicles came into force in the National Capital Region (NCR) on 1st April 2000 and has been extended to Mumbai, Chennai, and Kolkata. Apart from reducing pollution locally, these norms result in increased energy efficiency and, therefore, reduced GHG emissions. A drive for awareness and training of drivers has been undertaken, and the commercial manufacture of battery operated vehicles has begun in India. This will promote low/no carbon emitting vehicles. In Delhi, large-scale switch has taken place from petrol and diesel to CNG, with over 50,000 vehicles having already been converted.

To control vehicular pollution, mass emission standards for various categories of motor vehicles have been progressively tightened. Bharat Stage III emission norms were effective in 11 mega cities, namely, National Capital Region, Mumbai, Kolkata, Chennai, Bengaluru, Ahmedabad, Hyderabad/Secunderabad, Kanpur, Pune, Surat, and Agra, whereas Bharat Stage II emission norms were applicable in the rest of the country. Bharat Stage IV emission norms have been effective from 1st April 2010 in the 11 mega cities, and Bharat Stage III emission norms have been effective for the rest of the country from the same date, as notified on 9th February 2009.

Bharat Stage (BS) IV emission norms have been effective from 01.04.2010 in 13 identified cities (Delhi/NCR, Mumbai, Kolkata, Chennai, Bengaluruangalore, Hyderabad (including Secunderabad), Ahmedabad, Pune, Surat, Kanpur, Agra, Solapur and Lucknow) and BS-III in the rest of the country effective from 01.04.2010. Supply of BS-IV Petrol and Diesel commenced from 1st April, 2010 in all the 13 identified cities as per the roadmap laid down Auto Fuel Policy. BS-III fuels were introduced in the country in a phased manner with the latest phase being completed in September, 2010.

In line with the policy of finding alternates to oil for the transport sector, the Ministry of Petroleum and Natural Gas (MoPNG) has set up a Hydrogen Corpus Fund with a corpus of Rs100 crore, with contribution from five major oil companies and Oil Industry Development Board (OIDB), for supporting R&D in various aspects of hydrogen, which could substitute part of natural gas as transport fuel in future. R&D Centre of Indian Oil Corporation Ltd is initiating steps in this direction.

To encourage the production of bio-diesel in the country, the MoPNG has announced a bio-diesel Purchase Policy in October 2005, which became effective from 1st January 2006. Under this scheme, oil marketing companies (OMC) will purchase bio-diesel for blending with HSD to the extent of 5% at identified purchase centres across the country. The policy has identified 20 purchase centres of the OMCs all over the country. The bio-diesel industry is still at nascent stage of growth, and efforts are being made to make the bio-diesel industry a sustainable feature of the economy.

MoPNG, vide its notification dated 20th September 2006, has directed the OMCs to sell 5% ethanol-blended petrol (EBP), subject to commercial viability as per the Bureau of Indian Standards specifications in the entire country except north-eastern States, Jammu and Kashmir, Andaman and Nicobar Islands, and Lakshwadeep with effect from 1st November 2006. Efforts are being made to ensure availability of ethanol on consistent basis for the EBP Programme and the OMCs are in discussion with the sugar industry to firm up the status of availability at various locations.

Maritime Transport: Given India's long coastline and the ever-increasing strain on the road/rail transportation system, coastal shipping offers a viable alternative that could complement the rail and road transport network in India. Moreover, this mode offers several benefits over rail and road across selected routes/distances. Coastal shipping is an environment-friendly and fuel efficient alternative to road and rail transport. It complements rail and road transport by providing a multi-modal integrated transport facility and substantially supports the reduction of emissions.

Industry

The industry sector has made significant advances in the conservation of energy. Government policies, campaigns by associations of industry, and strategic decisions by firms have all contributed to sizeable improvements in the intensity of energy use in industries. The major energy-consuming sectors are steel, cement, caustic soda, brick,

Indian Industry has played a crucial role in identifying and undertaking numerous climate- friendly transitions

aluminium, and electric power generation. Measures to improve energy efficiency include promotion of fuel-efficient practices and equipment, replacement of old and inefficient boilers and other oil-operated equipment, fuel switching, and technology upgradation.

High energy consuming industries like the Cement industry have adopted high end technologies and improved plants and equipment for the conservation of energy, reducing carbon dioxide emission and reduction of production cost. There has been a continuous reduction in the Specific Energy Consumption (SEC) in this industry. While in 1994-95 SEC in this industry was about 110 kWh/tonne of cement, it came down to 79 kWh /tonne of cement in 2008-09. Likewise, specific thermal energy consumption dropped from 800 Kcal/kg of clinker production to 726 Kcal/kg of clinker production in 2008-09. Some of the Indian plants are operating with the world's best specific energy consumption values.

Most of the refineries in the Public Sector Undertakings have adopted high-end technologies and environmental initiatives to minimize the impact of refinery operations with regard to effluent generation and solid waste generation. In addition, they have also installed and commissioned Hydro Cracker Units to treat high Sulphur content crude petroleum to produce Euro-III Grade Auto Fuel Product (High Speed Diesel) and have installed/ revamped catalytic reformer units for the production of Euro-III/IV Grade Motor Spirit. These high-grade fuels produce minimal emission and reduce GHG substantially besides reducing fuel consumption, thereby saving on natural resources and foreign exchange.

Bharat Heavy Electricals Ltd. endeavours and tries to keep itself in step with national policies and plans with respect to capacity addition, also addressing the environmental concerns. As a part of 'National Mission for clean coal (Carbon) technologies' the company would play a significant role in the development of Advanced ultra Supercritical (ADV-SC) technology in association with the Indira Gandhi Centre for Atomic Research (IGCAR) and NTPC.

The Ministry of Steel through various schemes and regulations of the Government is facilitating reduction in energy consumption and emission of environmental pollution in steel plants. Some of the steps/initiatives taken by the Ministry of Steel through various forums and mechanisms are:

Charter on Corporate Responsibility for Environment Protection (CREP) – The MoEF/CPCB in association with MoS and the main/major steel plants are committed to reduce energy consumption along with management of other aspects of the environment as per mutually agreed targets with the purpose to go beyond the compliance of regulatory norms. In particular, measures for reduction of energy consumption in respect of the following areas: injection of coal/tar in blast furnaces; and water consumption (in respect of which the primary target was achieved by most integrated plants) were targeted.

Under the CDM, the MoS is facilitating (through the National CDM Authority in the MoEF) adoption of **energy efficient clean technologies** in Iron and Steel plants. A large number of Iron and Steel plants have obtained host country approvals for availing carbon credit by adopting energy efficient clean technologies. There is also a scheme to facilitate diffusion of energy efficient low carbon technologies in steel re-rolling mills in the country to bring down energy consumption, improve productivity, and cost competitiveness; together with a reduction in GHG emission and related pollution levels.

MoS has been facilitating setting up of energy efficient, environment friendly projects known as Model Projects in different steel plants with financial assistance from Japan. These projects are implemented by New Energy and Industrial Technology Development Organisation (NEDO), Japan.

As a part of the National Mission for Enhanced Energy Efficiency (NMEEE), steel producing units consuming 30,000 mtoe or more will be designated consumers, in respect of whom a benchmark will be applicable. Steel manufacturing units operating at a level better than the benchmark will be eligible to obtain an Energy Saving Certificate (ESC) that can be traded in the market. Units will be given a lead-time to improve their energy consumption levels. Any designated consumer operating at a level inferior to the benchmark have to either pay penalty or purchase ESCs. BEE has been entrusted with this task of recommending benchmark levels to Ministry of Power. BEE is working closely with MoS for evolving the benchmarks in energy consumption in various technological routes of steel making using a wide variety of raw materials.

The Indian Steel industry has taken significant steps in improvement of productivity, conservation of natural resources and energy, import substitution, quality up gradation, environment management and research and development. Some notable developments are:

- **Installation of energy recovery coke ovens to meet power requirements as well as to reduce emissions:** energy recovery type coke ovens have been set up by many steel companies
- **Use of hot metal in electric arc furnaces:** setting up of basic oxygen furnaces is a capital intensive process and is successful only at a large scale. However, with the advent of modern electric arc furnaces, steel could be produced in electric arc furnace by use of hot metal that substantially replaces steel scrap and results in huge savings in electricity consumption
- **Adoption of continuous casting:** the first solidified form of steel in the melting shops used to be ingots. With the advent of continuous casting in the late 1970s, continuous cast blooms/billets/slabs resulted in significant energy savings as well as improved productivity. Adoption of thin slab casting has further resulted in additional energy savings in the hot strip mills
- **Reducing coke consumption in blast furnaces and improving productivity:** Indian Blast Furnaces used to consume as high as 850 kg of coke per tonne of hot metal and Blast Furnace productivity was hovering at less than one tonne per cubic meter per day. Introduction of modern technologies and practices, such as high top pressure, high blast temperature, pulverized coal injection, attention to burden preparation and distribution, higher use of sinter in place of lumps have resulted in reduced coke consumption and improved productivity. Today coke rate in some of the blast furnaces is less than 500 kg/tonne hot metal and productivity exceeds 2 tonne per cubic metre per day.
- **Efforts to reduce energy consumption and emissions:** Iron and Steel making is an energy intensive process. The international norm of energy consumption is 4.5 -5.5 Giga calories per tonne of crude steel. With the adoption of modern technology and equipment, beneficiation of raw materials and use of high grade imported coal, Indian Steel plants have been able to achieve energy consumption at the level of 6.5-7.0 Giga calories only. Further, steps are being taken to achieve much lower energy consumption and correspondingly lower GHG emissions by the end of the 11th plan.

Power sector

India has a diverse mix of power generation technologies with coal domination, and a significant contribution by large hydro. Among the many initiatives in the power sector, reforms and targeted technology improvements have helped to enhance the combustion efficiency of conventional coal technology, leading to the conservation of coal and savings in emissions. The reforms initiated include regulatory restructuring, corporatization, and privatization and unbundling of state-owned utilities. Corporatization is altering state electricity boards from state ownership and administration to business-like corporations, as defined by the Indian Company Act (1956). The Indian Electricity Act of 1910 and the Electricity Act of 1948 have been amended to permit private participation in the generation and distribution of power. Privatization in transmission has been encouraged by the recognition of exclusive transmission companies. Since 2007, which coincides with the end of the Tenth Plan, as many as 14 states have restructured or corporatized their power sector and unbundled their boards into separate entities for transmission, distribution, and generation; setting up of SERCs has become mandatory, a total of 25 states have either constituted or notified the constitution of SERC and 21 SERCs have issued tariff orders; in compliance with Section 3 of the Electricity Act 2003, the central government notified the National Electricity Policy in 2005. Similarly, National Tariff Policy was also notified in 2006. Further, in compliance with Sections 4 and 5 of the Electricity Act (2003), the central government notified the Rural Electrification Policy on 28th August 2006.

The share of hydro capacity in the total generating capacity of the country has declined from 34% at the end of the Sixth Plan to 25% at the end of the Ninth Plan. It is envisaged that in spite of growth in power generation and planned hydropower capacity addition, share of hydropower capacity would be 23% by 2012. A 50,000 MW hydro initiative was launched in 2003 for accelerated development of hydro in the country and preliminary feasibility reports of 162 projects totalling 48,000 MW were prepared. Out of these projects, 77 projects with total capacity of about 37,000 MW, for which first-year tariff is expected to be less than Rs 2.50 per unit, were selected for execution. In the Eleventh Plan, a capacity addition of about 16,553 MW has been earmarked, keeping in view the present preparedness of these projects. Projects totalling a capacity of 30,000 MW have been identified for the Twelfth Plan and therefore the effect of 50,000 MW initiatives would be visible in the Twelfth Plan period.

Atomic energy is an important source of electric power, which has environmental advantages and is also likely to be economical in the longer run. At present, nuclear energy installed capacity is 3900 MWe, which is 3.1% of the total installed capacity. The plant load factor (PLF) the of Nuclear Power Corporation of India Ltd (NPCIL) stations increased from 60% in 1995/96 to 82% in 2000/01, but it has decreased to 57% in 2006/07. Constraint in nuclear fuel availability is the main reason for lower PLF.

The Eleventh Plan power programme includes 3380 MWe of nuclear power plants. The Government of India is making efforts to import nuclear fuel from abroad, which is expected to improve the supply of nuclear fuel for nuclear power plants. It is also expected that the execution of nuclear projects will also be opened up to enable participation by other public sector units (PSUs) and private sector. The effect of this is likely to be visible in the Twelfth Plan period (2012–17). NPCIL has indicated a capacity addition of about 11,000 MW during the Twelfth Plan.

Apart from the above, the Ministry of Power has initiated several measures to improve the efficiency of power generation, leading to reduced CO2 emissions from the power sector. These initiatives are as under:

Introduction of Clean Coal technologies – With rapidly expanding thermal generation capacity, installation of large size Supercritical units is being encouraged with a view to having faster capacity addition and also to enhance efficiency, reduce coal consumption and GHG emissions. With the adoption of higher parameters, efficiency gain of about 2% is possible over Sub-critical units, thereby reducing carbon emissions. During the 11th plan, it is proposed that few units of 660/800 MW based on Supercritical technology would be commissioned. However during the 12th plan, it is estimated that around 50% of the coal-based thermal capacity addition would be through Supercritical units. Also, it has already been decided that in the 13th plan, coal-based thermal capacity addition will be mostly through Supercritical units.

Table 4.8a : 11th plan targets for Grid interactive renewable power (in MW)

Sources/Systems	Target for 11th plan
Wind power	10,500
Biomass power, Baggasse co-generation, Biomass Gasifiers	2,100
Small hydro (upto 25 MW)	1,400
Total	14,000

Renovation and Modernization (R&M) of old thermal power stations – CEA has prepared a 'National Enhanced Efficiency Renovation and Modernization Programme' for implementation during the 11th and 12th plans. This covers R&M of 18965 MW capacity, life extension of 7318 MW during 11th plan and R&M of 4971 MW and life extension of 16532 MW during the 12th plan. Renovation and Modernization and Life Extension (LE) of existing old power stations provide opportunities to get additional generation at low costs in short gestation periods. Besides generation improvement, it results in improvement of efficiency, environmental emissions and improvement in availability, safety and reliability.

Retirement of old and small size generating units – A number of small size units of 100 MW or less capacity are in operation in the country. The average Plant Load Factor of most of these units is very low, even less than 50%. These units are of the non-reheat type having very low design efficiencies. Such units are planned to be to retired in a phased manner over a period of the next ten years.

Highest priority to setting up of Hydro and Nuclear power plants – Priority has been set for developing cleaner resources like hydropower and nuclear plants and other renewable energy resources by the Government of India.

Promotion of Renewable Energy sources – The country has significant potential for generation from renewable energy sources. All efforts are being taken by the Government of India to harness this potential. The installed capacity as on 31.05.2011 for renewable energy sources is 18454 MW. MNRE has proposed (Table 4.8a) 11th plan capacity addition targets for grid interactive renewable power from sources such as wind, biomass, small hydro.

National Action Plan on Climate Change (NAPCC) – This has been discussed in detail elsewhere in this chapter. Noteworthy within this section is that the National Mission on Enhanced Energy Efficiency (NMEEE) intends to enhance energy efficiency in the country, and is aimed at large energy-intensive industries and facilities by way of implementing Perform, Achieve and Trade Scheme (PAT). Under the PAT scheme, nine sectors – cement, thermal power plants, fertilizers, aluminium, iron and steel, chlor-alkali, pulp and paper, textiles and railways – will be given targets for reducing energy consumption. The companies that better their targets will be allowed to sell energy-saving credits ECERTs to those failing to achieve the required cuts. All thermal power stations are covered under the preview of PAT scheme. The reduction targets for each power plant will be in terms of specific percentage of their present deviation of the operating Net heat rate from the design Net heat rate leading to reduced coal consumption and reduced CO2 emissions. The total target for the thermal power sector has been fixed at 3.1 million tonnes of oil equivalent to be achieved in a period of 3 years after notification. Bureau of Energy Efficiency is in the process of notifying the PAT scheme.

Alternate fuels

After stabilization of 5% ethanol blending petrol sales, the content of ethanol in petrol is considered for increasing up to 10% by the middle of the Eleventh Plan, subject to ethanol availability and commercial viability of blending. Depending upon the bio-diesel production and availability, the entire country may be progressively covered with the sale of 5% bio-diesel blended diesel by the end of the Eleventh Plan.

In India, shale formation is exposed to the surface in the region of Belt of Schuppen falling in Assam, Arunachal Pradesh, and Nagaland. The oil shale reserves are estimated at about 100 billion barrels. However, the production of shale oil requires large amount of energy and water. Environment and monetary costs have so far made production of oil from oil shale uneconomical. Shale gas is being explored as an important new source of energy in the country. The Directorate General of Hydrocarbons (DGH) has initiated steps to identify prospective areas for shale gas exploration and acquisition of additional geo-scientific data. Efforts in the direction to make the utilization of shale gas a viable option are being undertaken at a fast pace.

Alternate fuels occupies a significant policy space in India's future energy sector agenda

Gas hydrate is at R&D stage world over. A cooperation programme between DGH and US Geological Survey (USGS), USA, for exchange of scientific knowledge and technical personnel in the field of gas hydrate and research energy is in progress.

Rural energy

A majority of India's people, especially in rural areas, use traditional fuels such as dung, agricultural wastes, and firewood for cooking food. These fuels cause indoor pollution. Other primary source of cooking energy used by urban and rural household covers coke and charcoal, biogas, electricity, and other fuels. The situation in rural areas calls for the provision of sustainable and clean energy supplies. In this context, the role of renewable energy sources such as biogas, improved cook stoves, solar energy, and biomass-based systems to meet the basic needs of cooking, lighting, and water heating is important. The total quantities of traditional fuels used to meet the basic energy needs are substantial. The biomass-based fuels dominate particularly in rural areas.

Rajiv Gandhi Gramin LPG Vitaran Yojana (RGGLVY) is a programme adopted under the "Vision-2015" for the liquefied petroleum gas (LPG) sector, inter-alia, focuses on raising the population coverage of LPG in rural areas and areas where coverage is low. The RGGLVY for small-size LPG distribution agencies was launched on 16th October 2009. This scheme targets coverage of 75% of the population by 2015 by releasing 5.5 crore new LPG connections.

Pipeline network and city gas distribution network

There has been a substantial increase in the pipeline network in the country with current figures of 31 product pipelines of 10,959 km length. . The total crude pipeline length at present is 6559 km and LPG pipelines are 1824 km. With increased availability of gas in the country, the city gas distribution network has been expanded to cover CNG in 19 cities for domestic consumers, public transport, and commercial/industrial entities. In 'Vision-2015', provision of pressurized natural gas (PNG) to more than 200 cities across the country is envisaged.

Urban transport

Urban transport is one of the key elements of urban infrastructure. As compared to private modes of transport, public transport is energy efficient and less polluting. The public transport system also helps improve urban–rural linkage and improves access of the rural/semi-urban population in the periphery to city centres for the purpose of labour supply without proliferation of slums within and around cities.

In this background, the major objective of urban transport initiatives is to provide efficient and affordable public transport. A National Urban Transport Policy (NUTP) was formulated in 2006, with the objectives of ensuring easily accessible, safe, affordable, quick, comfortable, reliable, and sustainable mobility for all. In order to provide better transport, proposals for bus rapid transit system (BRTS) were approved for Ahmedabad, Bhopal, Indore, Jaipur, Pune, Rajkot, Surat, Vijayawada, and Vishakhapatnam cities under the JNNURM. During 2009/10, one more proposal for a BRTS in Kolkata has been approved under the JNNURM, taking the number of cities supported for BRTS to 10, covering a total length of 452.20 km.

The Government of India had approved the implementation of the Bangalore Metro Rail Project of 42.3 km length by Bangalore Metro Rail Corporation Ltd (BMRCL). The Government of India had approved the implementation of the east-west metro corridor of 14.67 km length in Kolkata by Kolkata Metro Rail Corporation Ltd (KMRCL). The Government of India has also approved the implementation of the Chennai Metro Rail Project of 46.5 km length by Chennai Metro Rail Ltd (CMRL). In addition, metro rail projects have been taken up on PPP basis in Mumbai for Versova–Andheri–Ghatkopar (11.07 km), Charkop to Mankhurd via Bandra (31.87 km) and in Hyderabad called Hyderabad Metro (71.16 km) with viability gap funding (VGF) support from the Government of India. In order to give proper legal cover to metro projects, the Metro Railways Amendment Act (2009) was brought into effect in September 2009, providing an umbrella "statutory" safety cover for metro rail work in all the metro cities of India. The Act was extended to the National Capital Region, Bengaluru, Mumbai, and Chennai metropolitan areas with effect from 16th October 2009.

Delhi Metro- A significant transition in Urban transportation

Forestry

Recognizing the role of forests as a carbon sink, India is promoting afforestation on an enormous scale. India, which has a fifth of its area under forests, is one of the few developing countries in the world where the forest cover is increasing, by 0.8 million hectares a year, despite the pressures of population growth and rapid economic development. This is neutralizing 11% of India's annual GHG emissions. India has more than doubled its budget for forestry in the year 2009/10 to Rs 8300 crore, and this increase is going to be sustained every year. New programmes to increase the capacity of frontline forestry personnel, improve forestry infrastructure, and control forest fires are also being implemented.

The 13th Finance Commission has recommended an additional Rs. 50 billion for the period 2010-2015 for the forestry sector. This resource is for sustainable management of forest resources and intensified conservation efforts by the States. The working plans of the various forestry divisions suggest that broadly a sustainable management regime is followed, which includes a scientific package of practices.

Infrastructure development and public private partnerships

Given the enormity of the investment requirements and limited availability of public resources for investment in physical infrastructure, it is imperative to explore avenues for increasing investment in infrastructure through a combination of public investment, PPPs, and, occasionally, exclusive private investment, wherever feasible. With the objective of stimulating and mobilizing increased private-sector investments, either from domestic sources or foreign avenues, the government has offered various incentives for the infrastructure sector for sustained economic growth. These include: allowing 100% foreign direct investment (FDI) (under the automatic route) in all infrastructure sectors, including the roads, power, ports, and airport sectors; 74% in telecom services and 100% in telephone equipment; 49–100% for various services in the aviation sector; extended tax holiday periods up to 10-year tax holidays (under section 80-IA of the Income Tax Act 1961) to enterprises engaged in the business of development, operation, and maintenance of infrastructure facilities; and emphasis on PPP as one of the preferred modes for project implementation.

The Government of India is actively encouraging PPPs through several initiatives. The appraisal mechanism for PPP projects has been streamlined to ensure speed, eliminate delays, adopt international best practices, and have uniformity in appraisal mechanism and guidelines. PPP projects that are economically essential but commercially unviable are provided financial assistance in the form of VGF and long tenor loans through the India Infrastructure Finance Company (IIFC) Ltd. In order to ensure quality project development activities by the states and central ministries, the India Infrastructure Project Development Fund (IIPDF) supports up to 75% of the project development expenses in the form of interest-free loans.

Many state governments have institutionalized measures to encourage private sector engagement in the creation of infrastructure and delivery of services. Infrastructure Development and Enabling Acts have been developed by Andhra Pradesh, Bihar, Gujarat, and Punjab. PPP policies and guidelines to facilitate PPP projects have been notified by Karnataka, Haryana, Orissa, Assam, Goa, Madhya Pradesh, and West Bengal. Other measures include developing sectoral policies for promoting PPPs, establishing nodal departments/ PPP cells, establishing VGF (to supplement the VGF provided by the central government), establishing project development fund (supplement Government of India grant under IIPDF), establishing panels of transaction advisers, and developing standardized bid documents, sectoral templates, and handbooks on PPPs.

Technology Transfer

For developing and emerging countries like India, economic development is a must in order to tackle the issues of poverty and achieving the MDGs. The UNFCCC, which supports the principle of common but differentiated responsibility, affords greater responsibility to the developed countries in addressing climate change issue. India's take on climate change, therefore, is that of avoidance as against reduction. However, in order to contain the disastrous effects of global warming, the developing countries will need to embrace climate-effective technologies. Technology transfer has, therefore, been awarded key significance in climate change negotiations.

Two mechanisms directly or indirectly contribute to technology transfer: the UNFCCC-related mechanisms where technology transfer is an explicit objective, such as projects supported by the Global Environment Facility (GEF), and those where technology transfer is a co-benefit, such as projects funded under the CDM.

Technology transfer under the Global Environment Facility mechanism

The GEF is an operating entity of the financial mechanism of the UNFCCC. It has become the largest public sector funding source to support the transfer of environmentally sound technologies to developing countries. The climate change focal area strategy programming has evolved over the years through the different replenishment cycles.

GEF portfolio in India: Under the replenishment cycles, the GEF portfolio for India is broadly spanned over five focal areas, including climate change (mitigation and adaptation), biodiversity, land degradation, and persistent organic pollutants (POPs).

The study of projects supported by the climate change focal area of the GEF reveals that many projects do contribute towards technology transfer, although the overall contribution from the portfolio is quite limited. There appears to be a rising trend of technology transfer in India, along with the various spillovers in the related industries. It is, however, found that the share of projects supported by the GEF has a major component in which there is no technology transfer. This trend is more or less consistent across all GEF replenishment cycles. However, in the latest cycles, there is some improvement in the overall share of projects involving technology transfer, but this is substantially inadequate. The same trend is visible in value terms also. The total funds contributing only to the technology transfer activities (the total project outlay from GEF to technology transfer projects) have shown an increasing trend, but the actual amount contributing to technology transfer activities is much smaller. While it could be useful to see the exact and direct contribution of the GEF mechanisms to technology transfer activities in India's portfolio, unfortunately this detailed information was not available for all the projects. But this would constitute important information to be revealed on the technology transfer aspect. For the projects for which some information is available, the percentage contribution of funds allocated directly, contributing to technology transfer, ranges from 6% to 88% for the various projects under the portfolio. The trend in the technology transfer for the GEF portfolio shows that of the projects that led to technology transfer, 50% of the projects resulted in indigenization of the technology and research, while 33% of the projects have led to technology transfer and capacity building in terms of training while only 17% amount to only equipment transfer under the portfolio.

Technology transfer associated with Clean Development Mechanism projects

Under the Kyoto protocol, the CDM projects have made some limited contributions to technology transfer. The analysis shows that the trend for technology transfer has been rising in the past few years and that technology transfer through various modes such as equipment and machineries and training has resulted in capacity building and in-house manufacturing and expansion as well, but the progress has been slow.

The central feature of the Kyoto Protocol is its requirement that countries limit or reduce their GHG emissions. To help countries meet their emission targets, and to encourage the private sector and developing countries to contribute to emission reduction efforts, the Protocol provides for three market-based flexibility mechanisms, one of which is the CDM.

Despite any explicit technology transfer mandate, several CDM projects have been found to contribute to technology transfer by financing emission reduction projects using technologies not available in the host countries. Still comparative assessment reveals that the component of technology transfer is inadequate and comparatively small. There is wide disparity across various project types and the analysis revealed that only in the solar and wind sector there was some degree of technology transfer involved followed by oil, gas, and the power sector. Some shift was observed in the waste management and waste-to-energy projects, but the component has been very less.

The detailed analysis of the technology transfer as a process has revealed that the transfer of technology has been showing a rising trend. With the inception of GEF and CDM, technology transfer has become a vital and recognized activity in India and has led to capacity building within the country, but the pace and progress are somewhat slow and need immediate and consistent ramp-up.

In conclusion, it is imperative to state that as far as the GEF portfolio is concerned, many completed projects exhibit that the technology transfer and capacity building have taken place across the nation, in various sectors. A fair amount of low-carbon technologies and know-how has been transferred and purchased, most involving cross-boundary acquisitions, but it is not adequate. Under the CDM portfolio, a few sectors have upgraded the technology strengths through technology transfer but a few sectors like the renewable sector of biomass, bagasse, and hydropower register neither upgradation of technology nor any technology transfer. Sectors like the tidal and wave energy are the unexplored areas till date under the portfolio. Amongst the total portfolio, the oil and gas, waste-to-energy, and industrial energy sectors show significant technology transfer unlike the other sectors where there is no or less technology transfer involved for projects.

Apart from the efforts undertaken through the mechanisms enabled by the UNFCCC and other multi and bilateral organizations, several steps are also being taken at the national level. The NAPCC is the first nation-wide overarching framework that maps the roadway to low-carbon and climate-resilient future, with significant focus on technology being a major driver.

Indigenization of technology is a must for ensuring, low-carbon technology penetration, owing to high costs of the technology. As climate change and its mitigation are seen as a collective responsibility of all countries in the world, diffusion of technology and capacity building should be the major focus as well, both at multilateral and national levels. The development of domestic technological capability is crucial because an endogenous technological change may lead to substantial reduction in carbon prices as well as GDP cost, and it is in this context that significant action on the technology transfer component should be addressed through various agreed mechanisms.

Apart from this, capacity building in terms of institutional infrastructure, development of skilled professionals, and better incentive structures for adoption of low carbon technologies will create a more favourable technology transfer environment, which can be achieved through structured and dedicated R&D expense allocations.

Re-emphasizing the importance of technology transfer to India so as to meet climate change related challenges, it is imperative to ramp up the mechanisms of technology transfer in terms of value as well as the portfolio significantly. This would not only help in mitigating significant carbon from the atmosphere but also help India in meeting its development goals.

References and Sources

CEA, 2008. *Hydro Development Plan for 12th Five Year Period (2012–2017).* Hydro Planning and Investigation Division, September 2008, Government of India

Indian Network for Climate Change Assessment (INCCA). November 2010. *Climate Change and India: A 4 × 4 Assessment. A sectoral and regional analysis for 2030s.,* Government of India

CMIE (Centre for Monitoring Indian Economy), 2010. *Energy and Agriculture.* CMIE

IEA (International Energy Agency), 2009. *IEA Scoreboard 2009.* IEA, Paris

Planning Commission, 2006. *Integrated Energy Policy (IEP) (2006).* Planning Commission, Government of India, New Delhi

IPCC (Intergovernmental Panel on Climate Change), 2007. *Summary for Policymakers.* In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. (Eds). Cambridge University Press, Cambridge, UK, pp. 7–22

MNRE (Ministry of New and Renewable Energy), 2010. *Annual Report* 2009–10. MNRE, Government of India

MoEF (Ministry of Environment and Forests), 2007. *India: Addressing Energy Security and Climate Challenge.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2009a. *The Guidelines on State Compensatory Afforestation Fund Management and Planning Authority (State CAMPA).* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2009b. *India's Forest and Tree Cover: Contribution as a Carbon Sink.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2009c. *India and Climate Change.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2009d. *State of Environment Report India 2009.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2009e. *India: Taking on Climate Change Twenty Recent Initiatives Related to Climate Change.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010a. *India: Greenhouse Gas Emissions 2007.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010b. *India: Taking on Climate Change Twenty Four Recent Initiatives related to Climate Change.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010c. *National Mission for a Green India (Under the National Action Plan on Climate Change).* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010d. *India: Taking on Climate Change Post-Copenhagen Domestic Actions.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010e. *Reforms in Environmental Governance with Special Reference to Establishment of National Environment Assessment and Monitoring Authroity (NEAMA).* Discussion Paper, MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010f. *The Wetlands (Conservation and Management) Rules, 2010.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2011. *Coastal Regulation Zone Notification.* MoEF, Government of India

MoEF (Ministry of Environment and Forests), 2010g. Presentations made at the National Consultation Workshop on State Action Plans on Climate Change, Government of India

MoPNG (Ministry of Petroleum and Natural Gas), 2011. *Annual Report* 2009–10. MoPNG, Government of India, New Delhi

MoRTH (Ministry of Road Transport and Highways), 2009. *Annual Report* 2008–2009. MoRTH. Government of India, New Delhi

MoS (Ministry of Steel), 2011. Annual Report 2010-11. Government of India, New Delhi

NAPCC, 2008. National Action Plan on Climate Change. Government of India

NTPC (National Thermal Power Corporation India Ltd), 2010. *Annual Report* 2009–10. NTPC

Planning Commission, 2007. *Eleventh Five Year Plan 2007-2012.* Vol I–III. Planning Commission, Government of India. Oxford University Press, New Delhi

UNDP (United Nations Development Programme), 2003. *Human Development Report: 2003.* UNDP, Oxford University Press, New York

UNDP (United Nations Development Programme), 2007. *Human Development Report: 2007.* UNDP, Oxford University Press, New York

WCED (World Commission on Environment and Development), 1987. *Report of the World Commission on Environment and Development: Our Common Future.* UN Documents-Gathering a Body of Global Agreements. Retrieved from http://www.un-documents.net/wced-ocf.htm

Chapter 5 Research and Systematic Observation




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. Many countries, both the developed and developing ones, are spending a considerable amount of their resources on climate research that will help both - government 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 ends with a description 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 as well as 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-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.

Contents

Chapter 5 Research and Systematic Observation

CHAPTER 5 Research and Systematic Observation

Institutional Arrangement

The Government of India attaches high priority to the promotion of R&D in multi-disciplinary aspects of environmental protection, conservation and development including research in climate change. Several central government ministries/departments promote, undertake and coordinate climate and climate-related research activities and programmes in India. This is done through various departments, research laboratories, universities and autonomous institutions of excellence such as the Indian Institutes of Management (IIMs), Indian Institutes of Technology (IITs) and the Indian Institute of Science (IISc) with non-governmental and private organizations providing synergy and complementary support. The Ministry of Science and Technology (MoST), Ministry of Environment and Forests (MoEF), Earth System Science Organisation (ESSO)/Ministry of Earth Sciences (MoES), Ministry of Agriculture (MoA), Ministry of Water Resources (MoWR), Ministry of Human Resource Development (MHRD), Ministry of New and Renewable Energy (MNRE), Ministry of Defence (MoD), Ministry of Health and Family welfare (MoHFW), and Department of Space (DoS) are the key ministries/departments of the Government of India which promote and undertake climate and climate change-related research and systematic observations in the country.

The Indian Space Research Organisation (ISRO)/ Department of Space (DOS) has been pursuing studies on climate and environment and has developed considerable understanding about the processes governing the phenomena. The Centres of ISRO/ DOS, viz. National Atmospheric Research Laboratory (NARL), Space Physics Laboratory (SPL), Physical Research Laboratory (PRL), Space Applications Centre (SAC), and ISRO Satellite Centre (ISAC), with their inherent scientific and technical strengths, are engaged in various research studies, activities related to the Earth's climate system, and in designing sensors and satellites, and ground-based observation systems for studying the climate and environmental parameters.

With a view to understanding the scientific aspects of climate, ISRO, through its ISRO Geosphere-Biosphere Programme (ISRO-GBP), with multi-institutional participation, has been pursuing studies on climate over the past two decades. The studies have addressed atmospheric aerosols, trace gases, GHGs, paleo-climate, land cover change, atmospheric boundary layer dynamics, energy and mass exchange in the vegetative systems, National Carbon Project (NCP) and Regional Climate Modelling (RCM). ISRO has also carried out extensive campaigns integrating satellite, aircraft, balloon and ground-based measurements, jointly with many sister institutions in the country.

The satellite remote sensing data have been put into use over a wide spectrum of themes, which include land use/ land cover, agriculture, water resources, surface water and ground water, coastal and ocean resources monitoring, environment, ecology and forest mapping, and infrastructure development.

The MoST, MoEF, ESSO/MoES, MNRE, MoWR, MHRD and MoA operate an umbrella of coordinated premier national research laboratories and universities. The Council for Scientific and Industrial Research (CSIR) is the national R&D organization under the MoST, which conducts scientific and industrial research for India's economic growth and human welfare. It has a vast countrywide research network, comprising laboratories and field centres. In addition to these dedicated atmospheric research institutes, the MoST funds a parallel research network under the aegis of CSIR which has several research institutions for various scientific disciplines dedicated to applied scientific and industrial research. Atmospheric, environmental and oceanic research is one of its areas of focus and has been taken up by institutions like the National Physical Laboratory (NPL), the National Environmental Engineering Research Institute (NEERI), the Centre for Mathematical Modelling and Computer Simulations (CMMACS), the National Institute of Oceanography (NIO), and the National Geophysical

India has significantly enhanced its 'Satellite Monitoring' capabilities

Research Institute (NGRI). CMMACS has been actively involved in multi-scale simulation and quantification of sustainability and vulnerability under climate variability, climate stress and other natural hazards.

The Ministry of Environment and Forests (MoEF) undertakes coordination of integrated environmental, ecological and forestry research vis-à-vis climate change. In recognition of the need for more accurate, reliable and comprehensive understanding of the implications of climate change, MoEF launched the Indian Network for Climate Change Assessment (INCCA) in 2009. It has been conceptualized as a Network-based Scientific Programme designed to:

- Assess the drivers and implications of climate change through scientific research,
- Assess climate change through GHG estimations and impacts of climate change, associated vulnerabilities and adaptation,
- Develop decision support systems and
- Build national capacity towards management of climate change-related risks and opportunities.

Under the aegis of the Indian Council for Forestry Research and Education (ICFRE), the ministry supports several research institutions dedicated to environmental, forestry and ecological research. The ICFRE is actively engaged in advanced research with focused objectives of the ecological and socio-economic human needs of the present and future generations. ICFRE has established a Biodiversity and Climate Change (BCC) division to address national climate change and biodiversity issues related to forestry, and consolidate biodiversity information for unique ecosystems within the country. Research on absorption of GHGs (carbon sinks and reservoirs) and mitigation of global warming through increasing forest reserve are among the focused agenda of ICFRE.

The mandate of the Earth System Science Organisation (ESSO)/Ministry of Earth Sciences (MoES) is to emerge as a knowledge and information technology enterprise for the Earth System Science (atmosphere, hydrosphere, cryosphere and geosphere) for the Indian sub-continent and its ocean. The ESSO/MoES has established several climate research and systematic observatories, such as India Meteorological Department (IMD), Indian National Centre for Ocean Information Services (INCOIS) Hyderabad, Indian Institute of Tropical Meteorology (IITM) Pune, National Institute of Ocean Technology (NIOT) Chennai, National Centre of Antarctic and Ocean Research (NCAOR) Goa, Centre for Climate Change Research (CCCR) Pune, Earthquake Risk Evaluation Centre (EREC) New Delhi and National Centre for Medium Range Weather Forecasting (NCMRWF) Noida.

The IMD possesses a vast weather observational network and is involved in regular data collection activity, data bank management, research and weather forecasting for national needs. The NCMRWF conducts atmospheric and climatic research with particular emphasis on developing indigenous, customized Global Circulation Models (GCMs) and Regional Circulation Models (RCMs) for the Indian subcontinent and medium-range weather forecasting that will help socio-economic sectors such as agriculture and tourism, which are directly affected by climate variability, in formulating their short-term policies. IMD is also engaged in agriculture meteorological advisory services to farmers through in-house modelling and forecast (on a daily basis) for different Indian crop systems. It runs an agro-advisory services network with Indian Council for Agricultural Research (ICAR), which provides daily weather forecasts to farmers. The IITM is involved in various kinds of advanced climate and weather research; including climatology, hydrometeorology, physical meteorology and aerology, boundary layer, land surface processes, atmospheric electricity, climate-simulations, climate and global modelling/simulations. Research in advanced instrumentation and observational techniques is being carried out at the IITM along with other theoretical studies. INCOIS provides ocean data, information and advisory services to society, industry, the government and scientific community through sustained ocean observations and constant improvements through systematic and focused research, data and information management and ocean modelling to render ocean state forecasting services.

MNRE supports Research, Design, Development and Demonstration (RDD&D) activities to develop new and existing renewable energy technologies, processes, materials, components, sub-systems, products and services. It also conducts standards and resource assessment so as to indigenously manufacture renewable energy products and systems.

The MoWR coordinates surface and groundwater-related data generation, management and dissemination, technology implementation and all other related research activities through its organizations such as the Central Water Commission (CWC), the Central Ground Water Board (CGWB), the National Water Development Agency (NWDA), the National Institute of Hydrology (NIH), the Central Water and Power Research Station, the Central Soil and Materials Research Station, and various river boards. The ministry, through its National Commission on Integrated Water Resources Development (NCIWRD) and other collaborative research activities, is conducting water resource assessment, including evaluation of impacts of climate change on Indian water resources.

MHRD, through academic institutions like universities and IITs, facilitates several research programmes on weather, climate, atmosphere, environment, ecology, agriculture, forestry and related issues. These institutions are involved in climate research by developing appropriate infrastructure, participating in atmospheric observations, and modelling efforts on climate simulations using various internationally recognized GCMs/RCMs. The universities and IITs are generally engaged in project-mode, objective-oriented research-programmes.

The Department of Agricultural Research and Education (DARE) within MoA has a vast network of 97 ICAR institutes, 46 state agricultural universities, five deemed universities, one Central Agricultural University and 589 Krishi Vigyan Kendras (KVKs) spread across the country. The ICAR, as the premier institution for agricultural R&D, is working on different aspects of agriculture sustainability, including field research and modelling for Indian crop systems under projected climate change.

The MoHFW, through the Malaria Research Centre, has initiated climate change-related research due to the threat of the spread of anthropogenic health and vector-borne diseases, and has initiated sustained efforts for mitigating the harmful effects of these diseases. The Centre works in collaboration with various institutions that are actively involved in mainstream climate change research.

The Ministry of Defence conducts atmospheric and oceanic services with particular focus on defence interests. In addition, it also funds other agencies for advanced research on weather, climate, environment and oceans so as to meet operational needs.

Other than the government ministries, several autonomous institutions and NGOs are engaged in climate change-related research. IIM Ahmedabad and IIT Delhi are front-runners. NGOs like The Energy and Resources Institute (TERI), Development Alternatives, Centre for Science and Environment, and the Society for Himalayan Glaciology, Hydrology, Ice, Climate and Environment operate on project-based research mode on various topics such as climate change vulnerability, impacts and mitigation.

Apart from India-centric initiatives, climate change research is actively promoted by various international organizations like the World Climate Research Programme (WCRP), International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme (IHDP) and DIVERSITAS. These international programmes are being strongly supported by various Indian agencies.

Systematic Observation Networks

India has a centuries'-old tradition of systematic observations, in different fields such as meteorology, geology, agriculture, sea level and land survey, including mapping. Government departments, set up for specific purposes, have carried out these observations since the early 19th century. Observational networks have undergone changes according to the evolving needs, and have also been modernized to a fair extent. Developments in space-based systems have contributed considerably to observational capabilities. India has also participated in international observational campaigns, both regionally and globally, to further the understanding of the climate and its variability.

Atmospheric observations

There are 25 types of atmospheric monitoring networks that are operated and coordinated by the IMD. These include meteorological/climatological, environment/ air pollution and other specialized observations of trace atmospheric constituents. IMD maintains 559 surface meteorological observatories and about 39 radiosonde and 64 pilot balloon stations for monitoring the upper atmosphere. Specialized observations are made for agro-meteorological purposes at 219 stations and radiation parameters are monitored at 45 stations. There are about

70 observatories that monitor current weather conditions for aviation. Although severe weather events are monitored at all the weather stations, the monitoring and forecasting of tropical cyclones is specially done through three Area Cyclone Warning Centres (Mumbai, Chennai, and Kolkata) and three Cyclone Warning Centres (Ahmedabad, Visakhapatnam and Bhubaneshwar), which issue warnings for tropical storms and other severe weather systems affecting Indian coasts. Storm and cyclone detection radars are installed all along the coast and some key inland locations, to observe and forewarn severe weather events, particularly tropical cyclones. The radar network is being upgraded by modern Doppler Radars, with enhanced observational capabilities, at many locations.

In view of the importance of data assimilation in the tropical numerical weather prediction, IMD has been in the process of implementing a massive modernization programme for upgrading and enhancing its observation system. It has established 550 Automatic Weather Stations (AWS), out of which about 125 will have extra agricultural sensors like solar radiation, soil moisture and soil temperature. 1350 Automatic Rain Gauge (ARG) stations and 10 GPS have also been added and their number is planned to be increased substantially. In addition to this, a network of 55 Doppler Weather Radar (DWR) has been planned, out of which 12 are to be commissioned in the first phase. DWR, with the help of algorithms, can detect and diagnose weather phenomena such as hail and squall, which can be hazardous for agriculture. In addition, ISRO/ DOS has designed and developed indigenous ground observation systems such as Automatic Weather Station (AWS), Agro-meteorological (AGROMET) Tower and Doppler Weather Radar (DWR) for observations of weather parameters. So far, 1000 AWS, 24 AGROMET, 5 DWR have been installed by ISRO/DOS in the country. ISRO has also developed GPS Sonde and Boundary Layer LIDAR (BLL) for observing vertical profiles of atmospheric parameters. A new satellite, INSAT-3D is scheduled to be launched. INSAT-3D will usher a quantum improvement in satellite-derived data from multi spectral high-resolution imagers and vertical sounders. In addition, IMD is also planning to install wind profilers and radiometers to get upper wind and temperature data.

IMD is also augmenting its monitoring capability of the parameters of atmospheric environment. Trace gases, precipitation chemistry and Aerosols will be monitored in the country on a long-term basis. Aerosol monitoring will be carried out at 14 stations using sky radiometers, black carbon will be measured at 4 stations using aethelometers, Ozone measurements will be conducted in the North-East and Port Blair in addition to the existing stations in India and Antarctica; Turbidity and Rain Water chemistry will be measured at 11 stations and Radiation measurements will take place at 45 stations. The data will be monitored and exchanged globally as per the international protocols and quality control will be ensured as per international standards. Such data will be used in Carbon-cycle models to accurately estimate radiation forcing and quantify source and sink potential for policy issues under the UN framework.

High altitude Hanle observatory in Ladakh- proposed for monitoring ambient trace gas and aerosol concentrations

The IMD, in collaboration with the NPL plays an important role in climate change-related long-term data collection at the Indian Antarctic base – ‘Maitri’. Continuous surface meteorological observations (for about 22 years) are now available for Schirmacher Oasis with the National Data Centre.

The IMD collects meteorological data over oceans from ships that while sailing on the high seas, function as floating observatories.

Data archives and exchange

The tremendous increase in the network of observatories resulted in the collection of a huge volume of data. The IMD has climatological records even for the period prior to 1875, when it formally came into existence. This data is digitised, quality controlled and land archived in electronic media at the National Data Centre, Pune. The current rate of archival data is about three million records per year. At present, the total data holding is about 9.7 billion records. They are supplied to universities, industry and research and planning organizations. The IMD has prepared climatological tables and summaries/atlases of surface and upper-air meteorological parameters and marine meteorological summaries. These summaries and publications have many applications in agriculture, shipping, transport, water resources and industry-based research.

The IMD has its own dedicated meteorological telecommunication network with the central hub at New Delhi. Under the World Weather Watch Plan's Global Telecommunication System, New Delhi, it functions as a Regional Telecommunication Hub (RTH) on the main telecommunication network. This centre was automated in early 1976, and is now known as the National Meteorological Telecommunication Centre (NMTC), New Delhi. The websites of IMD viz. http://www.imd.gov.in and http://www.mausam.gov.in have been operational since 1st June, 2000. The websites contain dynamically updated information on all-India weather and forecasts, special monsoon reports, satellite cloud pictures updated every three hours, Limited Area Model (LAM) and Global Circulation Model (GCM) generated products and prognostic charts, special weather warnings, tropical cyclone information and warnings, weekly and monthly rainfall distribution maps, earthquake reports. It also contains a lot of static information, including temperature and rainfall normals over the country.

Augmentation of weather and climate forecasting capabilities

In view of the growing operational requirements from various user agencies, IMD has embarked on a seamless forecasting system covering short range to extended range and long-range forecasts. Such a forecasting system is to be based on a hierarchy of Numerical Weather Prediction (NWP) models. For a tropical country like India, where high impact mesoscale convective events are very common weather phenomena, it is necessary to have good quality high-density observations, both in spatial and temporal scales, to ingest into the assimilation cycle of a very high resolution non-hydrostatic mesoscale model. A major problem related to the skill of NWP models in the tropics is due to sparse data availability over many parts of the country and the near-absence of data from the oceanic region.

Data from AWSs, ARGs, DWRs, INSAT-3D and wind profilers is available in real time for assimilation in NWP models. A High Power Computing (HPC) system with 300 terabyte storage has been installed at the NWP Centre at Mausam Bhawan, New Delhi. All the systems have been started working in an integrated manner in conjunction with other observation systems in real-time. This has greatly enhanced IMD's capability to produce indigenous forecast products on different time scales. IMD also makes use of NWP Global model forecast products of other operational centres nationally and internationally to meet the operational requirements of day-to-day weather warning. Very recently, IMD has implemented a multi-model ensemble (MME)-based district level five-days quantitative forecasts in medium range.

There is a need to prioritize actions to improve monitoring of such extremes and refine models for their prediction and projection in longer scale. New levels of integrated efforts like Global Framework for Climate Services/ National Framework for Climate Services (GFCS/NFCS) are required to strengthen climate research at the existing and newer institutions in order to:

- Develop improved methodologies for the assessment of climate impacts on natural and human systems.
- Characterize and model climate risk on various time and space scales relevant to decision-making and refine climate prediction skills.
- Enhance spatial resolution of climate predictions, including improvements in downscaling and better regional climate models.
- Improve climate models to represent the realism of complex Earth system processes and their interactions in the coupled system.
- Develop a better understanding of the linkages between climatic regimes and the severity and frequency of extreme events.
- Enable progress in improving operational climate predictions and streamlining the linkages between research and operational service providers.

IMD undertakes continuous global climate monitoring and generation of climate diagnostics for the Indian region to report major climate variability and climate anomalies on monthly and seasonal scale through Indian Climate Observation System (ICOS). The major activities of the climate monitoring and climate information service are as following:

- Detailed special monsoon reports are being published every year.
- Generation of daily analysed rainfall data (at 1°x1° latitude/longitude and at 0.5°x0.5° latitude/longitude resolution).

Table 5.1: Atmospheric monitoring networks across the Indian region.

Atmospheric monitoring networks	
1 Surface observatories	559
2 Pilot balloon observatories	65
3 RS/RW observatories	39
4 Aviation current weather observatories	71
5 Storm detecting radar stations	17
6 Cyclone detection radar stations	10
7 High-wind recording stations	4
8 METOP/MODIS/NOAA HRPT Stations	3
9 Hydro-meteorological observatories	701
10 a Non-departmental rain gauge stations	
i Reporting	3540
ii Non-reporting	5039
b Non-departmental glaciological observations (non-reporting)	
i Snow gauges	21
ii Ordinary rain gauges	10
11 Agro-meteorological observatories	219
12 Evaporation stations	222
13 Evapo-transpiration stations	39
14 Seismological observatories	58
15 Ozone monitoring	
a Total ozone and Umkehr observatories	5
b Ozonesonde observatories	3
c Surface ozone observatories	6
16 Radiation observatories	
a Surface	45
b Upper air	8
17 Atmospheric electricity observatories	4
18 (a) Background pollution observatories	10
(b) Urban Climatological Units	2
c) Urban Climatological Observatories	13
19 Ships of the Indian voluntary observing fleet	203
20 Soil moisture recording stations	49
21 Dewfall recording stations	80
22 AWS	550
23 ARG	1350

Source: India Meteorological Department, Government of India

Oceansat-2 undergoing dynamic balancing test

- Generation of daily gridded temperature data (at 1°x1° latitude/longitude resolution) for various climate variability studies.
- Drought Monitoring Indices and Drought Analysis.
- Archival of climate related databases and data products (such as district/station normals, normal solar radiation parameters).

A dynamical statistical technique is developed and implemented for real-time cyclone genesis and intensity prediction. A number of experiments are being carried out for the processing of DWR observations to be used in 'nowcasting' and mesoscale applications. The procedure is expected to be available in operational mode soon. Various multi-institutional collaborative forecast demonstration projects are being initiated to strengthen the forecasting capabilities of IMD.

Satellite-based observations

INSAT Systems:

The establishment of space systems and their applications are coordinated by national level committees, namely INSAT Coordination Committee (ICC), Planning Committee on National Natural Resources Management System (PC-NNRMS) and Advisory Committee on Space Sciences (ADCOS).

Indian National Satellite (INSAT) system, established in 1983, is the largest domestic communication satellite system in the Asia-Pacific region with nine satellites in operation - INSAT-2E, INSAT-3A, INSAT-3C, INSAT-3E, INSAT-4A, INSAT-4B, INSAT-4CR, GSAT-8 and GSAT-12 as well as KALPANA-1, an exclusive meteorological satellite. The INSAT system is a joint venture of the Department of Space, Department of Telecommunications, All India Radio and Doordarshan for communication applications and India Meteorological Department for meteorological observations. The overall coordination and management

GSAT-4 ready to enter CATVAC

of the INSAT system rests with the INSAT Coordination Committee.

The INSAT-3A and Kalpana-1 satellites carrying Very High Resolution Radiometer (VHRR) have been providing data for generating cloud motion vectors, cloud top temperature, water vapour content, etc., facilitating rainfall estimation, weather forecasting, genesis of cyclones and their track prediction. In addition, CCD (Charge-coupled Device) Camera on INSAT-3A, provides images every 3 hours in three channels (ie., VIS, NIR and SWIR) at 1km spatial resolution. The satellite also has Data Relay Transponders (DRT) to facilitate reception and dissemination of meteorological data from in-situ instruments located across vast and inaccessible areas.

Earth Observation Systems

The Indian Earth Observations (EO) system, since its beginning in the late 70s, has emerged as a strong constellation of geostationary and polar orbiting satellites, carrying a variety of sensors, providing observations over land, ocean and atmosphere. There are currently nine remote sensing satellites in the orbit (TES, Resourcesat-1, Resourcesat-2, Cartosat-1, 2, 2A and 2B, RISAT-2 and Oceansat-2) providing remote sensing data in a variety of spatial, spectral and temporal resolutions, meeting the needs of many applications. Data from these satellites have been extensively used to monitor land and water resources, such as agriculture, surface water and groundwater, soil, forest cover and type, wetlands, coastal zone including mangroves and coral reefs; wastelands, desertification status; glaciers and their retreat, seasonal snow-cover changes; etc. These efforts have helped in creating not only national level inventories, but also in studying the changes occurring in large eco-systems.

Oceanic observations

A comprehensive ocean observation network programme was launched, after its importance was duly recognized. This programme aims to understand the structure and dynamics of the ocean, improve the predictability of the ocean and climate, provide inputs for the sustainable development of a coastal ecosystem and generate ocean information and advisory services.

A network of observation systems was set up to critically gauge ocean dynamics and its influence on weather and climate at different temporal and spatial scales. The Indian National Centre for Ocean Information Services (INCOIS) continues to play a lead role in the Indian Ocean region and is associated with a number of international initiatives, such as Indian Ocean Global Ocean Observing System (IOGOOS), Regional Co-ordination of Argo Programme and Partnership for Observation of Global Ocean (POGO). INCOIS also serves as the National Argo Data Centre and Argo Regional Data Centre for the Indian Ocean region.

A major achievement was the development of an *in situ* Ocean Data and Information System (ODIS) and its integration with the existing data base. This allows querying, visualising and downloading of in situ data online from a wide variety of in situ ocean observation systems. The application was developed using Open Source software/tools.

Ocean Observation system consists of in situ (such as a buoy or a ship) measurements to capture changes in time and depth and Remote sensing (satellites, aircraft, radar, etc) systems to capture the spatial and temporal dimensions of change in surface properties.

An Automatic Weather Station (AWS) was installed onboard ORV Sagar Nidhi to measure wind, air temperature, humidity, air pressure, long wave and short wave radiation and sea surface temperature (SST). The data is being received at INCOIS in real time through INSAT. This was undertaken as a pilot experiment for establishing a network of ship-mountable AWS in the Indian Ocean region with real time data transmission through INSAT. The data are used for real time validation of ocean forecasts as well as for weather predictions.

INCOIS continues to act as the Argo Regional Data Centre (ARC) for the Indian Ocean region. 15 floats that use Iridium communication and 22 floats with ARGOS communication were procured. 18 Argo floats with the facility of measuring near-surface temperature were deployed in the Indian Ocean; of which 7 were deployed in the Bay of Bengal. 3 Argo floats provided by the University of Washington were deployed (using ORV Sagar Sampada) in the Arabian Sea. Two of them contained additional sensors for oxygen while the third contained a sensor for chlorophyll (BIO-ARGO). 79 of the 175 floats deployed by India over the past years, are providing sub-surface temperature and salinity data. At present, together with the deployment of other countries, 621 floats are active in the Indian Ocean.

The surface currents using Argo drift locations over the past 5 years were estimated and compared with other climatologies based on ship drifts and surface drifters. It was found that the surface currents derived from Argo floats are overestimating the surface currents of climatology. Ocean temperature and salinity data from Argo profiling floats, satellite measurements of sea-surface height (altimeter) and the time variable gravity field (GRACE) were used to investigate the causes of Indian Ocean mean sea level rise between 2003 and 2008. It was found that the total sea level rise in the Indian Ocean is due to the contribution of both thermal expansion and increase in water level due to the ice melt.

In addition, 20 drifting buoys and 4 deep-sea current meter moorings were deployed in the Indian Ocean in 2009. The

XBT and XCTD (Expendable Bathy Thermograph and Conductivity Temperature Depth) observations were also continued on a routine basis along major shipping lines (412 XBT profiles and 56 XCTD profiles). As part of the effort towards establishing the Bay of Bengal observatory, one mooring consisting of current meters and CTDs at different levels (up to 100m) was deployed in the northern Bay of Bengal in November 2009. This mooring provides the high frequency temperature, salinity and currents in the top 100m layer.

Measurements of trace constituents and air pollution monitoring

The Central Pollution Control Board (CPCB) is executing a nation-wide programme of ambient air quality monitoring known as the National Air Quality Monitoring Programme (NAMP). The network consists of 342 operating stations covering 127 cities/towns in 26 states and 4 Union Territories. The objectives of the NAMP are to determine status and trends of ambient air quality; to ascertain whether the prescribed ambient air quality standards are violated; to identify Non-attainment cities; to obtain knowledge and understanding necessary for developing preventive and corrective measures and to understand the natural cleansing process undertaken in the environment through pollution dilution, dispersion, wind-based movement, dry deposition, precipitation and chemical transformation of pollutants generated.

Under NAMP, four air pollutants viz. Sulphur Dioxide (SO_2), Oxides of Nitrogen as NO_2, Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM / PM10) have been identified for regular monitoring at all the locations. The monitoring of meteorological parameters such as wind speed and wind direction, relative humidity (RH) and temperature was also integrated into the monitoring of air quality. Pollutants are monitored over 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) twice a week, to have 104 observations in a year. The monitoring is being carried out with the help of Central Pollution Control Board, State Pollution Control Boards, Pollution Control Committees and National Environmental Engineering Research Institute (NEERI), Nagpur. CPCB coordinates with these agencies to ensure uniformity and consistency of air quality data, while providing technical and financial support for operating the monitoring stations.

Cities under National Air quality monitoring programme

The IMD established 10 stations in India as a part of World Meteorological Organization's (WMO) Global Atmospheric Watch (GAW - formerly known as Background Air Pollution Monitoring Network or BAPMoN). These were established with the objective of documenting long-term changes in the composition of trace species of the atmosphere. The Indian GAW network includes Allahabad, Jodhpur, Kodaikanal, Minicoy, Mohanbari, Nagpur, Port Blair, Pune, Srinagar and Visakhapatnam. Atmospheric turbidity is measured using hand-held Volz's Sunphotometers at wavelength 500nm at all the GAW stations. Total Suspended Particulate Matter (TSPM) is measured for varying periods at Jodhpur using a High Volume Air Sampler. Shower-wise wet-only precipitation samples are collected at all the GAW stations using specially designed wooden precipitation collectors fitted with stainless steel or polyethylene funnel precipitation collectors. After each precipitation event, the collected water is transferred to a large storage bottle to obtain a monthly sample. Monthly mixed samples collected from these stations are sent to the National Chemical Laboratory, Pune, where they are analysed for pH, conductivity, major cations (Ca, Mg, Na, K, NH_4^+) and major anions (SO_4^{2-}, NO^{3-}, Cl^-).

Terrestrial observations

Cryospheric observations

The Geological Survey of India (GSI) conducts a systematic study of glaciers. In 1974, it established the Glaciology Division for northern region, with its headquarters at Lucknow. The Eastern Region Division was established at Kolkata in 1979. GSI carried out glaciological studies in Jammu & Kashmir (Neh-Nar glacier, 1974-1984); Himachal Pradesh (Gara, 1973-1983; Gor Garang, 1975-1985; Shaune Garang; 1981-1991); and Uttar Pradesh (Tipra Bamak, 1980-1988; Dunagiri, 1984-1992). Besides these, the Harmuk and Rulung glaciers in Jammu & Kashmir and Zemu and Changme Khangpu glaciers in Sikkim have also been studied. It also carried out snow-cover assessments of the Beas basin, Dhauliganga valley and Sind Valley. GSI has thus completed the first generation glacier inventory of UP, HP, J&K and Sikkim. They have largely confined their study to mass balance, glacier recession, suspended sediment transfer and geo-morphological studies.

The Survey of India (SOI), the oldest scientific department of the Government of India, set up in 1767, is the national survey and mapping organization of the country. The most significant contribution of SOI in the study of glaciers is the accurate demarcation of all glaciers on topographical maps that can provide a vital data source for glaciological research.

The IMD established the glaciology Study Research Unit in the Hydromet Directorate in 1972. This unit has been participating in glaciological expeditions organized by the GSI and the DST. The unit was established for: (i) determination of the natural water balance of various river catchment areas for better planning and management of the country's water resources (ii) snow melt run-off and other hydrological forecasts (iii) reservoir regulation (iv) better understanding of the climatology of the Himalaya and (v) basic research of seasonal snow cover and related phenomena. The IMD has established observing stations over the Himalayan region to monitor weather parameters over glaciers.

The Snow and Avalanche Study Establishment (SASE), a defence research organization has been working in the field of snow avalanches since 1969. The emphasis has been to mitigate snow avalanche threat by various active and passive methods. Avalanche forecasting and avalanche control measures form the front-line research areas of this establishment. The basic research in snow physics, snow mechanics and snow hydrology naturally followed in pursuit of the solutions to problems related to snow avalanches. SASE has established about 30 observatories in the western Himalayan region, which are very close to the glacier environment. The data collected at these observatories mostly pertains to weather, snow and avalanches. In addition, a chain of Automatic Weather Stations (AWS) has been established at different places in the western Himalayan region. Of these, two have been installed on a glacier.

In addition, several other academic and research institutions like the Wadia Institute of Himalayan Geology (WIHG), Physical Research Laboratory (PRL) and the Jawaharlal Nehru University (JNU) have been actively taking part in the study of Himalayan glaciers. Satellite-based observations of the glaciers and their mass balance characteristics are also being carried out regularly by the Space Applications Centre (SAC).

The Himalayas govern the climate and weather of the region and drive the major weather system. Heavy snowfall events over the western Himalayan region and the subsequent avalanches affect the life and property of the inhabitants. The impact of weather events is enhanced by topography, which makes the area more prone to cloud-bursts, flash floods and landslides. The existing observational network (surface, upper air, radar) over these regions is very sparse. Automatic Weather Stations have been established in the western Himalayan region under the multi-institutional project PARWAT for sustained real time collection of meteorological data. Three upper air stations are also established at Jammu, Manali and Sasoma to meet the weather forecasting requirements of the specific region.

Ecosystems: The country is very rich in biodiversity resources - from cold deserts to tropical forests. Biodiversity resources are directly valued as food for humans, fodder for animals, energy sources as fuel, nutrients like leaf manure and structural materials like pharmaceuticals, fibre, fragrances, flavours, dyes and other materials of special interest. A record of India's plant wealth indicates that there are approximately 17,500 species of angiosperms, 48 species of gymnosperms, 1,200 species of ferns, 6,500 species of algae, 14,500 species of fungi, 2,500 species of lichens, 845 species of liverworts and 1,980 species of mosses. Several organizations are involved in the observational and research aspects of the flora and fauna of the country, as also the different ecosystems.

The Forest Survey of India (FSI), an organization under the MoEF, has undertaken the assessment of forest resources in the country since 1965. As per its current mandate, the FSI has to assess the forest cover of the country in a two-year cycle, which is published regularly in the form of 'State of Forest Report' (SFR). Many research institutions and Agricultural Universities under the ICAR are also engaged in data collection and research in the agriculture sector. The agronomy division of the ICAR, over the past 50-60 years, has gathered soil parameters for agricultural resource management. Agriculture-related weather data and grain-wise agricultural yield data are collected at the local level at evenly distributed sites all over the country.

Keeping in mind the immense importance of extended range forecasting in agriculture applications, the Extended Range Forecast System for Climate Risk Management in Agriculture (ERFS) has been launched with active collaboration of the Indian Institute of Technology (IIT) Delhi, India Meteorological Department (IMD), National Centre for Medium Range Weather Forecast (NCMRWF), Space Application Centre (SAC) Ahmedabad and Indian Council of Agricultural Research (ICAR). The objective of the ERFS is to generate and disseminate information on rainfall and temperature with a lead-time of 25-30 days. It is expected to give sufficient time to the farmers to plan their cropping activities and also help the policy makers take necessary corrective measures to arrest any contingency that might arise. Under the ERFS, forecast for each month at the regional/district level is the ultimate goal. Experimental monthly rainfall forecast for the monsoon 2010 was generated on meteorological sub-division scales and in respect of 13 identified districts and disseminated to the identified farmers/users for risk management purposes.

In order to strengthen the current capabilities of in-season multiple crop estimation through a combination of Remote Sensing, Econometric, Agro-met and Land-based observations, a scheme called Forecasting Agricultural Output using Space, Agro-meteorology and Land-based observation (FASAL) was launched in August 2006. The agencies involved in the project are Space Applications Centre (SAC) Ahmedabad, Institute of Economic Growth (IEG) New Delhi and India Meteorological Department (IMD) Pune.

The Central Water Commission (CWC) under the MoWR, operates a national network of about 878 hydrological observation stations. The data observed at field units is processed at various levels and archived. The CWC also imparts training to various research institutions, universities, central and state pollution control boards for systematic collection of river water samples.

The Central Ground Water Board (CGWB), another institution under the MoWR, monitors the ground water levels from a network of 14,995 stations (mostly dug wells) distributed evenly throughout the country. Dug wells are being gradually replaced by Piezometers for water level monitoring. Water levels are measured four times during the year in the months of January, April/May, August and November. The ground water samples are collected during April/May for analyses of chemical changes. The generated data is used to prepare maps of ground water level depths, water level contours and changes in water levels during different time periods. The data is also being used to prepare long-term change trends in water levels. The CGWB has categorized the Indian subcontinent into 12 basins. At the basin level, several parameters are being monitored and are available with the CWC for various national research needs.

Research Programmes

Climate and global change

IMD has established a National Climate Centre linked to National Data Centre, holding data of about 9.7 billion records. The centre brings climate status reports on variability and trends of climate parameters at local/regional/national levels. A coordinated research programme on Global and Regional Climate Change (GRCC) was launched during the XIth Plan to build a National Climate Change Monitoring and Research Network. A Programme office has been established at the ESSO/MoES Headquarters to operate the GRCC programme to integrate all the envisaged activities in support of supplementing 'unified scientific response' to global warming, launched under the NAPCC. As a part of GRCC, a dedicated Centre for Climate Change Research (CCCR) to undertake studies on the scientific aspects of climate change at the Indian Institute of Tropical Meteorology (IITM) Pune has been established. CCCR is focusing on all scientific issues including modelling the susceptibility of various agricultural crops, their yield and diseases, water, nitrogen, ozone, GHG flux measurements and CO_2 cycle sequestration.

Ensembles of regional model simulations are being generated for downscaling the monsoon variability projections over the South Asian region. This will be the first time that projections based on model simulations conducted from India will be participating in the IPCC assessment. It has the ability to capture summer monsoon characteristics over South Asia within 17-ensemble members from 20th century simulations of Quantifying Uncertainty in the Model Projections (QUMP). United Kingdom's Hadley Centre Coupled Ocean-Atmospheric Climate Model version 3 (Had CM3) is examined to select potential ensemble member fields among the 17, which have most closely reproduced the observed summer monsoon climate variability.

Six among the 17-ensemble runs of QUMP experiment are found to be reproducing mean summer monsoon climate reasonably well and these experiments are used to drive the Regional Climate Model (RCM-PRECIS) to generate a 50km grid scale under A1B Scenario (Medium Emissions) runs over South Asia continuously for the period 1961-2100. The three-member ensemble runs of RCM- PRECIS have been completed. The results are under critical evaluation and the simulations in respect to the remaining 3-ensemble QUMP members are currently underway. A framework of three regional climate models (PRECIS, WRF and Reg CM) is currently being built to examine the following spatial characteristics associated with the summer monsoon in the coming decades: (i) To quantify future climate scenarios for India under different emission scenarios as well as 'committed climate change' scenarios, during the 21st century including various intermediate time slices, (ii) To develop ensembles of regional climate change scenarios and quantify uncertainties and (iii) To examine the nature of possible changes in the frequency and intensity of extreme weather and monsoon climate variability associated with the expected climate change over India.

INCOIS continued the ocean modelling activities using four ocean General Circulation Models, namely, Regional Ocean Modelling System (ROMS), Modular Ocean Model (MOM), Hybrid Coordinate Ocean Model (HYCOM) and Colorado University Princeton Ocean Model (CUPOM). Amongst them, the ROMS was set up for the Indian Ocean Forecasting System (INDOFOS),which is the first of its kind in the Indian Ocean for operational purposes. The model is forced with the 5-day forecasted surface winds and atmospheric fluxes obtained from the National Centre for Medium Range Weather Forecasting (NCMRWF) New Delhi. The simulations for 2000-2008 were extensively validated against the observations from *in situ* platforms and satellites.

The Indian Ocean Modelling and Dynamics (INDOMOD) Project, initiated during the IXth Five-Year Plan, was contemplated to develop a variety of wide-range coupled ocean-atmosphere models for application of the monsoon variability studies and ocean state forecast. The programme now has 25 projects, which are envisaged by the Indian Institute of Science, Bengaluru; Indian Institute of Technology, Delhi; Indian Institute of Technology, Kharagpur; National Institute of Oceanography, Goa; Centre for Mathematical Modelling and Computer Simulation, Bengaluru; Andhra University, Visakhapatnam; Hyderabad University, Hyderabad; Cochin University of Science and Technology, Kochi; Annamalai University, Chennai; Jadavpur University, Kolkata and Allahabad University, Allahabad.

The Satellite Coastal Oceanographic Research (SATCORE) continued by strengthening value added services such as conducting Cal/Val exercises, organizing dedicated bio-optical cruises, and modelling initiatives. The programme also continued its close links with the international programme ChloroGIN through the Indian Ocean GOOS (IOGOOS) network. The programme continued the generation dissemination of chlorophyll, and SST maps (for countries in the Indian Ocean region,namely India, Sri Lanka, Iran, Kenya, Maldives, Oman, Tanzania and Thailand) and in situ time-series measurements of chlorophyll and radiances along the selected transects around India. Additionally, several value-added services like custom-mapped and binned satellite data products, and the data on total suspended matter (TSM) were generated and disseminated on a routine basis. An inter-comparison exercise, named SICOME-001, was conducted off Visakhapatnam to establish the variances in the measurements made under the SATCORE network.

The physical, chemical and dynamical aspects of the atmosphere - lower, middle and upper atmosphere including the monsoons, coupled land-ocean-atmospheric system, geosphere-biosphere interactions and development of technology are the main thrust areas of climate research. A Weather Research Forecast (WRF) model with 30km resolution and a ROCM (Regional Ocean Circulation Model) was chosen to develop an Indian regional climate modelling strategy. A coupler, through which daily coupling and transfer of fluxes between ocean surface and atmosphere have been developed, indicated the sea surface temperatures (TMI-SSTs) are well correlated and the cold bias has been rectified. Study of the outputs of 25 coupled climate models (used for IPCC AR4) indicated bias in all the models and finally evaluated 10 select climate model's output parameters over south Asia, in particular, the ENSO monsoon and Indian Ocean Dipole relationships. The projections at the end of the 21st century showed that although the monsoon circulation has weakened, there is significant increase in mean monsoon precipitation over India under the climate change experiments. Studies of the atmospheric energetics during the onset phase and active phase of the monsoon season and inter-comparison of model simulations with different resolutions, predictability studies of the atmosphere using error growth studies on low dimension mesoscale and global models are in progress. Further, studies on 'Energetics of zonal waves and intra-seasonal variability of Indian monsoon', 'Sensitivity of sea surface temperature over Indian Ocean and land cover/vegetation classes on Indian summer monsoon precipitation', 'Numerical simulation of western disturbance and associated extreme weather using a mesoscale model' and 'Establishment of a coupled climate and carbon cycle modelling activity and investigation of the effects of CO_2 fertilization' have been initiated. Studies on Sea level variations over the Bay of Bengal, with respect to occurrence of different combinations of ENSO and Indian Ocean Dipole (IOD), using satellite altimeter data showed significant characteristic features due to the combined effect of ENSO and IOD events. In some cases, the occurrence of one event overrides the characteristic features of other events. Rapid ecosystem response to the episodic events (such as rainfall) on the bio-geochemistry of the coastal waters off Visakhapatnam and significant decrease in dissolved oxygen levels due to enhanced primary production triggered by land-driven material exported by heavy rainfall were observed.

Atmospheric trace constituents

In India, a number of research activities related to the measurement of atmospheric trace constituents are being carried out by different national laboratories, institutions and universities to investigate various research problems, individually as well as jointly, with financial support provided by different government and international agencies.

The determination of GHG emissions from different sectors such as energy, industries, enteric fermentation, manure management, forestry, land use, land-use change, and waste are being carried out by various research organizations. These include the National Physical Laboratory, National Chemical Laboratory, Indian Institute of Science, Central Mining and Fuel Research Laboratory, Jadavpur University, Kolkata , Central Leather Research Institute, National Dairy Research Institute, Indian Agriculture Research Institute and Central Rice Research Institute among others. However, considering the vast coverage these studies need to address, due to the diverse mix of technology, geographical and social parameters, these studies are just a beginning and will require strengthening, both in terms of institutions and financial resources to meet the research requirement.

Under the aegis of India's Second National Communication to UNFCCC project, several country-specific emission coefficients have been developed, such as those for methane emissions from paddy cultivation and CO_2 emissions from Indian coal, road transport, ammonia production and cement manufacturing. An assessment of 'Greenhouse Gas Emissions of India for 2007 by sources and removal by sinks from Energy, Industry, Agriculture, Land Use, Land-Use Change and Forestry (LULUCF) and Waste sectors' by INCCA was released on 11th May 2010. This assessment was an outcome of the contribution of more than 80 scientists from 17 institutions across India.

The aerosols and atmosphere interactions are studied through the development of hand held Sunphotometers using filter photo detectors as sensors to monitor aerosol optical thickness, columnar water vapour and ozone concentration in the atmosphere. Some of the regional studies include: (i) The measurement of organic and black carbon and chemical constituents of ambient aerosols at a suburban site of the Indo-Gangetic plain; (ii) The impact of aerosols and gaseous pollutants in ambient air on physiological parameters of human health due to agricultural crop residue burning at Patiala; (iii) The role of Polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC) and ammonia in aqueous phase atmospheric autoxidation of Sulphur dioxide; (iv) Ambient air pollution and its sources in the background sites of different hill spots in the northwestern Himalaya; (v) Characterization, toxicity and health risk assessment of PAH in particulate matter and emissions from different combustion fuels; (vi) Spatial and temporal dynamics of urban heat island in Delhi and its implication for the air quality of Delhi and (vii) The study of distribution and sources of ambient Ammonia over northwest India.

The National Carbon Project (NCP) of IGBP in terms of soil carbon pool assessment (SCP), vegetation carbon pool assessment (VCP) and soil and vegetation fluxes (SVF) using flux tower measurements, observations from space and other collateral data and ground measurements are being studied through Net Primary Productivity (NPP) modelling from flux tower to national scale with the biosphere model, which is mainly to identify changes in phytomass. The NCP will cover multi-constraint modelling, satellite derived top-down (atmospheric CO_2) and bottom-up (Remote Sensing-based inventory approach and inclusion of atmospheric transport) approaches in the near future.

The continuous measurement of aerosols using ARFI network (ARFINET), which has grown to a chain of more than 30 stations, has further consolidated the measurement network. ARFINET has data compiled up to 2009, in a common format; which could be effectively used by the scientific community, for various R&D purposes. Aerosol Radiative Forcing experiments cover the projects related to Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB) and Regional Aerosol Warming Experiment (RAWEX). Under ICARB, multi-platform field campaigns, involving synchronous measurement of several aerosol parameters from the network, onboard ship and aircraft, balloons and satellites have been conducted. RAWEX is being carried out to assess the impact of regional warming by elevated absorbing aerosols in regional atmospheric warming, monsoon system, weather and climate. The research studies on Atmospheric Trace Gases, Chemistry and Transport over India from the high altitude balloon experiment, are engaged in determining the concentrations of CFCs and N_2O and their significant role in depleting the ozone concentrations in the stratosphere. Also, the Atmospheric Dust Chemistry and Transport Modelling programme under IGBP has been working on the Organic Carbon and Element Carbon (Black Carbon) emissions in various cities in India and their contribution to radiative forcing. The initial observations of atmospheric boundary layer studies over the Bay of Bengal region have detected that the variable convective processes have significance in modulating regional weather and climate. Under IGBP, a network of about S20 Agro-Met Stations (AMS) has been established across the country and the datasets are being collected and stored on MOSDAC server. Integrated science plans for canopy characterization through in situ measurements on phenology, LAI, soil moisture, photosynthesis and biomass are being carried out as part of the research activity.

Under the aegis of INCCA, the ‘Black Carbon Research Initiative - Science Plan’ of the National Carbonaceous Aerosols (NCAP) was launched on March 29, 2011. The initiative is significant especially because there is an emergence of interest in the role of Black carbon (BC) in global warming, since aerosols may modify the planetary albedo. The Carbon Research Initiative builds on the existing work of ISRO, ESSO/MoES and other experts, which would involve over 101 institutions with 65 observatories nationwide. The study would lead to long-term monitoring of aerosols; monitoring of impact of BC on snow; estimating magnitude of BC sources using inventory (bottom-up) and inverse modelling (top-down) approaches and modelling BC atmospheric transport and climate impact.

The major focus of the Atmospheric Environment and Global Change project of NPL is the operation of a micro-pulse lidar for continuous measurements of aerosols and clouds; estimation of vertical distribution of ozone over Delhi, Pune and Thiruvananthapuram, revealing significantly high tropospheric ozone during January-February; estimation of budget of carbonaceous aerosols from biofuels from the district-wide sampling in Delhi; detecting the influence of monsoon-associated mesoscale convection systems on the tropical tropopause region; estimation of aerosol radiation forcing over Kanpur during pre-monsoon; single scattering Albedo and aerosol radiation forcing estimation over Delhi for five years (2002-06); seasonal variation of aerosol black carbon and its impact over radiation flux over Delhi; investigation of some anomalous features in the Martian ionosphere using Mars global surveyor data; interesting new data sets on CO from snow pack in polar regions; size distribution among surface aerosols in 2007 using GRIMM spectrometer; continuation of regular ambient observations related to surface ozone, NOx, CO, NMHC, column content of Ozone, water vapour AOD and UV radiation as well as theoretical explanation of low stratospheric ozone over Indian subcontinent and the work related to the model for forecasting the local time of clearance of fog.

Ambient air quality monitoring carried out at various cities/towns in the country, under National Air Monitoring Programme (NAMP) provide air quality data that form the basis for identification of areas with high air pollution levels and in planning the strategies and development of action plans for control and abatement of air pollution. Data generated over the years, reveal that particulate matter (SPM & RSPM) are exceeding more than the permissible levels at many locations, particularly in urban areas. The air pollution problem becomes complex due to the multiplicity and complexity of air polluting sources (e.g. industries, automobiles, generator sets, domestic fuel burning, road side dust, and construction activities). Source apportionment study, primarily based on measurements and tracking down the sources through receptor modelling, helps in identifying the sources and the extent of their contribution. The Auto Fuel Policy document of Government of India also recommended carrying out source apportionment studies. Accordingly, source apportionment studies have been initiated in six major cities viz. (i) Delhi, (ii) Mumbai, (iii) Chennai, (iv) Bengaluru, (v) Pune and (vi) Kanpur. Besides, separate projects on the development of emission factors for vehicles and development of emission profiles for vehicular as well as non-vehicular sources have also been taken up.

World Meteorological Organization (WMO) through their programme Global Atmospheric Watch Urban Research Meteorology and Environment (GURME) has recognized the System of Air Quality Forecasting and Research (SAFAR). It implied that this effort is at par with international standards as stipulated by stringent scientific guidelines for confidence in quality control and quality assurance. SAFAR establishes forecast and 'nowcast' systems through Automatic Weather Stations, Doppler Weather Radar and other observing systems. The entire system provides and displays the information on weather and air quality in real time and forecasts the future weather and level of pollution at various key locations through wireless true colour digital display panels. It includes real time data and forecasting of major air pollutants such as Ozone, NOx, CO, PM2.5, PM10, Black Carbon and Benzene.

Reconstruction of past climate

The main thrust of research at Birbal Sahni Institute of Palaeobotany, Lucknow, lies in coordination with other palaeobotanical and geological research in various areas such as diversification of early life, exploration of fossil fuels, vegetational dynamics, climatic modelling and conservation of forests. This is the only centre in the world where palaeobotanical research is being conducted from the Archaean to recent times. It includes archaeobotany and tree ring analysis for the evaluation of climate change. The major collaborative research studies in the context of climate change are: Cenozoic vegetation and climate changes in China and India and their response to the Himalayan uplift; palaeobotanical studies on Indian and Brazilian sedimentary basins; Palaeoclimate of marine and coastal areas;study of Antarctic Gondwana plant fossils and multi-disciplinary integrated study on Antarctica, Arctic and southern ocean palaeoclimate based on Palynology, palynofacies, phytoplankton, clay mineralogy and rock magnetism of lake and marine sediments. IGBP's Quantitative Multi-Proxy Paleomonsoon Reconstruction (QMPRC) programme attempts to reconstruct the SW and NE monsoon precipitation over different regions of India quantitatively using tree rings and speleothems, spanning the last 20,000 years and to check for consistency with other proxies. The multi-proxy parameters for Quaternary palaeoclimate reconstructions are vegetation dynamics, relative sea level changes and anthropogenic influences. The environmental magnetism group has been involved in two palaeoclimate studies. The first of these studies attempts the reconstruction of the last glacial to early Holocene monsoon variability from relict lake sediments of the Higher Central Himalaya in Uttarakhand. The second study deals with the reconstruction of the variability of the southwest monsoon during the past, using samples from the continental margin of the southeastern Arabian Sea.

Climate variability and change

India's climate is dominated by the summer monsoon, which shows spatial, inter-annual and intra-seasonal variability. Climate variability has tremendous impact on agricultural production and water availability. Recognizing the role of land, atmosphere and oceanic processes in modulating the monsoon variability, a multi-disciplinary, decade-long Indian Climate Research Programme (ICRP) has been evolved to study the climate variability and climate change issues in the Indian context. The ICRP aims to undertake land-ocean atmosphere field experiments, the analysis of the available past data sets on climate and agriculture, and climate modelling. It includes the analysis of weather and climate data from ground-based, ship-based and satellite-based measurements. Under ICRP, the special emphasis is to evolve and implement multi-agency, multi-disciplinary coordinated field experimental campaigns to investigate the land-ocean atmosphere interactions and their role in monsoon variability. Studies on the development and testing of coupled ocean-atmosphere models for climate and monsoon diagnostic studies using General Circulation Models (GCM), a multi-institutional, coordinated field programme on `Bay of Bengal and Monsoon Experiment (BOBMEX)' and a multi-institutional, coordinated field experiment on 'Arabian Sea Monsoon Experiment (ARMEX)' have been initiated under ICRP. Time series measurements on atmospheric and oceanographic parameters were monitored using two oceanographic research vessels and met-ocean buoys. These observations were supplemented by the surface and upper-air observations taken by the east coast weather network of India Meteorological Department.

The implementation of 'Continental Tropical Convergence Zone (CTCZ)' was launched by ESSO/MoES. CTCZ objectives will address physical processes taking place on synoptic, meso, cloud and cloud microphysical scales and their interactions. Monsoon involves land-ocean-biosphere-atmosphere interactions and their feedbacks, and these issues are given importance in CTCZ. The direct and indirect effects of aerosols on monsoon variability on different time scales are among the objectives of this study. Special efforts are being made to elucidate the nature of the cloud systems over land and measure critical components of water and heat balance in selected basins/watersheds in the monsoon zone to understand the impact of land surface processes and to gain insight into genesis of cloud systems and their propagation over land and ocean. CTCZ is a multi-year programme involving special field experiments over land and ocean, in situ cloud observations with instrumented aircraft, analysis of existing data from conventional platforms as well as satellites, buoys, Argo floats, and theoretical/ numerical model studies with active participation from all concerned institutions in India. A pilot phase of CTCZ was implemented from 1st July - 31st August 2009, utilizing most of the existing observational weather monitoring networks including Radars, aerosols, agro-meteorological stations, met-ocean data buoys, Argo floats and drifters, two ships (ORV Sagar Kanya and OTV Sagar Nidhi), two aircrafts with state-of-the-art instrumentation, additional radiosonde systems at Kharagpur and over northern Bay of Bengal, three micrometeorological towers (Kharagpur, Ranchi and Anand) and stand-alone atmospheric observing systems (Micropulse Lidars, Sodar, Desdrometers) at few locations north of 18^{o}N, up to the foothills of the Himalayas. Efforts are underway to undertake main mega field experiments during 2010 and 2011, mustering all possible infrastructure and expertise to understand the monsoon dynamics over the Indian region. Further, studies on 'Oceanographic observations in the northern Bay of Bengal deep convection during CTCZ', 'Oceanographic observations in the southern Bay of Bengal cold pool during CTCZ campaigns', 'Oceanographic observational component during CTCZ', 'Surface energy budget and boundary layer structure over the Bay: An observational study during CTCZ', 'CTCZ pilot phase 2009: XCTD observations in the northern Bay of Bengal', and 'Interactions between the atmospheric boundary layer and deep convection over the CTCZ domain' have been underway and have contributed significantly to the understanding of monsoon dynamics.

A two-dimensional interactive chemical model of the lower and middle atmosphere has been developed to study the atmospheric chemistry-climate interactions. The radiative forcing due to the growth of GHG owing to human activities for the past three decades has been simulated. The Cloud Physics Laboratory in Pune University is presently a unique facility, which carries out cloud studies in similar conditions in the atmosphere. The availability of such a facility for cloud-related research would be of paramount interest to physicists in the relevant field.

Other than these major efforts, many small-scale projects have been and are being carried out. Some are also proposed in the near future to better understand the Indian weather and climate. For example, to understand the nature of coupled ocean-atmosphere system, an experiment has been executed over the Indian oceanic region. The focus of research was the Bay of Bengal. This experiment has given insights into tropical convection. The results will have a major impact on our understanding of the coupling of the monsoons to the warm oceans and modelling of climate.

In addition, various programmes for future needs like biomass energy, coal-bed methane recovery for commercial usage, energy efficient technology development, improvement of transport systems, small-scale hydro-electric power stations, and development of high-rate biomethanation processes as a means of reducing GHG emissions are already being conducted or proposed.

There is a broad understanding on the need to include research on greenhouse gas emissions from reservoirs. This area is intended to be included in future research programmes.

Satellite data for monitoring weather and impact of climate change

The meteorological data of the INSAT system is processed and disseminated by INSAT Meteorological Data Processing System (IMDPS) of India Meteorological Department (IMD). The products derived from the satellite data include: cloud motion vectors, water vapour, sea surface temperature, long-wave radiation, quantitative precipitation estimates, upper tropospheric humidity and Normalised Difference Vegetation Index. Cloud images in the Visible, Infra-red and Water Vapour Channel are obtained from the satellites. The products are used for weather forecasting - both synoptic and numerical weather prediction. For quick dissemination of warnings against impending disaster from approaching cyclones, specially designed receivers have been installed at the vulnerable coastal areas in Andhra Pradesh, Tamil Nadu, Orissa, West Bengal and Gujarat for direct transmission of warnings to the officials and public in general, using the broadcast capability of INSAT. IMD's Area Cyclone Warning Centres generate special warning bulletins and transmit them in local languages to the affected areas every hour.

Remote sensing application projects at national, regional and local levels are being carried out through NRSC, Hyderabad and its five Regional Remote Sensing Centre (RRSC) located at Bengaluru, Dehradun, Jodhpur, Kharagpur, and Nagpur, as well as SAC, Ahmedabad and North-Eastern Space Applications Centre (NE-SAC), Shillong. State and central government departments, State Remote Sensing Applications Centres and others are also associated in the execution of these projects.

Climate change has a strong influence on natural systems. Monitoring and assessment of impact requires long-term databases of parameters gathered employing remote sensing and ground-based methods; and suitable models for forecasting the changes. In this context, various studies have been carried out by ISRO/ DOS Centres, in the fields of agriculture, hydrology, ocean productivity, coastal zones, and regional weather patterns. Some of the major application projects, carried out during the year, are highlighted below.

- **Glacial Retreat in the Himalaya:** Satellite remote sensing data has been used to map and monitor the Himalayan glaciers at 1:50,000 scale in Indus, Ganges and Brahmaputra basins. A total of 32392 glaciers have been studied, covering an area of 71182sq.km glaciers. Advance/ Retreat of 2190 glaciers have been monitored for over 15 years, which revealed 76% of glaciers have retreated, 7% advanced and there was no change in 17% of glaciers. Average glacier retreat was estimated to be 3.75%. Further, the mass balance of 700 glaciers has been carried out. An algorithm based on Normalized Difference Snow Index was developed using visible and short wave infrared data of AWiFS sensor of Resourcesat satellite for snow cover mapping at 10 days interval. Snow cover was monitored for 33 sub-basins distributed in different climatic zones of the Himalaya for four consecutive years starting from 2004.
- **Desertification Mapping:** Climate acts as an important factor in the onset of desertification, especially for the influencing factors, which are natural in origin. Nation-wide inventory of desertification status mapping at 1:500,000 scale, using satellite data has been carried out, and the statistics generated show that about 105.48mha is under desertification in the country, which is nearly 32.07% of the total geographic area. This will serve as a baseline for further monitoring.
- **Land use/ land cover mapping:** Land use/ land cover mapping of the country, using IRS data, is being done periodically, starting from 2004-2005. This effort has provided, on an annual basis, the net sown area for different cropping seasons, and an integrated map showing different land use/ land cover categories. This database would serve as baseline information on land use/ land cover for climate change related studies in the years to come.
- **Coastal Zone Studies:** Coastal landuse maps showing Ecologically Sensitive Areas (ESAs) and high tide and low tide lines on 1:25,000 scale have been prepared using LISS-IV data. Inventory of vital coastal habitats e.g., mangroves and coral reefs have been carried out on 1:25,000 scale using IRS data for the entire Indian coast. Coral reefs of the Central Indian Ocean have also been mapped using recent satellite images.An approach has been developed to assess coastal vulnerability due to sea level rise for Andhra Pradesh, Tamil Nadu and Gujarat coasts.
- **Biodiversity Characterization:** This project, carried out in multiple phases for the whole country, has generated vegetation type maps using IRS data, superimposed over the landscape ecology layer, towards establishing the biological richness, biodiversity disturbance gradient, etc., at landscape level. Prioritisation of areas for bio-prospecting and biodiversity conservation have also been carried out. This database, organized as web-based Biodiversity Information System (BIS), is being used for policy planning, implementation, and operational forest management and benchmarking of species.
- **Wetland Inventory:** Wetlands are dynamic and exhibit rapid temporal fluxes in the structure and function of the ecosystem. Wetlands also play important role in groundwater recharge, and provide unique habitats for wide range of flora and fauna. The wetland maps generated for the country, using IRS data, are helping in conservation planning, methane emission and related studies.
- **Wasteland Mapping:** About 16% of the country is characterized by wastelands, both cultivable and non-cultivable. Reclamation of such lands is necessary for improving the ecology and enhancing agricultural

productivity. Mapping and monitoring of wastelands, over the entire country, has been carried out using IRS data for implementing various reclamation/ development activities. Wastelands Change Analysis from 2005-06 to 2008-09 on 1:50,000 scale also has been carried out.

- **Water Resources Information System:** 'India-WRIS', a web-enabled single window water resources information system, is being developed with the available information (both spatial and non-spatial data). The ßeta version with some of the important databases has already been launched. Further development of the information system is underway, which consists of 12 major systems, 30 sub systems and 108 layers with more than 4000 attributes as per requirements of CWC.
- **Integrated Land and Water Resources Management Plans:** Space technology applications have been extensively put to use in the country for planning integrated development of land and water resources at watershed levels. Many projects carried out in this direction include Integrated Mission for Sustainable Development (IMSD) for around 25% of country's geographical area, community-driven 'Sujala Watershed Development Project (SWDP) in Karnataka etc. Such efforts have helped in drawing appropriate developmental plans at watershed/micro-watershed levels, catering to the needs of Drought Prone Area development Programme (DPAP), National Watershed Development Programme for Rain-fed Areas (NWDPRA), etc. The implementation of the locale-specific developmental plans have also resulted in reducing soil erosion, moisture conservation, increased crop yield, and enhanced overall income of households.
- **Command Area Development:** Management of irrigation water in command area requires information on a variety of terrain features besides total demand and its distribution. Multi-temporal IRS satellite data is being used operationally in the country for performance evaluation of command areas - involving cropping systems, cropping intensity, water-use efficiency from head-end to the tail-end, etc.
- **Enhancing Irrigation Efficiency:** Using high-resolution IRS data, under the Accelerated Irrigation Benefit Programme (AIBP), the status of irrigation infrastructure is being studied to assess the existing gap between the irrigation potential created and utilized. IRS data has also been used to map and monitor the status and spatial extent of water logging, soil salinity and alkalinity in major and medium irrigation commands. Using multi-temporal satellite data, capacity evaluation of the major reservoirs was also carried out. In order to control land/soil degradation due to salinity and alkalinity and improve agricultural productivity, high-resolution IRS data is being utilized for planning reclamation measures.
- **Disaster Management Support (DMS):** The unique combination of Remote Sensing (IRS), Meteorological and Communication (INSAT) satellites, together with aerial survey systems and contemporary microwave satellites, put to use in tandem, provide periodic observations and emergency communications support for monitoring and management of natural disasters in the country, such as tropical cyclones, floods, agricultural drought, earthquake, landslides and forest fire. These efforts are carried out by ISRO under the exclusively tailored Disaster Management Support (DMS) programme, institutionalised in association with concerned ministries/agencies. Space-based inputs are also being used for planning disaster mitigation measures.

Climate Change - impacts, vulnerability and adaptation research

During the preparation of India's Initial National Communication to the UNFCCC (INC), preliminary research was initiated on vulnerability assessment due to climate change on various socio-economic sectors and natural ecosystems in India. Indian climate change scenarios at the sub-regional level were developed to estimate impacts on ecological and socio-economic systems. In the Second National Communication to the UNFCCC (SNC), the networks are being strengthened to consolidate the study of impacts, vulnerability assessment and adaptation for climate change for the short, medium and long–term, across regional, sub-regional and national levels. The Indian Network for Climate Change Assessment (INCCA) under MoEF conducted a major assessment: **'Climate Change and India: A 4x4 Assessment- A Sectoral and Regional Analysis for 2030s',** to measure the impact of climate change in the 2030s on four key sectors of the Indian economy, namely Agriculture, Water, Natural Ecosystems and Biodiversity and Health; in four climate-sensitive regions of Indiaviz.the Himalayan region, the Western Ghats, the coastal area and the North-East region. This comprehensive assessment was conducted with the involvement of more than 43 scientists and 19 institutions. This '4x4 Assessment' examined the implications of climate change for India in 2030s (short term) deduced from a Regional Climate Model Had RM3 (Hadley Centre Regional Model Version 3) run for A1B scenario.

Programme on Climate change Research in Terrestrial environment: PRACRITI a programme on space-based global climate change observation has been launched to develop mechanisms to quantify the state of changing climate and model its impact on the terrestrial ecosystem. The PRACRITI programme presently consists of studies related with modelling the impact of climate change on agriculture, Himalayan cryosphere and hydrology as well as Sensor system studies for monitoring greenhouse gases. The programme is inter-disciplinary in nature and involves the collaboration of various agencies such as ICAR, CSIR, SASE, IITs.

The Indian Council of Agricultural Research (ICAR) launched a National Network Project on **'Impacts, Adaptation and Vulnerability of Indian Agriculture to Climate Change'** to assess the vulnerability of Indian agro-ecosystems to global warming and analyse adaptation and mitigation strategies. The network has focused initially on a comprehensive understanding of the impacts of global changes on different sectors of agricultural production viz. food crops, plantation crops, horticultural crops, fish, livestock, agro-forestry, soil, water, market and policy. This network has been expanded in the XIth plan with 25 centres. Further, climate change has been identified as a 'priority area' for National Agricultural Innovations Project (NAIP). This project will prepare Indian agriculture to face the emerging challenges, including those from climate change.

'National Initiative on Climate Resilient Agriculture' has been conceptualised to address the problems related to abiotic and biotic stresses. The scheme has three components: (i) strategic research on adaptation and mitigation of important grain and horticulture crops, livestock and fisheries, (ii) demonstration of best technologies in 100 'most vulnerable' districts to cope with current climate variability and (iii) capacity building of researchers, planners and other stakeholders.

The flagship CSIR programme on climate change: **Integrated Analysis for Impact, Mitigation and Sustainability (IAIMS),** is a multi-scale, multi-science modelling initiative through a network of institutions such as C-MMACS, CIMAP, IICT, IICB. The objectives of the programme are to: (i) Develop, calibrate and validate a multi-scale simulation platform for regional climate, (ii) Quantify and delineate natural climate variability and anthropogenic climate change through monitoring and modelling, (iii) Interface models of biological and socio-economic processes to models of climate dynamics, (iv) Generate reliable projections of climate change through validated models and develop adaptation and mitigation solutions.

Global climate models will be capable of generating solutions at spatial resolution of a district within a decade or so. The models of relevant processes need to be interfaced with the basic climate simulations and projections for application to local sustainability. This calls for a multi-science approach to sustainability and mitigation in a changing climate. Similarly, an effective modelling platform for climate change, sustainability and mitigation, combining different paradigms like continuum and discrete modelling is necessary.

Climate Change mitigation research

Solar Energy Research Initiative (SERI) of DST supports activities aimed at improving efficiency of materials, devices, systems and sub-systems, including innovative R&D demonstration projects. The programme also facilitates and encourages inter-institutional linkages to develop state-of-the-art products and development of critical mass of R&D strengths for Solar Energy Research. Applications of Solar Energy in areas other than power generation are being explored and assessed of their potential to provide convergent technology solutions under real-life conditions. The programme also demonstrates hybrid solar power systems integrated on various R&D pathways and multiple technology alternatives for distributed energy use to validate their viability to meet rural energy needs under public-private partnership mode.

Ministry of New and Renewable Energy (MNRE) has launched the National Biomass Cook Stoves Initiative, to ascertain the status of biomass cook stoves and to identify ways and means for development and deployment of efficient and cost-effective biomass cook stoves in the country. The Advanced Biomass Research Centre (ABRC) project is being undertaken by Indian Institute of Science, Bengaluru for biomass research and to identify gaps and ways to address the issues for technology development and advanced research for promotion of biomass energy in the country. The project has special focus on advanced research in thermo-chemical conversion, technology packages development, and development of specifications, test protocols and standards for biomass energy systems.

The growing concerns about energy security and environmental pollution caused by ever increasing use of conventional fossil fuels has led to a continuing search for environment friendly renewable fuels. Biofuels, which primarily include biodiesel and bio-ethanol, have been recognized the world over as the most suitable substitutes for petro-based fuels. In the Indian context, biofuels assume special importance, particularly from the energy security point of view, as the domestic supply of crude oil meets less than 30% of the demand. Several initiatives have been taken to supplement petro-based fuels with biofuels. MNRE is primarily involved in the development of a National Policy on Biofuels, besides Research, Development and Demonstration (RD&D) on transport and stationary applications using bio-fuels, strengthening the existing institutional mechanism and overall coordination regarding biofuels. The Indian Institute of Technology, Mumbai; VIT University, Vellore; and The Energy and Resources Institute (TERI), New Delhi are actively engaged in setting up modular pyrolysis units to process various agricultural and agro-industrial biomass wastes at decentralized locations for utilization of multi-feedstocks such as agricultural and agro-industrial biomass wastes and wood wastes. In order to direct research at second-generation biofuels, several focus areas include: (i) Lignocellulosic ethanol/bio-butanol production,(ii) Green diesel and BTL, (iii) Algal Biofuels and (iv) Bio-refineries.

The R&D project through C-WET has significantly expanded in recent times. Some of the recent activities include a performance quantification study on two 20-years design-life exhausted 200 KW wind turbine gear boxes after nano-coating, and establishment of 2 MW wind turbine for carrying out various R&D activities.

A broad-based research, development and demonstration (RD&D) programme for development and promotion of technologies like Hydrogen Energy, Fuel Cells, Electric and Hybrid Electric Vehicles, Geothermal Energy and Tidal Energy has been envisaged through research, scientific and academic institutions, national laboratories, universities, industries, state agencies and non-governmental organizations. Besides these, a broad-based RD&D programme on the different aspects of hydrogen energy technologies including hydrogen production, its storage and utilization for stationary, motive and portable power generation applications using internal combustion engines and fuel cell technologies has been planned.

Among the various forms of energy contained in the seas and oceans, tidal energy has been developed on a commercial scale. The potential sites of tidal power in India are in the Gulf of Kutch, Gulf of Cambay in Gujarat and the delta of the Ganges in West Bengal. In order to develop and harness about 8000-9000 MW of estimated tidal energy potential for power generation, the Ministry is implementing a programme on tidal energy.

A broad based programme for research, development and demonstration of Battery Operated Vehicles (BOV)/ Hybrid Electric Vehicles/Plug Hybrid Electric Vehicles with the objective of promoting BOVs and to get feedback on their performance in operating conditions has also been encouraged.

International Cooperation

International collaboration in earth sciences

Recognizing the importance of scientific and technical cooperation in Earth Observations and Earth Sciences, an MoU was signedby ESSO/MoES and NOAA (on behalf of the US Government) for Development of the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA) for improving weather and monsoon forecasts; Development of the South Asian Regional Reanalysis (SARR) to advance understanding, modelling, and prediction of monsoon Hydroclimate Variability and Change; Development of Climate Monitoring and Prediction System for the South Asian region for different temporal scales; Development of Climate Model and Ocean Assimilation Analysis for the Indian Ocean region for seasonal and decadal time scales; Tropical Cyclone Research; Tsunami Science, Detection, Analysis, Modelling, and Forecasting; Greenhouse gas Measurement and Research and Dynamical Seasonal Prediction of Indian summer monsoon rainfall.

IMD is actively participating in the International Cooperation Programme of Meteorology and allied subjects between the Government of India and the Governments of USA, Russia, Japan, China, Australia, Mauritius, France, Sri Lanka, Bangladesh, Maldives, Nepal, Iceland, Myanmar etc and under SAARC and WMO.

Indo-Korea partnership

The Ministry of Earth Sciences and Korea Meteorological Administration, Republic of Korea signed an Agreement of Cooperation (MOU) on 29th September 2010 in the field of Earth Sciences and Services. The main objective of the Agreement of Cooperation is to enable in-depth understanding and joint development of skilful forecasting capabilities of various weather and climate-related phenomena, especially because India and

Korea share similar weather conditions and atmospheric phenomena and have common interests and goals. Some of the prioritised areas of cooperation include aviation meteorological services, numerical weather prediction in various ranges and Asian monsoon.

International collaboration in science and technology

DST continued with the execution of its mandated responsibility of (i) Negotiating, concluding and implementing S&T agreements between India and other countries at bilateral and regional levels and (ii) Providing interventions on S&T aspects of multi-lateral bodies. This responsibility was carried out by DST in close consultation with the Ministry of External Affairs; Indian Missions Abroad; Science Counsellors posted in Indian Missions located in USA, Germany, Japan, Russia; S&T related ministries and sectoral ministries of Government of India; Indian scientific agencies and Indian science and engineering academies. DST continued its engagement with industrial and engineering associations/platforms in guiding initiatives to leverage international partnerships for joint research and technology development in domains of national priority.

International collaboration in space programmes

International cooperation has become an integral part of space programmes of all the countries across the globe. DoS has been pursuing bilateral and multi-lateral relations with space agencies and space-related bodies with the aim of building and strengthening existing ties between countries; taking up new scientific and technological challenges; refining space policies and defining international frameworks for exploitation and utilization of outer space for peaceful purposes. Formal cooperative arrangements in the form of either Agreements or Memoranda of Understanding (MoU) or Framework Agreements have been signed with Argentina, Australia, Brazil, Brunei Darussalam, Bulgaria, Canada, Chile, China, Egypt, European Organisation for Exploitation of Meteorological Satellites (EUMETSAT), European Space Agency (ESA), France, Germany, Hungary, Indonesia, Israel, Italy, Japan, Kazakhstan, Mauritius, Mongolia, Myanmar, Norway, Peru, Russia, Spain, Sweden, Syria, Thailand, the Netherlands, Ukraine, United Kingdom, United States of America and Venezuela.

ISRO's maiden mission to the Moon, the Chandrayaan-1, has been an exemplary example of international cooperation with international payloads. Two scientific workshops in January and September 2009 were organized, involving scientists of international payloads to share and discuss the invaluable data that emanated from this mission. Though the mission served for less than a year, it has achieved its mission objective to the satisfaction of the global scientific community. It has also earned several national and international laurels and has been instrumental in the ISRO-NASA joint discovery of water molecules on the moon surface, unattained by any of the previous missions of such nature. A Follow-on mission, Chandrayaan-2 will be jointly developed with Russia and will have an Indian orbiter and Russian lander, Russian rover and Indian mini-rover. There will also be opportunities for scientific instruments from other countries in Chandrayaan-2 mission.

The Indo-French joint satellite mission called MEGHA-TROPIQUES for the study of the tropical atmosphere and climate-related aspects such as monsoon and cyclone is making steady progress. It will have the MADRAS payload, for detection of rain through microwave analysis, and an atmospheric sounder called ROSA from Italy integrated into it. ISRO will use the well-proven IRS satellite bus, provide a PSLV launch, operate the satellite, collect and distribute the data.

Another joint mission with France for studying the ocean from space, using altimetry, is also progressing well. CNES will provide a radar altimeter instrument called ALTIKA and an onboard relay instrument for the international ARGOS data collection system, while ISRO will provide the satellite platform, launch and operations. There will also be international scientific cooperation in validating and calibrating the instruments and analysing the data from these two missions.

Considering the strong global demand for data from MEGHA-TROPIQUES, ISRO, CNES and NASA have agreed to integrate this satellite into the Global Precipitation Measurement (GPM) constellation of satellites. With this, MEGHA-TROPIQUES will be one of the eight satellites contributing to the global scientific community to study and understand the dynamics of climate system.

ISRO and the Canadian Space Agency (CSA) are working on the development of the Ultraviolet Imaging Telescope (UVIT) planned on ISRO's multi-wavelength astronomy satellite ASTROSAT.

India continues to play an active role in deliberation on the Science, Technology and Legal sub-committees of the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS). At the recommendation of the Indian delegation, UNCOPOUS included a new agenda on 'Space and Climate Change'. India also played a major role in other multi-lateral forums including United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP), International COSPAS-SARSAT system for search and rescue operations, International Astronautical Federation (IAF), Committee on Earth Observation Satellites (CEOS), Committee on Space Research (COSPAR), Inter Agency Debris Coordination Committee (IADC), Space Frequency Coordination Group (SFCG), Coordinating Group on Meteorological Satellites (CGMS), International Global Observing Strategy (IGOS), International Space University (ISU), Asian Association for Remote Sensing (AARS), International Society for Photogrammetry and Remote Sensing (ISPRS).

Internationally, ISRO plays an active role in sharing its expertise and satellite data for the management of natural disasters through various multi-agency bodies like International Charter for Space and Major Disasters, Sentinel Asia and UN-SPIDER. Sharing of Experience in Space (SHARES) is a scheme initiated by ISRO under which training in different applications of space technology is provided to scientists from other developing countries. The Centre for Space Science and Technology Education for Asia and the Pacific (CSSTE-AP) has been set up in India under the initiative of the UN Office for Outer Space Affairs (UNOOSA) and offers a nine-month post graduate diploma course in Remote Sensing and Geographic Information Systems (starting in July - every year), Satellite Communication (starting in August - every alternate year), Satellite Meteorology and Global Climate (starting in August - every alternate year) and Space and Atmospheric Science (also starting in August - every alternate year).

International collaboration in ocean monitoring/ research

INCOIS has played a key role in establishing frameworks of collaboration with oceanographic research institutions worldwide for gathering and sharing of data, and enhancing capacity by taking a lead in capacity building programmes. India, being the founder member of Intergovernmental Oceanographic Commission (IOC), continued to be a Member of the Executive Council. The regional alliance in the Indian Ocean for GOOS (IOGOOS) secretariat has been functioning at INCOIS since its inception in 2002. The IOGOOS membership has grown from 19 to 25 institutions representing 15 countries. Some of the major initiatives of IOGOOS are: (i) setting up of an Indian Ocean Panel working towards a strategy and implementation plan for Indian Ocean observations for climate, (ii) Data and information management, (iii) Remote Sensing and capacity building strategy, (iv) Prawn Pilot Project, (v) Keystone Ecosystems Project, (vi) Shoreline change monitoring project and (vii) Indian Ocean ChloroGIN initiative. IOGOOS members have played a key role in Argo deployments and enhancing the tropical moored buoy array. Further, INCOIS continued to serve as the Regional Argo Data Centre for the Indian Ocean region under International Argo Project. INCOIS continued to play a major role in the Partnership for Observation of Global Ocean (POGO), an international network of major oceanographic institutions in the world established to promote and enhance the implementation and integration of global oceanographic activities. The India-Brazil-South Africa Cooperation Network (IBSA)–Ocean is an emerging trilateral cooperation between India, Brazil and South Africa in the field of ocean science and technology, which is a major milestone in understanding the regional influence in global climate variability and utilization of ocean resources and space.

International collaboration in agriculture

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has initiated a programme to boost India-Africa partnership on agricultural research-for-development to fight poverty in dry lands and launched ICRISAT South-South Initiative (IS-SI) partnership between India and Africa for more opportunities for increased financial and technical support and enhanced public-private partnerships on research-for-development.

International collaboration in environment and forests

MoEF has about 20 bilateral cooperation agreements with a number of countries such as the U.K., France, Germany, Denmark, Sweden, Norway and the E.U. Indo-UK Collaborative Research Programme on Climate Change – Impact and Adaptation - Phase II is a joint collaborative research programme between the Government of United Kingdom, Department of Energy and Climate Change and the Ministry of Environment and Forests, Government of India. The institutions are responsible for undertaking research activities on various components. The future cooperation of India-Norway relates to biodiversity and bio-safety, chemicals and environmental hazards, climate change, glaciology and sustainable development. Indo-Swedish Joint Working Group on Environment identified the issues of climate change, biodiversity, hazardous waste management, clean technology and zero-discharge in polluting industries and air quality management for mutual cooperation. The cooperation in the field of environment protection with Egypt focuses on waste management, air and water quality, use of bio-fuels, protection of wetlands and water conservation etc.

International collaboration in new and renewable energy

The Indian Renewable Energy Programme has received increased recognition internationally in recent years. The Ministry of New and Renewable Energy cooperates through international bilateral/multi-lateral cooperation frameworks between India and other countries for cooperation in New and Renewable Energy. The focus of the interaction for cooperation has been to explore opportunities for exchange of scientists to share experience and for taking up joint research, design, development, demonstration and manufacture of new and renewable energy systems/devices by R&D institutions/organizations of both countries and thereby establishing institutional linkages between institutions of India and other countries. The major cooperation between the Ministry of New and Renewable Energy, includes the Department of Energy of the USA on Cooperation in the Development of Bio-fuels; Ministry of Climate and Energy, Government of the United Kingdom; Federal Republic of Brazil on Cooperation in Wind Resources; the Government of the Republic of Cuba; Indo-Iceland Renewable Energy Cooperation with the Ministry of Industry of the Republic of Iceland; Department of Resources, Energy & Tourism, Government of Australia; University of Saskatchewan, Indo-Canadian Renewable Energy Cooperation; Indo-Italian Renewable Energy Cooperation with the Ministry for Environment, Land and Sea of Italy; with the Secretariat of Energy of the United Mexican States; the Department of Energy, Republic of The Philippines; Ministry of Energy, Government of The Kingdom of Thailand; the National Energy Commission, Republic of Chile; India-Scotland Renewable Energy Cooperation with the Government of Scotland; The Ministry of Industry, Tourism and Trade of the Kingdom of Spain; Ministry of Power of the Islamic Republic of Iran, The National Renewable Energy Laboratory, United States Department of Energy on Solar Energy Research and Development; India-Sweden Renewable Energy Cooperation with the Ministry of Enterprise, Energy and Communications of Sweden; The Ministry of Electricity and Energy of the Arab Republic of Egypt and India-Uruguay Renewable Energy Cooperation.

In addition, interaction with USA and Japan for cooperation in New and Renewable Energy is being pursued under India-US Energy Dialogue and India-Japan Energy Dialogue, respectively. Interaction with EU for cooperation in New and Renewable Energy is being pursued under India-EU Energy Panel. A multi-lateral cooperation framework called Asia-Pacific Partnership on Clean Development and Climate (APPCDC) enables interaction for cooperation with USA, China, South Korea, Japan, Canada and Australia.

References and Sources

Attri, S.D. and Tyagi, Ajit, 2010. Climate Profile of India, Met Monograph No. Environment Meterology-01/2010, 1-122

ISRO, 2008. *Space Technology Applications for Climate Change.* Indian Space Research Organisation, Department of Space, Government of India

MoES, 2008-09. *Annual Report.* Ministry of Earth Sciences, Government of India

MoST, 2009-10 to 2010-11. *Annual Report.* Ministry of Science and Technology, Government of India

MoEF, 2009-10 to 2010-11. *Annual Report.* Ministry of Environment and Forests, Government of India, New Delhi

MNRE, 2009-10. *Annual Report.* Ministry of New and Renewable Energy, Government of India

MoWR, 2009-10. *Annual Report.* Ministry of Water Resources. Government of India, New Delhi

MHRD, 2009-10. *Annual Report.* Ministry of Human Resources Development. Government of India, New Delhi

MoA, 2009-10. *Annual Report.* Ministry of Agriculture, Government of India, New Delhi

Planning Commission, 2007. *11th five-year plan - Vol I-III.* Planning Commission, Government of India, New Delhi

Chapter 6

Education, Training, and Public Awareness




This chapter provides information on activities related to climate change education, training, and public awareness It highlights only the salient activities from a wide canvas of climate change education, training, and awareness efforts happening at all levels: public, private, and civil society. India's economy is closely linked to its natural resource base (water, biodiversity, mangroves, coastal zones, grasslands) and climate-sensitive sectors such as agriculture, forestry, and energy (hydro). Climate change may alter the distribution, quality, and availability of India's natural resource and affect millions of its inhabitants. Spreading awareness about climate change issues is considered to be an effective way of dealing with the challenges and threat of climate change, and the Government of India, along with its various network organizations, is committed to the cause. This chapter elucidates the efforts in this direction by various central ministries and departments, state governments, and public/private/NGO institutions. It also highlights India's various international research collaborations, aimed at improving the understanding of the issues of climate change.

Contents

Chapter 6 Education, Training, and Public Awareness

CHAPTER 6 Education, Training, and Public Awareness

Introduction

In line with the Government of India's commitment to spreading awareness about climate change education and strengthening the scientific network, the National Mission on Strategic Knowledge for Climate Change (NMSKCC) was identified to build a vibrant and dynamic knowledge system that would inform and support national action for responding effectively to the objectives of sustainable development. In order to further facilitate the implementation of the National Action Plan, the National Knowledge Commission to the Prime Minister was also identified as being an important component regarding climate change education. It is envisaged that, the Commission would carry out the following activities.

- Build excellence into the educational system to meet the knowledge needs/challenges and increase India's competitive advantage.
- Improve management of institutions engaged in intellectual property rights.
- Promote knowledge applications in agriculture and industry, and knowledge capabilities to make government an effective, transparent, and accountable service provider to the citizen.
- Promote widespread sharing of knowledge to maximize public benefit.

Both, the NMSKCC and the Knowledge Mission have been approved by the Prime Minister's Council on Climate Change. The various activities under the aegis of the two missions are subsequently underway.

One of the most important features of a vibrant democracy is the flow of information across stakeholder groups. Information regarding emerging planning and policy imperatives, qualitative and quantitative profiling of resources, and knowledge sharing are important elements in this process.

Three major institutional mechanisms have been evolved by the Government of India so as to streamline the country's response to climate change challenges. They are as follows.

1. **Inter-ministerial and Inter-agency Consultative Mechanism:** As preparatory to articulate policies and develop India's climate change response strategy, the MoEF being the nodal Ministry for Climate Change, constituted an inter-ministerial and inter-agency Consultative Group for Climate Change negotiations. This includes eminent national experts and has a political sub-group and a modelling sub-group on climate change. As forestry issues have gained importance, a separate sub-group on forestry issues was set up during the year 2007/08.
2. **Expert Committee on Impacts of Climate Change:** In pursuance of the announcement made by the Finance Minister while presenting the Union Budget 2007/08, the government set up the Expert Committee on Impacts of Climate Change on 7 May 2007 under the chairmanship of Dr R. Chidambaram, Principal Scientific Adviser to the Government of India. The Terms of Reference of the Committee were to study the impacts of anthropogenic climate change on India and to identify measures that we may have to take in the future in relation to addressing vulnerability to anthropogenic climate change impacts. The Expert Committee included eminent persons from various disciplines such as academia, science, and various government ministries and concerned departments.
3. **Prime Minister's Council on Climate Change:** A Coordination Committee chaired by the Prime Minister, named the Prime Minister's Council on Climate Change, was constituted in June 2007 to coordinate national action for assessment, and adaptation to and mitigation of climate change. The first Meeting of the Council was held in July 2007 and the second meeting of the Council was held in November 2007. One of the important decisions, among many other decisions, had been to prepare a national document compiling actions taken by India for addressing the challenges due to climate change and the action that it proposes to initiate.

National-level Programmes and Activities

India, in recognition of the above emerging challenges, devised a National Action Plan on Climate Change (NAPCC), which was released by the Prime Minster of India on 30 June 2008; outlining its strategy vis-à-vis climate change. Prepared by the specially constituted Prime Minister's Council on Climate Change, the document was intended to provide a concrete roadmap detailing how India plans to move forward in addressing the challenges posed by climate change. The Plan, while recognizing the immense threat posed by climate change, starts by first and foremost marrying climate change to development concerns in no uncertain terms. The very first line states, "India is faced with the challenge of sustaining its rapid economic growth while dealing with the global threat of climate change." Thus, the goal of development is unambiguously underscored, and climate change is recognized as a major problem, not least because it could hurt development targets.

The National Environment Policy (2006) provides the basis for the integration of environmental considerations in the policies of various sectors, with emphasis on economic and social development. Multiple initiatives of the government help integrate diverse goals and approaches (including renewable energy and energy-efficient technologies, joint forest management, water resources management, agricultural extension services, web-enabled services, and target-specific environmental education) and represent a broad spectrum of efforts to integrate climate change concerns in the planning process. It will be obvious that such information support and technical assistance interventions build capacities that can sustain transition to environmentally efficient production and consumption systems, duly recognizing the cross-cutting nature of impacts and the opportunities to synergize for optimal results.

The role of seven important ministries, their departments, and extension services in generating awareness on environment and, in particular, climate change is presented below.

Ministry of Environment and Forests

Within the government structure, the Ministry of Environment and Forests (MoEF) is the nodal agency for climate change issues in India. It has created a mechanism for increasing awareness and enhancing research in various areas by giving grants for wide ranging research programmes and creating centres of excellence. These cover issues related to the environment as well as climate change. Some of these initiatives are discussed subsequently.

The emergence of environmental issues at the top of the global agenda in the context of climate change concerns underlines the need for collective endeavour for the protection of the environment. This warrants informed and voluntary participation of all sections of the people in the movement for conservation and preservation of environment. Awareness of people about emerging environmental issues is an essential prerequisite for such participation. Effective implementation of environmental management and conservation programmes depends on imparting education, raising awareness, and training in the relevant areas. Without an adequate awareness of the impending challenges and their implications, few people would be motivated to participate actively in the programmes on environmental conservation. Environment education and awareness thus assume critical importance. The "Environmental Education, Awareness, and Training" is a flagship scheme of the Ministry for enhancing the understanding of people at all levels about the relationship between human beings and the environment and to develop capabilities/skills to improve and protect the environment.

Over the recent years, the MoEF has made efforts to fulfil its objectives of environmental education and awareness in a variety of ways, using institutional structures for information dissemination and outreach. Realizing the importance of environmental information, the Government of India, through the MoEF, in December, 1982, established an Environmental Information System (ENVIS) as a plan programme. The focus of ENVIS, since inception, has been on providing environmental information to decision-makers, policy planners, scientists, engineers, and research workers all over the country.

Since environment is a broad-ranging, multi-disciplinary subject, a comprehensive information system on it necessitates the involvement and effective participation of concerned institutions/organizations in the country, which are actively engaged in work related to different subject areas of the environment. ENVIS has, therefore, developed itself with a network of such participating institutions/organizations for the programme to be meaningful. A large number of nodes, known as ENVIS Centres, have been established in the network to cover the broad subject areas of the environment with a Focal Point in the MoEF. These nodes are supposed to create websites on specific environment-related subject areas (see Box 6.1 for more information on the activities of the ENVIS).

The ENVIS network addressing both the subject-specific areas and status of the environment and related issues, established under ENVIS Scheme, has continued its information-related activities, database development, publication of requisite information packages through newsletters, abstracting services, and query-response services over the years. The process is facilitated by updating and maintaining an information base that includes both descriptive information as well as numerical data.

The Ministry's website also provides various kinds of environment related information (Figure 1(a)), with a special focus on climate change and related activities (Figure 1(b)). The website has been revamped with better look, content, and design, adopting the latest technologies for appropriate and timely information dissemination.

Box 6.1 Environmental Information System (ENVIS)

It is a virtual system managed under the umbrella of the Ministry of Environment and Forests for archiving information and data on various environment-related activities, including climate change. The website of this activity is http://www.envis.nic.in/. The themes covered include chemical waste and toxicology, ecology and ecosystems, flora and fauna, environmental law and trade, environmental economics, environmental energy management, media, environment education, and sustainable development, state of environment report and related issues, and population and environment. The ENVIS Focal Point publishes Paryavaran Abstracts, a quarterly journal carrying abstracts of environmental research in the Indian context. It also publishes ENVIRONEWS, a quarterly newsletter, which reports important policies, programmes, new legislations/ rules, important notifications, and other decisions taken by the Ministry from time to time. The website of the Ministry, http://envfor.nic.in, was developed and is maintained by the ENVIS Focal Point.

Figure 1 (A): Snapshot of the website of the Ministry of Environment and Forests (MoEF)

Figure 1 (B): Snapshot of the website of the Ministry of Environment and Forests (MoEF) highlighting a separate section on climate change related activities

Climate change awareness initiative

The Ministry has also been extremely active in organizing and implementing outreach, education, and capacity building activities for different age groups throughout the country. Some of the sensitization programmes undertaken for climate change education and capacity building include the following.

Public awareness: During the year 2008/09, as per the Media Action Plan (MAP) adopted by the Ministry, the following major activities were supported/ sponsored.

- **"Vatavaran"** Travelling Film Festival 2008 was organized in eight cities across the country.
- The World Environment Day was celebrated on the theme: "CO_2: Pick Right! Towards Sustainability and Growth".
- **"Kaun Banega Bharat Ka Paryavaran Ambassador"** Campaign was launched on the World Environment Day 2008 by the President of India. The campaign for the MoEF was carried out by the Centre for Environment Education (CEE) in partnership with Arcelor Mittal.
- 125 street plays titled **"Khuli Hawa Ki Talash Mein"** were staged through the Centre for Education and Voluntary Action (CEVA) initiative for spreading awareness on environmental degradation in several states.
- Fifteen episodes of **"Sarokar/Kasoti"**, a 15-minute weekly environmental television magazine, covered various environmental protection measures and were telecast on Doordarshan and other regional channels.
- Thirteen episodes each of **"Koshish Sunhare Kal Ki"** and **"Fantastic Four"** on environmental issues were produced and disseminated through All India Radio.
- An Audio Visual Resource Centre (AVRC) was set up at the Centre for Media Studies (CMS), New Delhi, to streamline information and formatting of 500 video films produced/held by the Ministry.
- Thirteen documentaries on environmental issues were produced and telecast through Public Service Broadcasting Trust.
- Films on man–animal conflict and river pollution by Surabhi Foundation, distribution of environmental films among 10,000 member schools of the National Green Corps (NGC) Programme by the CMS, and TV Spots on Climate Change by the Centre for Science and Environment (CSE) were other major media activities commissioned during the year.
- Four training-cum-workshops on policy and legal issues / international conventions / biodiversity conservation and climate change/training of trainees were also undertaken.
- A Low Carbon Campaign was launched through Prasar Bharti Broadcasting Corporation of India during the Commonwealth Games 2010 in collaboration with the Ministry of New and Renewable Energy (MNRE) and Bureau of Energy Efficiency (BEE) by telecasting 30 public service messages and innovatively linking 10 Shera (mascot) pop-ups with energy- and environment-related issues.

The scope of the efforts to develop a comprehensive understanding of environmental and climate change issues in India extends beyond the diverse sensitization activities conducted through and by the Ministry. High quality scientific research contributes to updating the wealth of available knowledge on these issues and building confidence in various climate change adaptation and mitigation efforts.

Indian Network for Climate Change Assessment (INCCA), established by the MoEF in October 2009, is a network-based initiative and approach to make science the salient input for policy-making in climate change (see Box 6.2 for more details).

Box 6.2: Indian Network for Climate Change Assessment

Indian Network for Climate Change Assessment (INCCA), established by the Ministry of Environment and Forests (MoEF) in October 2009. , is a network-based programme to make science, particularly the "3 Ms" – Measuring, Modelling, and Monitoring – the essence of India's policy-making in the climate change space. It brings together over 120 institutions and over 220 scientists from across the country. The first report of the INCCA – an updated emissions inventory of greenhouse gases of anthropogenic origin of India for 2007 – was released on 11 May 2010. A comprehensive "4 × 4" assessment of key sectors in India – agriculture, water, natural ecosystems and biodiversity, and health – and key geographic "hotspots" – the North East, the Indian Himalayan region, the Western Ghats, and the coastal areas – was released in November 2010.

A group has also been constituted under INCCA, comprising scientists from the Indian Institute of Tropical Meteorology (IITM), Indian Space Research Organisation (ISRO), and MoEF to run specific regional models for the Indian sub-continent for the monsoon season so as to enable better assessment of impacts and reduction of uncertainties in monsoon projections over the South Asian region. Among other activities, the various knowledge institutions are grouped according to their respective expertise and capabilities to estimate greenhouse gas (GHG) emissions and develop country-specific emission factors from various sectors such as the energy, industrial processes, agriculture activities, land use change and forestry, and waste management.

The work programme in its present effort is designed to ensure adaptation assessments in the national context. Currently, the MoEF is in the process of generating multiple climate and socio-economic scenarios at the national scale, improving the national impact assessments of water resources, agriculture, forestry, natural ecosystems, coastal zones, human health, and energy. Studies have also been launched to address adaptation issues associated with climate change of key sectors using an integrated assessment methodology at select climate hotspots.

The key outcomes of this network-based programme are envisaged to (i) generate a comprehensive knowledge base on scientific issues related to climate change for informed decision making, (ii) enable integration of climate change concerns in the planning process and help in preparation and implementation of climate-specific roadmap within the National Action Plan on Climate Change, (iii) provide scientific information so as to strengthen India's position during international negotiations, and (iv) build capacity of institutions so as to enable training of new researchers in various aspects of climate change through climate-related projects awarded to different institutions.

Department of Science and Technology

The Department has initiated many programmes and initiatives encompassing the various aspects of climate change concerns. These are as follows.

1. **The Monsoon and Tropical Climate (MONTCLIM) and Indian Climate Research Programme (ICRP)** were implemented to focus on monsoon climate variability/change at different time scales and modelling atmospheric processes and technology development for atmospheric science research. Under this programme, various trainings/workshops were organized for sustained capacity building of personnel involved in climate change assessment, such as (i) Dynamic Simulation Modelling of Crop Weather Interactions in Brassica at CRIDA, Hyderabad, (ii) Agromet Database Management at CRIDA, Hyderabad, (iii) Land Surface Process Experiment (LASPEX) at Gujarat Agricultural University, Anand, (iv) XBT-training at National Institute of Oceanography, Goa, and (5) Geosphere–Biosphere Interactions Workshop organized at Guwahati.
2. **The Himalayan Glaciology Programme** was launched with the objective of understanding the behaviour of glaciers, in general, and their interaction with climate and hydrological systems. This programme also envisages to train manpower, develop expertise, and create necessary facilities for monitoring the state of Himalayan glaciers. Three Automatic Weather Stations (AWS) have been set up by the Snow and Avalanche Study Establishment (SASE), under Defence Research and Development Organisation (DRDO) at Manali, to provide real-time data on specific meteorological parameters that are expected to help understand microclimate of the glacier system. Live field-observation-based training courses in glaciology were organized by the Geological Survey of India (GSI).
3. A training course on "**Applications of ICP-MS in Earth System Sciences**" was organized to impart theoretical and practical training on geochemical analysis of major, minor, trace, and ultra-trace elements, including rare earth elements (REE) and precious metals for studies in earth, ocean, and atmospheric sciences.

Ministry of New and Renewable Energy

The MNRE also organized various programmes to promote better understanding of renewable energy issues. The

Information, Training and Commercial Services (ITCS) of the Centre for Wind Energy Technology (C-WET) organized international training course on “Wind Turbine Technology and Applications” to help countries in Asia and Africa in the domain of wind farm development. Numerous trainings related to wind resources, wind energy technologies, wind energy prediction methodology, wind energy measurements and prospects, and Clean Development Mechanism (CDM) were also organized. C-WET also publishes a quarterly newsletter “PAVAN” on wind energy development and maintains a bilingual website www.cwet.tn.nic.in for information dissemination.

The MNRE has also implemented the Information and Public Awareness (I&PA) programme, primarily through state nodal agencies and with the active involvement of organizations such as the Directorate of Advertising and Visual Publicity (DAVP), Doordarshan, All India Radio, Department of Post, and Petroleum Conservation Research Association (PCRA). Over 350 public awareness campaigns with the help of mobile exhibition vans (MEVs) and Vigyan Rail have been organized throughout the country so far. The Ministry currently constituted District Advisory Committees (DACs) on renewable energy, in order to encourage the participation of district-level functionaries in popularizing the use of renewable energy systems and devices. It publishes a bimonthly newsletter titled “Akshay Urja” in Hindi and English, and trains news media specialists. In addition to websites, an interactive solar-powered touch screen information kiosk has been installed at the Ministry’s Facilitation Centre, providing information on various MNRE initiatives.

The **Ministry of Agriculture** is also engaged in studies that explore several dimensions of climate change. Among the many climate-centric initiatives of the Ministry, the prominent ones are as follows.

- A decision support system, named InfoNitro (Information on Nitrogen Management Technologies in Rice), has been developed to quantify balance of nitrogen in soil, greenhouse gas (GHG) emission, and nitrogen use efficiency with the prominent management technologies relevant to rice.
- The National Food Security Mission (NFSM), a centrally sponsored scheme, was launched from 2007/08 in 312 identified districts of the 17 rice, wheat, and pulses growing states, with the aim of increasing production. New farm practices have been encouraged. Capacity building of farmers has been encouraged through farmers’ field schools.

  A drought-specific management manual has been developed by the National Institute of Disaster Management in consultation with central ministries, state governments, various scientific, technical, and research organizations, and several grassroot-level organizations. The manual is divided into several sections. The section on mitigation provides information on artificial recharge of groundwater, traditional water harvesting and conservation methods, rainwater harvesting, water saving technologies, and improved water-saving farm practices. It also discusses long-term irrigation management, afforestation, crop insurance, and community participation in drought mitigation.

Some important initiatives on information and public awareness by the Indian Council of Agricultural Research (ICAR), through its Department of Agricultural Research and Education (DARE), an autonomous institution under the Ministry of Agriculture, are as follows.

- A Digital Dissemination System (AGROWEB) for Indian Agricultural Research has been developed, which helps in developing the web-based interface to cater to the information needs of the vast stakeholders. In addition, it is also responsible for publishing and maintaining a Knowledge based System (E-PKSAR) and the project “Mobilizing Mass Media Support for Sharing Agro-information”; which is expected to provide crucial information for accelerated and sustainable transformation of Indian agriculture through print and electronic mode, targeting Panchayati Raj institutions, private sectors, and other stakeholders. It is envisaged that such an intervention would help in poverty alleviation and income generation.

Ministry of Earth Sciences

GURME (GAW (Global Atmospheric Watch) – Urban Research Meteorology and Environment program) International Workshop on Air Quality Forecasting was organized in 2008 to help understand advanced air quality modelling systems so as to meet the future challenges involving high resolution meteorological data and emission inventory of chemical pollutants.

A joint Indian Institute of Tropical Meteorology (IITM)–Asian Disaster Preparedness Center (ADPC) Training Workshop on Synthesizing Observed Local Variability and Climate Extremes (SOLVE) was organized as a part of the Climate Risk Management Technical Assistance

Support Project (CRM TASP) in which ADPC and IITM are the partners.

The **Ministry of Water Resources** printed and distributed 6 lakh "Meghdoot Postcards" with the design of rainwater harvesting structures and with message on the conservation of groundwater. The Central Ground Water Authority has organized mass awareness programmes and training on rainwater harvesting, including rooftop rainwater harvesting at different locations of the country. During 2007/08, chemists from various laboratories participated in mass awareness programme and trade fairs and prepared posters, handouts, and diagrams on water quality for display. They demonstrated the testing of various chemical parameters present in water and their impact on human body. The importance of water quality in artificial recharge of groundwater through rainwater harvesting and for drinking, agricultural, and industrial purposes was also explained to progressive farmers, visitors, and students.

Groundwater management training programmes were also organized, wherein many people from local government, NGOs, and voluntary organizations were trained.

Ministry of Power

- BEE, with support from United States Agency for International Development (USAID), developed the Energy Conservation Building Code (ECBC) in India under the USAID ECO-II Project. The Ministry of Power launched ECBC in May 2007 for its voluntary adoption in the country. ECO-III Project has been assisting BEE in the implementation of ECBC, and has carried out a number of activities. These include ECBC awareness and training programmes; development of ECBC tip sheets on building envelope, lighting, heating, ventilation, and air conditioning (HVAC), and energy simulation; capacity building; and fast dissemination of information and knowledge related to ECBC amongst practicing architects, building designers, energy auditors/consultants, state designated agencies (SDAs); and municipalities.
- A few energy end-use sectors in India are gradually adopting newer technologies and management techniques to improve energy efficiency. However, penetration of these at the national/sectoral level has remained slow. Keeping this in view, ECO-III Project has taken an initiative to establish Regional Energy Efficiency Centres (REECs), mainly to provide public education and awareness, facilitate demonstration (showcasing products), promote technology development (incubation), and catalyse energy efficiency amongst the energy end-users and general public at large.
- With support from Asia-Pacific Partnership, ECO-III is supporting three REECs focusing on domestic appliances, buildings, and industrial furnaces of small and medium enterprises (SME). Initial funds are being provided by the government. However, REECs: in an effort to become self-sustainable in the longer run, plan to diversify their funding from multiple sources through public-private partnership.
- Energy efficiency in buildings has been a priority area for BEE, considering the substantial growth that is taking place in the Indian services sector. BEE has been working with various stakeholders to promote energy efficiency in existing buildings and voluntary adoption of ECBC in new buildings. However, as a long-term strategy, ECO-III Project, with support from BEE and Asia-Pacific Partnership, is empowering the faculty members of architecture and engineering institutions (through "training of trainer" programmes) as well as the students by providing access to world class reference material and preparing them as next-generation professionals to face energy efficiency challenges in the building design and the construction sector.
- The Ministry of Power has also instituted National Energy Conservation Awards to motivate industrial units to conserve energy and improve end-use energy efficiency. This award scheme has been extended to the aviation sector and manufacturers of BEE Star labelled appliances. Indian industrial units, office buildings, hotels and hospitals, zonal railways, state designated agencies, municipalities, and BEE's star labelled product manufacturers, who are leading the way in becoming more energy efficient, were awarded by the Ministry of Power in a function organized on the occasion of National Energy Conservation Day, on 14 December 2009. These annual awards recognize innovation and achievements in energy conservation by the industries, buildings, railways, state-designated agencies, and municipalities, and raise awareness about energy conservation.

State-level Initiatives

A conference was organized involving ministries/ departments of environment and forests of various state/UT governments, on 18 August 2009, which was addressed by the Prime Minister. In the Conference, all the state governments were called upon to prepare State Level Action Plans on Climate Change (SLAPCC), consistent with the strategy outlined in the NAPCC. Accordingly, action has been initiated for the preparation of SLAPCC consistent with the NAPCC in a time-bound manner. The SLAPCC will enable communities and ecosystems to adapt to the impacts of climate change effectively. The Ministry has launched coordinated efforts, in collaboration with several international agencies, to support state governments in this initiative. Three specific projects proposed by GTZ, DFID, and UNDP have already been endorsed by the Ministry.

The departments of environment in the various state government and local government are also playing an active role in creating awareness and implementing various capacity building and research initiatives towards adaptation and mitigation. Some of the examples at a sub-national level are as follows.

Maharashtra

- **The Maharashtra-ENVIS Centre:** Climate Change – Interactive Forum has been established to understand and define "climate change" and its links with local scenarios, which help undertake mitigation measures accordingly.
- The Government of Maharashtra has signed an MoU with The Energy and Resources Institute (TERI) to incorporate climate change related issues on a priority basis in its policies, plans, and projects. The study "Assessing climate change vulnerabilities and adaptation strategies for Maharashtra" is a two-year joint TERI-UK Meteorology Office research project to assess the regional impacts of climate change by using advanced modelling techniques. The project will focus, in particular, on projected climate change impacts like changes in temperature, precipitation, and sea level rise, and relate these impacts to Maharashtra's water resources, agriculture, coastal areas (particularly Mumbai), and important rural and urban livelihood systems. Many training and orientation workshops for building local capacity on vulnerability assessment and adaptive policy-making are planned to be organized.
- The World Institute of Sustainable Energy (WISE), a non-profit institute based in Pune, has undertaken the task of developing State Level Clean Energy Technology Action Plan for climate change mitigation in the states of Maharashtra, Karnataka, and Rajasthan.
- The Department of Environment has recently issued climate change related guidelines pertaining to the use of energy saving instruments in government buildings.

Andhra Pradesh

The Centre for Climate Change and Environment Advisory, within the Andhra Pradesh government, is envisaged to function as follows:

- Act as a think-tank and help translate government goals, objectives, and policy priorities in climate change and environmental management.
- Reform agenda into tangible policy and climate change adaptation actions by the state. Provide technical support and advisory services to state, municipal, local governments, and national and international organizations in the areas of climate change and environment.
- Create a knowledge hub and document best industry practices and models in climate change and environmental management.
- Create and house technology and geographic information system (GIS) interfaces in climate change and environmental management.
- Provide a platform for industry and others for carbon market and its modelling and provide environment–economic models for adoption by the industry and other agencies.

Through a research cooperation with Bioforsk, the project "Climarice-II", supported by the Norwegian Ministry of Foreign Affairs through the Royal Norwegian Embassy (RNE), New Delhi, has collaborated with other partners including, International Pacific Research Centre (IPRC), Hawaii; Tamil Nadu Agricultural University (TNAU), Coimbatore, along with International Water Management Institute (IWMI), Hyderabad. This network has been formulated as a case study for establishing strong institutions that enables management- and application-oriented research for farmers so as to meet the challenges of extreme floods and droughts.

Gujarat

The Department for Climate Change in the Gujarat government funds research in green technology; prepares a comprehensive multi-dimensional climate change policy for Gujarat state – Conservation of Land, Water and Air; and coordinates with all other departments with respect to climate change.

It is envisaged that various universities within the State will undertake R&D on climate change along with the introduction of new courses and teachers training modules on climate change, as a part of the Government of Gujarat's initiative on building educational curriculum to spread awareness about climate change. It is also envisaged that public participation and public awareness would play important roles in addition to cooperation with national and international agencies. It will also carry out a study on the impact of global warming along the state's 1600 km coastline. Gujarat currently has 29% share of the entire country's carbon credit. The state government further intends to launch "Green Credit Movement" on the lines of carbon credit.

The Gujarat government launched a state-wide campaign to create awareness on climate change and its impact on environment and human life. The Gujarat Ecology Commission (GEC) under the state Department of Forests and Environment has been made the nodal agency for the campaign. GEC has also developed a logo with tagline "You can beat the climate change too!" and have released a character called "Jeeva Bapa"—a man dressed in traditional Gujarati attire, which will be used during the campaign to educate school students and rural population. The Gujarat Forest Department manages a "Social Forestry Programme" for planting trees on non-forest lands and became a pioneer to improve green cover of the state. The objectives were to increase the number of trees in Gujarat, promote the participation of people and institutions, and convert unproductive land to productive use as a part of the state's agenda towards sustainable growth.

Kerala

The Kerala government envisages to have a separate institutional set-up to study the issues related to climate change and prepare itself in advance to face them. It would be implemented by the State Council for Science, Technology and Environment.

Madhya Pradesh

The Madhya Pradesh government created a dedicated cell on CDM in Environmental Planning and Coordination Organisation (EPCO) to create awareness amongst Indian organizations about CDM and its benefits and to build capability for developing and implementing CDM projects. The prime objectives of the Cell include creating awareness about CDM and training of resource persons on the various dimensions of CDM.

The government is also in the process of establishing partnerships with institutions like TERI, Development Alternatives (DA), Confederation of Indian Industries (CII), and Federation of Indian Chambers of Commerce and Industries (FICCI) in this field. FICCI, in partnership with Norwegian Development Agency (NORAD), is interested in taking up certain pilot projects for CDM-related activities to prepare a status paper on CDM-related project and potential available in the state. State Carbon Fund is envisaged to be created in EPCO for capacity building activities and project formulation cost.

Tamil Nadu

The Department of Environment in Tamil Nadu proposed and implemented several schemes during the Tenth Five-year Plan, which include conservation of coastal ecosystem, land management, preparation of the status of environment report, conservation of wetland ecosystem, implementing eco-cities programme, forming biodiversity conservation network, environment R&D, setting up an agency for environmental projects, and generating environment education and awareness.

The draft Second Master Plan of the Chennai Metropolitan Development Authority (CMDA) offers direction on the greening project. A project to plant 35,000 trees in six municipal corporations in the state has been initiated at a cost of Rs 40 million. Several other initiatives such as use of compact florescent lamps (CFLs), hybrid cars, and clean and renewable energy sources such as solar, geothermal, and wind power are taken up by the government on priority.

The United States Educational Foundation in India and the East West Centre, Honululu, have formed an action group called Full Bright Environmental Action Group to create awareness on various environmental issues such as climate change and its implications, importance of safe drinking water in rural areas, eco-sanitation, harmful effects of overuse of pesticides in agriculture, and solid waste management in the region.

Delhi

The Government of Delhi initiated the idea of adoption of CDM concepts in all infrastructural initiatives. The infrastructural agencies in general agreed to adopt various concepts in implementing CDM projects, which, inter alia, include energy conservation, use of CFL and electric chokes, solar water heating systems, efficient street-lighting, efficient use of water pumps, energy-efficient buildings, promotion of light-emitting diodes (LEDs), use of solar air-conditioning, and afforestation.

The Mahatma Gandhi Institute will be involved in research, planning, capacity building, and imparting training on global warming issues and climate change. It will be under the Department of Environment. The Energy Efficiency and Renewable Energy Management Centre of the Delhi government, earlier geared towards integrated rural renewable energy, will now engage in partnerships and conduct research on non-fossil fuel energy development. Delhi's new Action Plan on Climate Change lays heavy emphasis on forest plantation, CFL lighting, and using renewable energy like solar energy and clean public transport.

The Department of Environment sponsored a project "Environmental Consequences Due To Urbanization". This project is an attempt to prepare a GHG emissions inventory for Delhi, which will help in developing baseline information on emission levels and identifying major sources and sectoral contributions. To fulfil these objectives, estimation has been done using two approaches – top-down and bottom-up – using IPCC Tier 1 Methodology. On-site monitoring of GHGs was also carried out at 64 sites across Delhi using CO_2 and CH_4 automatic analysers. Based on the carbon map, various policy measures have been recommended in the report.

Karnataka

The state government formulated a renewable energy policy to harness green and clean renewable energy sources in the state for environmental benefits and energy security. The objectives of the policy are as follows.

1. To harness environment-friendly renewable energy sources and to enhance their contribution to socio-economic development.
2. To meet and supplement rural energy needs through sustainable renewable energy projects.
3. To provide decentralized energy supply to the agriculture, industry, commercial, and household sectors.
4. To supplement efforts in bridging the gap between demand and supply of power with renewable energy sources and strengthening the grid and evacuation systems and arrangements for renewable energy projects.
5. To support efforts for developing, demonstrating, and commercializing new and emerging technologies in the renewable energy sector, and towards this end, help establish linkages with national and international institutions for active collaboration.
6. To create public awareness and involve users/local community in establishing, operating, and managing renewable energy projects while undertaking capacity building measures.
7. Establish dedicated renewable energy "special economic zones" (SEZ) to promote renewable energy projects.
8. Give necessary support and facilitation to entrepreneurs and investors to successfully implement renewable energy projects without delay and to attract more investment in the state by private developers.

Assam

The Department of Environment and Forests, Assam, started a pilot project called "Natural Resource Management and Integrated Livelihood Project (NARMIL)" under the Assam Agricultural Competitiveness Project (AACP), with the objective of improving livelihood of the communities through integrated approach of rural development and natural resource conservation in forest fringe communities in 15 villages. Joint Forest Management Committees at village level and NGOs are the implementation partners with the Department of Forests, Assam.

Uttarakhand

The Uttarakhand Jal Vidyut Nigam Ltd (UJVNL) – a state government undertaking – is spearheading efforts in the state to address challenges due to climate change. UJVNL is, therefore, mandated to participate in the global carbon market through the purchase of high quality certified emission reductions (CERs) credits from climate-friendly projects in Uttarakhand. UJVNL has taken pioneering steps in availing the CDM benefits from Greensite projects, and has prepared PIN, or Project Idea Note, and the respective PDD, or Project Design Document, for four small hydro projects. UJVNL is also taking appropriate steps to avail the CDM benefits from renovation and modernization of the existing power plants.

West Bengal

Kolkata, capital of West Bengal, launched an LED pilot as part of the Climate Group's Lightsavers Programme. The Climate Group and the Kolkata Municipal Corporation

(KMC) have unveiled an extensive LED pilot project. The trial will see LED streetlights installed across nine arterial roads in Kolkata, with 350 lights being tested in total. The project will evaluate the performance of LED luminaries with respect to illuminance, uniformity, colour, temperature, durability, longevity, and colour shift, over two to three years. The project is being carried out as a joint collaboration with the Government of India's BEE, the West Bengal State Electricity Distribution Company Ltd (WBSEDCL), and the West Bengal Pollution Control Board (WBPCB), with overall facilitation by the Climate Group.

There exists a climate vision plan for Howrah, being drawn up by the Howrah Municipal Corporation. The plan calls for creating an underground sewer system across the city (the present drainage system runs on the surface), regular testing of water supplied by the civic body, and monitoring the use of groundwater. Among other measures in the pipeline are implementation of a scheme of traffic rationalization, imposition of green tax on industrial units that emit excessive CO_2, conservation of the Hooghly river, upgrading of the public health infrastructure to tackle diseases resulting from climate change, and setting up of disaster management units.

Himachal Pradesh

In order to achieve the objectives of National Action Plan on Climate Change (NAPCC) and dovetail state's initiatives with the centre, the Himachal Pradesh government has formed State Level Governing Council on Climate Change. The overall objective of the Council would be to monitor targets, objectives, and achievements of the national missions specified in NAPCC. The centre will be a repository of databases on environment, natural resources, and climate change.

The state has constituted a voluntary "Environment Fund" for protecting environment and combating climatic changes. The Government of Himachal Pradesh has drafted a climate change policy to strengthen its green initiative and earn maximum benefits of carbon credits under the Clean Development Mechanism (CDM). The draft policy prepared by the Environment and Scientific Technology Department has been circulated amongst all stakeholders for comments and suggestions, considering substantial impact on viability of hydropower projects, cropping patterns, and geographic shift in horticultural activities.

Some Select Government-supported Education and Outreach Initiatives

The 25 ENVIS Centres of the Government of India function as a dynamic network of numerous institutions in the country, based on which it is easy for stakeholders to access relevant information rapidly. The network comprises ENVIS nodes in several government departments, institutions including the Botanical Survey of India, the Zoological Survey of India, the Wildlife Institute of India, the G.B. Pant Institute of Himalayan Environment and Development, and the Central Pollution Control Board, and various NGOs, including the Bombay Natural History Society, TERI, and the Centre for Environment Education.

National Green Corps (NGC) Programme: it is a well established and recognized fact that the children can be catalysts in promoting a mass movement about various environmental issues. Being future citizens, inculcation of environment-friendly attitudes and behavioural patterns amongst them can make a significant difference to the long-term efforts for the protection of the environment. The MoEF has, hence, embarked upon a major initiative for creating environmental awareness among children by formulating NGC in 2001/02. In less than nine years since the programme has been in operation, it has been catapulted into a mass movement of children for maintaining and preserving the environment. A total of 130,931 eco-clubs have so far been established in NGC schools across the country.

National Environment Awareness Campaign (NEAC) fulfils the need gap for a mass movement for the protection of the environment, which needs no emphasis. The concerns of the people for the environment need to be harnessed into voluntary action. This requires a network of nodal agencies and grassroot-level organizations. The NEAC was, hence, launched in mid-1986 with the objective of creating environmental awareness at the national level. In this campaign, nominal financial assistance is provided to NGOs, schools, colleges, universities, research institutes, women and youth organisations, army units, government departments, etc. from all over the country for raising awareness and conducting action-oriented activities. The awareness activities could be seminars, workshops, training programmes, camps, padyatras, rallies, public meetings, exhibitions, essay/debate/painting/ poster competitions, folk dances and songs, street theatre, puppet shows, preparation and distribution of environmental education resource materials, etc. Action components could be plantation of trees, management of household waste, cleaning of water bodies, taking up water harvesting structures, use of energy saving devices, etc. Diverse target groups encompassing students, youths, teachers, tribals, farmers, other rural population, professionals, and the general public are covered under the NEAC. The programme is implemented through designated regional resource agencies (RRAs) appointed for specific states/ regions of the country. Thirty-four RRAs appointed by the Ministry are involved in conducting, supervising, and monitoring the NEAC activities. The theme for NEAC 2009/10 was climate change, covering sub-themes such as plantation activities, solar cookers and solar heaters, restoration and maintenance of waterbodies, wetland conservation, and energy conservation.

Indian Agricultural Research Institute (IARI) carries out important investigations on spatial and temporal diversity of GHGs and emissions from agro-systems, sources and sinks and their relationships, modelling carbon and nitrogen dynamics, vulnerability to climate variations, characterization of climate parameters of agricultural importance, agronomy, sustainable land-use systems, and policy initiatives. The Indian Council of Agriculture Research (ICAR) also organized a summer school on photosynthetic efficiency and crop productivity under climate change scenarios. The other areas under its domain include participatory rural appraisals and optimization tools for site-specific management, decision support systems integrating natural resources inventory, simulation of soil and water processes, and conservation practices in watersheds. The University of Agricultural Science, Bengaluru, has established the Centre for Studies in Global Climate Change and Food Security, which would act as an important research centre to facilitate climate change specific research.

Indian Council of Forestry Research and Education (ICFRE) is an apex body in the national forestry research system, working on holistic development of forestry through need-based policy education and extension services. The Biodiversity and Climate Change Division builds capacities on CDM vis-à-vis forestry for the benefit of forestry officials and assesses policy aspects in international negotiations. Case studies on carbon mitigation potential and assessment of barriers in afforestation and reforestation are important approaches being followed by the institute. The institute is also linked with the EU initiative through an information dissemination and policy reform agenda programme. The Forest Survey of India (FSI) is similarly engaged in many activities, and forest cover, diversity, and abundance mapping are the important thrust areas of the institute. Some of the other related areas are near-real time monitoring of fires and investigations on land-based protected areas, and marine and freshwater systems. These include assessments of coral reefs, mangroves, and vegetation in the Ganga basin.

Wildlife Institute of India organizes several capacity building programmes on vulnerability assessment and adaptation due to climate change with reference to agriculture, forestry, and natural ecosystems for senior forestry officials and other stakeholders in the areas of zoo management, interpretation, and conservation.

National Dairy Research Institute, Karnal, works on the impacts of climate change on milk production in buffaloes and their links with roughages on milk production and methane emissions. Links with livestock management and agro-forestry have also been studied.

National Carbon Project, Regional Climate Modeling and Impact Assessment, Specific Atmospheric Assessment Projects and the ISRO Geosphere Biosphere Programme are some of the important programmes that address issues and contribute to an overall understanding of parameters responsible for the observed climatic changes. Several training and capacity building programmes are inherent parts of these initiatives.

Regional Research Laboratory, Bhubaneswar, undertakes research on energy conservation in industries. Several training programmes on these aspects have been and are being organized. The **Central Leather Research Institute** developed a report on the development of environment-friendly technologies through the modernization of various sectors. The **Indian Institute of Petroleum** delivers several certification programmes to enhance technical capabilities of stakeholders, particularly on pollution abatement.

Department of Science and Technology, through its various departments and missions, including WAR, or Winning, Augmentation and Renovation, for Water, Solar Energy Research Initiative, and Monsoon and Tropical Climate, are making significant contribution in the domain of climate change research, capacity building, and assessment exercises. Similarly, the **India Meteorological Department (IMD)** publishes various types of climate data products/publications for the benefit of end-user agencies.

National Physical Laboratory, the National Chemical Laboratory and the Central Institute of Mining and Fuel Research are some of the institutions working on GHG inventories and emissions, chemical substitution, energy conservation, atmospheric chemical dynamics, and specific technical assistance programme.

National Climate Center (NCC) is responsible for long-range forecast, climate monitoring, diagnostics, and development of climate data products. It released its annual climate summary for the first time in 2004. The recently published summary is for the year 2008. The **National Institute of Oceanography** specializes in areas of oceanic climate change and sea level and its impacts and is involved in numerous kinds of research and outreach programmes.

IITM has developed Climate Change Data Archive and Retrieval Systems that are useful for decision-making. One of the main objectives of the IITM is the "estimation of change and uncertainties in the South Asian summer monsoon rainfall under different climate change scenarios – based on dynamic downscaling of monsoon rainfall using regional climate models". The model data will be needed by different user groups for conducting impact assessment studies.

Various countrywide autonomous and non-governmental institutions are actively engaged in general environmental awareness programmes and activities, encouraged and supported by the Government of India, with special focus on climate change. Information on some selected agencies is presented subsequently.

The Centre for Science and Environment (CSE) publishes several newsletters, magazines, films, interactive electronic media, and technical publications aimed at sensitizing stakeholders across all strata of the society. This is in addition to its important role in advocacy with a special emphasis on equity and environmental justice. IIT Delhi and IIT Madras joined hands with CSE to launch the landmark Indian Climate Research Network on 6 March 2010 in Delhi. The Green Schools Programme of CSE acts as Environment Education Unit (EEU), aimed at encouraging and identifying "green" – environment-friendly – schools. Under this programme, students are trained and encouraged to carry out a rigorous "environmental self-audit" of their schools' use of resources, primarily on parameters related to water, air, land, energy, and waste.

Institute for Rural Management, Anand, has organized a series of management development programmes on climate change mitigation and adaptation. The **Indian Institute of Technology, Kharagpur, Indian Institute of Management (IIM), Lucknow, IIM, Bangalore, Institute for Social and Economic Change (ISEC), Maulana Azad National Institute of Technology (MANIT), and IIM, Ahmedabad,** organized seminars on strategically important management and policy aspects relevant at the national, regional, and global levels, particularly on aspects of natural resources management, technology and economic aspects, support for entrepreneurs and industrialists on various aspects of mitigation and adaptation, and energy management.

Indian Institute of Technology, Kharagpur, is engaged in the advancement of the use of renewable energy in rural India. The PK Sinha Centre for Bio-Energy at IIT, Kharagpur, India's first integrated bio-energy centre, works on climate change and economic challenges.

The Centre for Environment and Education (CEE), through its various offices associated with the seven regional cells across India, reached out to diverse stakeholders on location-specific scoping, mitigation, and adaptation measures. Some of the activities were as follows.

- CEE Himalaya has held series of teachers training workshops on disaster risk reduction and climate change adaptation in Baramulla, Kupwara, Srinagar, and Gandarbal districts of Jammu and Kashmir. The programme aims at grooming teachers as "Green Ustads", who have the basic understanding of the changing dynamics of global climate and the mitigation of risks caused by the changing climate.
- As a part of "Disaster Risk Reduction Awareness and Preparedness Campaign in Schools in the Kashmir Valley", students from around 2000 schools are learning about the natural disasters and various preventive measures. These schools were also a part of CEE's "Pick Right" and "Kaun Banega Bharat ka Paryavaran Ambassador" campaigns. Schools from Ladakh, Himachal Pradesh, and Uttarakhand also participated in this campaign.
- Community-based disaster preparedness initiative has been taken up in 50 villages falling in five districts of Jammu and Kashmir. The villagers analyse local climate change, availability of water, and seasonal variations along with other risks and hazards. They map natural resources and develop contingency plans involving suitable alternatives to tackle risks.

C.P.R. Environmental Education Centre (CPREEC) organized an exhibition on climate change at its premises

Climate Change Awareness initiatives

on 16–28 February 2009. Several schools brought their students in batches to view the exhibition. A booklet on climate change was developed and distributed among the school students. As a part of the exhibition, CPREEC also conducted "poster designing competition" for the school students of Classes VI to XI on 28 February 2009. CPREEC, in collaboration with the British Council of South India, launched the "Indo-UK Films for Schools Project" on Climate Change for Tamil Nadu on 12 November 2009, which was followed by a workshop for teachers.

The National Strategy on Climate Change in India (NSCCI) has aimed at the following.

1. Designing a National Climate Policy and incorporation of it in Eleventh Five-year Plan. It also envisages to analyse co-benefits of several policies to tackle the challenges due to climate change (both in terms of mitigation and adaptation) and thereafter suggest suitable remedial policy measures to bridge the various gaps.
2. Integrating environment, ecology, and climate change concerns in Indian fiscal federalism framework.

The specific project involved construction of an environmental performance index for all states in India. The index scores are envisaged to be a basis on which a "grant for environmental management" would be disbursed between states. The project would also delve into the possibility of a climate change response facility for states that are most vulnerable to the ill-effects of climate change. This project would be conducted under the aegis of ICSD. The centre has also embarked on a pilot application of participatory approach to investigate local vulnerability and adaptation to climate variability and water stress in Uttarakhand.

Climate Change Outreach and Awareness Programme through the USAID assists local institutions in becoming better providers of information on climate change. The other institutions involved in this programme are CII, IIM, Ahmedabad, FICCI, TERI and Credit Rating and Information Services India Limited (CRISIL).

Development Alternatives received the prestigious "Development Market place 2009" award for its innovation on creating a reality show for communicating climate change risks to rural women and youth in Bundelkhand, and to undertake adaptation measures with multiple benefits.

Integrated Research and Development (IRADE) is a "Centre of Excellence" in the area of urban development on "Climate Change Vulnerability and Adaptation" of the Ministry of Urban Development, Government of India. It aims at identifying important options for mitigation and adaptation, which are aligned with development plans of Indian cities, and preparing state governments for tackling the challenges and providing policy prescriptions for vulnerable areas.

M.S. Swaminathan Research Foundation has carried out extensive outreach activities on the management of coastal systems using community-based models for mangrove restoration and rehabilitation and livelihood generation. This has integrated identification and characterization of novel genetic combinations from mangrove species offering tolerance/resistance to abiotic stresses. Amongst its other activities, it carried out the following.

- Established the "*Community Food Security System*" consisting of seed, grain and water banks to achieve stability of food production and elimination of chronic and transient hunger induced by various factors including climate change.
- Hosted an inter-disciplinary dialogue on the theme "*Community Management of Climate Change: Role of Panchayats and Nagarpalikas*" to prepare a well-defined roadmap for empowering local communities with knowledge and skills relevant to enhancing their

capacity to manage the adverse impact of climate change. A series of consultations involving various panchayat leaders have been initiated to discuss the possible components of such a legislation.

- Hosted a "*National Dialogue on Adaptation to Climate Change*". Participants included Cabinet Ministers, Prime Minister's Special Envoy for Climate Change, Secretaries from various ministries, State Secretaries, donor agencies, members of Planning Commission, academics, and various NGOs.

Centre for Social Markets (CSM) runs the Climate Challenge India initiative to reframe the climate debate in India and to create a proactive, opportunity-led approach towards addressing it. CSM is active in many national and international networks on sustainability, corporate responsibility, climate change, and other issues. Public awareness building and mobilization to make political constituencies more receptive to the need for change are central to the campaign. Business and city elites are another target for focused engagement and leadership. The Climate Challenge India initiative was to promote a proactive domestic response to climate change in India, as also the City Dialogues on Climate change. Working closely with the arts and culture community, the campaign uses creative media technology to reach out to India's geographically and linguistically diverse communities, building a nationally relevant knowledge and communications platform in the process. An important directory about institutions working on various aspects of climate change has also been published.

Climate Project is an international non-profit organization founded by Nobel Laureate Al Gore in June 2006 and is dedicated to calling attention to what it believes are global problems associated with climate change. The Climate Project-India (TCP-India) is an independent chapter of this international organization. It has trained over 120 presenters in India, who voluntarily raise awareness about climate change by interacting with media, corporations, or by simply making presentations to their own communities and networks. TCP-India supports these presenters by providing guidance and updated information. It has, in a short span, trained over 700 presenters, comprising representatives from the civil society.

Climate, Energy and Sustainable Development Analysis Centre (CESDAC) is aimed at providing an information base to facilitate developing countries of Asia and the Pacific in coping with the potential threats due to climate change and includes educational and training programmes, which emphasize the teaching of the concepts and methods of sustainable development, including the need for diversity of solutions in different national and regional circumstances. It also undertakes publications on climate change, innovative approaches to energy efficiency, environmental education, and sustainable development challenges in Asia and the Pacific. A Quarterly Scientific Journal Asia Pacific Journal of Environment and Sustainable Development is planned to be launched for this purpose.

National Museum of Natural History (NMNH) is devoted to environmental education using such means as theme-based exhibition galleries, experiential resource centres such as Discovery Room and Activity Room, and educational and outreach activities, depicting the country's rich natural heritage and natural history. A snapshot of some of the important activities carried out is as follows.

- **Earth Day** on 22 April 2008: On the occasion of the "Earth Day", NMNH invited school students to participate in an "On-the- Spot Essay Writing Competition"
- **Summer Programme 2008:** ''Exploring Nature and Environment" for the students of Standard VIII, IX, and X. The programme was being conducted from 15 May to 15 June 2008. The programme was a unique mix of lectures, slide/CD presentations, and institutional visits. It also involved presentation of projects, quiz contest, declamation contest, nature photography, art out of waste, preparation of nature magazine, and nature study tour to a wildlife sanctuary as its constituent activities.
- To sensitize school children on the matters for preservation of the ozone layer, a declamation contest was organized on 16 September 2008 in Delhi and NCR.

Climate Change Awareness initiatives: Capacity building and training

Private Sector Initiatives

Industry associations have also played an active role in awareness generation through various activities like preparing technology transfer projects, conducting workshops and training, bringing out publications, and through interactive and knowledge- based websites.

CII promotes and engages industry stakeholders in the development of technologies, processes, and approaches to deal with climate change in the overall perspective of development, corporate governance, sustainability reporting, and much more. It was an "Observer" at the UNFCCC meetings in the "BINGO" category. It is engaged in formulating corporate climate change strategies, developing GHG emission inventory, carbon footprinting, GRI sustainability reporting, conducting CDM awareness workshops, energy audit and management, and implementing the Carbon Disclosure Project (CDP) in India. It has organized the following.

- Seminars in different cities in relation to business missions from the UK on climate change / clean energy solutions / waste management between 2005 and 2007. It also facilitated an industry interaction with Sir Nicholas Stern in 2006.
- CEOs Mission to the UK led by the President of CII and others on clean coal technologies and carbon sequestration, waste-to-energy and renewable energy in 2007.
- Training services for members as well as CII offices on developing corporate climate change strategies with the support of the German government's development cooperation department.

The CII also releases various publications in the form of manuals, case study booklets, papers, reports, periodicals, and newsletters to facilitate sustainable development activities for industries (Box 6.3).

The CII Centres of Excellence work towards enabling and implementing ideas. For instance, the CII-ITC Centre for Sustainable Development facilitates business transformation by embedding the concepts of sustainable development during the stages of formulating strategies, taking decisions and finalizing processes. The CII-Sohrabji Godrej Green Business Centre (a joint initiative of the Government of Andhra Pradesh, Godrej & Boyce Mfg. Co. and CII, with the technical support of USAID) is a unique model of public–private partnership. The Centre strives to become the "Centre of Excellence" for energy efficiency, environment, green buildings, renewable energy, water and climate change activities in India. The various services being offered are: green building rating, world class energy efficiency, green audits, renewable energy services, green business incubation, exhibit of green equipment and materials at the technology centre, and information and database centre.

Box 6.3: Snapshot of publications by CII for industries

1. CII Discussion Paper "Building a Low-carbon Indian Economy"
2. Report on "Energy Trading and Derivatives"
3. Bi-monthly e-newsletter titled "Sustainability Outlook"
4. Infomercial in public interest on "Climate Change and How it Affects our Health"
5. Report on "India's Ecological Footprint - A Business Perspective"
6. Corporate GHG inventory programme guide
7. Manual on best practices in Indian and International cement plants
8. Quarterly periodical titled "Sustainability Tomorrow"
9. CDP India Reports annually
10. National and international best practices manual in the pulp and paper sector
11. Case study booklet on renewable energy
12. Directory on green building material and service provider
13. Green building reference guides - LEED-India for New Construction (NC) and Core and Shell (CS)
14. Indian Green Building Council (IGBC) green homes rating system
15. IGBC green factory building rating system

Associated Chambers of Commerce and Industry of India (ASSOCHAM) interfaces with the government on policy issues and interacts with counterpart international organizations to promote bilateral economic issues. ASSOCHAM has set up an Energy Efficiency and Conservation Promotion, Guidance, Counselling and Consultancy Centre with the assistance of Indian Renewable Energy Development Agency Ltd (IREDA). The Centre provides information on the various financing schemes available at IREDA for energy efficiency and conservation projects.

Federation of Indian Chamber of Commerce and Industry (FICCI) constituted its Climate Change Task Force in July 2007 to evolve an industry position on climate change, examine measures by industry for mitigation, and develop a consensus on policy, regulatory, and fiscal measures that would be required to formulate effective mitigation strategies. The Task Force released its first report in December 2007 at a conference organised by FICCI during the UN Climate Change Conference (COP-13) in Bali, Indonesia. The Task Force released its second report in December 2008 at COP-14 in Poznan, Poland. The FICCI has also been involved with the following.

- Undertaken a project on "Clean Development Mechanism (CDM) in the Post-2012 Climate Change Regime", under a climate strategies initiative. The objectives of the project envisaged review of performance of CDM projects, analysis of scope of reforms in the current CDM framework, making CDM work for SMEs, and identifying ways of promoting equitable distribution of CDM (geographical, across companies, project scale).
- Been associated with the Methane to Markets (M2M) Partnership since 2006 and is also undertaking a project under the M2M Partnership as part of a USEPA grant. The first workshop was jointly organized by FICCI and USEPA in March 2006 on landfill gas to energy projects. In 2007, FICCI organized a two-day conference "Advancing Project Development in India through Public Private Partnerships", jointly with USEPA, USAID, USTDA, and Government of India.
- Launched the maiden India Carbon Market Conclave in November 2007, in partnership with the MoEF, Government of India, the World Bank, and International Emissions Trading Association (IETA). The Conclave has garnered participation of global carbon market players from 30 countries, Indian project developers from 43 sectors, and diverse stakeholders.
- Organized a SAARC CDM Conference on 1 September 2009 in collaboration with the MoEF and Ministry of External Affairs, Government of India
- Organized the Indo-Norwegian Seminar on Renewable Energy and Climate Change on 20 October 2008

Indian Chamber of Commerce (ICC) is another industry association engaged in the climate change and sustainable development initiatives. It organized the following events.

- Environment Partnership Summit 2008: A technical session on "Climate Change and Carbon Trading: Issues and Road Ahead" was organized followed by a CEO Forum on Climate Change, namely, "Reducing carbon footprint – Corporate Best Practices and Experience Sharing".
- "CDM@East" on 19 December 2008: Aimed at serving as a platform for mapping the risks and threats associated with climate change and exploring business opportunities and possibilities to forge profitable alliances and ventures that exist for CDM in eastern India.
- Environment Partnership Summit 2009: "Strengthening Global Ties for a Greener Business" in February 2009.
- Environment Partnership Summit 2010: "Low Carbon High growth – A Road Map for Global Competitiveness" on 11–13 February 2010.

It publishes "Environment Watch"—a quarterly newsletter containing relevant facts, notifications, information and opportunities on climate change issues. The magazine also includes a monthly market report on CDM registration and carbon credit markets. The ICC Climate Change Charter was also released during the Environment Partnership Summit 2010.

Many private sector companies have launched corporate social responsibility (CSR) initiatives similar to ICICI's Go Green Initiative – which reaches out to staff within and to customers. ICICI Foundation collaborates with and supports the Environmentally Sustainable Finance (ESF) group at Centre for Development Finance (CDF) in Chennai (www.ifmr-cdf.in) to identify ways in which resources for growth can be more effectively channelled to support environmental sustainability. ESF focuses on research and action to inform environmental policy-making and implementation, integrate environmental sustainability into development initiatives, and support scalable commercial and non-profit interventions to make India's economy more environmentally sustainable from the bottom up.

International Cooperation

With the participation of different delegations from the Prime Minister's Special Envoy on Climate Change, MoEF, various other central and state government agencies, NGOs, and private sector organizations, India has played an active and important role in many international negotiations.

The MoEF participated in the G8+ Environment Ministerial meeting in Siracusa, Italy, on 22–24 April 2009. Several meetings of the Major Economies Forum on Energy and Climate Change (an initiative launched by the USA) were held in Washington, Paris, Mexico, and Rome, in which the MoEF and officials from the Ministry of External Affairs (MEA) and BEE participated under the leadership of the Prime Minister's Special Envoy on Climate Change.

One of the important events in this series was the summit on climate change organized by the UN Secretary-General in the UN Headquarters at New York on 22 September 2009. This was attended by the Minister of State, Environment and Forests. India has consistently been represented by high-level delegations to the Conference of Parties held from time to time and has engaged constructively in the climate change negotiation process.

India and China engaged in regular consultations in the format of "BASIC" to coordinate positions and take care of the interests of developing countries. Immediately after the Copenhagen Conference, the Ministry organized the Second Ministerial Meeting of the BASIC countries' environment ministers in New Delhi on 24 January 2010 to take stock of the post-Copenhagen developments and chalk out a coordinated strategy of negotiations.

The Ministry, in collaboration with the United Nations Department of Economic and Social Affairs (UNDESA), organized a high level conference on "Climate Change: Technology Development and Transfer" on 22–23 October 2009 in Delhi to focus on technology-related issues under negotiation. The Conference, organized in association with the FICCI, was attended by 58 country delegations and 30 ministers from various countries and was addressed by the Prime Minister.

Bilateral/other initiatives on climate change

The Minister of State (Independent Charge), Environment and Forests, accompanied by a delegation of officials, visited China, US, and Denmark to hold bilateral consultations on climate change and matters related to environmental cooperation. As a result of an understanding reached during the Minister's visit to China; India and China signed (in October 2009 in New Delhi) a Memorandum of Agreement on Cooperation on Addressing Climate Change. The Agreement is intended to enhance cooperation with China and promote mutual understanding and coordination on international issues related to climate change while providing opportunities for cooperation in areas of research, development, and diffusion of technologies.

The Agreement establishes a China–India Working Group on Climate Change for exchange of views on issues related to domestic policies, international negotiation, and implementation of related cooperation projects. The Secretary (Environment and Forests) also led an Indian delegation to the South Asia Regional Conference on Climate Change in the Himalayan Region, organized by the Government of Nepal in Kathmandu in September 2009, in order to foster regional cooperation in the domain of climate change.

The Ministry also participates in the sessions of Inter-governmental Panel on Climate Change (IPCC) and engages bilaterally with several countries in the field of climate change. India has signed an MoU with Italy, Canada, and Denmark for promoting cooperation in the field of CDM. During October 2009, India and Norway signed an MoU on cooperation in the area of climate change and implementation of CDM Projects under the Kyoto Protocol.

A Joint Work Programme on Climate Change issues between India and EU is being formulated. India is also engaged in discussions with World Bank, DFID, and GTZ to launch specific studies/projects for adaptation to climate change in chosen areas/regions of the country. These projects will be so designed so as to ensure that they are consistent with the objectives of the National Action Plan. As a member of the Asia Pacific Partnership on Clean Development and Climate (APP-China, Japan, South Korea, Canada, US, and India), the Ministry, in coordination with the Ministry of External Affairs, Ministry of Coal, and Ministry of Power participated in the meetings of the APP held in Gold Coast, Australia, and Shanghai. The partnership focused on development, diffusion, and transfer of clean and more efficient technologies and functions through eight task forces in the area of aluminium, buildings and appliances, cement, fossil energy use, coal mining, power generation and transmission, renewable energy and distributed generation, and steel industry through public–private sector coordination.

References and Sources

DoE (Department of Environment), 2010. *Delhi Climate Change Action Plan.* DoE, Governemnt of Delhi

ICAR (Indian Council of Agricultural Research), 2008/09. *DARE/ICAR Annual Report 2008–2009.* Department of Agricultural Research and Education, Ministry of Agriculture, Government of India

MHRD (Ministry of Human Resource Development), 2008–09. *Annual Report.* Department of School Education and Literacy, Department of Higher Education, MHRD, Government of India, New Delhi

MoC (Ministry of Coal), 2008/09. *Annual Report.* MoC, Government of India, New Delhi

MoCIT (Ministry of Communications and Information Technology), 2008/09. *Annual Report.* MoCIT, Government of India, New Delhi

MoEF (Ministry of Environment and Forests), 2006. *Climate Change Dialogue: India Country Presentation.* MoEF, Government of India, New Delhi

MoEF (Ministry of Environment and Forests), 2008/09 to 2010/11. *Annual Report.* MoEF, Government of India, New Delhi

MoEF (Ministry of Environment and Forests), 2009. *Delhi Statement on Global Cooperation on Climate Technology.* MoEF, Government of India, New Delhi

MoEF (Ministry of Environment and Forests), 2009. *State of Environment Report 2009.* MoEF, Government of India, New Delhi

MoEF (Ministry of Environment and Forests), 2010. *India: Taking on Climate Change – 24 Recent Initiatives Related to Climate Change.* MoEF, Government of India, New Delhi

MoF (Ministry of Finance), 2008/09. *Annual Report.* Ministry of Finance, Government of India, New Delhi

MoM (Ministry of Mines), 2008/09. *Annual Report.* MoM, Government of India, New Delhi

MoP (Ministry of Power), 2008/09. *Annual Report.* MoP, Government of India, New Delhi

MoRTH (Ministry of Road, Transport and Highways), 2008/09. *Annual Report.* MoRTH, Government of India, New Delhi

MSME (Ministry of Micro, Small and Medium Enterprises), 2008/09. *Annual Report.* SME, Government of India, New Delhi

NAPCC, 2008. *National Action Plan on Climate Change.* PM's Council on Climate Change, Government of India, New Delhi

Planning Commission, 2002. *10th Five-year plan – Vol. I-III.* Planning Commission, Government of India, New Delhi

Planning Commission, 2004/05 to 2008/09. *Annual Report.* Planning Commission, Government of India, New Delhi

Planning Commission, 2007. *11th Five-year plan – Vol. I-III.* Planning Commission, Government of India, New Delhi

Planning Commission, 2007. *Reports of the Task Forces on Governance, Transparency, Participation and Environmental Impact Assessment and Urban Environmental Issues in the Environment and Forests Sector for the Eleventh Five Year Plan (2007-2012).* Planning Commission, Government of India, New Delhi

Websites Referred:

Center for Climate Change and Environment Advisory (http://www.cccea.in/about.htm)

The Embassy of Norway in India (http://www.norwayemb.org.in/)

ENVIS Center Himachal Pradesh (http://www.hpenvis.nic.in/index.aspx)

ENVIS Center Maharashtra (http://envis.maharashtra.gov.in/)

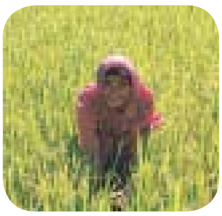
Department of Environment, Government of Delhi (http://delhi.gov.in/wps/wcm/connect/environment/)

The Climate Group (http://www.theclimategroup.org/)

The Ministry of Environment and Forests, Government of India (http://enfor.nic.in/)

Chapter 7

Constraints, Gaps and Related Financial, Technical and Capacity Needs

In accordance with India's national circumstances and development priorities, a description of the constraints and gaps, and related financial, technical, and capacity needs, as well as proposed activities for overcoming the gaps and constraints associated with the implementation of activities, measures, and programmes envisaged under the United Nations Framework Convention on Climate Change (UNFCCC) and with the preparation and improvement of national communications on a continuous basis has been provided in this chapter. The chapter presents some projects that were identified for building research capacity and implementing climate change related projects in India as part of the preparatory process for future national communications. The coverage is not an exhaustive elucidation of India's financial and technological needs and constraints. With more scientific understanding and increasing awareness, further areas of work could be identified.

Contents

Chapter 7 Constraints, Gaps and Related Financial, Technical and Capacity Needs

CHAPTER 7

Constraints, Gaps and Related Financial, Technical and Capacity Needs

The Indian government visualizes the SNC as an opportunity to enrich and enhance India's experience in identifying constraints, gaps, and related financial, technical, and capacity needs to adequately fulfil our obligations under the UNFCCC, including continuing need for improving the quality of national greenhouse gas (GHG) inventories, carrying out regional and sectoral assessment of vulnerabilities and adaptation responses, and communicating information on a continuous basis.

The broad participatory domestic process for preparing India's SNC has contributed to an improved understanding of the challenges associated with formulating an appropriate policy response for addressing climate change concerns in India, while simultaneously building capacity in diverse disciplines such as inventory estimation, emission coefficient measurements, vulnerability assessment and adaptation, and inventory data management.

Continuing Need for Reporting of Information on Implementation of Convention

Inventory estimation

The GHG emissions inventory for Non-Annex I countries is to be reported to the UNFCCC Secretariat as per 17/CP.8 guidelines for the SNC. GHG inventory reporting requires detailed activity data collection and estimation of country-specific emission coefficients. The level of inventory reporting depends on the data quality and methodology employed and is indicated as Tier-I, -II or -III as per the Revised 1996 Intergovernmental panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, IPCC Good Practice Guidance (2000), the Land use, Land-use Change and forestry (LULUCF) Good Practice Guidance (2003), and the IPCC Guidelines for National Greenhouse Gas Inventories (2006). Despite the comprehensive initiation of activities under the SNC project, there is considerable scope for improvement. The inventory estimation has to be made at more disaggregated level, preferably at Tier-II or -III levels for the key sources. Finer sub-sectoral-level estimates of activity data and emission factors (EF) have to be developed. Similar and consistent formats have to be adopted for data reporting and ensuring consistency in generating activity data by organizations. The major constraints and gaps in Indian GHG inventory estimation are now presented.

Non-availability of relevant data

This is a prominent concern, especially in developing countries, where time series data required for GHG inventory estimation is not available for some specific inventory sub-categories. For example, in the waste sector, still details about annual municipal solid waste (MSW) generation, collection, and dumping, and dumpsite characteristics are not available beyond 5 to 10 years for even the large metropolitan cities, while for smaller cities, the data availability is poor and therefore, a lot of extrapolation is undertaken for estimation of methane from the entire country.

Another constraint is the non-availability of data for informal and less organized sectors of the economy. These include agriculture, forestry, and many small-scale industries (SSI) like brick, sugar, glass and ceramics, dyes, rubber, plastic, and chemical and engineering products. The SSI sector in India comprises modern and traditional industries encompassing the continuum of the artisans and handicrafts units on the one hand and modern production units producing a wide range of products on the other. Many of these industries, along with domestic and commercial sectors, are informal as far as energy accounting is concerned.

Similarly, improvements in activity data for various sub-categories of agriculture-related GHG emissions are critical. The key activity data includes livestock population, synthetic fertilizer application, areas under different water regimes for rice paddy cultivation, and agriculture crop residue generation for various crops. Under the LULUCF sector, areas under different land use categories, above-ground biomass and mean annual increment, soil carbon density, fuelwood, and commercial timber consumption have considerable uncertainty.

National GHG inventory preparation is a continuous process of improving the reliability and consistency of inventory assessments. The Indian GHG inventory for the SNC has been mostly reported using Tier-I and -II approaches. Tier-III methodology has also been used for certain key sources. As India plans to move to higher tier and more detailed inventory assessments in subsequent communications, the data gaps have to be identified, and corrective action has to be taken. Since the GHG inventory reporting year lags behind the year of assessment by about four to five years for developing countries, the above data has to be generated now for use in subsequent national communications. This requires sustained commitment of resources and setting up of appropriate institutional frameworks.

Data non-accessibility

This is yet another peculiar problem associated with data in developing countries. Since data collection requires considerable effort and resources, it is often treated as proprietary. Moreover, some data required for refining inventories to Tier-III level is treated as trade secret by the respective firms and is not easily accessible. These firms have to be, therefore, sensitised about the data needs for inventory reporting and refinement. Systems have to be devised for regular publication of relevant information in desired formats for national GHG inventory estimation.

Another issue is non-availability of data in electronic form. However, with the increased penetration of computers, information is becoming electronically available. In some instances, security concerns lead to data non-accessibility, like satellite imageries, while the procedures also delay access to data.

Data organization constraints

The different levels of GHG inventory reporting, called tiers, require different data quality. Although data required for initial levels is already in public domain through the annual reports and data statistics made available by various ministries and departments of the Government of India, the data is not organized in desired formats. Considerable data organization, consistency checks and data management are required.

There is also inconsistency in some data sets released by the central and state governments for some activity data. Another gap area is that the sectoral data for various fuels does not match across different ministry reports, in a few instances. Many of the industries are reasonably organized. However, accounting of all the energy resources is not available for all the industries. The sectoral definitions for different fuels may not be consistent even in the same ministry document. For example, the national consumption of Low Sulphur Heavy Stock (LSHS) is combined and reported together for the entire transport sector while for diesel consumption, separate data is provided for road, aviation, shipping, railways, and other transport, thereby enabling inventory under Tier-I only.

Development of representative emission coefficients

To capture Indian situations and circumstances, beginnings have been made to generate India-specific emission coefficients by undertaking *in situ* measurements in some key source categories and define the range in uncertainties in the estimates through statistical methods. However, time and budgetary resources available under the project constrain the coverage under this activity. For uncertainty reduction in GHG emissions, India needs to undertake *in situ* measurements for many more activities to capture the Indian realities. The sample size has to be statistically determined for all the categories covered under the National Communication. Some critical gap areas covering the key source categories for Indian GHG emissions are as follows.

- Measurement of GHG emission coefficients from power plants, for new technologies.
- Measurement of GHG emission coefficients for road transport sector, for newer technologies.
- GHG emission coefficients measurements from fully/ partially informal energy-intensive sectors such as brick manufacturing, sugar, and ceramics.
- GHG emission coefficient measurement from industrial processes like lime production and use, aluminium production, soda ash use, pulp and paper production, etc.
- GHG emission measurements and activity data assessment for biomass used for energy purpose.
- Measurement/estimation of GHG emission coefficients (especially N_2O) for different types of soils in India.

These activities necessitate significant additional scientific work, requiring considerable resources. Technical capacity has to be built in more institutions to conduct these *in situ* measurements. Instrumentation upgradation and process accrediting have to be done for many existing laboratories.

Need for greenhouse gas inventory estimation on a continuous basis

The GHG inventory estimation needs may be estimated at three levels: (i) data needs, (ii) capacity development and enhancement needs, and (iii) institutional networking and coordination needs.

The data needs are based on the data gaps and constraints explained earlier (Table 7.1). These include designing consistent data reporting formats for continuous GHG inventory reporting, collecting data for formal and informal sectors of the economy, enhancing data quality to move to higher tier of inventory reporting, and conducting detailed measurements for India-specific emission coefficients. Capacity development has to be at two levels: institutions and individual researchers. Institutional capacity development requires financial support, technological support, instrumentation, and networking. Individual researcher capacity development is required to sensitize and train data generating teams in various sectors and at different institutions about GHG inventory estimation process, so that the researchers would be better equipped to collect and report the desired data on a continuous basis. Institutional networking and coordination are critical factors for establishing new data frameworks and reporting formats in various sectors. Industry, ministries, and government departments have to coordinate closely for this. The SNC NATCOM project has made strides in this direction in India at various levels (formation of INCCA facilitated the creation of such a network-based institutional structure through which the GHG inventory for 2007 was published). However, sustained and timely financial and technological support is critical to sustain and strengthen this process.

Land use, Land-use Change and Forestry Sector (LULUCF) - Constraints and Needs

The LULUCF sector in India has the potential to be a major source or sink of CO_2 in the future. The uncertainty in the estimates of inventory in the LULUCF sector is shown to be higher than other sectors such as energy transformation, transportation, industrial processes, and even agriculture. The availability and access to information on activity data, emission coefficients, and sequestration rates in the LULUCF sector in India are limited, and the uncertainty of the data is high, as in most countries. Thus, there is a need for improvement in the information generation processes for the inventory so as to reduce the uncertainty involved in the estimation of GHG inventory in the LULUCF sector.

Table 7.1: Gaps and constraints in greenhouse gas inventory estimation

Gaps and constraints	Details	Possible approach
Data organization	Data not available in Intergovernmental Panel on Climate Change (IPCC)-friendly formats, for inventory reporting	Consistent reporting formats
	Mismatch in top-down and bottom-up data sets for same activities	Regular monitoring and consistency check on collected data
	Mismatch in sectoral details across different published documents	Consistent reporting formats
Non-availability of relevant data	Time series data for some specific inventory sub-categories, for example, municipal solid waste sites	Generate and maintain relevant data sets
	Data for informal sectors of economy	Data surveys
	Data for refining inventory to higher tier levels	Data depths to be improved
Data non-accessibility	Proprietary and trade secret data for inventory reporting at Tier-III level	Involve industry, industry associations, and monitoring institutions
	Data not in electronic formats	Standardize data reporting and centralize data in usable electronic format
	Security concerns	Protocols to access data
	Procedural delays	Awareness generation
Technical and institutional capacity needs	Training the activity data generating institutions in inventory methodologies and data formats	Extensive training programmes
	Institutionalize linkages of inventory estimation and climate change research	Wider dissemination activities
Non-representative emission coefficients	Inadequate sample size for representative emission coefficient measurements in many sub-sectors	Conduct more measurements, statistical sampling
Non-availability of resources to sustain National Communication networks		Global Environment Facility (GEF)/International timely funding

Inventory in LULUCF sector requires activity data on area under different forest types and the area subjected to land use change as well as the changes in carbon stocks of different land use categories or forest types. The data needs, features and current status are given in Table 7.2, and a snapshot of the future actions related to inventory estimation, vulnerability assessment, and adaptation-related activities is given in Table 7.3.

The forestry sector is projected to be adversely impacted by climate change, threatening biodiversity, and forest regeneration and production. The impacts and vulnerability studies conducted in India have only made preliminary assessment due to modelling and data limitations.

There has been significant improvement from India's Initial National Communication (INC) due to improved methods adopted for GHG inventory (IPCC Good Practice Guidelines, 2003) methodology for LULUCF sector and improved dynamic global vegetation modelling for assessing the impacts of climate change. However, the inventory estimates as well as impact assessments are characterized by data limitations and uncertainty. Thus, there is a need for initiating long-term studies to monitor the carbon stocks and changes as well as impacts of climate change on forest vegetation parameters .

During INC, an equilibrium model – BIOME4 – was used for assessing the impacts of climate change on forest vegetation. This study as well as other studies conducted in India faced limitations of regional climate projections at finer grid scales, access to only equilibrium models, and lack of climate, vegetation, and soil data needed for projecting impacts of climate change on vegetation. The tropical forests such as those in the Western Ghats are highly diverse, with vegetation changing every few kilometres. However, equilibrium models such as BIOME, MAPPS, and TVM-IMAGE have been applied to model changes in global biome boundaries, and thus, may have limitations for regional scale assessments. Dynamic forest models are required to simulate the transient response

Table 7.2: Data needs for greenhouse gas inventory in the land use, land-use change and forestry sector

Sl. No.	Data fields	Format in which required	Status/problems
1	Terrain (elevation/topography), aspect data	Digital elevation model (DEM) directory (resolution 1:250,000 with 50,000 desirable in select areas especially with greater elevation range)	Available in public domain but data under classified domain, that is, one-third of the data not available, including coastal areas and international boundaries
2	Land use data	Processed satellite data (1:250,000 with 50,000 desirable in select areas, especially with greater elevation range)	Satellite data (1:50,000), non-availability of processed data, costs involved
3	Soil profile data	Digital (1:250,000 with 50,000 desirable in select areas especially with greater elevation range)	Status (1:250,000) available
4	Hydrological data	Water quality and sediment load – location specific	Data needs to be consistently organized
		Groundwater data (location of observation wells), dynamic data on water table fluctuations, groundwater utilization patterns	
5	Meteorological data	Daily precipitation data, minimum, maximum, and average daytime temperatures, PAN evaporation data, relative humidity, sunshine hours, solar radiation, and wind speed. Time period is 50 years	No access to recent data (last five years or so)
6	Forest cover, vegetation map	Spatial data sets (1:250,000 with 50,000 desirable in select areas especially with greater elevation range)	Widely scattered datasets, the Forest Survey of India (FSI) has not classified a large proportion of the forest areas
7	Forest resource surveys	Tree species, abundance, timber volume, etc	Widely scattered data sets; practically nothing in digital/ electronic form
8	Long-term vegetation data	Permanent preservation plots	Data widely scattered; location of plots on ground unknown in many cases
9	Plant and animal species distribution	Spatial digitized data for select species	Data widely scattered, may not be digitized
10	Non-timber forest products (NTFPs)	Species and volumes, prices	Data widely scattered
11	Forest plantations	Species and spatial extent, year of plantation	Data widely scattered
12	Protected Area (PA) network	Digitized maps (1: 250,000)	Data widely scattered
13	Socio-economic data sets (demography)	Village, tribal, and forest dependent datasets	Scale availability might be a concern

of vegetation to climate change as each species or plant functional type responds differently. In a rapidly changing climatic environment, there would be no chance for plant communities to reach equilibrium or climax stage and they would be dominated by early to mid-successional species. As a prerequisite to identifying finely tuned adaptation strategies, research on the impacts of climate change on forests needs to be strengthened. There have been significant efforts to improve the methods, models, and scenarios for generating more accurate estimates of the future climate, its impact, and cost of damages, and for the formulation of appropriate adaptation measures. Country level, particularly, regional level impact assessments are necessary for the formulation and implementation of adaptation policies and strategies. This requires developing methods and models and generating local climate, land use, and vegetation data. An improved understanding of the effects of changing temperature, water availability, ambient CO_2 concentrations, and photoperiod on the establishment, growth, water use efficiency, stomatal conductance, and biomass allocation of forests is needed.

The climate impact assessment for SNC was conducted using a dynamic vegetation model IBIS. However, this too had several data limitations and uncertainties. IBIS is known to over-predict grasslands, and at the same time, IBIS tends to simulate a fairly strong CO_2 fertilization effect. IBIS is also known to have limitations in characterizing nitrogen dynamics. IBIS model, in its current form, does not include a dynamic fire module. It does not account for changes in the pest attack profile in a changed climate. At the same time, climate projections are currently not available in probabilistic terms, which currently limits us from presenting a probability-based forest dynamics scenario for India. There is uncertainty in climate projections, particularly in precipitation at down-scaled regional levels. Land-use change and other anthropogenic influences are not factored in the model projections. Afforestation and regeneration (for example, on abandoned croplands or wastelands) are also not taken into consideration. Finally, due to lack of regional model predictions for short (2025) and medium term (2050), we are not able to provide policy-relevant recommendations for short and medium periods. But it is very important to recognize the likely trends in the impacts and adopt win-win adaptation strategies, initiating at the same time research to reduce uncertainties in climate projections and dynamic vegetation modelling.

Research and monitoring to increase understanding of climatic impacts and adaptation strategies in forest sector

To assist policy-making in India, reliable regional projections of climate change and vegetation response are necessary. The regional-level Atmosphere-Ocean Global Circulation Models (AOGCM) projections currently have several limitations. A consistent set of high-resolution information of climate change for different regions, which can be used as likely climate change scenarios, is not yet available. The methodologies to generate such data are still maturing, and the limitations, especially for impact applications, are likely to remain till significant modelling developments occur. Also, the information available currently is insufficient, and existing climate models lack the spatial details required to make confident projections. India has a large diversity of tropical and sub-tropical forest ecosystems subjected to diverse socio-economic pressures. Climate change will be an additional stress on the complex forest ecosystems. There is a need for systematic long-term research, monitoring, and modelling programme to study the status of forests, response of forests to changing climate, model future responses, and develop adaptation strategies. Currently, there is little effort to understand climate change and forest response related aspects in India. Some potential specific research and monitoring programmes are given in Table 7.4.

Gaps and constraints

There are numerous gaps and constraints, which hamper in undertaking research activities related to the forestry sector. These gaps and constraints are there in the forms of lack of knowledge, lack of technologies in developing countries, non-availability of finance, non-availability of relevant data, data non- accessibility, data organization constraints, lack of well-framed and effective policy framework, etc. The details of these gaps and constraints are summarized subsequently.

1. Knowledge gaps

Although climate change is a global issue for discussion, there are some gaps and constraints visible in the knowledge of adaptation and mitigation aspect of forestry. Key knowledge gaps include the linkages between impacts of climate change and adaptation and mitigation options. More research is required to better understand climate change challenges and cost-effective solutions at the local levels and to fill knowledge gaps. Despite the emergence of more and more regional and country-

Table 7.3: Greenhouse gas inventory and impact modelling studies	
Greenhouse gas inventory studies	**Impact, vulnerability and adaptation modelling studies**
1. Forest inventory studies to monitor the stocks and fluxes of carbon in different forest and plantation types	1. Long-term monitoring of vegetation response to climate change through establishment of permanent plots in different forest zones and management systems
2. Estimation and monitoring of land use change matrix at the national and state level	2. Development of India-specific plant functional types and all the physiological parameters required for dynamic global vegetation modelling
3. Estimation and monitoring of soil carbon stocks in different land use systems as well as land use change systems	3. Impact assessment using multiple dynamic global vegetation models
4. Monitoring of forest fires in different regions and the biomass burnt	4. Impact assessment using multiple climate models and multiple scenarios of climate change
5. Developing models for soil carbon dynamics in different land use systems	5. Identifying the indicators of vulnerability of forest ecosystems and developing vulnerability index maps
6. Developing carbon balance models for Indian land use systems	6. Monitoring of different adaptation practices and their implications for resilience of different species to projected warming and climate change
7. Capacity building in forest departments for forest inventory	7. Developing monitoring mechanisms for adaptation projects
8. Generating database for Clean Development Mechanism and Greening India Mission projects for estimating carbon benefits	

Table 7.4: Potential research and monitoring programmes in land use, land-use change and forestry	
Sl. No	**Research theme/programme**
1	Strengthening the forest area monitoring programme according to forest types at finer spatial resolution
2	Studies to assess and project socio-economic pressures and drivers contributing to forest degradation and loss
3	Field ecological studies to monitor the response of forest vegetation to changing climate at different latitude and altitudinal zones, through long-term permanent research plots
4	Field and laboratory studies to develop plant physiological and phenological characteristics of different forest types as input to climate impact dynamic vegetation models
5	Research programmes to achieve indigenization of input parameters for climate impact models
6	Improvement in regional projections of climate parameters; regional climate modelling
7	Development of transient ecosystem models that deal with multiple stresses: climate change and socio-economic
8	Regional climate model grid level database generation for dynamic vegetation modelling; vegetation characteristics, climate parameters, and socio-economic pressures
9	Studies to identify forest policies and silvicultural practices that contribute to vulnerability of forest ecosystems and plantations
10	Studies to identify forest policies, strategies and silvicultural practices to reduce vulnerability and enhance resilience of forest ecosystems to projected climate change.

specific studies on climate change in India in recent years, knowledge gaps remain huge. There is an urgent need for undertaking more research at regional level to better understand the climate change and its impact, risks and vulnerability, adaptation needs, and mitigation potential at local levels. To undertake such type of research activity, there are many barriers. Some significant gaps from aspects of knowledge are as follows.

- Knowledge and information gaps on climate change and solutions at local levels.
- Lack of International and regional cooperation in knowledge.

As climate change is an issue of discussion at international, national, and regional levels, it is basically a local and location-specific phenomenon and forests have extreme capacity to mitigate the impact of climate change, but climate change also affects the adaptive and mitigative potential of forests. So it is necessary to develop or design location-specific methodologies and strategies of adaptation and mitigation for the forestry sector. Otherwise it will not be able to cope up with climate variability. Since, local forest-related knowledge is declining in most regions of the world, it is important to strengthen and upgrade the knowledge of local and indigenous community for better adaptation and mitigation.

2. Financial gaps

There is a need to translate policy statements into strategies and strategies into budgetary allocations. There is an urgent need for action and investment planning for the research activities of the forestry sector. It is important to make simple and easy approachable rules and regulations to funding the project work related to adaptation and mitigation activity.

3. Research gaps

There is a considerable gap in our knowledge on various aspects of climate change, such as

- First, there is much to learn about the potential magnitude and rate of climate change at the regional and local levels, and subsequent impacts on the full range of biodiversity endpoints and ecosystems.
- Second, there is no consolidated literature of proven biodiversity conservation techniques, or climate adaptation techniques, covering all the eco-regions of India.
- Third, detailed analyses need to be developed for each of the priority climate change threats to biodiversity and other natural resources.

A further strategic approach is needed for detailed research on different ecosystem services and functions to estimate the potential impacts of climate change. Such research could develop adaptation mechanisms and/or highlight mechanisms that have already been implemented by local people in response to the changing environment. Detailed indicative research is also essential to define mitigation strategies at the policy level, which need prioritizing at the government/international level. Apart from the above, some potential areas of research that should be considered are the inter-comparison of key physical and biological processes along a series of transects placed over the region; the establishment of a comprehensive regional database; and an in-depth study of the major forest areas of India.

4. Technological and capacity building gaps

The forestry sector has not been able to tap into the advances in technology to the optimal level, and there is a vast gap in the current technology applications and their adaptation to the day-to-day working of forest research. Besides, the local capacity to collect data at regional level is weak. Before implementing technological advances in statistical data reporting work, it is necessary to build adequate capacity for the collection of data from primary sources. The primary data collector should be well versed not only with the terminology of the database, but also with the importance of such a database to ensure sincerity in the work. The capacity-building programmes should have a sustainable structure aiming at timely upgradation with the technology. Use of local and wide area networks is essential to ensure on-time data availability.

5. Monitoring mechanism

There is a need for more organized and structured monitoring system for better output in research activity related to climate change. This monitoring needs to be done at regional and national levels at regular intervals.

6. Institutional constraints

There are some institutional constraints to undertake research activity in the field of adaptation and mitigation in the forestry sector. In view of the growing complexities of economic development and the technical issues involved, it seems necessary to remove the institutional constraints in the country in an efficient and coherent manner.

7. Gaps and constraints at policy level

India was among the first few countries in the world to provide for the protection and improvement of the environment in the national constitution, and it has taken several steps in designing policies and legislation to overcome environmental problems.

Since the National Action Plan on Climate Change (NAPCC) is still in its initial phase, enormous work will need to be done. Cumulatively, over a period of several years, the Missions of NAPCC could help in gradual removal of bottlenecks at the policy level, as well as boost a strategic shift to enhance adaptation/mitigation activities. There is also a need to develop sector-specific climate policies, measures, and regulations that could help in adaptation and mitigation activities.

8. Gap and constraints in data collection and impact assessment capacity

There exists a significant data gap. Climate change is an interdisciplinary subject that cuts across physics, chemistry, biology, earth sciences, economics, technology development, etc. Therefore, multiple data sets are required even to simulate the current situations by different models. Current data on climate, natural ecosystems, forest boundaries, forest productivity, soils, and socio-economic parameters, amongst others, is continuously required. It is essential to have accessibility to databases that reflect national and regional concerns. Various agencies in India are presently collecting such data on a regular basis. However, efforts need to be made to establish an effective mechanism for sharing and accessing this data in formats that can be easily deciphered.

The forest sector provides an interesting opportunity to analyse and understand the synergy/trade-off between mitigation and adaptation. Thus, it is necessary to model and study the opportunity to promote mitigation in adaptation programmes and projects.

Improving data collection and sharing results at national, regional, and international levels will improve the work quality regarding adaptation and mitigation. It can also increase the detail of climate impact assessments to a scale that is meaningful for optimizing adaptation and mitigation measures, and operating nearly real-time early warning and hotspots warning systems for forestry in India. This refers particularly to the 10–15 years time horizon over which the reliability of impact projections is probably acceptable and the planning of responses is probably realistic.

9. Need for long term observations

New systematic observations that are long term in nature must be taken up on a continuous basis in India to add to the South–South database on physical and biological systems, for example, data on forest vegetation types. In India, forest observation plots were established in the early nineteenth century to observe the changes in nature of forest vegetation in different regions. However, most of these plots have not been continuously observed, and as a result, data on the vegetation types, forest soil characteristics, etc. is not easily available, which could have been effectively used for modelling. There is an urgent need to revive these plots. The data variables from these plots have to be observed for a long period of time to attribute the effects of climate on various systems. The results need to be shared through a network of institutions engaged in these studies.

10. Climate-related capacity needs in forestry

Country capacity to assess and apply adaptation and mitigation measures in forestry is weak at two levels: national institutional frameworks and adaptive capacity of local populations to climate change and variability. To implement national climate change and forest policies, there is need for in-depth knowledge of appropriate methods and tools as well as awareness of available funding mechanisms, such as the carbon market and adaptation funds established under the IPCC.

Extension services will need to be strengthened substantially in order to address adaptation and mitigation for them to provide an efficient interface between policy-makers and the forest community. Recognizing that climate change will alter many existing equilibriums, socio-economic dynamics must be considered, and the role of all the partners may need to be re-examined or redefined.

Identification of specific research themes related to adaptation and mitigation aspects of forests

Our present state of knowledge on the relationship between climate and plant performance is grossly inadequate for the purpose of modelling future climate change impacts. Research in the following areas is thus a key prerequisite for coming up with robust adaptation strategies.

1. **Ecological research on plant and animal species and communities in relation to climate variability and change:** Keeping in view the sensitivity of plant and animal species to climate variability and change, the ecological studies of plant and animal species, plant–animal interactions, and community in relation to climate variability and change are required to be carried out.
2. **Dynamic vegetation modelling of climate change impacts on forest ecosystems, biodiversity and adaptation:** The few studies so far conducted in India are largely based on equilibrium models, which assume that one forest type is replaced by another forest type under changing climate. The varying climate tolerances of different plant species and the transient phase response of plant species subjected to climate change are not analysed. There is a need to adapt the existing dynamic vegetation models for application to the diverse tropical forest types in order to analyse the implications of climate change at species level. The ultimate goal is to develop adaptation strategies and practices to reduce vulnerability of forests to climate change. The modelling effort should incorporate adaptation.
3. **Impact of climate change on mitigation potential, carbon sinks, and adaptation:** India has a large afforestation programme, and it is important to understand the likely impacts of climate change to ensure sustainable management of forests and flow of timber, industrial wood, and non-timber products and conservation of biodiversity. There is a need to analyse the climate impacts using dynamic vegetation models and developing adaptation strategies.
4. **Mitigation potential assessment:** There is also

a need to develop a database on biomass growth rates and soil carbon accumulation rates in forests and plantation systems in different agro-ecological zones of India. This data is required for a realistic assessment of the mitigation potential of the forest sector in India.

Agriculture – Research Themes for Adaptation to Climate Change

Agriculture is a key sector in India, as a vast population base of the country still lives in rural areas and depends for its food and livelihoods requirement on agriculture. The agriculture sector is hugely dependent on climate parameters such as rainfall and temperature, and therefore, a significant amount of the country's resource needs to be expended in identifying appropriate adaptation strategies for the agriculture sector, so as to ensure food security for the nation as well livelihoods security for its vast population. Some adaptation strategies are listed below, which would require considerable research resources in the future.

Conservation Agriculture (Efficient use of resources): Resource conserving technologies involving zero or minimum tillage with direct seeding, permanent or semi-permanent residue cover, and crop rotations have the potential to improve the efficiency of use of natural resources, including water, air, fossil fuel, and soil. Among other things, the efficiencies gained include less land and time needed to produce the required staple cereals and allowing farmers to diversify crops and cropping patterns or pursue other gainful activities. The technologies can improve the sustainability of the cropping system by conserving the resource base and higher input use efficiency and also mitigating GHG emission.

Change in crop management: Crop management, such as short, medium, and long duration variety; change in sowing time, which includes early as well as late sowing relative to current sowing time; increasing the seed replacement rate by the farmers; and change in irrigation patterns and fertilizer application for increased input use efficiency, should be pursued.

Crop diversification: Diversification of crop and livestock varieties, including the replacement of plant types, cultivars, hybrids, and animal breeds with new varieties intended for higher drought or heat tolerance, has been advocated as having the potential to increase productivity in the face of temperature and moisture stresses. Diversity in seed genetic structure and composition has been recognized as an effective defence against disease and pest outbreak and climate hazards. Moreover, the demand for high value foods such as fruits, vegetables, dairy, meat, eggs, and fish is increasing because of growing income and urbanization. This is reducing the demand for traditional rice and wheat. Diversification from rice–wheat to high value commodities will increase income and result in reduced water and fertilizer use. However, there is a need to quantify the impacts of crop diversification on income, employment, soil health, water use, and GHG emission. The most significant problem to overcome is that diversification is costly in terms of the income opportunities that farmers forego, that is, switching crop varieties can be expensive, and making crop diversification typically less profitable than specialization. Moreover, traditions can often be difficult to overcome and will dictate local practices.

Adjusting cropping season: Adjustment of planting dates to minimize the effect of temperature increase- induced spikelet sterility can be used to reduce yield instability, by avoiding having the flowering period to coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semi-arid tropics may include changing the cropping calendar to take advantage of the wet period and avoiding extreme weather events (for example, typhoons and storms) during the growing season. Cropping systems may have to change to include growing suitable cultivars (to counteract compression of crop development), increasing crop intensities (that is, the number of successive crop produced per unit area per year) or planting different types of crops. Farmers will have to adapt to changing hydrological regimes by changing crops.

Augmenting production and income: Production can be enhanced by improved crop management, improved adverse climate tolerant varieties, improved seed sector, using technology dissemination mechanisms, making available capital and information, which are the key reasons for yield gaps. Watershed management programme can yield multiple benefits. Such strategies could be very useful in future climatic stress conditions. Income can be increased from agricultural enterprises by suitable actions such as accelerated evolution of location-specific fertilizer practices, improved fertilizer supply and distribution system, improved water and fertilizer use.

Early warning system and crop insurance: Improved risk management can be carried out through early warning system and crop insurance policies that encourage crop insurance and can provide protection to the farmers if their farm production is reduced due to natural calamities. In view of these climatic changes and the uncertainties in future agricultural technologies and trade scenarios, it will be very useful to have an early warning system of environmental changes and their spatial and temporal magnitude. Such a system could help in determining the potential food-insecure areas and communities, given the type of risk. Modern tools of information technology could greatly facilitate this.

Water management: *In situ* soil–water management, particularly in arid and semi-arid regions, where crop growth is severely limited by water deficit even if nutrient availability is adequate, is important for enhancing productivity and organic carbon content of soil. Water harvesting techniques and micro catchments are extremely beneficial in increasing biomass production in arid climates. Waste water and solid waste in agriculture should be recycled as freshwater supplies are limited and water has competing uses, and it would become even more constrained in changed global climate. Industrial and sewage waste water, once properly treated, can also be a source of nutrients for crops. Since water serves multiple uses and users, effective inter-departmental coordination in the government is needed to develop the location-specific framework of sustainable water management and optimum recycling of water.

Post-harvest management: Harvest and post-harvest management should be carried out for minimizing the losses due to extreme climatic events or mean climate change conditions. Providing community-based post-harvest storage spaces at village level can help the farmer to save the produce from exposure to any climate related extreme event. Research efforts are required to design the storage structures and efficient processes for changed climate scenarios.

Harnessing the indigenous technical knowledge of farmers: Farmers in South Asia, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge for a range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness this knowledge and fine-tune it to suit the modern needs.

Agriculture: mitigation of climate change

Agriculture has the potential to cost-effectively mitigate GHGs through changes in agricultural technologies and management practices. Mitigation of GHG emission from agriculture can be achieved by sequestering carbon in soil and reducing methane and N_2O emissions from soil through change in land use management. Changing crop mixes to include more plants that are perennial or have deep root systems increases the amount of carbon stored in the soil. Cultivation systems that leave residues and reduce tillage, especially deep tillage, encourage the build-up of soil carbon. Shifting land use from annual crops to perennial crops, pasture, and agro-forestry increase both above- and below-ground carbon stocks. Changes in crop genetics and the management of irrigation, fertilizer use, and soils can reduce both N_2O and methane emissions. Such options are not only important for global warming mitigation but also for improving soil fertility.

Sequestration of C in agricultural soil: Mitigation of CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil through application of organic manure, change in soil management, and restoration of soil carbon on degraded land. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro-aggregation, and mulching can play an important role in sequestering carbon in soil. Sequestration of carbon in soil is not only important for global warming mitigation but also for improving soil fertility.

Mitigating methane emission from rice fields: The strategies for mitigating methane emission from rice cultivation could be altering water management, particularly promoting mid-season aeration by short-term drainage; improving organic matter management by promoting aerobic degradation through composting or incorporating it into soil during off-season drained period; use of rice cultivars with few unproductive tillers, high root oxidative activity, and high harvest index; and application of fermented manure like biogas slurry in place of unfermented farmyard manure. Direct-seeding of rice (DSR) could be a potential option for reducing methane emission. Methane is emitted from soil when it is continuously submerged as in case of conventional puddled transplanted rice. However, the DSR crop does not require continuous soil submergence, thereby reducing or totally eliminating methane emission when it is grown as an aerobic crop. As the DSR reduces methane emission drastically it has considerable potential (about 75%) to reduce the global warming potential (GWP) compared to conventional puddled transplanted rice.

Efficient manure management using biogas plant for global warming mitigation: Biogas technology, besides supplying energy and manure, provides an excellent opportunity for mitigating GHG emission and reducing global warming through substituting firewood for cooking, kerosene for lighting and cooking, and chemical fertilizers. The global warming mitigation potential of a family-size biogas plant is about 10 t CO_2 eq/year.

Mitigating N_2O emission: The most efficient management practices to reduce N_2O emission are site-specific nutrient management and use of nitrification inhibitors such as nitrapyrin and dicyandiamide. There are some plant-derived organics such as neem oil, neem cake, and karanja seed extract, which can also act as nitrification inhibitors.

Livestock Sector - Opportunities and Challenges.

The livestock sector is one of the significant contributors to GHG emissions in India. Large uncertainties exist in the livestock enteric methane emission estimates due to variations in livestock breeds, body weights, growth, feed quality and resources and their digestibility, milk production, and emission coefficients.

Livestock species of India are well-adapted breeds, and prospects for these animal species to adapt to increased air temperature through traditional breeding and genetic modifications appear to be promising. More research on possible adaptation of these species to elevated CO_2 is needed. The loss in milk yield of these adapted species has been observed to be small due to rise in temperature, suggesting that adapted species will more consistently yield produce under climate change scenarios in tropical latitudes than in temperate latitudes.

Livestock production with scientific management practices will reduce production losses. Livestock management and proper housing under tropical conditions will help in abating extreme productivity losses. The livestock producer awareness of livestock threshold for physiological stress can help in the adaptation of livestock to climate change and reducing losses due to temperature variability and rise due to climate change. Impacts of climate change on livestock after adaptation are estimated to result in small percentage changes in income; these changes tend to be positive for a moderate global warming, especially when the effects of temperature rise are taken into account. The effectiveness of adaptation in ameliorating the economic impacts of climate change on livestock across India will depend on local or on regional resource endowments.

A review of various adaptation strategies needs to be carried out to estimate future requirements of livestock (species and breeds) to assess the impact of climate change. There should be a scientific development of impacts inventory for different livestock species based on quantitative modelling outputs and qualitative assessments. Assessment of the impacts in monetary values for policy decisions making, use of multipurpose adapted livestock species and breeds to minimize impacts, and superior breeds with higher productivity (meat, milk, wool or draught) may be encouraged only for commercial use, and a livestock mix at farm level has to be made available to our farmers. Farmers need to be educated about the consequences of climate change and options. Preventive methods for diseases and vector spread may be taken. Use of suitable animal management practices (some strategies and the related description is given in Table 7.5) to reduce negative impact on yield and production by short-term and long-term strategic planning is to be formulated and executed at grassroot level.

Mitigating methane emissions from livestock production system

Methane production from livestock, either directly through the livestock production system or indirectly through changes in the biodiversity, has significantly contributed to the GHG flux emanating from India. Livestock production can also result in emissions of N_2O. However, there are ways through which GHG emissions can be reduced from livestock through various kinds of management and technical strategies, which would at the same time enhance production efficiency and result in lower emissions per unit of milk or meat produced.

There are a number of options that exist to assist in minimizing the effect of heat stress on livestock. The two primary options are making some ration adjustments and altering the environment that the animals live in. Mitigation of methane production from ruminants has both long-term environmental and short-term economic benefits. Manipulations in rumen through different possible options are beneficial to reduce the methane production by decreasing the fermentation of organic matter in the rumen, shifting the site of digestion from the rumen to the intestine, diverting H^+ for more propionic acid production, and inhibiting the activity of methanogens.

In addition to the enteric fermentation contribution of methane from ruminants, one of the major GHG emission contributions from livestock production is from forage or feed crop production and related land use. Proper

Table 7.5: Strategies for adaptation studies in the livestock sector

Strategy	Description
Breeding strategies	Adaptation strategies should not only consider the tolerance of livestock to heat, but also their ability to survive, grow, and reproduce in the conditions of poor nutrition, and infestation with parasites, and onset of diseases. Such measures could include: (i) identifying and strengthening local breeds that have adapted to local climatic stress and feed sources and (ii) improving local genotype through crossbreeding with heat- and disease-tolerant breeds.
Scientific and technological development	Working towards a better understanding of the impacts of climate change on livestock, developing new breeds and genetic types, improving animal health, and enhancing water and soil management would support livestock adaptation measures in the long term.
Livestock management systems and water management	Efficient and affordable adaptation practices need to be developed for the rural poor who are unable to afford expensive adaptation technologies. These practices include provision of animal shade and water to reduce heat stress of temperature rise and using improved methods of harvesting water resources through the introduction of simple techniques for localized irrigation (for example, drip and sprinkler irrigation), accompanied by facilities to harvest and store rainwater.
Awareness programmes	Information about climate change is a crucial component of adaptation. It is very important that the knowledge on livestock is shared with local farmers/communities. Training in agro-ecological technologies and practices for the production and conservation of fodder improves the supply of animal feed and reduces malnutrition and mortality in animals due to climate change.

pasture management through rotational grazing is the most cost-effective way to mitigate GHG emissions from feed crop production. Animal grazing on pasture also helps reduce emissions. Introducing grass species and legumes into grazing lands can enhance carbon storage in soils. Improving the management of animal waste products through different mechanisms, such as the use of covered storage facilities, is also important. The level of GHG emissions from manure (methane, N_2O, and methane from liquid manure) depends on the temperature and duration of storage. Long-term storage at high temperatures results in higher GHG emissions. In the case of ruminants, pasture grazing is an efficient way to reduce methane emission from manure because storage is not necessary.

Agriculture contributes to about 17.6% of the total GHG emissions of the country (MoEF, 2010). Considering the growing demand for food in the near future and the need for ensuring food and nutritional security of the nation, the Department of Agriculture and Co-operation (DAC) proposes an emphasis on growth in food production rather than on mitigating GHG emissions from the agriculture sector. However, apart from the two broad areas proposed for further research in mitigation of climate change i.e. emission from rice fields and N_2O emission due to nutrient management; there is a need to develop research themes that have more focus on mitigating GHG emissions from the livestock sector (According to MoEF, 2010; out of the total GHG emissions from the agriculture sector, a majority share i.e. 63.6% is contributed by livestock).

Vulnerability Assessment and Adaptation

The six critical priorities of the Indian planning process are as follows:

1. Economic security
2. Energy security
3. Environmental security
4. Water security
5. Food security
6. Provision of shelter and health for all

Climate change would impact all of these in varying degrees. Linking of these priority concerns with climate change policies is the key to harmonizing sustainable development and climate change actions. Research has been initiated under the SNC process to assess potential impacts of climate change on some of these concerns, such as Indian agriculture, water resources, forestry, coastal zones, natural ecosystems, human health, industry, and infrastructure, including construction of consistent climate change scenarios for India and assessment of extreme events using existing models and expertise. The work involves assimilation of existing research work, identification of vulnerable sectors and areas, and a few specific case studies for each sector. Lack of data and national databases, resource scarcity, unavailability of sub-regional and sectoral impact assessment scenarios, lack of modelling efforts and trained manpower, and limited national and regional networking of institutes and researchers are some of the constraints highlighted. The key conclusions that emerged from these assessments are as follows:

First, during the current century, under plausible global emissions scenarios, the climate over the Indian sub-continent would be significantly altered, with regional variations in temperature and precipitation as well as in the distribution of the extreme climatic events like hurricanes.

Second, this would be a century of development for India, accompanied by rising incomes, stabilized population (by the later half of the century), integration with global markets, and enhanced social-infrastructure. The effects of this would be increased energy consumption on the one hand and enhanced mitigative and adaptive capacity on the other.

Third, climate change would impact the key sectors of the Indian economy, and in the absence of adaptation strategies, could cause significant damage. The water, agriculture, and forest sectors would experience direct impacts. In these sectors, understanding the regional variability of climate change across different agro-climatic zones would be the key to develop the response strategies. The ecosystems would experience direct stress from the altered climate. The impacts would vary across species and regions. Thus, it is important to identify the vulnerable species, examine their migration capabilities, and develop strategies to enhance resilience and survival.

Fourth, the direct and indirect effects of climate change on health are vital. While the temperature rise and increased precipitation may exacerbate the vector-borne diseases such as malaria and its spread to newer areas, such as higher altitudes in Himalayan mountains; the rising incomes, medical inventions, and increased supply of social infrastructure would cause benign effects that would mitigate the health impacts.

Fifth, the human activities as well as natural processes along the long coastline of India are especially vulnerable to changes in climatic parameters and secondary effects like the rising sea level and increased hurricane activities. Globalization processes are already adding environmental stresses in coastal regions, as trade tends to concentrate economic activities and population in the coastal areas.

Finally, in summation, the impacts and vulnerability would be decided on the one hand by the extent of climate change and on the other by the pace and quality of development in the country. While a successful global climate regime could keep the concentrations of GHGs in the atmosphere within dangerous limits, the quality of development would be the prime insurance at the national level to deal with the adverse impacts of climate change.

The key tasks to address vulnerability and adaptation may be viewed in the matrix of strategies and geographic hierarchy (Table 7.6). Climate change is a long-term issue, that is, the change in climatic parameters and their impacts would continue to exacerbate over decades and centuries. Therefore, the type and intensity of interventions would enhance with the expiry of time. Strategically, we therefore propose only the immediate, that is, near-term tasks to keep adjusting to the advancing knowledge of climate change and its impacts, emerging technologies, and emerging signals from the global policy regime.

In the short-run, that is, within a decade, the immediate tasks are to enhance capacity for scientific assessment,

Table 7.6: Key tasks for addressing vulnerability and adaptation needs

Geographic Hierarchy/Strategies	Local	National	Regional/ global
Capacity building	Monitoring, observation, awareness/assessment at state/ district/city/ community levels	Scientific assessment, measurement, models, national research agenda	Participation in global/regional modelling and assessments
Knowledge/information	Locale-specific databases, scenarios and assessment, local monitoring networks	Research networks, National databases (for example, NATCOM), scientific and policy models, national scenarios, technology inventory	Interface with IPCC assessments, interfacing with regional/ global databases, scenarios and assessments, technology inventory database
Institutions/ partnerships	Community initiatives, early warning networks	Stakeholders networks, public/ private programmes	UNFCCC processes, trans-boundary impacts assessment
Policy/ instruments	Locale-specific adaptation plans, community-based adaptation programmes	Science-policy linkage, economic instruments (for example, insurance, R&D funds), integration with national development/ planning process	Adaptation funds, trans-boundary regulations
Technology	Locale-specific technology adaptation	Targeted R&D, technology transfer protocols, demonstration/ pilot projects	Scientific exchange, technology transfer

generate awareness among the stakeholders, and institutionalize learning processes. These tasks were effectively initiated within the process for preparing the INC. A network of research institutions exists in India, which houses excellent competences in different areas of assessment (like INCCA). In India, other organized stakeholders like the industry associations and NGOs are already participating in the climate change activities. The institutionalization of the existing research initiatives – first via coordinated networks and later via the creation of centres of excellence – would be a key task. The global assessments, especially by the IPCC, are pertinent inputs into the national assessment. Indian experts are contributing to the IPCC assessments over the past decade. Organizing a cell of experts, especially those participating in the current global assessments, and linking it with the government processes would enhance the Indian assessment, besides improving inputs from the country into the IPCC assessments. The Indian Network for Climate Change Assessment (INCCA) has been constituted to institutionalize the various aspects of climate change related research.

While major investments in adaptation technologies may wait, creating technology knowledge base would be essential to reduce transaction costs and transition time. In case of projects building long-life assets, such as infrastructure, including future climate change in the project impacts assessment would be critical. In the short run, building partnerships is another key task. Awareness among stakeholders is essential for this. In brief, the short-term tasks would focus on soft processes that involve capacity building for assessment, technological learning, partnerships among stakeholders, databases and models to support policy making, vertical-geographical integration of assessment, instituting policy-science interface between government and researchers, and initiating pilot work on economic instruments, such as insurance, for efficient implementation of response strategies.

The medium and long-run tasks would best get crafted with time. Though the specifics of these tasks and timetable of their implementation are uncertain, an *a priori* speculation of these tasks indicates that instituting measurement systems to assess the extent of impacts in critical sectors would be an important task. The involvement of local actors in developing and implementing adaptation response strategies is critical since the impacts by their very nature are sector- and locale-specific. A vital task would be to institute self-driven and efficient mechanisms under a global umbrella such as the insurance markets, and adequate funds for adaptation technology development and transfer to Non-Annex I countries.

In the final analysis, any new initiatives, institutions, and policies are executed through existing institutions and under prevailing conditions. The apparently perfect strategies designed to address a specific issue, such as climate change, would be implemented via markets, institutions, and organizations that are far from perfect in developing countries. The tasks delineated above, therefore, will have to be moderated and adapted to the realities of the prevailing national dynamics. In India, the present policy dynamics are imbued with reforms perspective. This offers positive opportunities for efficient execution of new initiatives. This notwithstanding, the vulnerability and adaptation strategies to deal with climate change have inherent implementation difficulties on three counts. First, efficient markets to deal with natural climate variability are weak. This is evident from the incomplete and inadequate insurance cover for crop failures and against hurricanes. Second, the insurance market to address the added variability from anthropogenic climate change operates over the distorted baseline of existing insurance market for natural climate variability. The incremental damages due to anthropogenic forcing on climate are difficult to isolate from the baseline climate variability. This makes it difficult to assess incremental damages as well as incremental cost of adaptation. Third, implementation and coordination failures are frequent in developing countries. The damages, therefore, may far exceed those feasible under an efficient system. Vulnerabilities, therefore, appear exaggerated compared to what they would be under an efficient market system or an effective public governance system. The National Action Plan on Climate Change has underscored the use of market mechanisms, wherever and whatever extent possible, in mitigating harmful impacts due to climate change.

The future poses added perception problems for vulnerability assessments. Sector specialists, who are generally scientists or domain experts, carry out most assessments. The scientific assessments make projections of impacts of climate change on specific sectors in a distant future, such as 100 years from now. However, the scientific assessments often fail to grasp the significantly altered social, political, and economic dynamics that would exist after 100 years, especially in developing countries. The scientific assessments thus err in assuming future climate to be operating in the present society. For instance, the impacts assessment on agriculture miss the fact that farmers of distant future in India would be living in a country with high average annual per capita income and would operate their farming business in an interconnected world with significant global trade in agriculture commodities, having access to superior weather-resistant seeds and efficient cultivation practices. The country would be less likely to have food security as its prime concern, and farmers are unlikely to face starvation. Similarly, the residents of India then would have better access to health and sanitation services and improved medicines. The malaria would be less likely to spread under such conditions, unlike in the present society exposed to the future hot and humid climatic conditions. The key to valid vulnerability assessment would be to assess the future impacts of climatic changes in the context of the then prevailing socio-economic conditions through articulated and structured socio-economic scenarios.

These observations point to a vital nexus between development and climate change. Conventionally, the vulnerability assessments and search for adaptation solutions have been confined to climate change science and policy. The development is then viewed as exogenous to the assessment, at best offering some ancillary benefits. The climate change vulnerability and adaptation assessments conducted for India under the SNC project validate the alternate perspective that considers development as the key contributor of adaptive and mitigative capacities. This perspective shifts the search for adaptation solution away from climate change science and policy to the broader domain of development policies. The real baselines then emerge as the point of departure of the analysis rather than as barriers to achieving efficient solutions in the ideal domain. Development then emerges as the source of solutions for climate change and its impacts, rather than its root cause. The key lesson is that the national development priorities, driven along sustainable pathways, can be the drivers of benign environmental changes. Thus, the integration of well-crafted development and climate actions would not only benefit development, but shall also redress the climate change vulnerabilities in developing countries. The architecture of an effective climate change regime thus rests on the foundation of a robust development regime. If there is to be a reorientation of the energy and other sectors in developing countries to meet the climate change and sustainable development challenges, there is a wide agreement that technology will play a central role in this transformation.

India makes capital goods to the tune of INR 260,000 crores. This sector comprises Heavy Electrical Machinery, Earth Moving Machinery, Industrial Machinery, Engineering Sector and Machine Tools. The sector has a 'multiplier' effect on energy consumption. Energy efficient machinery will save MWs of energy during its lifecycle. Indian technologies for the manufacture of these machineries lag behind the international best designs from energy use perspective. The Indian industry needs technology, finance and standards in order to achieve global standards.

In the case of automobiles, emission norms have already been introduced and the study of manufacturing plan of electric mobility in the Department of Heavy Industry is underway. In Heavy Industrial and Electrical Machinery sector, Working Group on Capital Goods & Engineering Sector recommended the manufacture of machinery with new technology with certain percentage of value addition and import of brand new energy efficient machineries as against import of second hand machines by the Indian industry.

Technology Needs for Adaptation and Mitigation

Given that the technology needs of the developing countries in relation to climate challenges are diverse and that deployment often requires a range of activities (not only technical, but many others as well), the term "technology transfer" provides too narrow a perspective and framework for successfully leveraging technologies for meeting climate challenges. The agenda for moving ahead must be viewed with the understanding that the necessary elements must be appropriately tailored both to the specifics of the technology as well as national circumstances. At the same time, the importance of controlling GHGs "through the application of new technologies on terms that make such an application economically and socially beneficial" must also be recognized, as highlighted in the UNFCCC.

Framework for leveraging technology for meeting the climate challenge (Also see Table 7.7):

1. **Financial assistance:** In cases where the high cost is the barrier to the deployment of improved energy technologies that advance climate mitigation as well as the development agenda, industrialized countries will need to fund the incremental costs of these technologies. Such an approach has already been implemented by the Global Environmental Facility

(GEF). One possibility may be to develop a policy of graduated financial assistance, where a portion of the incremental costs would be covered by developed countries.

2. **Technology deployment in Annex I countries:** There is an urgent need to begin deploying improved energy technologies in industrialized countries. In the case of technologies in the pre-commercial or early deployment stage, enhancing deployment in industrialized countries could be the fastest route to cost reduction, as the benefits of "learning-by-doing" accumulate. While large-scale deployment is unlikely to take place in the absence of national climate mitigation policies, targeted policies aimed at key technologies need to be implemented sooner rather than later.

3. **Joint technology development:** This involves a cooperative technical programme that is driven by technology needs of developing countries rather than the technology agenda of industrialized countries. Such a programme would have elements that cover all aspects of technological development, from basic research to demonstration and early deployment, with the combination of activities for any specific technology being shaped by a nuanced understanding of the innovation gaps for that technology. In the case of mature, well-developed commercial technology such as supercritical power plants, this programme would involve refinement and adaptation of technologies to meet local conditions. In the case of emerging technologies such as fuel cells, the programme would involve some joint applied R&D, significant adaptation to local conditions, and even joint demonstration activities.

4. **Knowledge sharing for enhancing deployment:** This is particularly important where non-economic barriers hinder the deployment of technology that otherwise make sense from the economic, climate and/or Sustainable Development point of view. Sharing of experiences in industrialized or other developing countries and adopting policy approaches to overcome these barriers should be very helpful. At the same time, exploration of new and innovative mechanisms should also yield valuable results. Furthermore, analysis and development of appropriate policies and programmatic approaches, tailored to the needs of specific technologies and national circumstances, would be helpful. It also would be useful to explore alternative ways of enhancing and accelerating innovation such as innovation challenges/prizes, the creation of guaranteed markets, and IP-sharing approaches.

Table 7.7: A taxonomy of energy technology needs and activities to enhance innovation

Domain	Key issue	AREA OF ACTIVITY								
		Examples	Basic sciences	Applied R&D	Product development/ technology adaptation	Demo/ early deployment	Large - scale deployment	Financial subsidy	Policy/ business Analysis	Knowledge sharing
Commercial technology	Cost, adaptation	Ultra- supercritical power plants, hybrid cars, solar-PV systems			✓	✓	✓	✓	✓	
Commercial technology	Market organization, information, finance	Advanced space conditioning, compact fluorescent lamps (CFLs)			✓	✓	✓		✓	✓
Emerging/ pre-commercial technology	Technology risk, cost, adaptation	Integrated gasification combined cycle (IGCC), fuel cells, light emitting diodes (LEDs), 2nd/3rd generation biofuels		✓	✓	✓		✓	✓	
Enabling technologies	Leveraging local capabilities for participating in value-chains	Materials	✓	✓						✓
"Local" technology/ product	Limited technology/ product development	Cook stoves, biomass gasifiers, solar lanterns		✓	✓	✓	✓	✓	✓	✓

5. **Capacity building in Non-Annex I countries:** Since climate challenge is a long-term challenge, a case can be made that building local innovation capacity in developing countries will be critical for helping with adaptation, development of appropriate technologies, and effective deployment. This would not come about just from staffing a few high-tech laboratories, but also from training the next generation of technically competent people. Therefore, it is critical to strengthen local education and research institutions and ensure that they link up to international innovation activities.

Research and Systematic Observation

Weather, climate, and oceanographic research

The Indian Atmospheric and Oceanographic Research is committed to enhance the knowledge of Asian summer monsoon (ASM) under various objectives, such as, climate modelling, monsoon studies, climatic tele-connections, predictability of weather and climate, climate change and related socio-economic impacts, severe weather systems, middle and upper atmosphere, boundary layer and land surface processes, observation system, and data archive and dissemination.

Main thrust of research in the Atmospheric Sciences in India is to improve the capabilities of the existing General Circulation Models (GCMs) and paleao-climatological models—to simulate the past, present, and future of the ASM under the projected biogeophysiological changes. Parameterization of sub-grid scale physical processes, including convection and land surface processes to improve the skill of models and inclusion of orography, is another thrust area. Improving the model resolution for better understanding of the ASM is also considered as the main objective in modelling research. Other objectives are to resolve several important ASM phases, like active and break phases, inter-annual variability, monsoon trough, inter-tropical convergence, southern hemispheric equatorial trough, easterly jet, low level jet, etc. Interaction between the tropics and extra tropics in the monsoon region is yet to be understood, which includes the role of blocking, shifts of the westerly jet, and other major anomalies in the circulations of both the hemispheres. Development of physical and mathematical models of energy and mass exchange in the boundary layer of agro-ecosystems and other land surface processes is also projected for the near future.

Detailed analysis of ENSO–monsoon relationship using Tropical-Ocean-Global-Atmosphere (TOGA) and other support from World Climate Research Programme (WCRP) is projected. Understanding the synoptic scale and mesoscale phenomena in monsoon region using satellite cloud imagery/ocean-land-remote sensing data, radar, and other conventional data is proposed. Kinematics and dynamical study of different phases, such as onset, progression, withdrawal, break, and active phases, is also considered as a thrust area. Interrelationship between ASM and other global circulations is to be worked out by statistical approach. Detailed study of winter monsoon in India, which is the least studied part in Indian meteorology, is proposed as an important task to enhance our knowledge base and to improve the winter time agriculture system.

Instrumental capabilities are to be improved by developing various ground-based remote sensing systems, such as LIDARS, SODARS, spectrometers, photometers, and radiometers. These are supposed to enhance the capability of studying trace gases, including aerosols, ozone, CO_2 etc. Role of CO_2 and other such constituents in the evolution of atmospheric processes leading to climate of the given region is to be studied for understanding the atmosphere–biosphere reactions.

Extreme events

Under the theme of extreme events, India is intended to study the pre-monsoon thunderstorm activities in the north-eastern region of India, intense vortices within the monsoon system such as lows, depressions, mid tropospheric cyclones, and offshore vortices.

To lower the impact of loss due to cyclonic activities, installation of Doppler radars along the Indian coast is being carried out. Multi-sensor instrumented aircraft flights are to be incorporated for this purpose. Three-dimensional models are also being developed for simulation and prediction of cyclones. Support is being taken from physical factors or synoptic features for studying the cyclones favourable for the development and movement of cyclone over Indian seas, with particular interest like re-curvature and looping, and formation and maintenance of cyclone eye. Associated phenomena, such as the storm surges, are being modelled.

Agriculture sector research

The future pathway for agriculture research includes inventorizing, characterizing, and monitoring natural resources using modern tools and techniques. Development of sustainable land use plans for each agro-ecological sub-region in the country is underway. Another agenda is to develop a system, which regulates the fertilizers usage by increasing the fertilizer-use efficiency by 8–10% from the current level and its integrated use with organics by enhancing the contribution of organics, including bio-fertilizers. Management and monitoring of soils for sustainability, on-farm irrigation water management to enhance water-use efficiency, refinement of technology for economical utilization of poor and marginal quality waters for agriculture, and development of location-specific model watersheds in various agro-ecological zones of the rain- fed areas to enhance the productivity are planned for the future. Weather-based expert systems for enhanced prediction and improvement in agriculture meteorology advisory services are planned for near future. Increasing overall cropping intensity with emphasis on energy efficiency and alternate agriculture, especially with crops requiring low water, is proposed to be investigated. Development of agro-forestry system to enhance tree cover in agricultural lands to support the supply of fodder, fuel, industrial wood, and small timber requirements on a sustainable basis and monitor climate change and mitigation of its adverse effects on agricultural production systems is also planned.

Table 7.8: Directions (meteorological and oceanographic satellites)

Name	Launch	Usage
CARTOSAT-2+	2004/05	Remote sensing satellite
INSAT 3 series+	2004/05	Meteorology, telecommunications, extension programmes
RISAT-1+	2005/06	Remote sensing satellite
OCEANSAT-2+	2006/07	Remote sensing satellite
ASTROSAT+	2005/06	Astrophysics, environment, meteorology
KALPANA 2+	2005/06	Meteorology, environment
MEGHA-TROPIQUES+	2006/07	Meteorology, oceanography, environment

Space sciences

Indian Space Research Organization (ISRO) has initiated development of many future satellites, with particular emphasis on meteorological and oceanographic objectives (Table 7.8). ISRO has been launching satellites with advanced payloads and is progressing in the direction of advancing space science knowledge in India.

Sustenance and enhancement of established capacities

Capacity building, networking, and resource commitment form the core of institutionalizing Indian climate change research initiatives. These involve a shared vision for policy-relevant climate change research, scientific knowledge and, institutional capacity strengthening (enhanced instrumentation, modelling tools, data synthesis, and data management), technical skill enhancements of climate change researchers, interagency collaboration and networking improvement, and medium to long-term resource commitment. A step, with the formation of INCCA, has been made in the right direction and it is proposed to be expanded to include multiple stakeholders at all levels and forums.

Several anchors have to be developed for sustenance and enhancement of established capacities in India based on policy needs and disciplines. Policy research includes diverse needs such as international climate change negotiation related research, contribution to the IPCC process, sub-regional sectoral and integrated impact assessment, adaptation/response strategy formulation, mechanisms for mitigation and adaptation project selection and financing, and climate-friendly technology identification and diffusion in multiple sectors.

Sporadic research efforts are continuing in India since the last decade, such as the ALGAS, or Asia Least cost Greenhouse Gas Abatement Strategy, initiative; independent climate change related research initiatives by government ministries such as the Ministry of Environment and Forests, Ministry of Water Resources, Ministry of Health and Family Welfare, Ministry of Agriculture, Ministry of Science and Technology, among others; and the National Communication project; apart from a few initiatives at individual expert and institution level. Many Indian scientists and researchers have contributed and continue contributing significantly to the IPCC process. India's SNC project has, for the first time, brought these together in a formal network to cover diverse research areas such as preliminary sub-regional sectoral impact assessments, GHG emission coefficient development for a few key source categories, and institutional networking (INCCA).

However, the procedures, methodologies, and data requirements for GHG inventory preparation are not known to most of the institutions generating activity data in various sectors. On the other hand, a few research teams in the country have the latest international expertise in preparing GHG inventories. The National Communication project has attempted to network the two. However, the capacity building initiatives have to be continued, widened, and strengthened. The existing capacity gaps have to be identified, prioritized, and then strengthened gradually. The focus has to be to institutionalize the process. Climate change research has to catch the attention and imagination of the younger Indian research community, especially in the universities and premier academic institutions. The second stage would be to keep these researchers engaged in their pursuit. This is particularly important in a developing country perspective where lack of incentives and resources divert trained manpower to better job avenues, creating a vacuum in national capacity building efforts. There have to be sustained capacity building efforts for a reasonable time so that the process then becomes self-sustaining and institutionalized. Timely and sustained international funding is critical to realize this effort.

The networking efforts have to be simultaneously and consistently extended to interface the research community with industry and policy-makers. Industry would benefit from latest scientific research and GHG accounting practices. On the other hand, industry concerns and capabilities would also be reflected in research. The 42 laboratories of Council of Scientific and Industrial Research (CSIR) across the country are meant to provide interface between the industry and scientific research. Climate change concerns have to be brought into focus in this networking, especially with regard to their linkages with sustainable development.

Constraints and Gaps Related to GEF Programmes

This section covers national capacity development needs for climate change related projects. Global Environment Facility (GEF) is one of the mechanisms of the UNFCCC to promote projects aimed at providing global environmental benefits. The official GEF pipeline has only very few projects from India, while the list of project concepts in the country is quite large. The GEF Cell in the Ministry of Environment and Forests has over 75 submissions of project concepts.

GEF programmes and policies are constantly evolving. GEF portfolio and operational programmes are increasing. The programmes keep increasing (sustainable transport, integrated ecosystem management, agro-biodiversity); the strategic priorities within programmes keep changing; the focal areas have increased (land degradation and POPs); and many more executing agencies are knocking at its doors.

The growth in amounts allocated to India's portfolio of GEF projects has slowed. Until 1996, a sort of parity was maintained between allocations to the two largest developing countries. However, since then, India's portfolio of "single-country projects" has slipped from being the second largest in the world to being the fourth largest. If country allocations to global and regional projects were also considered, India would slip further behind.

Although GEF can only meet a small portion of the country's financing requirements for sustainable development, it may act as a catalyst for broad-based involvement of various stakeholders. GEF normally funds only one project of a type in a country. Since so few projects have closed, it is still too early to assess how successful replications have been, but we need to undertake concerted efforts to analyse, document, and disseminate to clearly established target audiences, good practices distilled from pilot projects.

Suggestions to overcome constraints and gaps include creating web-based eligibility programme; creating

Table 7.9: Indicative portfolio of India's ongoing GEF projects

S.No.	Project Name	GEF Executing Agency	Project Status
1	Alternate Energy	Indian Renewable Energy Development Agency	Completed
2	Development of High Rate Bio Methanation Processes as Means of Reducing Greenhouse Gas Emissions	Ministry of New and Renewable Energy	Completed
3	Optimizing Development of Small Hydel Resources in Hilly Areas	Ministry of Environment and Forests	Under Implementation
4	Coal Bed Methane Capture and Commercial Utilization	Ministry of Environment and Forests	Under Implementation
5	Energy Efficiency	Indian Renewable Energy Development Agency Ltd (IREDA)	Completed
6	Selected Options for Stabilizing Greenhouse Gas Emissions for Sustainable Development	Ministry of Environment and Forests	Under Implementation
7	Biomass Energy for Rural India	Department of Rural Development, State Govt. of Karnataka	Completed
8	Enabling Activity for the Preparation of India's Initial Communication to the UNFCCC	Ministry of Environment and Forests	Completed

9	Removal of Barriers to Energy Efficiency Improvement in the Steel Re-rolling Mill Sector	Ministry of Steel	Completed
10	Electric 3-Wheeler Market Launch Phase	Ministry of Environment and Forests (MoEF) and Bajaj Auto Ltd, India, (BAL)	Under Implementation
11	Removal of Barriers to Biomass Power Generation, Part I	Ministry of New and Renewable Energy	Under Implementation
12	Enabling activities for Preparing India's Second National Communication to UNFCCC	United Nations Development Programme	Under Implementation
13	Achieving Reduction in GHG Emissions through Advanced Energy Efficiency Technology in Electric Motors	International Copper Association (ICA)	Completed
14	Energy Conservation in Small Sector Tea Processing Units in South India.	Ministry of Environment and Forests	Completed
15	IND Programmatic Framework Project for Energy Efficiency in India (PROGRAM)	Bureau of Energy Efficiency	Under Implementation
16	Energy Efficiency Improvements in the Indian Brick Industry	Ministry of Environment and Forests (MoEF) through The Energy Resource Institute (TERI)	Under Implementation
17	Improving Energy Efficiency in the Indian Railway System - under the Programmatic Framework for Energy Efficiency	Indian Railways (IR)	Under Implementation
18	Promoting Energy Efficiency and Renewable Energy in Selected Micro SME Clusters in India – under the Programmatic Framework for Energy Efficiency	Micro, small and medium enterprises (MSME), BEE, IREDA and Small Industries Development Bank of India (SIDBI)	Under Implementation
19	IND Energy Efficiency Improvements in Commercial Buildings – under the Programmatic Framework for Energy Efficiency	Bureau of Energy Efficiency	Under Implementation
20	Coal Fired Generation Rehabilitation Project	World Bank	Under Implementation
21	Chiller Energy Efficiency Project – under the Programmatic Framework for Energy Efficiency	ICICI Bank	Under Implementation
22	Sustainable Urban Transport Project	Ministry of Urban Development	Under Implementation
23	Financing Energy Efficiency at Micro, Small and Medium Enterprises (MSMEs)	India Bureau of Energy Efficiency	Under Implementation
24	Low Carbon Campaign for Commonwealth Games 2010 Delhi	Commonwealth Games Organizing Committee	Under Implementation
25	Market Development and Promotion of Solar Concentrators based Process Heat Applications in India	Solar Energy Centre, Ministry of New and Renewable Energy	Under Implementation

non-transferable individual, systemic and institutional capacity for implementing projects in the sector ministries; determining national priorities to sequence and develop individual projects; streamlining approvals and endorsements to reduce processing delays through single window processing and inter-ministerial coordination, creating a project mix with small grants, medium-sized and full-sized projects and their structural graduation; and facilitating project development and implementation through project champions.

GEF Portfolio in India

The current portfolio of India's GEF single country and global/regional projects is presented in Table 7.9. Under the replenishment cycles, the GEF portfolio for India is broadly spanned over five focal areas, including climate change, biodiversity, land degradation, and POP.

Climate Change Projects

Improvements for future national communications

India would like to immediately launch the activities for preparing the Third National Communication, reflecting commitment to the UNFCCC and would access further funding from the GEF for this purpose. The following table (Table 7.10) indicates the proposed project proposals so as to maintain continuity in the preparation of information for future national communication and also simultaneously ensure implementation of the Convention.

Table 7.10: Project proposals for preparation of information and implementation of the Convention.			
Sl. No	**Type/ sector**	**Title**	**Description**
A	National Communication	Preparation of Third National Communication proposal document	The project will assist India in preparing a detailed proposal for "Enabling Activities for the Preparation of India's Third National Communication to the UN Framework Convention on Climate Change (UNFCCC)".
B	National Communication	Enabling activities for the preparation of India's Third National Communication to the UNFCCC	The project will assist India in undertaking enabling activities to prepare Third National Communication to the Conference of Parties in accordance with the UNFCCC and build capacity to fulfil its commitments to the Convention on a continuing basis.
B.1	**Inventory estimation**		
1	All	Data format preparation for greenhouse gas (GHG) inventory reporting	Presently, the data being reported by the various ministries and departments at resource and sector level shows some mismatch and the consistency cannot be easily verified. It is imperative that the available data formats be reorganized for removing mismatch and inconsistency in reporting data at intra- and inter- ministerial levels in appropriate GHG inventory reporting formats.
2	Energy	Strengthen the activity data for GHG emission estimates from India's transport sector	Analysis of the current vehicle types and their distribution in various cities of the country and fuel use.
3	Energy	GHG emission measurements and activity data assessment for biomass used for energy purpose	GHG emission measurements and activity data assessment for biomass used for energy purpose.
4	Energy and industrial processes	GHG inventory estimation	Data collection and GHG Inventory estimation to climb the tier ladder to II/III tiers from the current Tier-I for the various sub-sectors.
5	Agriculture	Inventory estimation	Evaluation of sources and sinks of GHGs related to agricultural activities at disaggregated level, including data collection and validation of livestock, by age, sub-regional crop production, and sub-regional synthetic fertilizer use.
6	Land use, land-use change and forestry (LULUCF)	Land use pattern assessment for India for GHG inventory estimation	Periodically monitoring and estimating the area under different forest types as well as preparing a land use change matrix, describing the extent of land use change from one category to another, preferably at ½°×½°.
7	LULUCF	Assessment of wood, agriculture products, forestry & consumption in India for GHG inventory estimation	Estimating the fuelwood and commercial roundwood consumption, dung cake production and consumption, and agriculture crop residue consumption in India.
8	LULUCF	Assessment of carbon pools in India for GHG inventory estimation	Estimating different terrestrial carbon pools, namely, vegetation biomass, soil, and litter carbon stocks under various land use categories and assess changes in carbon-pools.
9	Waste	Activity data improvement for the waste sector.	Data collection and GHG inventory estimation to climb the tier ladder to II/III tiers for the various sub-sectors.
10	LULUCF	Inventory estimation	Inventory of forest soils of India.
11	LULUCF	Assessment of carbon pools in India for GHG inventory estimation	Measurement of above- and below-ground pools and fluxes under different forest types in India.
12	LULUCF	Inventory estimation	Inventorization, characterization, and management of forest invasive species.
13	Agriculture	Inventory estimation	Measurement techniques for GHG emissions from livestock and livestock manure—approaches to measuring and standardizing measurements.
14	Agriculture	Inventory estimation	Modelling GHG emissions from animal agriculture in India.
B.2	**Uncertainty reduction in inventory estimation**		
15	Energy	Development of CO_2 emission factors, linking coal beds with power plants, and impacts on their immediate environment—dispersion and transportation of emitted pollutants	(i) This project envisages GHG emission measurements from 40 power plants (coal- and gas-based). (ii) Evaluation of the changing sectors of coal use, including small-scale sectors. Investigation of characteristics of coal in the country, linking them to the various coalfields, which are used in the power plants. Comparative evaluation of the reliability of emission measurements by direct measurement, traditional mass balance approach, and continuous monitoring system. (iii) This will also carry out dispersal modelling and ascertain the levels of emissions in and around the plants. Will explore the sequestration potential of planned forest cover around the plants.

16	Energy	Development of mass emission measurement system for GHGs from the automotive vehicles	This will involve development and integration of techniques and systems for measurement of GHGs (CO_2, CH_4, N_2O) along with direct toxic emissions (CO, HC, NOx and PM) for conventional and alternative fuels. Measurements and data generation for emission factors in g/km of about 60 vehicle technologies and vintage combinations. Procurement and commissioning of measurement and sampling systems for GHGs.
17	Energy	GHG emission measurement from large point sources—steel plants	This project envisages GHG emission measurements from 10 steel plants. The process-based emissions will be distinguished and will be measured separately.
18	Energy	GHG emission measurement from large point sources—petroleum refineries	GHG emission measurements from five petroleum refineries.
19	Energy	CH_4 emission measurements from the coal mines	Cover 100 coal mines, including opencast mining, for CH_4 emission coefficient measurements.
20	Energy	CH_4 emission measurement from oil and natural gas venting, flaring, and transport	Cover all the major oil exploration sites in India.
21	Energy	GHG emission measurement from informal /partially informal energy intensive sectors	GHG emission measurements from fully/partially informal energy-intensive sectors like brick manufacturing, sugar, ceramics, etc. About 10 sectors are proposed to be covered here. The major ones being brick (sample about 100 kilns), sugar (sample about 50 units), soda ash (sample about 5 units), textile (sample about 20 units), ceramics (sample about 30 units), and chemical and dyes (sample about 30 units).
22	Industrial process	Reduction of uncertainties in GHG emissions factor in lime and cement sectors in India	This project will help to reduce the uncertainties in CO_2 emission coefficients derived for the INC. The work programme will entail systematic collection of CO_2 fluxes, samples of raw materials, and intermediate and final products for analysis. About 50 cement plants representing prevalent technologies for producing cement in India will be covered.
23	Industrial processes	GHG emission coefficient measurements from industrial processes	GHG emission coefficient measurements from industrial processes like, aluminium production, soda ash use, pulp and paper production, etc.
24	Agriculture	Nitrous oxide emission from selected agricultural fields of rice and paddy	Irrigated rice and dryland farming are major sources of CH_4 and N_2O in selected agro-ecological zones consisting of irrigated as well as dryland farming. The project will measure CH_4 and N_2O emission coefficients from these.
25	Agriculture	(i) Measurement of CH_4 and N_2O emission coefficients for rice cultivation (ii) Development of emission coefficient of non-CO_2 gas emissions from major agriculture crop residue	This will involve setting up a network of stations for continuous and more refined measurement of these emissions for the entire season of rice growth and year, assessment of fertilizer used, types of cultivars planted, soil carbon, etc. to ascertain the dependence of CH_4 and N_2O emissions on these parameters. Also individual measurements of changes in CH_4 emission under increased CO_2 environment using FACE facility will be carried out.
26	Agriculture	Measurement of CH_4 and N_2O emission coefficient from enteric fermentation in animals and manure management	This will involve establishment of CH_4 emission coefficients from different types of animal categories in India, with focus on the major emitters and N_2O emission coefficients measured from different types of manure management.
27	Agriculture	Measurement of N_2O emission coefficients from major soil types in India	This will involve establishment of network of stations for taking year long measurements of N_2O for representative soil types in India.
28	Agriculture	Soil carbon content assessment	To assess the organic carbon contents of Indian Agricultural Soils at ½º × ½º grid.
29	LULUCF	CO_2 emission and uptake measurements in specific forest types/areas to ascertain their net sink capacity	(i) This will involve establishment of towers inside and outside forests fitted with online CO_2 measuring equipment and weather parameters, including temperature, humidity, and wind direction.(ii) Determination of the rate of photosynthesis, transpiration, leaf area, and canopy cover of different native and planted species vis-à-vis reduction in GHGs, especially CO_2.
30	LULUCF	Soil carbon measurements, soil carbon cycle modelling, remote sensing and generation of GIS-based mapping of land use for Indian forest	(i) Setting up of network of stations for measuring soil carbon for different soil types in India. The measurements will be carried out according to the Intergovernmental Panel on Climate Change (IPCC) specification of soil depths.(ii) Carbon cycle modelling will be developed.(iii) To get a perspective of the land use and forestry of the Indo-Gangetic region of India, GIS based maps will be developed by decoding remote sensed data for use in emission inventory from this source in the future.

31	LULUCF	Uncertainty reduction	Generating emission factor/sequestration factors for GHG inventory in the LULUCF sector of India.
32	Waste	Measurement of emission coefficients from domestic and commercial waste water	(i) Measurement of CH_4 emission coefficient from domestic waste water with distinctive composition.(ii) Measurement of CH_4 emission coefficients from representative major effluent producing industries.
33	Waste	CH_4 emission from selected landfill sites	CH_4 measurements will be carried out in identified major landfill sites in cities with population greater than one million. The likely cities to be selected for this study will be Mumbai, Delhi, Chennai, Kolkata, Bangalore, Hyderabad, and Ahmedabad in India, where systematic collection and dumping of solid waste take place.
34	All	Undertake climate change related environmental studies (background measurements)	Continuous *in situ* monitoring of concentrations of GHGs (CO_2, N_2O and CH_4) from baseline stations at Kodaikanal and Shillong using gas chromatographic analysers. Regional grab sampling programme for GHGs using stainless steel sampling flasks and gas chromatographic analysis from a central laboratory.
B.3	**Vulnerability assessment and adaptation**		
35	Climate change modelling	Generation of high resolution regional climate change scenarios and investigating their impact on the Indian monsoon and on extreme climate events	(i) This will involve detailed diagnostic analysis of climate model control runs to assess the skill in simulation of present day climate and its variability over India.(ii) Analysis of perturbed simulations with SRES emission scenarios to quantify the climate change pattern over India with reasonable high resolution during the 21st century. (iii) Application of regionalization techniques to improve the assessment of climate change on regional scale. (iv) Study of the sensitivity of monsoon climate to natural/anthropogenic perturbations by model output diagnostics and numerical experiments. (v) Perform climate change experiments with global AOGCMs as well as regional climate models, with special emphasis on the development of realistic scenarios for the Indian region.(vi) Examination of the nature of possible changes in the frequency and intensity of severe weather and climate events (for example, droughts/floods, cyclonic storms, etc.). (vii) Interaction with various impact assessment groups and design specific climate change data products for use in their models through workshops and meetings.(viii) Ware house for the storage of all validated and downscaled AOGCM data products for South Asia, designed for regional climate change impact assessment, high-resolution scenario data for different administrative units of India (for example, states) and provide regular upgradation to keep pace with developments in the area.
36	Indian emission scenarios	Generation of future GHG emission scenarios for India	Articulation of alternate development pathways for India and quantification of key driving forces. These alternate scenarios will be congruent to IPCC-SRES scenarios and Indian climate change scenarios.
37	Various relevant sectors	Development of vulnerability and adaptation scenarios for India	Develop sub-regional vulnerability and adaptation scenarios for India which integrate the cross linkages between different sectors of the economy. These scenarios will be congruent to the Indian climate change and emission scenarios.
38	Agriculture	Assessment of vulnerability of Indian agriculture sector due to impacts of climate change and formulation of adaptation strategies	(i) Studying the impacts of enhanced level of CO_2 using Mid-FACE facility in the country on grain yield of cereals important to the economy (rice and wheat). The cereals under each category should be of different types of cultivars. Incorporating these results into modelling.(ii) Case study to understand the impacts of climate change on important crops in the country using modelling approach and formulating a matrix of alternate cultivar/cropping pattern/farming practices, etc. to adapt to climate change.
39	Water resources	To study the impact of climate change on the water resources and to develop adaptation strategies	(i) To assess water resources nationally, taking into account the climate change. (ii) To identify future water scarce zones in the country. (iii) To undertake case studies in some of the anticipated water-scarce zones in the country and devise adaptation strategies for availing water.
40	Water resources	Reducing uncertainties in assessing climate change variability and extreme events such as droughts and floods in India	Enhancing the temporal and spatial resolutions of GCM/RCM models to be more specific to India and using the precipitation and temperature series thus generated, as input to hydrologic models for forecasting drought/floods' variability and extremes in select water-stressed river basins (Sabarmati in Gujarat and Palar in Tamil Nadu), and select flood-prone basins (Ganga and Meghna).

41	LULUCF	To study the impact of climate change on forestry and formulate adaptation strategies	Develop current (and past) climate and vegetation type linkages and correlation and geographic maps of distribution. Evaluate, adapt, and develop vegetation response models suitable for the complex, diverse vegetation types in India. Assess the vulnerability of different ecosystems to different scenarios of climate change. Assess the impacts of different climate change scenarios on vegetation ecosystems in terms of shifts in boundary, changes in area, biodiversity, regeneration and growth rates, and carbon sink capacity. Evaluate different adaptation options and implementation barriers to reduce adverse impacts of climate change. Develop policy, institutional and financial measures to implement adaptation measures.
42	Natural ecosystems	To study the impacts of climate change on natural ecosystems such as the Sundarbans	This will involve study and modelling of impacts of climate change, including sea level rise on the dominant forest species in Sundarbans. Modelling the impacts of sea level rise on appearance and disappearance of Islands in the Sundarbans area.
43	Human health	To study the impacts of climate change on human health	This will involve identification of areas where malaria and diseases related to extreme heat or cold events will be prevalent in the future climate scenarios. Identification of communities most susceptible to climate change. Undertaking case studies integrating climate change and socio-economic scenarios. Development of adaptation matrix to combat the impacts of climate change.
44	Extreme events and coastal zones	Impacts of climate change and extreme events on coastal zones	(i) This study will include development of a sea level rise scenario due to climate change along the coastline of India. Study on impacts of sea level rise on specifically densely populated area with important infrastructure. (ii) Impacts of sea level rise on fisheries.
45	Energy	Integrated model development for assessment of impacts on energy sector	Developing software modules for impact assessment of climate change on energy sector and "soft linking" the same with models of inventory estimation to get an integrated view.
46	Energy and infrastructure	Impacts of climate change on energy and infrastructure in the country	(i) This study will involve specific case studies to evaluate the impacts of climate change on the energy availability and urban infrastructure in India. (ii) Evaluation of adaptation strategies, including insurance to combat the impacts.
47	Energy and infrastructure	Development of urban policy response for integrating climate change and sustainable development	This will involve identification of issues in urban areas relevant to climate change and development of methodology for linking them to sustainable development.
48	Agriculture	Integrated assessment for vulnerability assessment	Climate change vulnerability on productivity and quality of plant species of medicinal importance.
49	LULUCF	Impact assessment on forests due to climate change	(i) Influences on forest diseases and mycorrhizal fungi.(ii) : Forest fungi: carbon losses and sequestration.(iii) Bamboo mycorrhizae.
50	LULUCF	Adaptation needs assessment	Socio-economic adaptation among forest-dependent communities to climate change.
B.4	**Capacity building/enhancement**		
51	Inventory estimation	To establish a GHG reference laboratory for generating and disseminating certified reference materials	(i) This will involve preparation and dissemination of gas-CRMs of CO_2, CH_4, and N_2O. Calibration of gas chromatographs (GCs) used for baseline monitoring for above gases.(ii) Preparation of uncertainty budget for baseline monitoring for above gases for homogenization of uncertainty of measurements. Validation of test methods and organization of proficiency tests for measurement of above gases.
52	Inventory estimation	Nodal centre for synthesis and coordination of uncertainty reduction in GHG emissions	This centre will essentially validate and synthesize, and ensure application of good practices for uncertainty management and quality assurance (QA) and quality control (QC). Periodic training will be conducted to update researchers on the latest good practice guidance for undertaking measurements and also train personnel for undertaking measurements in various sectors. Following the guidance specified by the IPCC good practices report, this agency will act as a third party for implementing the QA/QC measures.
53	Vulnerability assessment and adaptation	Integrated impact assessment for India including long-term emission scenarios, GHG abatement policies and adaptation measures	Develop an integrated impact assessment modelling framework for India using sectoral models, consistent scenarios, and databases. It is proposed to deploy modular integration that is integrating modules consisting of individual sectoral models, run using similar climate, emission, and socio-economic scenarios. The basic thrust will be on generating common and finely gridded databases for use in models.

54	Energy	Setting up of Indian energy systems model for medium and long-term energy and environmental policy	Economy–energy–environment modelling using Indian emission scenarios and shared databases developed under other projects. Major outputs will include projection of alternate GHG emission pathways, energy intensities, technology and fuel mix, and energy sector investment requirements for India in medium to long term.
55	All sectors	Organizational and institutional issues for climate change	Creating awareness at all levels (grassroots to policy) on climate change, vulnerability and adaptation issues for industry and infrastructure, energy, agriculture, LULUCF sectors, through sectoral workshops in various (vulnerable) regions of the country, dissemination, publication, etc.
56	All sectors	Educating and informing the corporate sector about the emission abatement technologies and projects.	(i) Create awareness about climate change in business sector, especially on impacts on industry, cleaner production, Clean development Mechanism (CDM), etc.(ii) Role of insurance as a tool of adaptation for long life assets.
57	LULUCF	Modelling efforts	Develop technical and institutional capacity for modelling, monitoring, and verification of C-stock changes in LULUCF projects involving: developing models for predicting changes in stocks of different pools in different types of forestry projects; building capacities of institutions to undertake these activities; assisting project developers and project promoters; and developing information packages.
58	LULUCF	Modelling efforts	(i) Evaluation of forest dynamics and climate change through permanent plots. (ii) Estimation of regeneration potentials of the dominant forest species. (iii) Investigation of plant invasion in the natural forest stands. (iv) Models for predicting tree and stand growth and yield.
59	LULUCF	Impact assessment	Evaluation and monitoring the impact of climate change on plant diversity in ecotone regions of important forest types.
60	LULUCF	Adaptation needs assessment	Valuation of forest ecosystem goods and services.
61	LULUCF	Modelling efforts	Ecological assessment of indigenous tree species for carbon sequestration under different agro-ecological regions in India.

Thematic project proposals

Some thematic potential project concepts that are over and above the specific projects presented in earlier sections are presented. These include projects for assessing vulnerability of various socio-economic sectors and natural ecosystems to climate change, enhancing adaptation to climate change impacts, undertaking GHG emission abatement projects, and implementing capacity building initiatives (Table 7.11). These, however, are indicative and not an exhaustive listing of concepts. New understanding, knowledge development, and resources and technology transfers from GEF will enhance India's capacity to augment this list in subsequent National Communications, and financial resources would be required to further develop these projects into full-scale projects for funding.

It is envisaged that activities to enable continuous reporting to the UNFCCC will involve more detailed development of local emission factors, thus reducing uncertainties in inventory estimates, focusing on methodological issues, helping develop regular monitoring networks, maintaining and enhancing national capacity through establishment of nodal centres for climate change research, undertaking impact assessment and adaptation related activities, and increasing public awareness through information dissemination and education.

India also needs to form a network of stations, which will monitor the background GHG concentrations in pristine areas and also concentrations in polluted areas. For this, measurement facilities need to be set up at pristine areas such as at Hanle in Ladakh (the Himalayas), which is a high altitude station in the northern part of the country, at Sundarbans in West Bengal, at Kodaikanal in the southern part of India nestled in the relatively pristine environment of the Western Ghats, and the Andaman Nicobar Islands in the Bay of Bengal. These stations need to run like the Global Atmospheric Watch (GAW) stations and should measure the GHG concentrations continuously. Along with this, concentrations of SO_2, NOx, atmospheric turbidity, and atmospheric radiation (both direct and diffused) need to be measured at these stations.

India has a large potential for implementing GHG abatement options. This is primarily because the power sector in India is still predominantly coal-based, and the vintage technology status in power and transport sector has considerable potential for efficiency improvements. Abatement projects are mainly in the areas of energy efficiency, renewable energy, and sustainable transport. Capacity to develop bankable detailed project proposals is to be enhanced in India, such as energy audit projects.

It is critical to ensure minimum performance standards, codes, and certification for energy auditors. Energy managers in industries need training. Commercial banks need to gradually build their own technical capacity. A project financing approach to lending has to be promoted rather than collateral-based loan financing, for energy efficiency.

In the Industrial Processes and product use sector, for a consistent and continuous GHG inventory estimation, it is increasingly imperative to involve a larger base of Industry Associations in the preparation of GHG inventory along with special attention to the involvement of industry associations of large energy consuming industries.

According to the present land-use pattern, agriculture occupies about 44% of the total geographical area. The present knowledge base in agriculture sector regarding the impact of climate change is limited to a combination of sporadic field studies and simulation models primarily restricted to impact of temperature rise, in particular 'the InfoCrop Dynamic Model'. So far, the information that we have on the impact scenario is limited to select crops such as paddy, wheat, potato, cotton, coconut, apple, grape, etc that shows differential behaviour of improvement and deterioration in the yield with increasing temperature. It has also been estimated that India loses 1.8 million tonnes of milk production due to climatic stresses, thus indicating possible threat to livestock. Growing stresses in the agriculture sector will have a significant bearing on human health. With the present day conditions, the Government of India is in the process of enacting the Food Security Act. Climatic variability and climate change will have a strong bearing on the mandate of this Act. Thus, a coordinated research on assessment of climatic variability and climate change vis-a-vis food grain production and public health should be prepared at the National level in the coming plan period.

Additionally, the forest sector provides large potential for abatement of carbon. Though the deforestation rate in India has reduced in the recent years, still, the vast degraded lands can be used for afforestation and hence for sequestration of carbon. For example, lands in and around mines and the abandoned agricultural lands can be the initial targets for afforestation.

In the Maritime transport sector, in order to move the cargo in an energy efficient and environmentally friendly manner and to attain sustainable development and to decongest our roads, greater focus is required in many areas, such as: giving a boost to coastal movement of freight, promoting modal shift from road and rail to coastal shipping and inland water transportation, investment in support for developing infrastructure (setting up more minor ports along the Indian coast and dedicated berths for coastal ships at all Indian ports, setting up of adequate ship repair facility and dry-docks along the Indian coast for catering to the growth of coastal shipping, setting up of LNG supply facilities, and setting up of rail and road connectivity at the ports to the nearest rail heads), incentivising the modal shift from road to coastal shipping through financial measure on the lines of the Marco Polo scheme[1] in the EU and through supporting mechanisms such as the Clean Development Mechanism.

Table 7.11: Research and demonstration project proposals for adaptation, vulnerability assessment, and abatement

Sl. No	Type/ sector	Title	Description
A	**Adaptation**		
1	Agriculture	Crop insurance and climate change	Research to understand performance of various insurance models to develop comprehensive crop insurance packages for Indian farmers.
2	Land use, land-use change and forestry (LULUCF)	Vegetation modelling	Develop, validate, and disseminate dynamic vegetation models for assessing impact of climate change on forest ecosystem at the regional level, including: evaluation of existing dynamic vegetation models; adaptation/ modification/development of dynamic vegetation models for application at regional scales; validation for current climate and vegetation; and, dissemination of information package on the dynamic vegetation model.
3	LULUCF	Ecosystem modelling	Long-term monitoring of vegetation response in Himalayan ecosystem/ Western Ghats with wide altitudinal gradient to changing climate, along the latitudinal and altitudinal gradient, specifically including monitoring climate changes and vegetation changes; establishing linkage between climate change variables and forest vegetation characteristics.

1. Marco Polo scheme aims to ease road congestion and its associated pollution by promoting a switch to greener transport modes for European freight traffic. Companies with viable projects to shift freight from roads to greener modes can turn to Marco Polo for financial support. A company with a project to transfer freight from road to rail or short-sea shipping routes or inland waterways will qualify for a Marco Polo grant.

4	LULUCF	Adaptation policies for forest ecosystems	To assess the impact of forest policies, programmes, and silvicultural practices, to enhance resilience or reduce the vulnerability of Himalayan ecosystems/Western Ghats with wide altitudinal gradient forest ecosystem to projected climate change. Specifically, it will include reviewing forest policies, programmes, and silvicultural practices in selected regions; suggesting policies, programmes and silvicultural practices to reduce the vulnerability of forest ecosystems; assessing the implications of biodiversity, silvicultural practices, and dominant species to determine the vulnerability of forest ecosystems.
5	LULUCF	Assisting adaptation for vulnerable plant species	Anticipatory planting of vulnerable plant species in Himalayan ecosystems/ Western Ghats to adapt to projected climate change involving; identifying vulnerable species that are likely to migrate; planting along altitudinal gradient; monitoring performance of species; and making recommendations on anticipatory planting practices.
6	Coastal zones	Integrated adaptation policies for coastal zones	Identifying points of integrating the adaptation policy, having elements of both coastal zone management and sustainable development, into national, regional, and local developmental planning and policies. Specifically, it will include: review of other policies, namely, disaster abatement plans, land use plans, watershed resource plans; understanding "local livelihood stresses" induced due to environmental factors such as groundwater degradation due to sea water intrusion, coastal flooding, and erosion; understanding and documenting the local traditional knowledge systems used in combating these non-climatic stresses; and climate change induced enhanced variability and extremes in flooding.
7	Agriculture	Small and marginal farmers	Develop suitable adaptation policy and implementation of few pilot schemes to enhance the adaptive capacities of small and marginal farmers in India.
8	Water resources	Arid and semi-arid regions	Developing check dams and water harvesting demonstration projects in each of the arid and semi-arid districts in India.
9	Agriculture, forestry, and water resources	Conventional adaptation practices	Develop a compendium of national indigenous and traditional practices on adaptation in selected sectors like agriculture, forestry, and water resources (floods and droughts) in various agro-ecological regions of India.
10	Industry	Research on innovations	Research on adaptation innovations in Indian industry for adaptation to climate change impacts.
11	Agriculture	Agronomic management	To evaluate alternate agronomic management options to sustain the agricultural production in relation to changed soil moisture availability in flood- and drought-prone regions.
12	All	Integrated impact assessment modelling for India	Developing integrated assessment model for India to assess impacts of climate change and corresponding adaptation requirement, in addition to understanding possible abatement and adaptation measures, in various sectors—water resources, agriculture, terrestrial and marine ecosystems, human health, human settlements, energy, and industry.
13	Agriculture	Conservation agriculture	Evaluation of conservation agriculture (zero tillage, direct-seeded rice, SRI, crop diversification, etc.) for climate change mitigation and adaptation benefits.
14	Agriculture	Resource efficiency	Assessing the scope of water and nutrient, use efficiency enhancing strategies for climate change adaptation options for rain-fed areas.
15	Agriculture	Rain-fed agricultural areas	Developing climate change adaptation options for rain-fed areas.
16	Agriculture	Adaptation strategies	Characterize germplasm for climatic stress tolerance and develop varieties for climate change adaptation using conventional and molecular tools.
17	Agriculture	Adaptation strategies	Development of C4 rice and wheat for climate change adaptation.
18	Agriculture	Adaptation strategies	Adaptation of the Indian marine and inland fisheries to climate change.
19	Agriculture	Adaptation strategies	Adaptation of hill and mountain agriculture to climate change.
20	Livestock	Adaptation strategies	Adaptation of livestock to climate change with modified shelter and improved nutrition.
21	Agriculture	Risk mitigation	Application of short, medium, and long-term weather forecasts in agriculture for reducing climatic risks.
22	Agriculture	Risk mitigation	Development of drought indices and promoting their use in adaptation by farmers and other stakeholders.
23	Agriculture	Risk mitigation	Development of pest and disease forecasting and surveillance system based on ground monitoring, simulation models, and remote sensing.
24	Agriculture	Adaptation strategies	Develop community-based rural livelihoods strategies to minimize adverse climatic impact in drought- and flood-prone regions.

25	Agriculture	Adaptation strategies	Evaluation and refinement of indigenous knowledge for climatic risks in the context of required production growth and mitigation.
B	**Vulnerability**		
26	All	Extreme events and identification of vulnerable regions in India	Impact assessment to address a range of possible increase in temperature scenarios in flood-, cyclone-, and drought-prone regions, as these different geographical regions are expected to experience variability in temperature changes due to climate change.
27	All	Economic scenarios and vulnerability to climate change	Conducting scenario-based studies for various possibilities of extent of climate change impacts, for example, for a range of increase in temperatures, rise in sea water level, deforestation, economic growth and emissions, abatement efforts, etc.
28	Infrastructure/ industry	Climate change impact on coastal infrastructure and industries	Coastal infrastructure is most vulnerable to sea level rise and extreme events. India has many industrial complexes close to the coastal areas. The infrastructure such as roads, railway lines, and ports will be adversely affected by the changing rainfall pattern and extreme events.
29	Energy	Impact of climate change on energy demand and resultant change in emission pattern	Increase in temperature and change in climate are likely to affect the energy demand. Almost all the sectors will experience change in the demand based on the location. The increased demand for energy will also affect the resultant emissions, as most of the increased demand will be fulfilled by the power sector, which depends primarily on coal.
30	Agriculture	Soil and crop productivity	Evaluating the impact of climate change and its variability on soil and crop productivity (five years).
31	Water	Impacts of climate change on water resources on transportation sector of agriculture goods	Will involve mapping the existing inter-state flow volume of agriculture goods and assessing impact of “drought” conditions on reduction in transportation and assessing opportunities for adapting to shortfalls in agriculture production relative to food security.
32	Agriculture	Developing genetic modified species	Will involve developing species and conducting trials of the same, and disseminating the findings through biotechnological advances for improving crop yields in drought-prone states.
33	Water resources	Assessing the effect of global warming on major Indian rivers and aquifers	This study will assess aquifers and their behaviour in Indian peninsula vis-à-vis their exploitation for water and hence greenhouse gas (GHG) emissions.
34	Water resources	Impact of climate change on water availability in Himalayan glaciers and rivers	Himalayan glaciers and rivers have an important role in the Indian water supply system. Temperature increase due to climate change may bring about changes in the Himalayan ecosystem, which will alter the water availability for India in short, medium, and long term.
35	Water resources	Developing hot spot (extreme scarcity) areas in the water resources sector and developing micro-level (household and community level) assessments of vulnerability and impacts of droughts	(i) This will involve preparing overlays of maps—such as maps for drought hazard, groundwater development and degradation, surface water development, road network, state domestic product, and state human development indices, and superimposing the same to assess hot spots for detail assessment of micro-level vulnerability assessment. (ii) Based on the identification of hot spot states as above, conducting field surveys in 100 randomly proportionate stratified sampled villages in each state for a total of 400 villages.
36	Water resources	Mapping vulnerable population due to climate change impacts on water resources	Mapping national-level temporal (at five years interval) and spatial (at state level) distribution of vulnerable population at risk at state level due to climate change impacts on water resources. This will involve mapping the current demographic trends in urban and rural population growths, overlaying the same with state developmental plans on infrastructure in water supply sector and water sector reforms parameters.
37	Industry and infrastructure	Assessment of impacts on industry and infrastructure	Assessing impacts on industry and infrastructure through: preparing a catalogue of historic extreme events, assessing the damages and providing the loss estimates in coastal and inland areas, showing the spatial distribution, developing detail GIS map covers with topographic, vegetation, and geological details showing the major industries and infrastructure systems and their components, and assessing sensitivities of different components with respect to various climate parameters.
38	Agriculture	Gridded database generation	To characterize the extent of rainfall variability, surface water and groundwater availability in various agro-ecological regions of the country at $1/2^o \times 1/2^o$ grid (or finer).
39	Agriculture, forestry, and water resources (livelihoods)	Asset vulnerability assessment	Research to understand vulnerability by assessing type and extent of various livelihood assets – social, physical, financial, institutional, and natural – of communities from various potential impact geographical regions.

40	Coastal zones	Vulnerability assessment at coastal village level	Assessing vulnerabilities of communities from 100 villages along the coast to climate change impacts by using sustainable livelihood framework. Analysing social dynamics and institutional landscape to identify points of leverage for short- and long-term adaptation interventions.
41	Health	Vulnerability assessment of areas where malaria has been predicted to shift in the climate change	Assessment of vulnerability of communities to be affected by malaria in areas above 1800 m and in coastal areas will be the focus of this study. The accessibility to health facilities and assessment of the current adaptation practices and the policies of the government will be reviewed to understand the adaptation needs of the afflicted communities in the climate change regime.
42	Health	Assessing vulnerability of communities exposed to extreme heat	Extremely high temperatures have been recorded in recent times in the northern, central, and south-eastern parts of the country, which have caused mortality. A study will be carried out to identify areas that will experience recurrent intense heat due to climate change, and assessment will be made of adaptation needs of the communities in the climate change regime. For this, the current adaptation practices, including the government policies, will be analysed.
C	**Abatement/ capacity development**		
43	Energy	To study the level of non-coking coal beneficiation and its impact on efficiency improvement/ abatement of GHG emission in thermal power stations	This will involve a detailed study of non-coking coals for the identification of quality parameter/s, including combustion behaviour. Estimation of the impact of coal quality on the boiler efficiency will be carried out. Quantitative assessment of the effects of the variations of fuel quality on the performance of the critical sub-processes involved in power generation and GHG emission will be done.
44	Energy	Validation of the multi stage hydrogenation (MSH) technology for converting coal to oil	(i) The aim is to confirm the results of the batch reactor studies. (ii) Establish viability of the process through generation of technical data, required for upscaling the process to higher scale. (iii) Research for increasing the present yield of distillates from 60% to between 85% and 90%. Commercial viability of this project to be carried out.
45	Energy	Utilization of GHGs (CO_2 and CH_4) for production of fuels and chemicals	This will involve conversion of CH_4 and CO_2, producing syngas with low H_2/CO ratio (nearer to one), which is highly desirable in gas-to-liquid fuel conversion technology using iron-based catalysts. Conversion of CH_4 by developing solid acid catalysts based on heteropoly acids and other catalysts to value-added chemicals like methanol, formaldehyde, and ethylene.
46	Energy	Abatement of GHG via *in situ* infusion of fly ash with CO_2 in thermal power plant: upscaling of the process vis-à-vis associated carbon sequestration and adoption	(i) This will involve characterization of fly ash samples from two to three representative thermal power plants of the country in respect of various physico-chemical parameters, including minerals and trace and heavy metals content. Experiments to be carried out, under laboratory conditions, on CO_2 infusion of these fly ashes at varying pressure.(ii) Assessment of extent of infusion of fly ash and consumption of CO_2 therein to be carried out. Experiments on leaching characteristics of fly ashes (treated and untreated) with CO_2 infusion following shake and column tests to be conducted.
47	Energy	Minimization of CO_2 and other polluting gaseous levels by suitably developing soft coke technology as the source of rural/semi urban domestic energy	This will involve development of more energy-efficient soft coke technology utilizing inferior coal. Making suitable provisions for less emitting/arresting the GHG. Improvement of the present technology for making it more suitable for rural use. Generation of data/techno-economic as well as socio-economic evaluation. Improvement in design/development of the fixed/ movable domestic soft coke cook stove in view of energy efficiency as well as emission of GHG.
48	Energy	Cleaner electricity production through fuel cell technology	The project will develop a 1 kW MCFC system operating at 650ºC. The performance of this system will be evaluated with reformed natural gas fuel.
49	Energy	CO_2 sequestration in geologic formations with enhanced coal bed methane (CBM) recovery	This will involve examination of the potential for CO_2 sequestration in geologic formations/un-mineable coal seams. Identification of un-mineable coal seams/geologic formations in India suitable for CO_2 sequestration will be done. Mathematical models will be developed for reservoir simulation of CO_2–CBM and for gas–water flow in coal beds.
50	Energy	Improvement in solar cell efficiency	R&D studies to improve the efficiency of solar cells to 15% at commercial level and 20% at research level. This will be added on the already ongoing programme of the Ministry of New and Renewable Energy.
51	Energy	Penetration of energy efficient technologies	Demonstration projects for increased penetration of efficient technologies (supply and demand management based) such as heat rate reduction, electric arc furnaces, energy-efficient processes, efficient lighting, agriculture pump sets, etc., in order to enhance scale and acceptance of efficiency interventions for GHG emission abatement.

52	Energy/petroleum	Geological storage of CO_2 in exploration/recovery of petroleum gas, etc.	This will involve injection of CO_2 in the petroleum wells for the recovery of petroleum gas and other products.
53	Energy	Removal/ absorption of CO_2 through absorptive media	This will involve identification and characterization of different absorptive media for CO_2 removal and its absorption in thermal power plants.
54	Energy	CO_2 decomposition through plasma technology	This will involve use of an arc discharge device where CO_2 will be dissociated to give rise to carbon and oxygen ions. A directionally aligned magnetic field can be used to separate out the carbon and oxygen ions. The carbon ions so deflected with the help of magnetic field can be separately collected.
55	Energy and agriculture	Recovery of CH_4 from landfills and paddy fields	The project will involve the study of CH_4 efflux in different seasons at various sites. The components of the measurements will include investigation on CH_4 production potential of different methanogenic bacteria under different conditions, the process of augmentation of CH_4 formation through biological and non-biological means, suppression of CH_4 oxidation through manipulation of edaphic factors, and use of inhibitors. The study will also investigate and demonstrate the options for maximum recovery of CH_4 gas from landfills and paddy fields for heat and electricity production.
56	Industrial processes	Ecologically friendly and value-added steel making process based on vertical retort direct reduction (VRDR)– submerged arc furnace (SAF)–electro slag refining (ESR) route	The proposed process attempts using hot charging of direct reduced iron (DRI) into submerged arc furnace (SAF)/ electro-slag crucible melting furnace (ESCF) from which the hot liquid steel enters the electro-slag casting equipment to produce high quality alloyed steel product of near-net shapes. The process is expected to be environment-friendly and techno-economically attractive even on a medium scale of operation. The process has the flexibility to treat various feed materials and produce a range of different steel products based on the local demand. Since the DRI based route by-passes the conventional components such as coke and sinter making, the process would require much less energy and would lead to substantial reduction in the emission of CO_2 to the atmosphere.
57	Industrial processes	Non CO_2 GHG emission abatement from process industries	Abatement demonstration projects in industries such as nitric acid, paper, adipic acid, etc.
58	Agriculture	Cost-effective abatement strategies for the Indian agriculture sector	Developing abatement strategies for GHG reduction; socio-economic evaluation of the abatement strategies; possible consequences of the suggested abatement options on agro-ecological system (short- and long-term consequences)
59	LULUCF	Enhancing agro-forestry in India	Implementing agro-forestry in dryland farms to increase the tree resources on farms, increasing the economic returns and increasing C-stocks in any rain-fed region/ states such as Karnataka, Andhra Pradesh, Tamilnadu, Madhya Pradesh, and Haryana. The scale of the project would be 20,000 ha, covering about 20,000–40,000 farms.
60	LULUCF	Energy plantation in India for GHG emission abatement	Provide biomass sustainably for generating biomass power, substituting fossil fuel energy in any of the states facing power shortage such as Karnataka, Tamil Nadu, and Andhra Pradesh, where power generation is mainly from coal-based power plants. The activities will involve: raising mixed species energy plantations in about 6000 ha in a phased manner; using high yielding package utilities; developing and implementing sustainable biomass harvesting practices to supply feedstock to biomass power utilities; and installing biomass power plant of 20 MW and supplying electricity to meet the decentralized power needs.
61	LULUCF	Carbon sink enhancement and sustainable development in villages	Developing, implementing, and disseminating an integrated and participatory approach for the re-vegetation of village ecosystems for enhancing carbon sinks, conserving biodiversity, and enhancing sustained flow of benefits to the local communities in the Western Ghats region in about 10,000 ha area, extending over 100 villages.
62	LULUCF	Degraded forest regeneration	To sequester carbon by regenerating degraded sal forests in Orissa, West Bengal or Bihar involving: regenerating degraded sal forests for timber and non-timber forest products; involving local communities in protection and management of regenerating forests; and promoting biodiversity.
63	LULUCF	Mangrove ecosystem rehabilitation	Rehabilitating about 20,000 ha of degraded mangrove ecosystem in Orissa to protect the coastal lands and sequester carbon involving: identifying degraded mangrove; protecting and regenerating mangroves; monitoring the biodiversity, growth rate and C-stock changes.
64	Energy, industry and infrastructure, and waste	Issues in technology transfer for abatement of GHG emissions in India	Facilitating transfer of technology from developed to developing countries through joint research and development, and adoption.

65	Industry	Fiscal instruments for emission abatement from Indian industry	Research and pilot projects.
66	Energy	Role of technology in abatement and adaptation of climate change impacts on energy sector	Conducting intensive studies for abatement and adaptation of energy-efficient technology and methods and identifying points of leverage in market chains and institutional regimes for demand side management measures for abatement.
67	Agriculture	Carbon sequestration in agriculture soils	Research and demonstration projects to sequester carbon in agricultural soils by adopting appropriate land use options.
68	Energy	Fuel switching	Research and demonstration projects for the penetration of low and no carbon fuels in the transport sector.
69	Industry	Energy efficiency improvement	Research and demonstration of energy-efficient technologies in energy-intensive small-scale industries in India.
70	Agriculture	Enteric fermentation	Research, development, and demonstration of low-CH_4 emitting feeds.
71	Energy	CO_2 capture and storage	Demonstration project for CO_2 capture and storage at one high concentration CO_2 stream plant in India.
72	Agriculture	Carbon sequestration	Carbon sequestration potential in Indian agriculture: biophysical and economic evaluation.
73	Livestock	Enteric fermentation	Potential of balanced feeding and feed additives in mitigating methane emission from livestock: feasibility and economic assessment.
74	Agriculture	Mitigation studies	Potential of organic farming as a strategy for GHG mitigation.
75	Agriculture	Mitigation studies	Optimal land use for maximizing productivity and income and reducing carbon footprint.
76	Agriculture	Mitigation and adaptation studies	Assessing the potential and cost of agri-horticulture and agro-forestry for climate change mitigation and adaptation.
77	Agriculture	Carbon sequestration	Carbon sequestration in soil through application of biochar.
78	Energy	Technology development	Sustainable bioenergy generation from rice straw for global warming mitigation.
79	LULUCF	Mitigation studies	REDD+ pilot studies for climate change mitigation.
80	LULUCF	Technology development	Development of clean technology to transform atmospheric CO_2 into value-added commercial products.
81	LULUCF	Adaptation studies	Eco-rehabilitation of mined out areas for mitigation of climate change.
82	LULUCF	Technology development	Biogas technology use and GHG emissions.
83	LULUCF	Carbon sequestration	Use of molecular procedures to define the microbial ecology of ruminal methanogenesis.
84	LULUCF	Mitigation studies	Use of additives and herbal compounds to improve efficiency of rumen fermentation and CH_4 mitigation.
D	**Integrated assessment**		
85	Energy	Impact of climate change on energy systems	Integrated assessment would require integrating supply of energy resources (commercial and traditional) and energy demand keeping in mind constraints posed by key drivers.
86	Built environment	Impact on and of built environment	The required alterations and adaptation strategies shall vary according to the building designs, materials used, technology employed, and most importantly, the location.
87	Livelihoods	Climate change impact case studies on livelihoods	Livelihoods depend upon endowment and conservation of natural resources, as well as infrastructure assets and man-made systems and institutions available in a region. Under future climate change, an integrated assessment is necessitated from the perspective of human development.
88	Gender	Integrating gender issues under climate change	Integrating future climate change issues with issues related to gender, particularly women, such as the burden of water on Indian households (particularly rural areas).
89	Health	Climate change impact assessment on human health and livelihoods	Global warming poses serious challenge to the health sector and hence warrants emergency health preparedness and response. Heat stresses, vector-borne diseases, and water contamination are some of the main health impacts projected due to climate change.
90	Water, energy	Climate change impact on water resources	Integrating water and climate change with the energy needs would be important from both the development as well as resource conservation perspective.

Some other thematic areas of research needing resources and support for further development, as appropriate are international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing, and financing research, data collection, and systematic observation, which may include the following:

- Forecasting energy requirements.
- Energy usage efficiency studies from producers to user groups.
- Socio-economic costs related to climate change, that is, increased vulnerability to climate change.
- Effect of climate change on marine infrastructure, business, and marine ecosystem.
- Conservation studies.
- Assessment of carbon abatement potential.
- Design of the Indian economic modelling in conjunction with global economic modelling based on carbon and energy intensities, and the cost reductions from trading, including the compatibility of domestic and international mechanisms, constraints on emissions trading, transaction costs, and marginal cost estimates.
- Analyses of "spill over" effects on Non-Annex I countries.
- Technology development and diffusion for cost-effective stabilization studies.
- Studies on emission pathways.
- Studies to assess incentive needed for the promotion of energy-efficient technologies.
- Promotion of research on energy-efficient building technologies.
- Conducting environment policy research for economic development and environmental changes.

Awareness generation and information dissemination are two important aspects for climate change initiative in India. It should aim at integrating climate change concerns in the national planning process. Workshops and seminars, promotion of independent research and publication in climate change related areas, and website development would be the main instruments of dissemination.

Dissemination is a continuous process that operates at three levels in India. Primarily, it has been the Government of India's initiative, where Ministry of Environment and Forests, the nodal agency, along with other ministries and government departments like the Ministry of New and Renewable Energy (MNRE), Ministry of Agriculture, Ministry of Power, Department of Heavy Industry, etc. have organized workshops, seminars, and meetings. The latter efforts are more focused on specific sectoral issues.

The second level of involvement is the participation of the Indian industry. The industry has shown keen interest in climate change concerns, especially in its linkages with energy efficiency improvements. Confederation of Indian Industry (CII), Federation of Indian Chamber of Commerce and Industry (FICCI), and Associated Chambers of Commerce and Industry of India (ASSOCHAM) are the three largest industrial associations in India. They have established special Climate Change Cells in their portfolio and are actively involved in organizing workshops to improve awareness level in the industry on climate change, especially on the multilateral funding mechanisms.

The third tier involves technical and academic institutions such as research institutes, and universities and NGOs. India has a thriving research and higher education network that should be sensitized to climate change. Academic institutes of international repute such as Indian Institutes of Technology (IITs), Indian Institutes of Management (IIMs), Indian Institute of Science (IISc), Council of Scientific and Industrial Research (CSIR) laboratories, Indian Agriculture Research Institute (IARI), and The Energy and Resources Institute (TERI) are already a part of the National Communication network. A network of institutions and researchers interested and working on climate change related areas is slowly emerging. However, these initiatives have to be strengthened and further built upon.

Needs for Adaptation to Climate Change

Reduction of GHG emissions, leading to stabilization of their concentrations in the atmosphere in the long run, will neither altogether prevent climate change and sea-level rise, nor reduce their impacts in the short to medium-run. Adaptation is a necessary strategy at all scales, from national to local, to complement climate change abatement efforts; together they can contribute to sustainable development objectives and reduce inequities.

In addition, the development of planned adaptation strategies to address risks and utilize opportunities can complement abatement actions to lessen climate change impacts. However, adaptation would entail costs and cannot prevent all damages. There are many constraints faced by the developing countries, including India, while deploying the scarce resources specifically for adaptation measures.

Lack of awareness at all levels

There is limited awareness among the developing countries, where there is inadequate research on adaptation studies. There is a lack of awareness at the policy-makers level as it is at the academic research level. This can be attributed to the uncertainty involved, complexity of climate change and its effects, and the kind of adaptation measures and policy needed. Nature of adaptation studies would differ from location to location and sector to sector in an economy and even at the micro level, across different economic activities in a locality. The studies also need to consider the stakeholders' perspective and their difference in endowment of resources and capacity.

Lack of research on formulating specific adaptation measures for various sectors

Sectoral adaptation measures would depend, to a large extent, on the awareness and understanding of the climate change impacts. The lack of research on sectoral impacts extends to adaptation research as well. Various sectors like water resources, agriculture, terrestrial and marine ecosystems, human health, human settlements, energy, and industry have their unique adaptation requirements, and there is a need for studies to understand the extent of climate change impacts and the possible adaptation measures in each of these sectors.

Lack of inter-linkages in adaptation policy formulation and appropriate market responses

Adaptation to climate change presents not only complex challenges, but also opportunities, in many sectors. Policy formulation on adaptation measures has to relate to the complex sectoral interdependence and interrelationships in climate change impacts. This area has been scarcely researched, and information necessary at the local level for adaptation policy planning is generally not available. This in turn also affects coordination with the market responses in adaptation. Market responses would not be forthcoming if there is no clarity in cause–effect in the absence of proper information. Further, policies don't reflect such clarity and free riding prevails. Developed countries have experienced cases of complacency and maladaptation fostered by public insurance and relief programmes. The developing countries, which may experience adverse effects of climate change, have to deal with equity issues and development constraints in market responses. Market responses have to be matched with extensive access to insurance and more widespread introduction of micro-financing schemes and development banking.

Lack of resources to implement adaptation measures

The costs of weather change events have risen rapidly despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness in the recent decades. Part of the observed upward trend in disaster losses over the past 50 years is linked to socio-economic factors, such as population growth, increased wealth, and urbanization in vulnerable areas. Moreover, climate change impacts occur in the long term, and for a sustained level research to enhance preparedness requires enormous resources in developing capabilities in knowledge and infrastructure.

Technological Needs

In the last decade, the Official Development Assistance (ODA) from Annex I countries to developing countries has declined in nominal and real terms to such an extent that private flows from developed to developing countries have gained importance in technology transfer. There is a significant need for augmenting funding of technology transfer from developed to developing countries, which seems to have receded in the last decade.

The Government of India has been promoting low CO_2 emission intensive technologies for sustainable development through programmes such as the Integrated Renewable Energy Programme. India has one of the largest programmes for promoting renewable energy in the world. Activities cover all major renewable energy technologies, such as, biogas, biomass, solar energy, wind energy, small hydropower, and other emerging technologies. MNRE is involved in the promotion for development, demonstration and utilization of various renewable energy-based technologies, such as, solar; thermal; solar photovoltaic; wind power generation and water pumping; biomass gasification/combustion/co-generation; small, mini, and micro hydropower; solar power; utilization of biomass, biogas, improved cook stove; geothermal for heat applications; power generation/energy recovery from urban, municipal and industrial wastes; and tidal power generation. Commercialization of several renewable energy systems and products is underway. India targets to add 10% of new additions to electricity generation capacity through renewable technologies by 2012. MNRE also deals with other emerging areas and new technologies, such as, chemical sources of energy, fuel cells, alternative fuel for surface transportation, hydrogen energy, etc.

Global thrust on climate-friendly technologies is presently focused on climate change mitigation, such as fuel cell cars, biotechnologies, nanotechnologies to reduce electricity demand, CO_2 capture and storage, etc. There is a growing need to develop technologies that reduce vulnerabilities of developing and least developed country populations to adverse impacts of climate change. These technologies have to be low cost and compatible with local environment and socio-economic situations for faster adaptation. Revival of and building upon conventional wisdom, such as water management in arid and desert areas, weather-proof low-cost housing, and less water intensive night soil disposal etc. is also required. Modern technologies should augment the conventional wisdom for adapting to climate change. Various ministries and departments of the Government of India are engaged in technology development on diverse fronts that have been synthesized through the Technology Information, Forecasting and Assessment Council (TIFAC). The continuing work of scientists will remain crucial, generating the knowledge needed to develop effective responses to the challenges of climate change. North-South and South-South cooperation on climate change is a necessity, especially from developing country perspective, as it needs the support for adaptation activities and technology transfer.

Capacity Needs

Beyond the sectoral and scientific or technological capacity needs on climate change, the critical need in India is to integrate the diverse scientific assessments and link them with policy-making. Science has to provide objective, scientific and technical advice to the policy-makers, especially for a complex process like climate change. While some experience of using integrated assessment models does exist in India, the capacity building in this area remains a double priority; first, to provide policy orientation to the scientific assessments and second, to provide robust scientific foundation to the policy-making. The development of assessment tools by interdisciplinary teams within developing countries is most vital. This would need commitment of sustained resources and institutionalization of multi-disciplinary and networking efforts within the scientific and policy-making establishments.

Climate change concerns, assessment challenges, and response strategies for diverse sectors and regions in India require an integrated assessment approach. Integrated assessment is an interdisciplinary process that combines, interprets, and communicates knowledge from diverse scientific disciplines from the natural and social sciences to investigate and understand causal relationships within and between complex systems. Integrated assessment attempts to present the full range of consequences of a given policy – economic or environmental, intended or unintended, prompt or delayed – in order to determine whether the action will make the society better or worse off, and by how much. It must be noted here that integrated assessment is also not a monolithic, uniform, unique, and universal model that can be applied to any context. It indicates an approach to policy-making that has to consider contextual issues and specific nuances of the sector under scrutiny to arrive at integrated policy assessment. For example, in deciding policy for water quality management in a particular place, integrated scientific advice should include the direct and indirect effects of urban development, agricultural run-offs, industrial pollution, and climate change induced increase in heavy precipitation events on water resources, along with many other factors.

Integrated approach also refers to integration over regions, sectors, and time scales. For example, the analysis of water availability may be first integrated at individual sub-basin levels, further integrated into individual river basin levels, and finally integrated at national level. Such integration across both multiple stresses and multiple scales is needed to provide the type of comprehensive analysis that policy-makers seek.

Integrated assessment of climate change has developed rapidly in the recent years into an important policy research area. In spite of this growing recognition, its methodological basis is rather narrow, especially in developing countries such as India. Methodological approaches include mathematical model simulations, shared databases, consistent future scenario generation for emissions, climate change, sub-regional impact assessment, and qualitative validation based on current climate change related events and experiences.

A framework for integrated assessment of climate change at the national level indicates the interactions of the country-level dynamics with global emissions and atmospheric change, global policy regimes, and international agreements (Figure 7.1). This framework also suggests national implementation arrangements. GHG emissions and climate change impacts have to be assessed on a continuous basis at sectoral and sub-regional levels. Institutional networking, shared and gridded databases, modelling capability enhancement, consistent scenario construction (climate change, emission, and impact) are the building blocks for this. New models may also be developed to capture developing country dynamics such as informal sectors, small and medium enterprises, and South-South cooperation.

Networking is a critical requirement for integrated assessment. The SNC activities have more than 100 interdisciplinary research teams spread across the country been networked together for a shared vision on climate change related research. Such initiatives have to be maintained and strengthened. Participation of the state and union territory government departments is to be encouraged in climate change activities. This will build capacities at the state level for implementing policy measures such as those for reducing vulnerability of various sectors and communities, disseminating and promoting climate-friendly technologies and initiatives, adaptation, and energy efficiency improvements.

Lastly, technology R&D, technology transfer, and technology diffusion in the country will need special attention. Since there are diverse disciplines involved in climate change, having a unified command and control regime may not be appropriate for these.

Financial Needs

The financial needs arise from the constraints detailed in previous sections. These cover four areas: continuous reporting to the UNFCCC, vulnerability assessment and adaptation due to climate change, capacity building, and GHG emission abatement through financial mechanisms. The financial needs are for research and actual projects for implementing climate change adaptation and abatement actions. These cover diverse sectors and require considerable technology transfers and financial resources. Given the magnitude of the tasks, complexities of technological solutions, and diversity of adaptation and mitigation actions envisaged, the incremental financial needs would be enormous to address and respond to the requirements of the Convention.

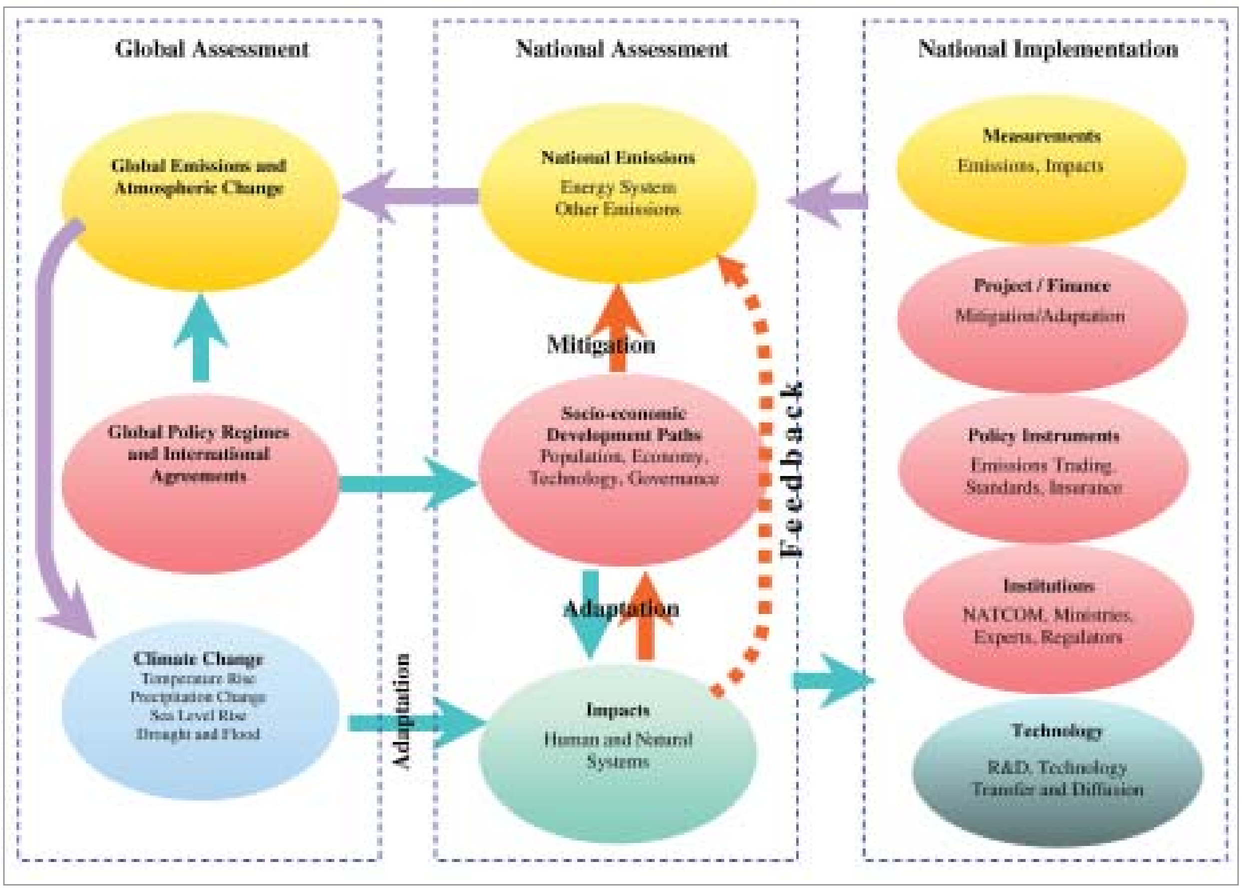


Figure 7.1: Framework for integrated assessment and implementation at the national level.

The systems and policies in developing countries are not tuned to handle even the present climate related stress and climate variability. Income disparities and population growth further constrain the opportunities and equitable access to existing social infrastructure. Projected climate change could further accentuate these conditions. The challenge then is to identify opportunities that facilitate sustainable use of existing resources. It entails considerations that make climate-sensitive systems, sectors, and communities more resilient to current climate variability. This will pave the way to enhance their adaptive capacity to future climate change. Faster economic development with more equitable income distribution, improved disaster management, sustainable sectoral policies, and careful planning of capital-intensive and climate-sensitive long-life infrastructure assets are some measures that assist in ameliorating India's vulnerability to climate change.

References and Sources

NATCOM, 2004. *India's Initial National Communication to the United Nations Framework Convention on Climate Change.* Ministry of Environment and Forests, Government of India, New Delhi

IPCC (Intergovernmental Panel on Climate Change), 2006. *IPCC Guidelines for National Greenhouse Gas Inventories.* Task Force on National Greenhouse Gas Inventories, IPCC

IPCC (Intergovernmental Panel on Climate Change), 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.* IPCC, Paris

IPCC (Intergovernmental Panel on Climate Change), 1996. *Good Practice Guidance and Uncertainty Management in National Green House Gas Inventories.* IPCC, Paris

IPCC (Intergovernmental Panel on Climate Change), 2000. *Good Practice Guidance.* IPCC, Paris

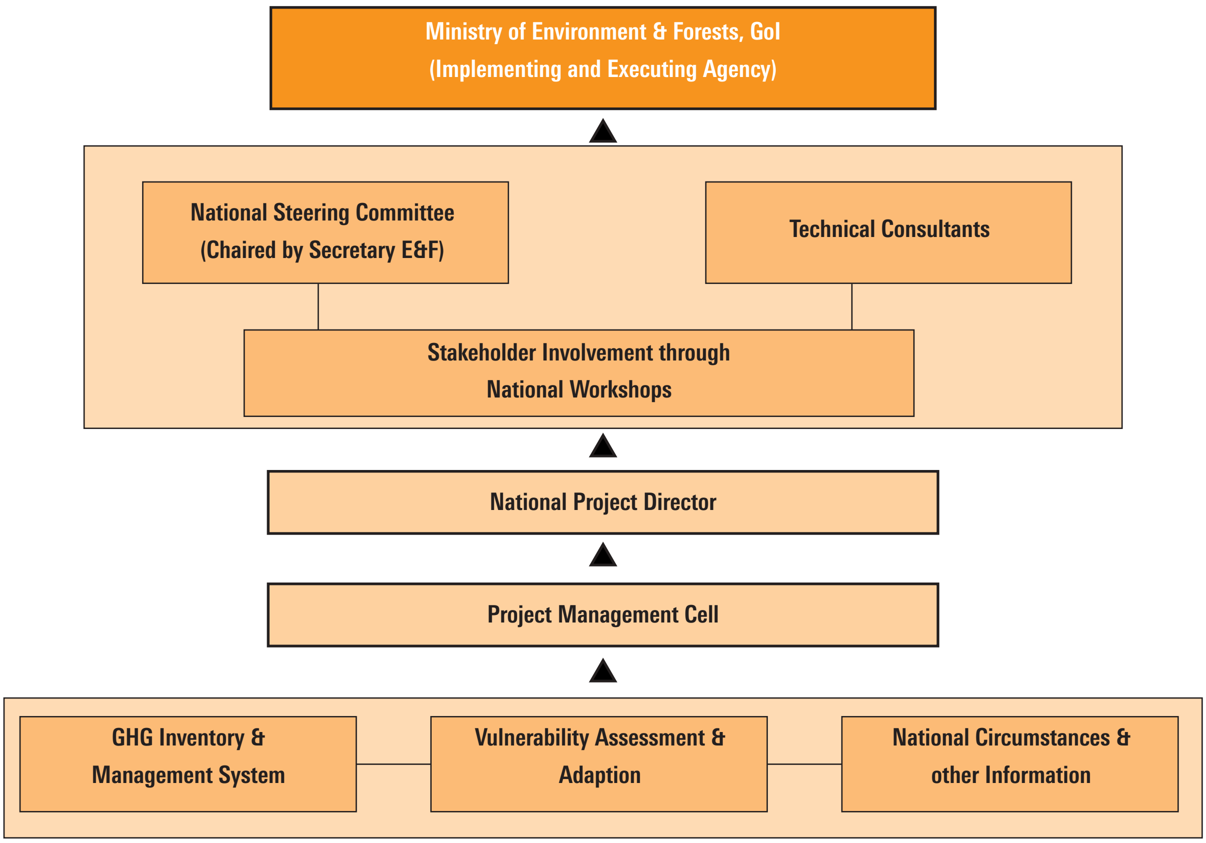
IPCC (Intergovernmental Panel on Climate Change), 2003. *Good Practice Guidance for Land Use, Land Use Change and Forestry.* Published by the Institute for Global Environmental Strategies (IGES) for the IPCC

MoEF, 2010. India: Greenhouse Gas Emissions 2007. Ministry of Environment and Forests, Government of India, New Delhi

Annexures

Annexure-I

The project on preparation of India's Second National Communication to the UNFCCC has been implemented and executed by the Ministry of Environment and Forests (MoEF), Government of India. A National Steering Committee under the Chairmanship of the Secretary, MoEF, Government of India oversaw its implementation. Technical Consultations were held with numerous experts of various disciplines as well as other Stakeholders, through consultative meetings and National Workshops. These experts advised on matters relating to the scientific and technical aspects of the various components of communication. A broad-based participatory approach involving more than 120 research teams from government ministries and departments, autonomous institutions and national research laboratories, universities, non-governmental agencies, industry associations, and private sector were involved in the process.

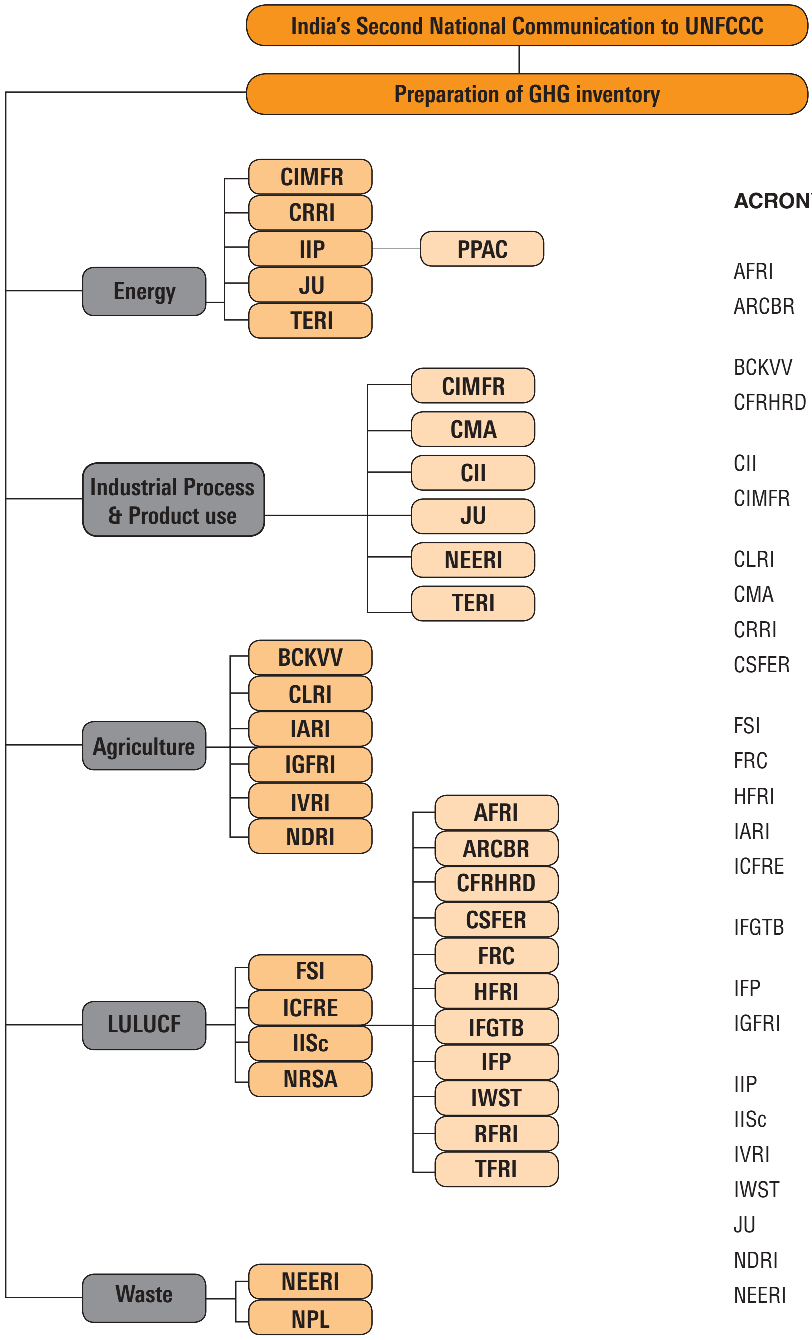


National Communication (NATCOM) Networks

Institutional networks were set up for GHG inventory estimation, measurement of emission coefficients, vulnerability assessment and adaptation (V&A), introductory context, general description of steps being taken to implement the convention, and other information such as case studies. The institutional mechanisms for each of these were different and unique, based on the requirements of the task. GHG inventory estimation required extensive sectoral data collection and validation, a framework of sectoral Lead Institutes supported by Participating Institutes was implemented. V&A required national level modelling for a macro view on the various sectors. These were conducted at premier national institutes under the guidance of prominent national experts. Independent case studies were also conducted to assess the broader canvas of V&A research requirements for a large country like India. The NATCOM network is categorised in three broad categories:

- GHG Inventory Network
- V & A Network
- National Circumstances Network

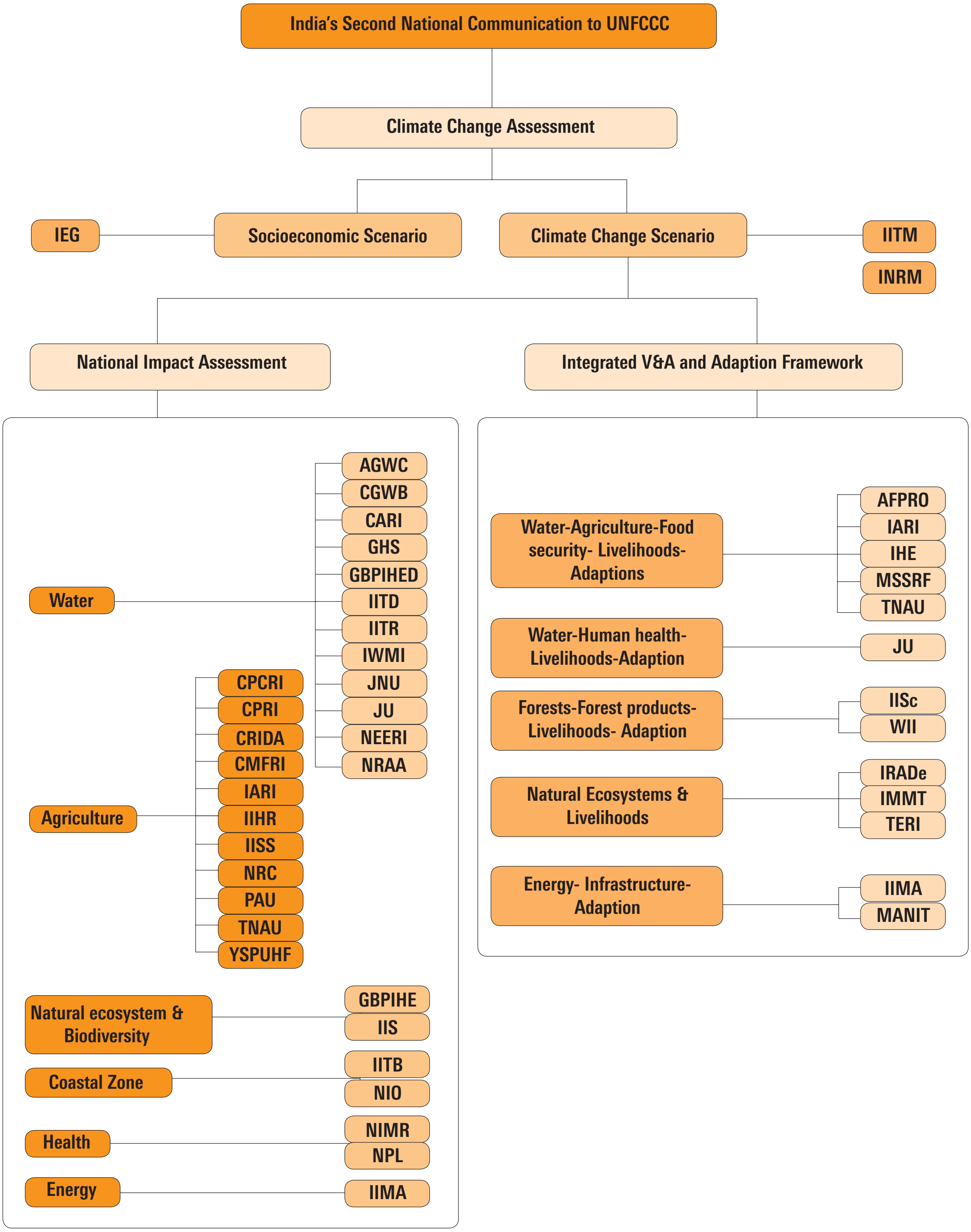
Institutional Framework
GHG Inventory Network



ACRONYMS

AFRI	:	Arid Forest Research Institute
ARCBR	:	Advanced Research Centre for Bamboo and Rattans
BCKVV	:	Bidhan Chandra Krishi Vishwa Vidyalaya
CFRHRD	:	Centre for Forestry Research and Human Resource Development
CII	:	Confederation of Indian Industry
CIMFR	:	Central Institute of Mining and Fuel Research
CLRI	:	Central Leather Research Institute
CMA	:	Cement Manufacturers Association
CRRI	:	Central Road Research Institute
CSFER	:	Centre for Social Forestry and Eco-Rehabilitation
FSI	:	Forest Survey of India
FRC	:	Forest Research Centre
HFRI	:	Himalayan Forest Research Institute
IARI	:	Indian Agricultural Research Institute
ICFRE	:	Indian Council of Forestry Research and Education
IFGTB	:	Institute of Forest Genetics and Tree Breeding
IFP	:	Institute of Forest Productivity
IGFRI	:	Indian Grassland and Fodder Research Institute
IIP	:	Indian Institute of Petroleum
IISc	:	Indian Institute of Science
IVRI	:	Indian Veterinary Research Institute
IWST	:	Institute of Woods Science and Technology
JU	:	Jadavpur University
NDRI	:	National Dairy Research Institute
NEERI	:	National Environmental Engineering Research Institute
NPL	:	National Physical Laboratory
NRSA	:	National Remote Sensing Agency
PPAC	:	Petroleum Planning and Analysis Cell
RFRI	:	Rain Forest Research Institute
TERI	:	The Energy and Resources Institute
TFRI	:	Tropical Forest Research Institute

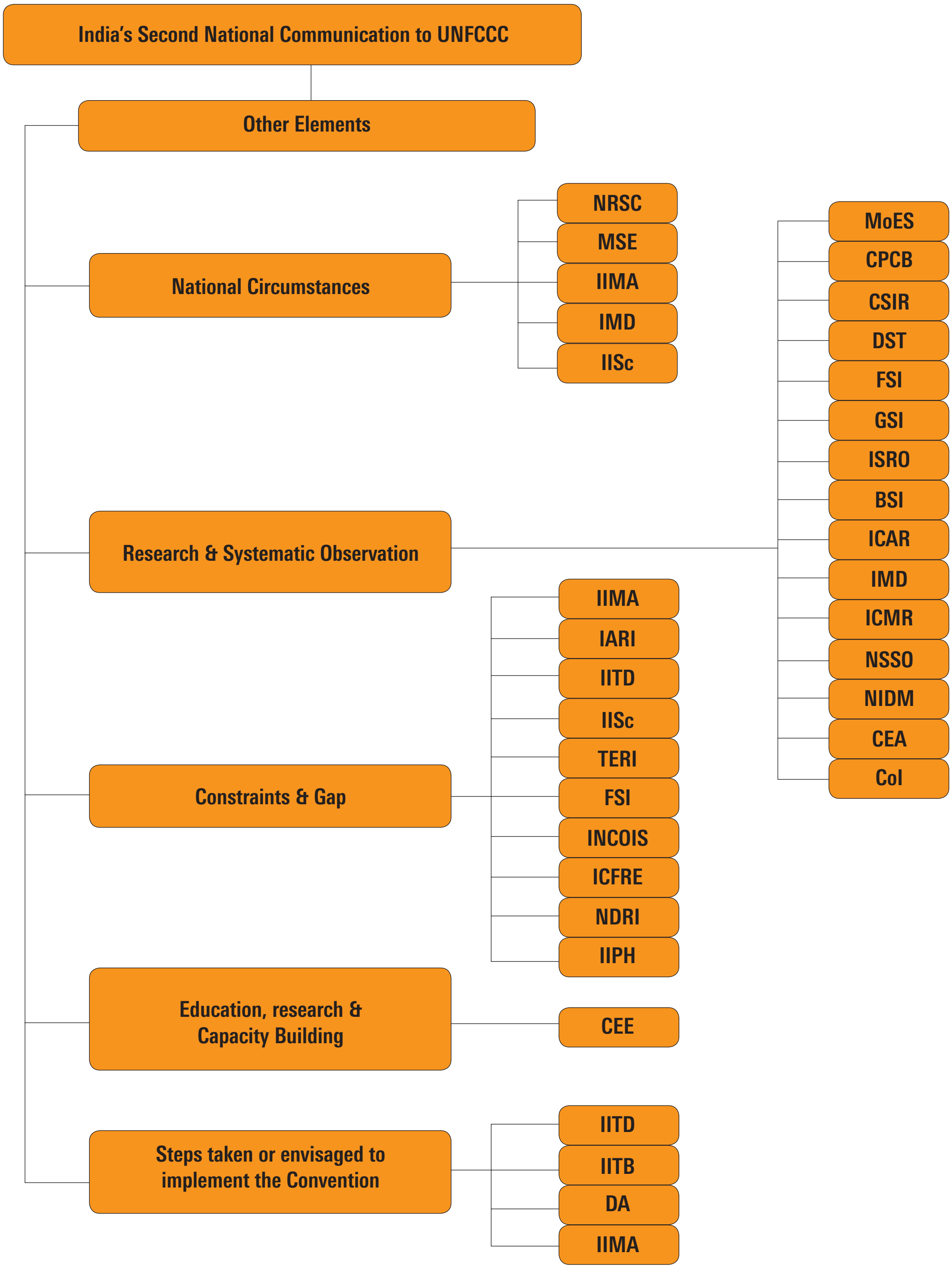
Institutional Framework
Vulnerability Assessment and Adaptation Network



Vulnerability Assessment
Acronym List

AGWC	:	Arete Glacier & Water Consultants
AFPRO	:	Action for Food Production
CARI	:	Central Agriculture Research Institute
CGWB	:	Central Ground Water Board
CMFRI	:	Central Marine Fisheries Research Institute
CPCRI	:	Central Plantation Crops Research Institute
CPRI	:	Central Potato Research Institute
CRIDA	:	Central Research Institute for Dryland Agriculture
GBPIHED	:	G.B. Pant Institute of Himalayan Environment and Development
GHS	:	Global Hydrological Solution
IARI	:	Indian Agricultural Research Institute
IEG	:	Institute of Economic Growth
IHE	:	Institute of Home Economics
IIHR	:	Indian Institute of Horticulture Research
IIMA	:	Indian Institute of Management, Ahmedabad
IISc	:	Indian Institute of Science
IISS	:	Indian Institute of Soil Science
IITB	:	Indian Institute of Technology, Bombay
IITD	:	Indian Institute of Technology, Delhi
IITR	:	Indian Institute of Technology, Roorkee
IITM	:	Indian Institute of Tropical Meteorology
IMMT	:	Institute of Minerals and Materials Technology
INRM	:	Integrated Natural Resource Management
IRADe	:	Integrated Research and Action for Development
IWMI	:	International Water Management Institute
JU	:	Jadavpur University
JNU	:	Jawaharlal Nehru University
MANIT	:	Maulana Azad National Institute of Technology
MSSRF	:	M.S. Swaminathan Research Foundation
NEERI	:	National Environmental Engineering Research Institute
NIMR	:	National Institute of Malaria Research
NRAA	:	National Rainfed Area Authority
NIO	:	National Institute of Oceanography
NPL	:	National Physical Laboratory
NRC	:	National Research Centre for Soybean
PAU	:	Punjab Agriculture University
TERI	:	The Energy and Resources Institute
TNAU	:	Tamil Nadu Agricultural University
WII	:	Winrock International India
YSPUHF	:	Dr. Y.S. Parmar University of Horticulture and Forestry

Institutional Framework
National Circumstances



National Circumstances
Acronym List

BSI	:	Botanical survey Survey of India
CPCB	:	Central Pollution Control Board
CSIR	:	Council of Scientific and Industrial Research
CEA	:	Centre for Electricity Authority
CEE	:	Centre for Environment Education
CoI	:	Census of India
DA	:	Development Alternatives
DST	:	Department of Science and Technology
ESSO	:	Earth System Science Organisation
FSI	:	Forest Survey of India
GSI	:	Geological Survey of India
IARI	:	Indian Agricultural Research Institute
IITD	:	Indian Institute of Technology, Delhi
IITB	:	Indian Institute of Technology, Bombay
IISc	:	Indian Institute of Science
ICFRE	:	Indian Council of Forestry Research & Education
ICAR	:	Indian Council of Agricultural Research
ICMR	:	Indian Council of Medical Research
ISRO	:	Indian Space Research Organisation
IIMA	:	Indian Institute of Management, Ahmedabad
IMD	:	Indian Meteorological Department
INCOIS	:	Indian National Centre for Ocean Information Services
IIPH	:	Indian Institute of Public Health
MoES	:	Ministry of Earth Sciences
MSE	:	Madras School of Economics
NDRI	:	National Dairy Research Institute
NRSC	:	National Remote Sensing Centre
NSSO	:	National Sample Survey Office
NIDM	:	National Institute of Disaster Management
TERI	:	The Energy and Resources Institute

Annexure-II

Abbreviations

ACRONYMS	EXPANSION
AAR	Area Accumulation Ratio
ABER	Annual Blood Examination Rate
ADB	Asian Development Bank
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
AOGCM	Coupled Atmosphere-Ocean General Circulation Models
API	Annual Parasite Index
ASSOCHAM	Associated Chambers of Commerce and Industry
BAPMON	Background Air Pollution Monitoring
CADA	Command Area Development Authority
CAGR	Compounded Annual Growth Rate
CDM	Clean Development Mechanism
CENPEEP	Centre for Power Efficiency and Environmental Protection
CERES	Crop Environment Resource Synthesis
CGMS	Crop Growth Monitoring Systems
CH_4	Methane
CII	Confederation of Indian Industry
CIMMYT	Centre for Maize and Wheat Research
CMA	Cement Manufacturers' Association
CMIE	Centre for Monitoring Indian Economy
CMFRI	Central Mining Research Institute
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
COP	Conference of Parties to UNFCCC
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
CRZ	Coastal Regulation Zone
CSE	Centre for Science and Environment
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DALYs	Disability-Adjusted Life Years
DDT	Dichloro-diphenyl-trichloroethane
DGVM	Dynamic Global Vegetation Model
DMMF	Dry Mineral Matter on Free Basis
DOD	Department of Ocean Development
DSSAT	Decision Support System for Agro-technology Transfer
DST	Department of Science and Technology
EMC	Energy Management Centre
EMCP	Enhanced Malaria Control Programme
ENSO	El-Nino Southern Oscillation
ESI	Economic Survey of India
FACE	Free Air Carbon dioxide Enrichment
FICCI	Federation of Indian Chamber of Commerce and Industry
FSI	Forest Survey of India
GAW	Global Atmospheric Watch
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographic Information System
GOI	Government of India
GWP	Global Warming Potential
HadRM	Hadley Centre Regional Model
HCV	Heavy Commercial Vehicles

IA	Integrated Assessment
IAM	Integrated Assessment Models
IGCC	Integrated Gas Combined Cycle
IGIDR	Indira Gandhi Institute of Development Research
INDOEX	Indian Ocean Experiment
INFOCROP	Informatics on Crops
IPCC	Inter-governmental Panel on Climate Change
IREDA	Indian Renewable Energy Development Agency
IWRM	Integrated Water Resources Management
JFM	Joint Forest Management
KRCL	Konkan Railway Corporation Limited
LCV	Light Commercial Vehicles
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land-use Change and Forestry
MNRE	Ministry of New and Renewable Energy
MoCM	Ministry of Coal and Mines
MoEA	Ministry of External Affairs
MoEF	Ministry of Environment and Forests
MoF	Ministry of Finance
MoHFW	Ministry of Health and Family Welfare
MoR	Ministry of Railways
MP	Montreal Protocol
MPI	Max-Planck Institute
MSEB	Maharashtra State Electricity Board
MSL	Mean Sea Level
MSW	Municipal Solid Waste
N	Nitrogen
N_2O	Nitrous Oxide
NAMP	National Anti-Malaria Programme
NAS	National Academy of Sciences
NATCOM	National Communication
NBP	Net Biome Production
NCA	National Commission on Agriculture
NCAR	National Centre for Atmospheric Research
NCR	National Capital Region
NGO	Non- Governmental Organization
NHT	Northern Hemispheric Temperature
NIES	National Institute of Environmental Studies
NMCP	National Malaria Control Programme
NMEP	National Malaria Eradication Programme
NMVOC	Non Methane Volatile Organic Compound
NOX	Nitrogen Oxides
NPD	National Project Director
NPL	National Physical Laboratory
NPP	Net Primary Productivity
NSC	National Steering Committee
NTFP	Non-Timber Forest Product
NTPC	National Thermal Power Corporation
OC	Organic Carbon
OECD	Organization for Economic Cooperation and Development
OH	Hydroxyl Radical
OPEC	Organization of Petroleum Exporting Countries
ORNL	Oak Ridge National Laboratory
OTC	Open Top Chambers
PC	Planning Commission
PCA	Principal Component Analysis
PCRA	Petroleum Conservation Research Association
PDSI	Palmer Drought Severity Index
PFBC	Pressurized Fluid Bed Combustion
PFC	Perfluorocarbon
PFT	Plant Functional Type
PIM	Participatory Irrigation Management
PLFA	Phospho Lipid Fatty Acid
PMC	Project Management Cell
PNUTGRO	Peanut Crop Growth Simulation Model
PSU	Public Sector Undertaking
PT	Perturbation Lifetime

PV	Photovoltaic
R&D	Research and Development
R&M	Renovation and Modernization
RCM	Regional Circulation Model
RET	Renewable Energy Technology
SAARC	South Asian Association for Regional Cooperation
SAC	Space Applications Centre
SAIL	Steel Authority of India Limited
SAR	Second Assessment Report of IPCC
SARP	System Analysis for Rice Production
SD	Standard Deviation
SEB	State Electricity Board
SF_6	Sulphur Hexaflouride
SGM	Second Generation Model
SHS	Solar Home Systems
SMD	Soil Moisture Deficit Ratio
SMI	Soil Moisture Index
SO_2	Sulfur Dioxide
SOI	Southern Oscillation Index
SPM	Suspended Particulate Matter
SPV	Solar Photo Voltaic
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
START	System for Analysis Research and Training
STIG	Steam Injected Gas Turbine
SWAT	Soil and Water Assessment Tool
T&D	Transmission and Distribution
TAR	Third Assessment Report of IPCC
TEAM	Tool for Environmental Assessment and Management
TEM	Terrestrial Ecosystem Model
TIFAC	Technology Information Forecasting and Assessment Council
UA	Urban Agglomerations
UMB	Urea Molasses Block
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
UVA	Ultraviolet Radiation - A
UVB	Ultraviolet Radiation - B
VA	Vulnerability Assessment and Adaptation
VI	Vulnerability Indicators
VOC	Volatile Organic Compound
WEAP	Water Evaluation and Planning System
WHC	World Heritage Convention
WHO	World Health Organization
WMO	World Meteorological Organization
WOFOST	World Food Study Programme
WRI	World Resources Institute
WSSD	World Summit on Sustainable Development
WTGROWS	Wheat Growth Simulator
WTO	World Trade Organization

Units and quantities

BCM	Billion Cubic Meter (equals 1km3)
C	Celsius
Gg	Giga gram
GW	Giga Watt
GWh	Giga Watt hour
ha	Hectare
hPa	hecto pascal
ka	Kilo annual
km	Kilometer
km^2	Square kilometer
km^3	Cubic kilometer
kW	kilo Watts
kWp	kilo Watts peak
M	Million
m^3	Cubic meter
Mha	Million hectare
MJ	Mega Joule
mm	millimetre
Mt	Million tonne
Mt-CO_2	Million tonnes of Carbon dioxide
Mt-CO_2 eq.	Million tonnes of Carbon dioxide equivalent
MW	Mega Watts
ppb	parts per billion by volume
ppm	parts per million by volume
ppt	parts per trillion by volume
t	ton
Tg	Tera gram
TJ	Tera Joule
toe	tons of oil equivalent
tons/cap	tons per capita
W/m^2	Watt per square meter

Conversion table

1Giga gram (Gg)	= 1000 tons
	= 10^9g
1Tera gram (Tg)	= 1 Million tons
	= 1000 Gg
	= 10^6 tonne
	= 10^{12}g
1 Tera Joule (TJ)	= 10^3GJ
	= 10^{12} Joules
1 Calorie	= 4.18 J

Annexure-III

Institutional Arrangement for India's Second National Communication

Secretary Ministry of Environment & Forests Paryavaran Bhawan, CGO Complex Lodi Road, New Delhi-3	Chairman
Special Secretary Ministry of Environment & Forests Paryavaran Bhawan, CGO Complex Lodi Road, New Delhi-3	Member
Principal Adviser (Environment) Planning Commission Yojna Bhawan, Parliament Street, New Delhi-1	Member
Principal Adviser (Energy) Planning Commission Yojna Bhawan, Parliament Street, New Delhi-1	Member
Secretary Department of Agriculture, Research & Education Ministry of Agriculture, Krishi Bhawan, New Delhi-1	Member
Secretary Department of Agriculture & Cooperation Ministry of Agriculture, Krishi Bhawan, New Delhi-1	Member
Secretary Department of Economic Affairs Ministry of Finance, North Block, New Delhi-1	Member
Secretary Ministry of New and Renewable Energy Block-14, CGO Complex, Lodi Road, New Delhi-3	Member
Secretary Ministry of Science & Technology Technology Bhawan, New Mehrauli Road, New Delhi-16	Member
Secretary Department of Coal Shastri Bhawan, New Delhi-1	Member
Secretary Ministry of Power Shram Shakti Bhawan, New Delhi-1	Member
Secretary Ministry of Heavy Industries & Public Enterprises Udyog Bhawan, New Delhi-1	Member
Secretary Department of Road Transport & Highways Ministry of Shipping, Transport & Highways Parivahan Bhawan, New Delhi-3	Member
Secretary Ministry of Petroleum & Natural Gas Shastri Bhawan, New Delhi-1	Member

Secretary Ministry of Water Resources Shram Shakti Bhavan, New Delhi -1	Member
Secretary Ministry of Health and Family Welfare Nirman Bhavan, New Delhi -1	Member
Secretary Ministry of Earth Sciences Block No. 12, Mahasagar Bhavan CGO Complex, New Delhi-3	Member
Secretary Ministry of Rural Development Krishi Bhavan, Dr. Rajendra Prasad Road New Delhi -1	Member
Secretary Department of Chemical and Petrochemicals Shastri Bhavan, Dr. Rajendra Prasad Road New Delhi -1	Member
Secretary Department of Fertilizers Shastri Bhavan, Dr. Rajendra Prasad Road New Delhi-1	Member
Secretary Department of Industrial Policy and Promotion Ministry of Commerce and Industry Udyog Bhavan, New Delhi-1	Member
Secretary Ministry of Steel Udyog Bhavan, Maulana Azad Marg New Delhi- 1	Member
Director General India Meteorology Department Ministry of Science & Technology Mausam Bhawan, Lodi Road, New Delhi- 3	Member
Joint Secretary (UN) Ministry of External Affairs South Block, New Delhi-1	Member
Representative United Nations Development Programme 55, Lodi Estate, New Delhi- 3	Member
Joint Secretary (Climate Change) Ministry of Environment & Forests Paryavaran Bhawan, CGO Complex, Lodi Road, New Delhi- 3	Member
Dr. Subodh K Sharma Adviser (NATCOM) Ministry of Environment & Forests Paryavaran Bhawan, CGO Complex Lodi Road, New Delhi-3	Member Secretary

Project Management Cell

Dr. Subodh K. Sharma
National Project Director, NATCOM
Ministry of Environment and Forests,
Government of India
Room No. 112 , 1st Floor
Paryavaran Bhavan, CGO Complex
Lodhi Road, New Delhi 110003
Ph: 91-11-24360861
E-mail: subodh.kumar@nic.in

Dr. Amir Bashir Bazaz
National Expert Consultant
NATCOM Project Management Cell
S – 212, IInd Floor, Panchsheel Park
New Delhi 110017
Ph: 91-11-26013876/ 26013869
E-mail: bazaz.amir@gmail.com

Dr. Sumana Bhattacharya
National Expert Consultant
NATCOM Project Management Cell
S – 212, IInd Floor, Panchsheel Park
New Delhi 110017
Ph: 91-11-26013876/ 26013869

Ms. Pooja Kotiyal
Project Associate - Technical
NATCOM Project Management Cell
S – 212, IInd Floor, Panchsheel Park
New Delhi 110017
Ph: 91-11-26013876/ 26013869

Dr. Rita Chauhan
Technical Consultant
NATCOM Project Management Cell
S – 212, IInd Floor, Panchsheel Park
New Delhi 110017
Ph: 91-11-26013876/ 26013869

Contributors to India's Second National Communication

Participating Institutions and Experts

Andaman & Nicobar Islands Forest & Plantation Corporation Limited
Port Blair-744102
A & N Islands (India)
Ph: +913192238986
Dr. Alok Saxena
Dr. Mani Saxena
Mr. J. George
Mr. A. K. Adak
Mr. T.B. Das
Dr. S. K. Bharti
Mr. John Kispotta
Mr. Vinod Atmaram Mendhe
Mr. Shyam Nath Hazari

Central Institute of Mining and Fuel Research Institute, Dhanbad
Council of Scientific and Industrial Research
Dept. of S&T, Govt. of India
P.O. FRI, Dhanbad 828108
Ph: +913262388268
Mr. S. Biswas
Dr. Ajay Kumar Singh
Dr. A. Choudhury
Dr. A. Mukherjee
Dr. J. Roy
Dr. P. Sarkar
Mr. M. Kumar
Mr. S.G. Sahu

Central Leather Research Institute
Adyar, Chennai 600020
Ph : 044-24911386
Dr. T. P. Sastry,
Mr. D Chandramouli
Dr. A. B. Mandal
Dr. Giriyappa Kollannavar,
Mr. S. Nithiyanantha Vasagam
Ms. V. Shashirekha
Dr. Mahadeswara Swamy

Central Plantation Crop Research Institute, Kerala
Dr. Soora Naresh Kunar

Central Potato Research Institute
Jalandhar –144003 (Punjab)
Ph: 0181- 2791474
Dr. J. P Singh

Central Road Research Institute
Mathura Road
New Delhi 110020
Dr. Anil Singh
Dr. S. Gangopadhyay
Mr. Chander Bhan

Dr. Y S Parmar University
Nauni, Solan 173230 (H.P)
Tel: 01792 252270
Prof. K. S. Verma
Dr M. S. Mankotia
Dr S. K. Bhardwaj
Dr Sudhir Verma

Forest Survey of India
Kaulagarh Road, P.O., IPE Dehradun 248195
Ph: 91-135-2755037
Dr. Jakati
Mr. Subhash Ashutosh
Mr. Rajesh Kumar
Mr. Raj Kumar Bajpai

Indian Agricultural Research Institute
NRL Building, Pusa, New Delhi – 110012
Ph: 91-11-25841866
Dr. Himanshu Pathak
Dr. Anita Choudhary
Dr. Arti Bhatia
Dr. Niveta Jain
Dr. S. Naresh Kumar
Dr. Dinesh Kumar
Dr. R. Choudhary
Dr. S.D Singh
Dr. Shantha Nagrajan
Dr. Madan Pal
Dr. A. Bhatia
Dr. Anjali Anand
Dr. Subash Chander
Dr. B. Banerjee
Dr. U. Meena
Mr. Amar singh

Indian Council of Forestry Research and Education
P.O. New Forest
Dehra Dun - 248006,
Uttarakhand, India
Ph: 0135- 2750296
Dr. V.K. Bahuguna
Dr. V.R.S. Rawat
Dr. Renu Singh

Indian Grassland and Fodder Research Institute
Near Pahuj Dam, Gwalior Road, Jhansi 284003
Ph: 0510-2730908
Dr. Sultan Singh
Dr. S. K. Nag
Dr. A. K. Mishra
Dr. B.P. Khushwaha

Indian Institute of Horticulture Research
Hessaraghatta Lake P.O.
Bangalore 560089 , India
Ph: 080 28466420-423
Dr. N.K. Srinivasa Rao
Dr. R.H. Laxman
Dr. R. M. Bhatt
Miss. H.Mamatha
Mrs. G. H. Ashwini

Indian Institute of Management
Vastrapur, Ahmedabad 380015
Ph: 91-79-26324827
Prof. P. R. Shukla
Dr. Amit Garg
Dr Minal Pathak
Ms Jigeesha Upadhyay
Ms Jyoti R. Maheshwari
Ms Amita Jataliya

Indian Institute of Petroleum
P.O. IIP, Mohkampur,
Dehradun
248005
Ph: 91-135-2660099
Dr. S. K. Singal
Dr M O Garg
Mr. Sunil Pathak
Mr. A K Aigal
Mr. L Robindro
Mr. Yograj
Mr. Vineet Sood

Indian Institute of Science
Bengaluru 560012
Ph: 91-80-23601455
Prof. N. H. Ravindranath
Dr. G. Bala
Dr. N. V. Joshi

Indian Institute of Soil Science
Nabibagh, Berasia Road
Bhopal – 462038
Ph: +91-755- 2730970
Dr. K. B. Hebbar

Indian Institute of Technology
Hauz Khas, New Delhi 110016
Ph: 91-11-26591186
Dr. Ashvani Kumar Gosain
Dr. Sandhya Rao

Indian Institute of Technology
Powai, Mumbai 400076
Ph: 912225767381
Dr. K. Narayanan
Dr. Anand Patwardhan
Dr. D. Parthasarathy
Dr. A. Inamdar
Mr. Santosh Kumar Sahu
Mr. Yogesh Y.Y. A.
Mr. V. J. Gandhi

Indian Institute of Tropical Meteorology
Dr. Homi Bhabha Road
Pashan, Pune 411008
Ph: 912024893600
Dr. K. Krishna Kumar
Dr. Savita Patwardhan
Dr. Ashwani kulkarni

Institute of Minerals and Materials Technology
Bhubaneswar 751 013, Orissa, India
Ph: 0674-2581635
Dr Manish Kumar
Dr G Roychaudhury
Dr C R Panda
Dr S N Das
Mr. Nrusingha Charan Mohanta

Institute of Economic Growth
University Enclave Delhi 110 007
Ph: (O)27667288
Dr. Purnamita Dasgupta
Dr. Kanchan chaudhary

Institute of Home Economics
University of Delhi
F-4, Hauz Khas Enclave
New Delhi-110016
Ph: (O)26532402
Dr. Savita Aggarwal
Dr. Geeta Punhani,
Ms. Jagriri Kher
Ms. Sakshi Saini

Indian Veterinary Research Institute
Izatnagar-243 122, U.P.,
Ph: +91-581-2301318
Dr. A.K. Verma
Dr. Putan Singh
Dr. V.B.Chaturvedi

Jadavpur University
Kolkata 700032
Ph: 91-33-24146666
Prof. Niladri Chakraborty
Dr. Joyashree Roy
Mr. Partho Pratim Mandal
Mr. Atish Nandy
Mr. Indranil Mukherjee

Madras School of Economics
Gandhi Mandapam Road,
Behind Government Data Center, Kottur
Chennai, Tamil Nadu, - 600 025
Dr. Kavi Kumar

Malaria Research Centre
Indian Council of Medical Research
22, Sham Nath Marg, New Delhi 110054
Dr. Ramesh C. Dhiman

Maulana Azad National Institute of Technology
Bhopal 462007 (M.P.)
Ph: 91-755-2670416
Dr. Manmohan Kapshe
Dr. Aashish Deshpande
Mr. Rajat Soni
Mr. Pankaj Singh

National Dairy Research Institute
Karnal – 132001
Ph: 91-0184 2259088
Dr. Madhu Mohini
Dr. KK Singhal
Dr. AK Tyagi
Dr. KSN Prasad
Dr Ranjan Mohanta
Ms Chanchal Dua
Mr Virender Kumar

National Environmental Engineering Research Institute
Nagpur
Nagpur – 440 020.
Ph: 2249885-88
Mr. J.K Bhattacharya
Mr. M.Karthik
Mr. Atul Vaidya
Dr. Paras Pujari
Dr. S.R. Wate
Dr. P.K.Labhasetwar
Dr. Anjana Singh
Mr. Piyush Mahore
Dr. S.Y. Bodkhe
Dr. Tapas Nandy
Mr. Pawan Aswale
Dr. S.P.M. Prince William

National Institute of Oceanography
Dona Paula, Goa 403004
Ph: 91-832-2450338
Prof. A .S. Unnikrishnan

National Physical Laboratory
K.S. Krishnan Marg
New Delhi 110012
Ph : 91-11-45608232
Dr. Prabhat K. Gupta
Dr. Chhemender Sharma
Dr. Nahar Singh
Mr. Monojit Chakraborty
Mr. Khem Singh
Mr. Shivraj Sahai
Mr. P. Johri
Ms. Tripti Aggarwal
Mr. A.K. Aggarwal
Ms. Vandana Gupta
Dr. M.K. Tiwari

National Research Centre for Soybean
Khandwa Road, Indore, M.P, India - 452 017
Ph: 091-0731-2476188
Dr. V.S.Bhatia

Punjab Agricultural University
Ludhiana -141004
Telefax No. : 0161-2401997
Prof Prabhajyot Kaur Sidhu
Dr Harpreet Singh

Tamil Nadu Agricultural University
Coimbatore 641003, Tamil Nadu
Ph: +91-0422 6611519
Dr. V.Geethalakshmi
Dr. K. Palanisami
Dr.C.R.Ranganathan
Ms. S.Poornima

Other Government Departments/Research Institutions

Advance Research Centre for Bamboo and Rattans, Aizwal

Alkali Manufacturers' Association of India, New Delhi

Arid Forest Research Institute, Jodhpur

Botanical survey of India, Kolkata

Census of India, New Delhi

Centre for Forestry Research and Human Resource Development, Chhindwara

Central Glass and Ceramic Research Institute, Kolkata

Central Ground Water Board, New Delhi

Central Mines Planning & Design Institute, Dhanbad

Central Plantation Crop Research Institute, Kasaragod

Central Pollution Control Board

Central Rice Research Institute, Cuttack

Central Statistical Organization, New Delhi

Central Water Commission, New Delhi

Centre for Electricity Authority, New Delhi

Centre for Social Forestry and Eco- Rehabilitation. Allahabad

Coal India Ltd, Kolkata

Council of Scientific and Industrial Research, New Delhi

Damodar Valley Corporation (DVC),Durgapur

Damodar Valley Corporation, Jharkhand

Department of Coal, Ministry of Coal,

Department of Mines, Ministry of Mines

Department of Power, Ministry of Power, New Delhi

Department of Science and Technology, New Delhi

Electronics Industries Association of India, New Delhi

Fertiliser Association of India, New Delhi

Foundation Chitegaon Phata, Nashik- Aurangabad

Geological Survey of India, Kolkata

Himalayan Institute of Mountaineering, Darjeeling

Holtec Consulting Engineers Ltd; Gurgaon

India Meteorological Department, New Delhi

Indian Bureau of Mines, Nagpur

Indian Chemical Council, Mumbai, Maharashtra

Indian Council of Agricultual Research, New Delhi

Indian Council of Medical Research, New Delhi

Indian Institute of Public Health, Hyderabad

Indian Institute of Soil Science, Bhopal

Indian Lead Zinc Development Association, New Delhi

Indian Mountaineering Foundation, New Delhi

Indian National Centre for Ocean Information Services, Hyderabad

India Semiconductors Association, Bangaluru, Karnataka

Indian Space Research Organisation, Bangaluru

Institute of Forest Genetics and tree breeding, Coimbatore

Institute of Wood Science and Technology, Bangaluru

Jawahar Institute of Mountaineering and Winter Sports, Pahalgam, Kashmir

Ministry of Earth Sciences, New Delhi

Ministry of Finance, New Delhi

Ministry of New & Renewable Energy, New Delhi

Ministry of Petroleum & Natural Gas, New Delhi

National Bureau of Soil Science & Land Use Planning, Bangaluru

National Bureau of Soil Science & Land Use Planning, Nagpur

National Horticultural Research and Development District, Maharashtra

National Institute of Disaster Management, New Delhi

National Sample Survey Office, New Delhi

National Remote Sensing Centre, Hyderabad

Navsari Agricultural University, Surat

Neyveli Lignite Corporation Ltd., Tamil Nadu

Orissa Space Application Centre, Bhubaneswar

Petroleum Conservation Research Association, New Delhi

Planning Commission, New Delhi

Reef Watch Marine Conservation, Mumbai

Regional Horticulture Fruit Station, Moshobra, Shimla

Regional Horticulture Research Station, Sharbo, Kinnaur

Steel Authority of India, New Delhi

Tropical Forest Research Institute, Jabalpur

University of Agricultural Sciences, Bangaluru

University of Agricultural Sciences, Dharwad

University of Kashmir, Sri Nagar

Vallabhbhai Patel Chest Institute, Delhi

Water Technology Centre for East Region, Bhubaneswar

West Bengal Irrigation and Water Works Department, Kolkata

Zoological Survey of India, Port Blair

Annexure-IV

Events for Education, Training and Public Awareness

2007

- National Steering Committee meeting, May 22, 2007, New Delhi,
- Inception workshop on India's Second National Communication to the United Nation Convention on Climate Change, May 28, 2007, New Delhi
- Workshop on Issues in Vulnerability Assessment and Adaptation in India, November 1&2, 2007, New Delhi

2008

- Training on methodology to develop GHG inventory in the Industrial Process and Product Use Sector, January 25,2008, New Delhi
- Consultative meeting on Energy Sector Greenhouse Gas Inventory Estimates for India's Second National Communication, April 28, 2008, at New Delhi.
- Consultative meeting on Land Use, Land Use Change and Forestry Sector, May 26 & 27, 2008, at IISC, Bengaluru.
- Workshop on Impacts, Vulnerability Assessment and Adaptation, August 11 & 12, 2008, at IIC, New Delhi
- NATCOM Consultative meeting on Livestock, Waste and Industrial Processes August 27, 2008, at New Delhi,
- NATCOM Climate Change Scenario, October 13 & 14, 2008, at IITM, Pune
- Consultative meeting on Socio Economic Scenario, November 7, 2008, at Institute of Economic Growth, New Delhi.
- National Steering Committee Meeting, November 20, 2008, at Ministry of Environment & Forests, New Delhi

2009

- Consultative meeting for assessing the progress of work in IPPU sector, January 12, 2009, at CII, New Delhi.
- Consultative meeting for assessing the Progress of work in energy sector, January 21, 2009, at TERI, New Delhi.
- Consultative meeting on Land Use, Land-Use Change and Forestry Sector, February 6, 2009, at NATCOM PMC New Delhi
- Consultative meeting on GHG Inventory Preparation from Agriculture Sector – Crops, March 9,2009 at NATCOM PMC, New Delhi
- Workshop on Interim Review Workshop on Vulnerability and Adaptation Component of Agriculture Sector of Second NATCOM (SNC) July 2, 2009 at CRIDA Hyderabad
- NATCOM interim review Workshop, October 13, 2009, Ashok Hotel, New Delhi
- National Workshop to review the Implementation of Work Programme towards a Comprehensive Assessment of Climate Change, October 14, 2009,at Ashok Hotel, New Delhi

2010

- NATCOM review meeting on LULUCF Sector, April 6, 2010 at Ministry of Environment & Forest, New Delhi
- NATCOM review meeting on Greenhouse Gas Inventory 2007, April 7, 2010, at NATCOM PMC, New Delhi
- NATCOM data extraction meeting, April15, 2010 at NATCOM PMC, New Delhi
- INNCA workshop, May 11, 2010 at Ashok Hotel, New Delhi
- Consultative meeting of INCCA on “Assessment of Impact of Climate Change on Agriculture in India with a focus on Four regions in India”, July 8, 2010 at NATCOM PMC, New Delhi
- National Workshop on India: Climate Change & India – A 4x4 Assessment, A Sectoral and Regional Analysis for 2030s, 16th November, 2010 at Ashok Hotel, New Delhi
- Consultative meeting on LULUCF Sector, December 27, 2010 at Ministry of Environment & Forest, New Delhi

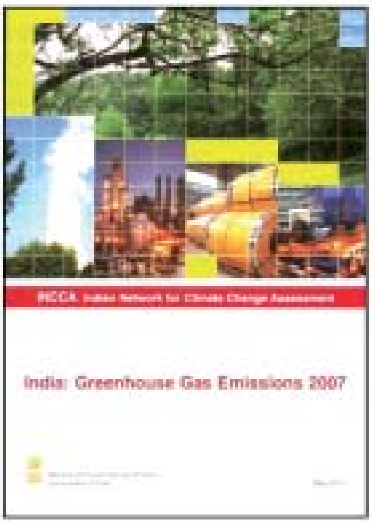
2011

- Consultative meeting for the review of SNC, January 20, 2011 at Ministry of Environment & Forest, New Delhi
- Consultative meeting on LULUCF Sector, January 21, 2011 at Ministry of Environment & Forest, New Delhi
- Consultative meeting on LULUCF Sector, February 23, 2011 at Ministry of Environment & Forest, New Delhi
- Review meeting on GHG Inventory, March14 & 15, 2011 at NATCOM PMC
- Launch Programme of Black Carbon Research Initiative, National Carbonaceous Aerosols Programme (NCAP) Science Plan, March 29, 2011 at Ashok Hotel, New Delhi
- National Steering Committee meeting, August 1, 2011, at Ministry of Environment & Forest, New Delhi
- National Review Workshop, September 20, 2011, at Hotel Ashok, New Delhi

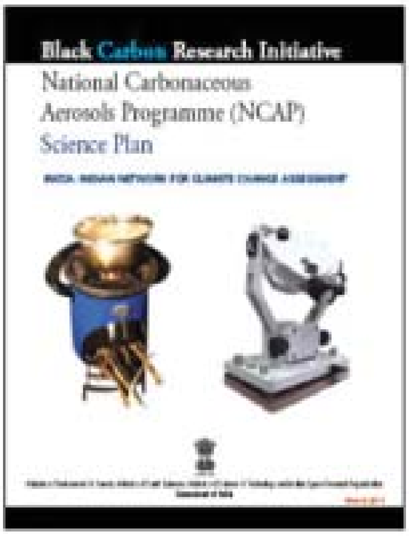
Annexure-V

Publications under the Aegis of India's Second National Communication

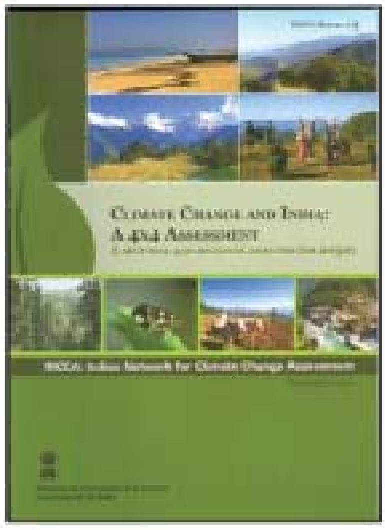
Reports



India's Green House Gases Inventory: 2007 *May 2010*

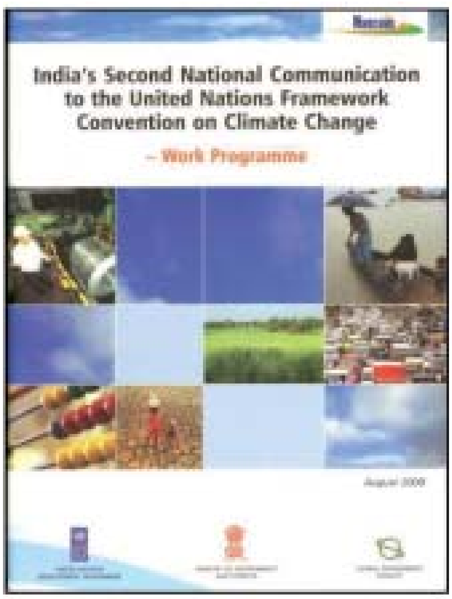


Science Plan: National Carbonaceous Aerosols Programme March 2011

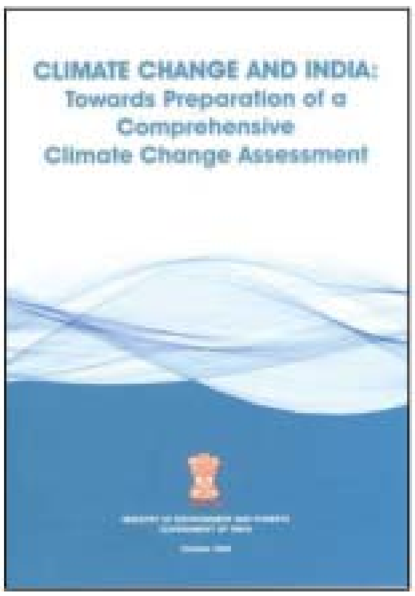


Climate Change and India: A 4X4 Assessment was released in November 2010

Brochures

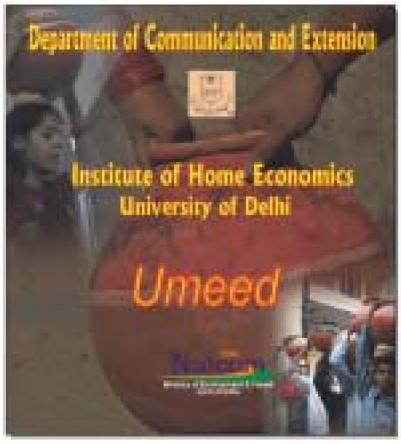


Work Program from India's Second National Communication To UNFCCC, August 2008

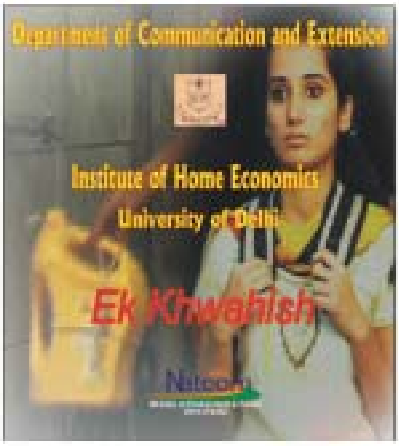


Climate Change and India a Comprehensive study of Climate Change, October, 2009

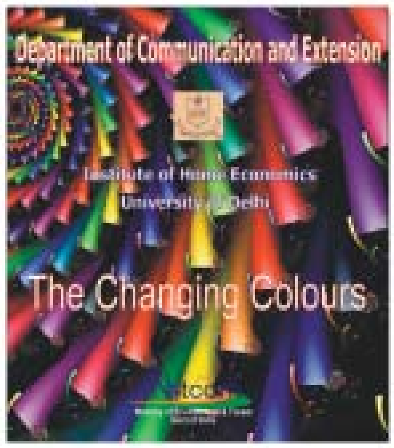
Video Films



UMEED (hope)

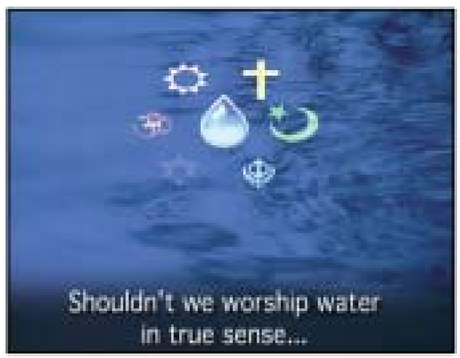


EK Khawish (One Desire)



THE CHANGING COLOURS
(Badalte Rang)

Documentary films



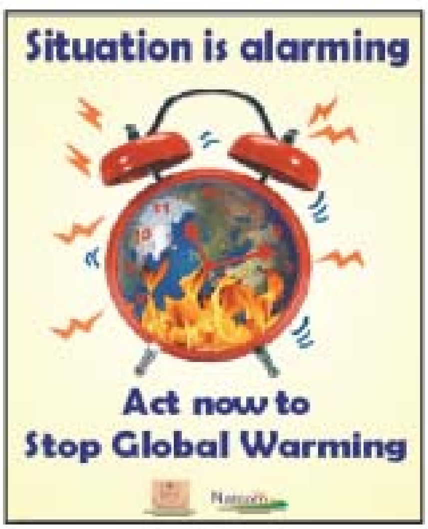
Posters

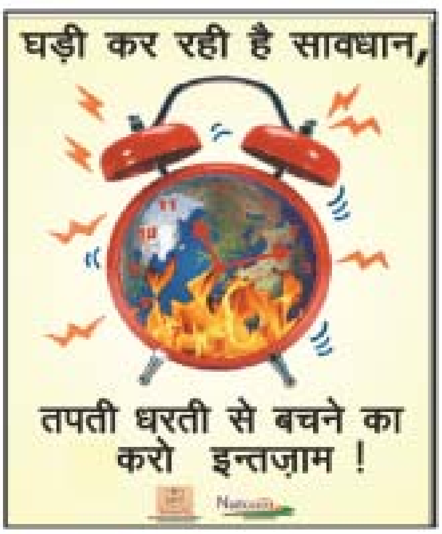

Cycling is a tool...
to make the Earth cool


तपन रोकने की चाहत
साइकिल दे सकती है राहत।

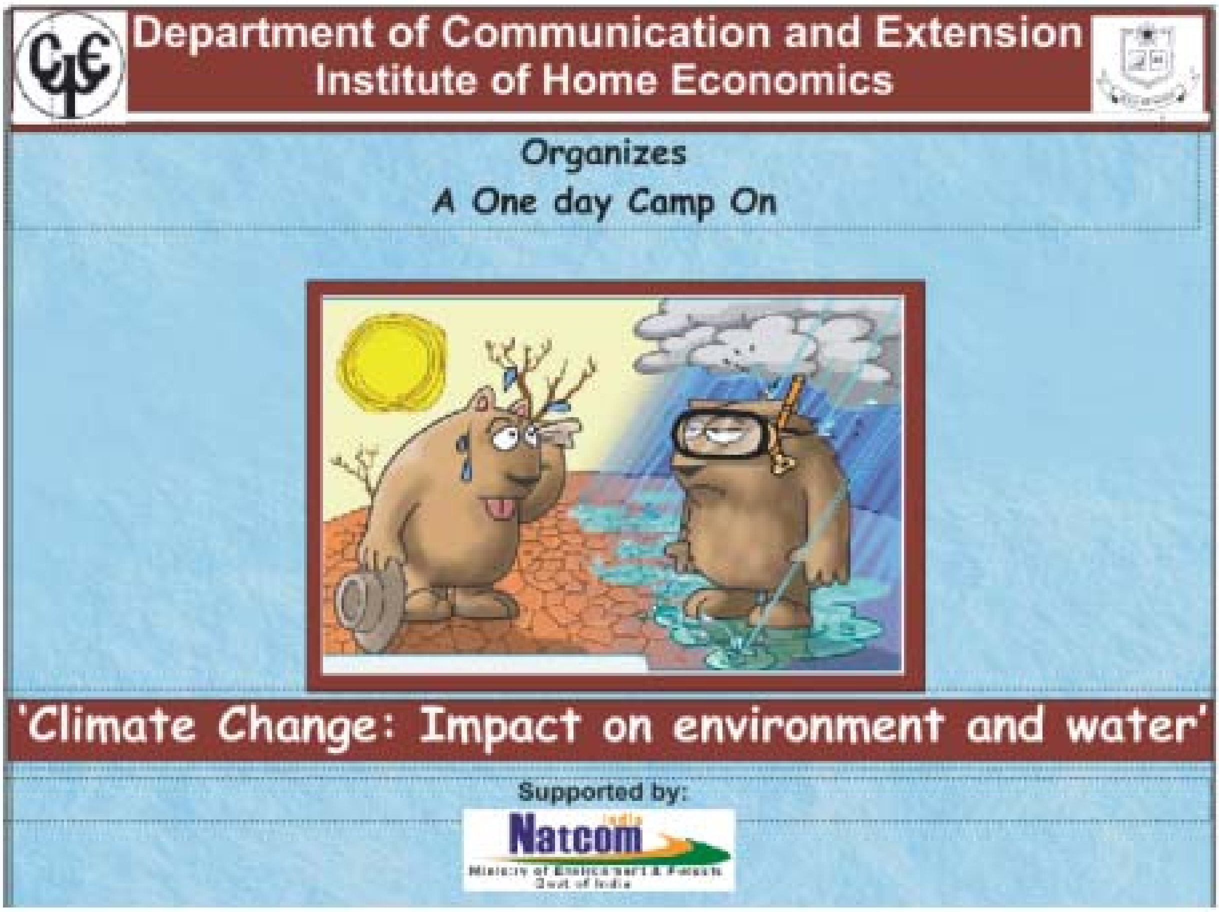

You too are responsible
for Global Warming!


तपन का प्रहार,
तुम भी हो जिम्मेदार!


Situation is alarming
Act now to
Stop Global Warming


घड़ी कर रही है सावधान,
तपती धरती से बचने का
करो इन्तज़ाम !

Banner


Department of Communication and Extension
Institute of Home Economics
Organizes
A One day Camp On
'Climate Change: Impact on environment and water'
Supported by:
Natcom
India

Annexure-VI

NATCOM NETWORK Spread all over India

Ahmedabad
Centre for Environment Education,
Ahmedabad, Gujarat

Indian Institute of Management,
Ahmedabad, Gujarat

Andaman & Nicobar Island
Andaman & Nicobar Islands Forest &
Plantation Corporation Limited
A & N Islands (India)

Zoological Survey of India,
Port Blair, Andaman & Nicobar Island

Aizawl
Advance Research Centre for Bamboo and Rattans,
Aizwal, Mizoram

Allahabad
Centre for Social Forestry and Eco- Rehabilitation.
Allahabad, Uttar Pradesh

Aurangabad
Foundation Chitegaon Phata,
Aurangabad, Maharashtra

Bhopal
Indian Institute of Soil Science,
Bhopal, Madhya Pradesh

Maulana Azad National Institute of Technology,
Bhopal, Madhya Pradesh

Bhubaneswar
Institute of Minerals and Materials Technology,
Bhubaneswar Orissa

Water Technology Centre for East Region,
Bhubaneswar, Orissa

Orissa Space Application Centre,
Bhubaneswar, Orissa

Bengaluru
Indian Institute of Horticulture Research
Bengaluru, Karnataka

National Bureau of Soil Science & Land Use Planning,
Bengaluru, Karnataka

Indian Space Research Organisation,
Bengaluru, Karnataka

University of Agricultural Sciences,
Bengaluru

India Semiconductors Association,
Bengaluru, Karnataka

Institute of Wood Science and Technology,
Bengaluru, Karnataka

Chhindwara
Centre for Forestry Research and Human Resource
Development, Chhindwara, Madhya Pradesh

Chennai
Central Leather Research Institute
Chennai

Madras School of Economics
Chennai, Tamil Nadu

M.S. Swaminathan Research Foundation
Chennai, Tamil Nadu

Naively Lignite Corporation Ltd.,
Chennai, Tamil Nadu

Coimbatore
Tamil Nadu Agricultural University,
Coimbatore, Tamil Nadu

Institute of Forest Genetics and Tree Breeding,
Coimbatore, Tamil Nadu

Darjeeling
Himalayan Institute of Mountaineering,
Darjeeling, West Bengal

Durgapur
Damodar Valley Corporation (DVC),
Durgapur, West Bengal

Delhi
Arete Glacier & Water Consultants
New Delhi

Cement Manufacturers' Association
National Capital Region

Central Road Research Institute
New Delhi

Confederation of Indian Industry,
New Delhi

Development Alternatives,
New Delhi

Global Hydrological Solutions
New Delhi

Indian Agricultural Research Institute,
New Delhi

Indian Institute of Technology Delhi
New Delhi

Institute of Economic Growth,
New Delhi

Institute of Home Economics
New Delhi

INRM
New Delhi

Integrated Research and Action for Development
New Delhi

National Institute of Malaria Research,
New Delhi

National Physical Laboratory
New Delhi

The Energy and Resources Institute
New Delhi

India Meteorological Department
New Delhi

Planning Commission
New Delhi

Indian Council of Agriculture Research
New Delhi

Ministry of Finance
New Delhi

Central Water Commission
New Delhi

Central Ground Water Board
New Delhi

Department of Science and Technology
New Delhi

Indian Mountaineering Foundation
New Delhi

Indian Lead Zinc Development Association
New Delhi

Alkali Manufacturers' Association of India
New Delhi

Vallabhbhai Patel Chest Institute
New Delhi

Department of Mines, Ministry of Mines
New Delhi

Department of Coal, Ministry of Coal
New Delhi

Department of Power, Ministry of Power
New Delhi

Petroleum Conservation Research Association
New Delhi

Ministry of Petroleum & Natural Gas
New Delhi

Ministry of New & Renewable Energy
New Delhi

Central Statistical Organization
New Delhi

Central Pollution Control Board
New Delhi

Council of Scientific and Industrial Research
New Delhi

Centre for Electricity Authority
New Delhi

Census of India
New Delhi

Ministry of Earth Sciences
New Delhi

National Sample Survey Office
New Delhi

National Institute of Disaster Management
New Delhi

Indian Council of Medical Research
New Delhi

Fertiliser Association of India
New Delhi

Electronics Industries Association of India
New Delhi

Steel Authority of India
New Delhi

Holtec Consulting Engineers
Gurgaon, NCR

Dehradun
Forest Survey of India,
Dehradun, Uttarakhand

Indian Council of Forestry Research and Education,
Dehradun, Uttarakhand

Indian Institute of Petroleum,
Dehradun, Uttarakhand

Dhanbad
Central Institute of Mining and Fuel Research Institute,
Dhanbad, Jharkhand

Dharwad
University of Agricultural Sciences,
Dharwad, Karnataka

Goa
National Institute of Oceanography,
Goa

Hyderabad
Indian National Centre for Ocean Information services,
Hyderabad, Andhra Pradesh

National Remote Sensing Centre,
Hyderabad, Andhra Pradesh

Indian Institute of Public Health,
Hyderabad, Andhra Pradesh

Izatnagar
Indian Veterinary Research Institute,
Izatnagar, Uttar Pradesh

Indore
National Research Centre for Soybean
Indore, Madhya Pradesh

Jorhat
Rain Forest Research Institute, Jorhat, Assam

Jalandhar
Central Potato Research Institute,
Jalandhar, Punjab

Jammu & Kashmir
Jawahar Institute of Mountaineering and Winter Sports,
Pahalgam, Kashmir

University of Kashmir, Srinagar, Kashmir

Jhansi
Indian Grassland and Fodder Research Institute
Jhansi, Uttar Pradesh

Jharkhand
Damodar Valley Corporation
Jharkhand

Jabalpur
Tropical Forest Research Institute
Jabalpur, Madhya Pradesh

Jodhpur
Arid Forest Research Institute
Jodhpur, Rajasthan

Karnal
National Dairy Research Institute
Karnal, Punjab

Kasaragod
Central Plantation Crop Research Institute
Kasaragod, Kerala

Kinnaur
Regional Horticulture Research Station
Kinnaur, Himachal Pradesh

Kolkata
Jadavpur University, Kolkata, West Bengal

West Bengal Irrigation and Water Works Department
Kolkata, West Bengal

Botanical Survey of India
Kolkata, West Bengal

Geological Survey of India
Kolkata, West Bengal

Central Glass and Ceramic Research Institute
Kolkata, West Bengal

Coal India Ltd., Kolkata, West Bengal

Ludhiana
Punjab Agricultural University
Ludhiana, Punjab

Lucknow
Ace Consultancy and Services
Lucknow, Uttar Pradesh

Mumbai
Indian Institute of Technology
Mumbai

Reef Watch Marine Conservation
Mumbai, Maharashtra

Indian Chemical Council, Mumbai, Maharashtra

Nagpur
National Environmental Engineering Research Institute
Nagpur, Maharashtra

National Bureau of Soil Science & Land Use Planning
Nagpur, Maharashtra

Indian Bureau of Mines, Nagpur, Maharashtra

Nasik
National Horticultural Research and Development Foundation, Nasik, Maharashtra

Orissa
Central Rice Research Institute
Cuttack, Orissa

Pune
Indian Institute of Tropical Meteorology
Pune, Maharashtra

Ranchi
Central Mines Planning & Design Institute
Ranchi, Jharkhand

Shimla
Regional Horticulture Fruit Station
Shimla, Himachal Pradesh

Solan
Dr. Y S Parmar University
Solan, Himachal Pradesh

Surat
Navsari Agricultural University
Surat, Gujarat

Sikkim
Government of Sikkim

Udaipur
Action for Food production
Udaipur, Rajasthan