Climate Resilient Green Growth Strategies for Punjab

Towards an Inclusive Development Agenda

teri
The Energy and Resources Institute

Global Green Growth Institute

GOVT. PUNJAB

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Contents

Abbreviations

AET	Actual Evapotranspiration
CAGR	Compound Annual Growth Rate
CCT	Clean Coal Technology
CDM	Clean Development Mechanism
CES	Clean Energy Substitution
CFLs	Compact Fluorescent Lamps
CGWB	Central Ground Water Board
COPD	Chronic Obstructive Pulmonary Disease
CrPC	Criminal Procedure Code
CSA	Critical Source Area
CUF	Capacity Utilization Factor
CUM	Capacity Utilization Measures
DEM	Digital Elevation Model
DSTE	Department of Science Technology and Environment
EC	Electrical Conductivity
ECB	Energy Conservation in Buildings
ECM	Energy Conservation Measures
EPI	Energy Performance Index
ET	Evapotranspiration
FDCs	Forest Dependent Communities
FGDs	Focused Group Discussions
FSI	Forest Survey of India
G-DSM	Ground Water Demand-Supply Management
GIS	Geographical Information System
GRIHA	Green Rating for Integrated Habitat Assessment
GSFD	Gross State Fiscal Deficit
HRUs	Hydrological Response Units
HVAC	Heating, Ventilation and Air Conditioning
HYVs	High Yielding Varieties
IEE	Industrial Energy Efficiency
IMD	Indian Meteorological Department
IPC	Indian Penal Code
IRR	Internal Rate of Return
JFMCs	Joint Forest Management Committees
KPIs	Key Person Interviews
LEAP	Long-Range Energy Alternatives Planning System
LED	Light Emitting Diode
LVDS	Low Voltage Distribution System
MFE	Motor Fuel Efficiency
MoEFCC	Ministry of Environment, Forests & Climate Change
MRC	Master Recession Curve
MSMEs	Micro Small and Medium Enterprises
MSP	Minimum Support Price
MUSLE	Modified Universal Soil Loss Equation
MVC	Motor Vehicle Control
NAMP	National Ambient Air Quality Monitoring Programme
NAO	North Atlantic Oscillations
NGT	National Green Tribunal
NPK	Nitrogen (N), Phosphorus (P), and Potassium (K)
NPMCR	National Policy for Management of Crop Residues

NRM	Natural Resource Management
NRSE	Northern Regional Power System
NRSE	New and Renewable Sources of Energy
OPC	Ordinary Portland Cement
PEDA	Punjab Energy Development Agency
PFI	Population Foundation of India
PID	Punjab Irrigation Department
PPCB	Punjab Pollution Control Board
PRECIS	Providing REgional Climates for Impacts Studies
PSERC	Punjab State Electricity Regulatory Commission
PSPCL	Punjab State Power Corporation Limited
PTM	Public Transport Measures
RES	Renewable Energy Sources
RSC	Residual Sodium Carbonate
SAPCC	State Action Plan on Climate Change
SCADA	Supervisory Control and Data Acquisition
SEC	Structural Economy Change
SME	Small and Medium Scale Enterprise
SPV	Solar Photovoltaic
SRES	Special Report on Emission Scenarios
SWAT	Soil and Water Assessment Tool
TMS	Transport Modal Shift
TOF	Trees Outside Forests
UFW	Unaccounted-for-Water
USGS	United States Geological Survey
WBCs	Water Balance Components
WRIS	Water Resource Information System

Executive Summary

Punjab is one of the fastest developing states in India. The state has posted a steady growth during the last decade. The state also achieved its growth target in the Eleventh Plan period. In terms of both net state domestic product as well as per capita incomes, the growth rate has been consistent. There has been a sectoral shift in the Punjab economy and the share of agriculture has fallen, while the share of tertiary sector has increased. The tertiary sector contributes a significant share in the state's domestic product, followed by the secondary and primary sector.

As per the Punjab State Action Plan on Climate Change, sectors of the economy will need to grow with lesser impacts on the environment, managing wastes, natural resources, and enhancing energy efficiency. Hence, a growth path of Punjab needs to be oriented towards a green growth path from now onwards, given the status of environment situation that has been created within the State.

The State has polices such as the Punjab Preservation of Sub Soil Water Act of 2009 which mandates that no farmer can sow paddy before the 10th of May. Agriculture Policy for Punjab, 2013, advocates that the strategy for agriculture development has to address the sustainability concerns while achieving the overall growth objectives. As per the policy, area under paddy should be restricted to 16 lakh hectares for maintaining the ground water balance. The draft Policy for Management and Utilization of Paddy Straw in Punjab, 2013, provides information on alternative options for utilizing paddy straw and challenges witnessed in collection and storage of the straw. The State, under the Green India Mission, envisions increasing area under forest and tree cover from 6.87 per cent to 15 per cent of the total geographic area by the year 2022 which is a highly ambitious target. The New and Renewable Sources of Energy Policy of 2012 seeks to promote renewable energy in the State including power generation from biomass and agricultural residue.

Climate change and resulting climate variability will have an impact on natural resources in the State. Given that the State's developmental activities are dependent on natural resources, for developing a climate resilient green growth strategy, it becomes important to understand as to what will be the impact of climate variability on the soil and water parameters. In addition, for considering inclusive development aspects, it becomes relevant to understand developmental activities, considering socio-economic aspects and perceptions of communities.

Climate Variability

- The model used in the study is PRECIS (Providing REgional Climates for Impacts Studies) model. PRECIS is a high resolution atmospheric and land surface model of limited area. A high resolution dynamical model was used to simulate a baseline run from 1970–2000 and for near future (2030s) to arrive at future climate variability over the study domain area.
- The analyses of baseline (1970–2000) and near future (2021–2050) climate simulations over the study area revealed an increase in future summer monsoon (June–September) precipitation in the near future relative to the baseline period. The increase in mean annual summer monsoon rainfall is in the range of 0–20 per cent of the baseline rainfall.
- The model shows overall warming within the study domain area in the near future. Annual Mean Temperature projected to increase by 1.2–1.4°C for 2021–2050 period relative to 1971–2000.
- The Mean Annual Minimum Temperature (Tmin) also is projected to increase over the Study domain area in the range 1.2–1.4°C. Mean Annual Maximum temperature (Tmax) over the State is projected to increase by 0.5–1.25°C. Relatively larger changes projected for minimum temperatures for the future. This corroborates with the historical trends over India.
- Increase in Minimum Temperature has many impacts not only over plants, crops but over human comfort as well. This also indicates that night time temperatures also will increase in the near future relative to the baseline period.
- The analysis indicates that towards late 2030s and early 2040s, the State will experience higher number of extreme wet days. This implies that in the near future, in the summer monsoon season there will be more break periods in terms of precipitation.
- A higher level of relative humidity is also expected in the near future.

Soil and Water Assessment

- The Soil and Water Assessment Tool (SWAT) is applied to understand the status of water and soil parameters spatially in 2030s. Outputs of the climate model, in terms of temperature and precipitation parameters are used as SWAT model inputs. In addition, spatial inputs are provided to the SWAT model to understand the changes in water resources, and potential implications of climate variability and cropping patters for Punjab's green growth and development.
- Industrial water requirement will increase by 10 per cent in 2020 and 15 per cent by 2030 as compared to 2010 water requirement. Domestic water requirement will increase by 29.8 per cent in 2020 and 64.8 per cent by 2030 as compared to 2010 water requirement. Irrigation water demand is expected to stay around 56.1 BCM during 2020 and 2030 unless crop diversification takes place on a large scale. It is projected that there will be a water deficit of 15.9 BCM in 2020 and 14.4 BCM by 2030 will be in the State.
- While, basins in the state show increased availability of surface and ground water owing to future climate variability, actual water availability will vary depending upon the existing land use, domestic and industrial water use. Basin wise crop diversification and physiography of the region will play major role in future water availability.
- It is expected to increase evapotranspiration of crops by 6 per cent to 8 per cent across all basins due to increase in temperature. Hence, actual irrigation requirement will increase by 100 mm to 133 mm for a crop needing 500 mm irrigation water, considering the flood water irrigation method which is dominant irrigation method in the state. Therefore on-farm irrigation management, use of alternate irrigation methods and conservation agriculture needs special attention.
- Based on the modelling exercise, it is found in the reference scenario, out of total blocks in Punjab about 85.5 per cent blocks are showing deficit. Out of 85.5 per cent deficit blocks in this scenario, 40.4 per cent blocks showed moderate to very high deficit and 45.2 per cent blocks showed low deficit.
- As compared to reference future scenario, policy scenario brings about 66.3 per cent blocks to no deficit to low deficit category and stills there will be 33.7 per cent blocks in moderate to very high deficit.
- In ambitious scenario, 71.1 per cent blocks will be no deficit to low deficit blocks and 28.9% blocks will be in the moderate to very high water deficit blocks category. This scenario brings major desired changes of bringing water deficit to the lowest level. Mainly it brings down high deficit block number (30 blocks) of reference scenario to 13 blocks in ambitious scenario, as well as it also increases low deficit block numbers from 75 block in reference future scenario to 85 blocks in ambitious scenario.
- By adopting crop diversification measure, the water requirement can go down from 27.4 BCM in reference scenario to 14.5 BCM in policy scenario and further down to 2.6 BCM in ambitious scenario.
- As soil is important part of agricultural production system, loss of fertile soil is major loss. Soil formation is very slow process and hence even moderate soil erosion is not desired. It was observed that Ravi and Beas may have very high changes in soil erosion in future (2020–35).

Energy Development in Punjab

- A new modified LEAP (Long-range Energy Alternatives Planning) model is developed for the state of Punjab. Here energy demand comprises of primary and secondary energy demand. The various end-use sectors are - agriculture, industry, transport, residential and commercial sectors. Energy efficiency aspects in all these sectors are considered while estimating total energy demand from these sectors.
- For green growth and development, constraints on pollutants like particulate matters (PM10, PM2.5) are also imposed on the model as while the state grows it also has to check the impacts of the growth on the pollutants. The annualized economic costs of these pollutants are to the tune of 2 per cent of the State GDP every year and hence it has been used as a constraint bound in the model.
- The scenarios were developed in the LEAP-Punjab model under different sets of options—the clean energy substitution (CES) measure, the industrial energy efficiency (IEE) measure, energy conservation in buildings (ECB), other energy

conservation measures (ECM), motor vehicle control (MVC) measure, renewable energy sources (RES) measures, capacity utilization measures (CUM), public transport measures (PTM), transport modal shift (TMS), motor fuel efficiency (MFE), and clean coal technology (CCT).

- Primary energy supply from coal will reduce as the state economy transits from a reference to a policy and ambitious scenario. The increase in renewable energy-based primary energy supply will also mean a rise in the capacity addition for renewable energy sources.
- Owing to the structural change measures an energy demand reduction of 37 per cent can happen by 2031 in comparison to 2005–06. The energy demand reduction can happen from efficient energy demand management practices in agriculture and industry. However, owing to a structural change there will be a marginal rise of energy demand in the service and commercial sector.
- It emerges that as a result of crop diversification measures, the energy consumption will go down in 2020s and 2030s.
- If the current pattern of ground water withdrawal and energy consumption in the agriculture sector across the Kharif and Rabi crops continues, then the ground water table can decline at a rate of more than 1 metre a year. Consumption of water by agriculture sector can also be tackled by breeding early maturing rice varieties, recently released varieties like PR 121 and PR 123. Further, use of laser land leveller, saving about 15 per cent of irrigation water and promotion of micro irrigation systems are also some of the ways of reducing the water consumption which can thereafter create a diminishing impact on electricity demand and subsidy.
- Through the targeting of reduction in electricity subsidies, electricity subsidy as a percentage of Gross State Fiscal Deficit can be reduced from current 73 per cent in reference scenario to 10 per cent in ambitious scenario in 2031.

Stakeholder Perspectives on natural resource management

- To understand stakeholder perspectives, field research was undertaken by TERI researchers at seven villages across four districts of Amritsar, Faridkot, Rupnagar, and Sangrur. Using structured questionnaire, 208 farmers were individually interviewed. Questionnaire-based farmer interactions and nominal focused group discussions were carried out to understand the farmer perspectives on status of forest and tree cover, groundwater, paddy straw management, and crop diversification. Moreover, key person interviews were undertaken to understand bottom-up implementation perspectives regarding these issues.
- Considering perspectives from village communities, important insights emerge considering the gender dimension of drivers. Women farmers have higher preference for positive environmental externalities and labour while male farmers give higher weightage for economic-drivers. Since women also seemed to be open to new technical know-how, it would be important for the State's policy-makers to consider the gender dimensions while refining their interventions on crop diversification.
- Structured questionnaire were used in Amritsar and Rupnagar for understanding aspects of crop diversification. In both the districts, depletion of groundwater, deterioration of soil health and burning of crop residues was perceived as the most important significant impacts of the rice-wheat cropping system. In Amritsar, farmers want to diversify to either maize, vegetable cultivation or diversify into dairying activities, while in Rupnagar farmers wanted to vegetable, maize and pulses. In Constraints to diversify was the inadequacy of labour and lack of policy support including higher minimum support price for alternate crops, subsidies, and state procurement.
- Stakeholder opinion gathered from field research suggests that the lack of effective market linkages, unstable market demand and economic returns for the proposed alternate crops, have failed to create a conducive environment for farmers to confidently venture out of paddy and wheat. There is a need for the state government to focus on the farm gate to market linkage for the alternative crops so that there is a stronger incentive for the farmers to shift to these crops.
- Field interaction revealed that farmers are aware of the negative impacts paddy straw burning exert on their local environment and community. Further, imposition of restrictions by the state government making paddy straw burning an offence, has made farmers more open to accept alternative residue management practice. To address the issue of paddy straw burning, the paddy straw management needs to be made cost-effective to the farmers.

- Farmers were found waiting for many days in the grain market to fetch a good price for their produce. Lack of timely access to market information for price discovery leave them with a narrow window between harvesting of paddy and sowing of Rabi crop, thereby pushing farmers to burn paddy stubble.
- For paddy straw management, both men and women felt that availability of labour would aid them most in paddy straw management. Benefit to environment is a motivation for women whereas cost and income received higher consideration by men.
- In terms of environmental benefits, farmers felt that happy seeder resulted in the most environmental benefits. The ownership and maintenance cost per annum is estimated as highest for making bales from paddy straw followed by seeding next crop with standing paddy stubble and incorporation of paddy straw into soil. Whereas in terms of operating costs per acre, Happy Seeder is the most expensive followed by mulcher and a baler.
- Most farmers felt that the tree cover had declined over the last five years. Farmer interactions highlighted that the government can play a major role in checking deforestation and maintaining records of the already existing tree tracts. Majorly, the farmers are not involved in agro-forestry but do view it as an option for crop diversification which could help in increasing the tree cover in the state. The most popular choice of tree for agroforestry came out to be Poplar, Eucalyptus, and fruit trees such as Mango and Kinnow.
- In order to understand the scenario of tree cover in the villages, an exercise of participatory spatial mapping was conducted. Largely, both men and women were not receptive to the idea of large scale agro-forestry, that would involve plantation of trees on their agricultural land or along roads which pass through agricultural lands; that is because they were of the belief that the tree shadows and leaf-fall would affect the crop growth.
- The farmers also informed that mostly all fields have some Guava, Kinnow, Jamun, Mango, Litchi plantations. Amongst these, Jamun trees were considered best for farm boundaries. It was informed that Saagwaan (teak) was a good option for agroforestry as its wood is expensive, has a good market, takes about 8 years to be ready for cultivation, and does not require much water. Speaking from their experience, farmers informed that Eucalyptus and Poplar extract quite a lot of water, shed leaves, and spoil crop yields.
- A majority of farmers are of the opinion that the quality of groundwater has degraded over the last few years and that the availability has also become worse.
- Interaction with farmers revealed that on an average, an electric pump-set needs to be changed in five to ten years with a new pump costing around INR 1 lakh. While on an average the cost for maintenance of a pump-set comes around INR 7000–8000 annually. The expenditure on electricity for farm activities is zero as the government provides free electricity for agricultural use.
- Field interactions revealed that while there was widespread compliance to the Punjab Preservation of Subsoil Water Act, 2009, senior bureaucrats at the district level stressed the need for emphasis on an awareness and education campaign on the need for groundwater savings. The stakeholder consultation with government officials in February 2014 revealed that the government intends to electrify all the tube wells by 2015, which is estimated to cost INR 700 crores and electricity consumption would be monitored only at the feeder level and not at the tube well level. This would worsen the fiscal deficit of the state government.
- There is scope to encourage and promote construction of artificial recharge structures at the village level. At present, there are no large-scale initiatives which assure groundwater recharge. There is a need to include and foster construction of groundwater recharging structures at the policy level so as to have a holistic development. Research studies and analytical insights from the exercise points to the opportunity to design a holistic Ground Water Demand-Supply Management (G-DSM) policy, capturing the unique challenges and opportunities for the way forward.

1

Initiative on Green Growth and Development in Punjab

1.1 Context

Punjab located in the north-western border of India is a small state occupying less than 2 per cent of the geographical area and inhabited by little more than 2 per cent of the total population of the country. With only 1.57 per cent of total geographic area of country, the state contributes significantly to India's food security. The State contributes 13–14 per cent of total food grain production of the country. The State falls in the Indus basin and is drained majorly by three rivers—the Ravi, Beas, and the Sutlej and other drainage channels including the Ghaggar drains remaining southern parts.

Punjab is one of the fastest developing states in India. The State has posted a steady growth during the last decade. The state also achieved its growth target in the Eleventh Plan period. In terms of both net state domestic product as well as per capita incomes, the growth rate has been consistent. There has been a sectoral shift in the Punjab economy and the share of agriculture has fallen, while the share of the tertiary sector has increased. Tertiary sector contributes a significant share in the state's domestic product followed by the secondary and primary sector. Punjab has done better than India's average in socio-economic development indicators such as income and life-expectancy but lags behind in gender-related indicators.

While the production potential of rice and wheat crops have almost been fully exploited, now there is a stagnation in the growth process, decline in real farm incomes, and over exploitation of natural resources vis-a-vis soil health and water quality and quantity.

Groundwater is a major source of water for agricultural, industrial, and domestic purposes. Over-exploitation of groundwater for use in agriculture has resulted in water stress, especially in central districts of the State. Biological diversity in the State indicates that agricultural biodiversity conservation is as important as wild biodiversity to support its agricultural base.

In the wake of climate change, socio-economic and ecological vulnerability increases and risk-based approaches become even more relevant. Thus, greener growth and sustainable development needs to take into account impacts of climate variability while strengthening policy interventions.

1.2 Motivation

As per the Punjab State Action Plan on Climate Change, sectors of the economy will need to grow with lesser impacts on environment, managing waste, natural resources, and enhancing energy efficiency. Therefore, a growth path of Punjab needs to be oriented towards a green growth path henceforth, given the status of the environment that has been created within the State.

Punjab at present has more than 80 per cent of its total geographic area under agriculture with wheat and paddy being the dominant crops. The increasing trend of paddy and wheat cultivation has brought the crop diversification index down. Increasing temperatures due to climate variability are likely to decrease wheat and paddy productivity. It becomes extremely relevant to understand the impact of climate variability and cropping patterns on water and soil parameters.

Growth of paddy cultivation in Punjab is largely attributed to provisions of high yielding varieties of paddy, minimum support price, assured irrigation resources, and evolved markets for paddy crops. Punjab produces around 17 million tonnes of paddy straw of which about 15 million tonnes of paddy straw produced in the state is being burnt in the fields every year Increasingly, natural resource management is gaining policy relevance in Punjab with the government stating clear intent on crop diversification, water conservation and increasing tree & forest cover.

The state has polices such as the Punjab Preservation of Sub Soil Water Act of 2009 which mandates that no farmer can sow paddy before the 10th of May. Agriculture Policy for Punjab 2013 advocates that the strategy for agriculture development has to address the sustainability concerns while achieving the overall growth objectives. As per the policy, area under paddy should be restricted to 16 lakh hectares for maintaining the ground water balance. The draft policy for Management and Utilization of Paddy Straw in Punjab 2013 provides information on alternative options for utilizing paddy straw and challenges witnessed in collection and storage of the straw. The State, under the Green India Mission, envisions increasing area under forest and tree cover from 6.87 per cent to 15 per cent of the total geographic area by the year 2022 which is a highly ambitious target. The New and Renewable Sources of Energy Policy of 2012 seeks to promote renewable energy in the state including power generation from biomass and agricultural residue.

Box 1.1 articulates green growth in the Indian context.

Box 1.1: What is Green Growth?

Green growth involves rethinking growth strategies with regard to their impact(s) on environmental sustainability and the environmental resources available to poor and vulnerable groups.

(Para 3.15, Thirteenth Finance Commission Report)

The Ministry of Environment, Forest and Climate Change recognizes, green growth and poverty eradication to contribute to the vision of sustainable development.

Climate change and resulting climate variability will have an impact on natural resources in the State. Given that the State's developmental activities are dependent on natural resources, for developing a climate resilient green growth strategy, it becomes important to understand as to what will be the impact of climate variability on the soil and water parameters. In addition, for considering inclusive development aspects, it becomes relevant to understand developmental activities considering socio-economic aspects and perceptions of communities.

1.3 Approach

This report brings together the analytical components for understanding aspects to inform decision-making for:

- Climate variability
- Soil and water
- Power generation
- Stakeholder perspectives on natural resource management

The analytical framework included three models (climate modelling, soil and water assessment tool, and energy modelling), case studies from field visits, and a comprehensive review of sector-wise interventions in Punjab.

Climate modelling for Punjab provides an analysis and evaluation of observed climatological information and assessment of near future climate variability over the State. Analyses methods include review of literature, obtaining the observed climatological data for the State and its trend analyses. A high resolution dynamical model is used to simulate (under A1B scenario) a baseline run from 1970–2000 and for near future (2030s: 2020–2050) to arrive at future climate variability over the study domain area.

In this integrated assessment, the Soil and Water Assessment Tool component takes inputs from spatial analysis as well as the climate model. The model takes into consideration parameters like drainage network, land use and cover pattern, soils, elevation, and climatic parameters for simulating water balance (rainfall, surface and ground water quantity, evapotranspiration, base flow and amount of water retained in soil), yield (crop and tree), and soil parameters.

The energy analysis intends to project a possible implications associated with various scenarios in the State. This will inform the state into the possible implications of existing sector plans and policies on energy security and finance of the State. The analyses attempts to capture a broad range of aspects of the State's power sector, from supply to demand, which will aid in the planning and decision-making process of the State.

The case studies component examines socio-economic aspects related to natural resource management in the State for further understanding the concerns of the local communities and other stakeholders with respect to aspects of crop diversification, paddy straw management, groundwater management, and green cover. This understanding aims to assist policy makers in evolving procedures with respect to planning and implementation of natural resource management programme. To achieve the objective, field researches have been undertaken by researchers at The Energy and Resources Institute (TERI) in four districts in the State. The research involves structured questionnaire-based interviews with farmers, focused group discussions (with both men and women), and key person interviews with officials at state, district, and village levels.

A sector-wise review was undertaken as an additional analytical exercise to identify areas of policy interventions. The review included developing discussion papers for air quality, water, forestry, biodiversity, waste management, renewable energy, demand side management, transport, industry, agriculture, buildings and climate change.

The project approach was presented in a workshop and in a meeting engaging government officials and experts. Their feedback was used to refine the scope of the project, research questions, and data consistency. The analyses were conducted in consultation with various departments at the state level. In addition, the case studies component facilitated consultations at the district level and at the village level.

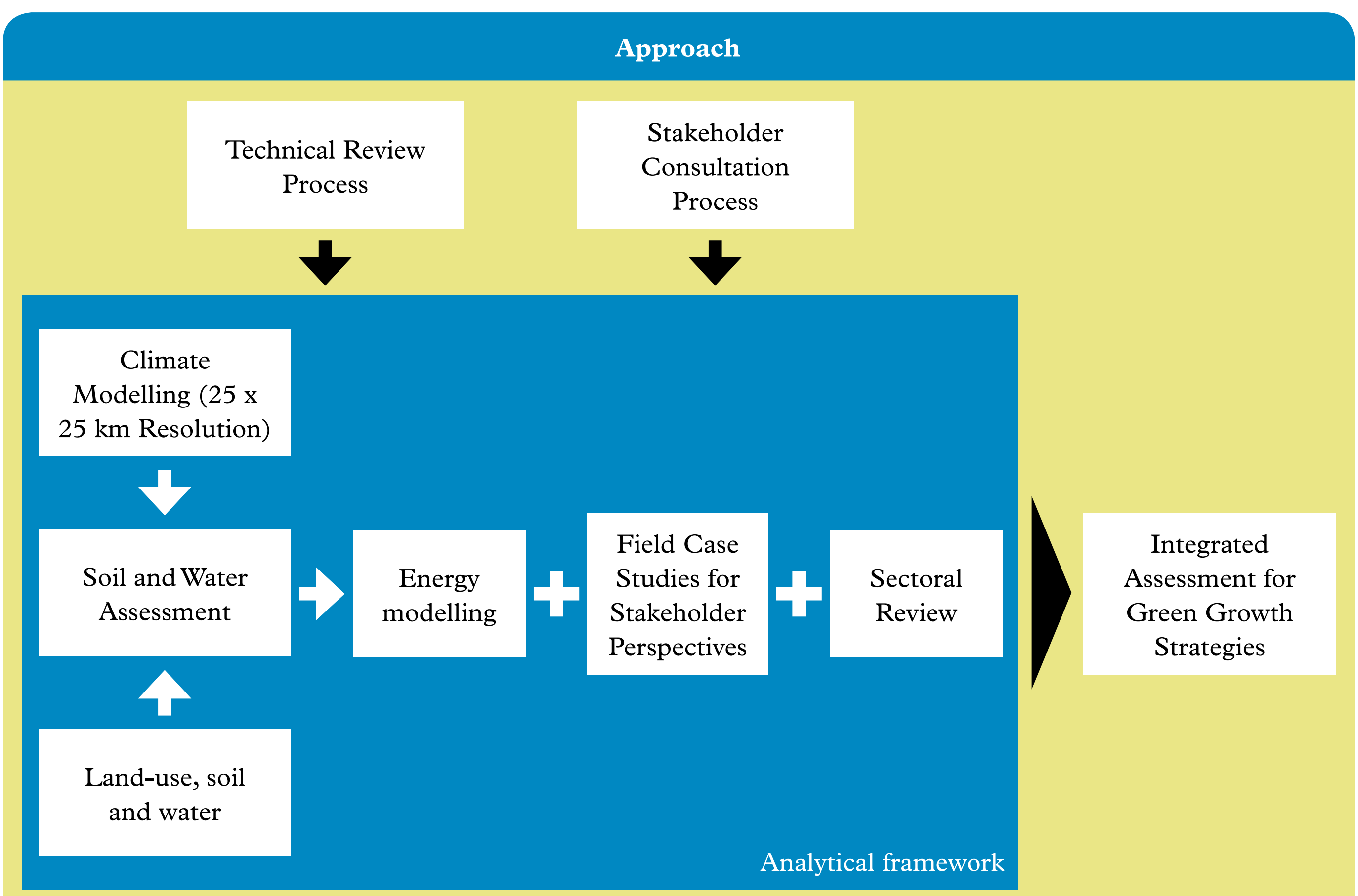

Figure 1.1: Approach for the Initiative

2

Climate Modelling for Punjab

2.1 Introduction

This component of the project involves establishing climatological information of Punjab and assessing near future climate variability over the State.

To establish the climatological information for the State of Punjab, historical trend analysis of the meteorological data and literature review has been carried out. Review on the existing literature on the climatological trends including extremes for various meteorological parameters over the Indian domain and on sub-divisional scale was done as the first step towards understanding the climate of the region.

After the historical data analysis, the model identification was carried out and a high resolution dynamical model was run under A1B scenario, simulating a baseline run from 1970–2000 and for near future time scale of 2020–2040 (2030s) to arrive at future climate variability over the study domain area. Analyses of extreme climate conditions were also performed.

2.2 Observed Climatological Trend over Punjab

2.2.1 Temperature

The state of Punjab shows a significant decreasing trend of -0.01°C/yr on annual mean maximum, mean minimum, and mean temperatures for the 1951–2010 period (Rathore et al., 2013) (Figure 2.1, left). The seasonal mean temperature trends for the same period shows a significantly decreasing trend for winters (-0.02°C/yr) and monsoons (-0.01°C/yr) but no trend for summers and the post-monsoon seasons (Rathore et al., 2013) (Figure 2.1, right).

The city wide analysis drawn over Amritsar shows a decreasing trend for maximum and minimum temperatures for 1949–2000 period with the average maximum temperatures showing a decrease by -1.0°C during the 41 year period (-0.02°C/yr) and the average minimum temperature by -0.4°C for the same period (SAPCC, 2014). A similar analysis for the city of Ludhiana (Kaur et al., 2006) indicates an insignificant decrease in annual mean maximum temperature but an increase in the annual minimum temperature at 0.07°C/yr for the period of 1970–2004 (SAPCC, 2012).

2.2.2 Rainfall

The state of Punjab shows a significant increasing trend for the long term 1871–2008 period but a negative trend for the 1951–2008 time period (MoEF, 2010). The annual average rainfall over the state of Punjab for the period 1951–2010 indicates a decreasing trend (-2.41mm/yr). The seasonal rainfall for winters (0.09mm/yr) and summers (0.22mm/yr) shows an increasing trend for the same time period whereas the monsoon and post-monsoon seasons show a decreasing trend of -1.49mm/yr and -0.13mm/yr (Figure 2.2, left). For the individual monsoon months, the trend for the time period of 1951–2010 shows a significant increasing trend for June at 0.51mm/yr and an increasing trend for September at 0.12mm/yr whereas July and August indicates a decreasing trend of -0.64mm/yr and -0.92mm/yr, respectively (Figure 2.2, right).

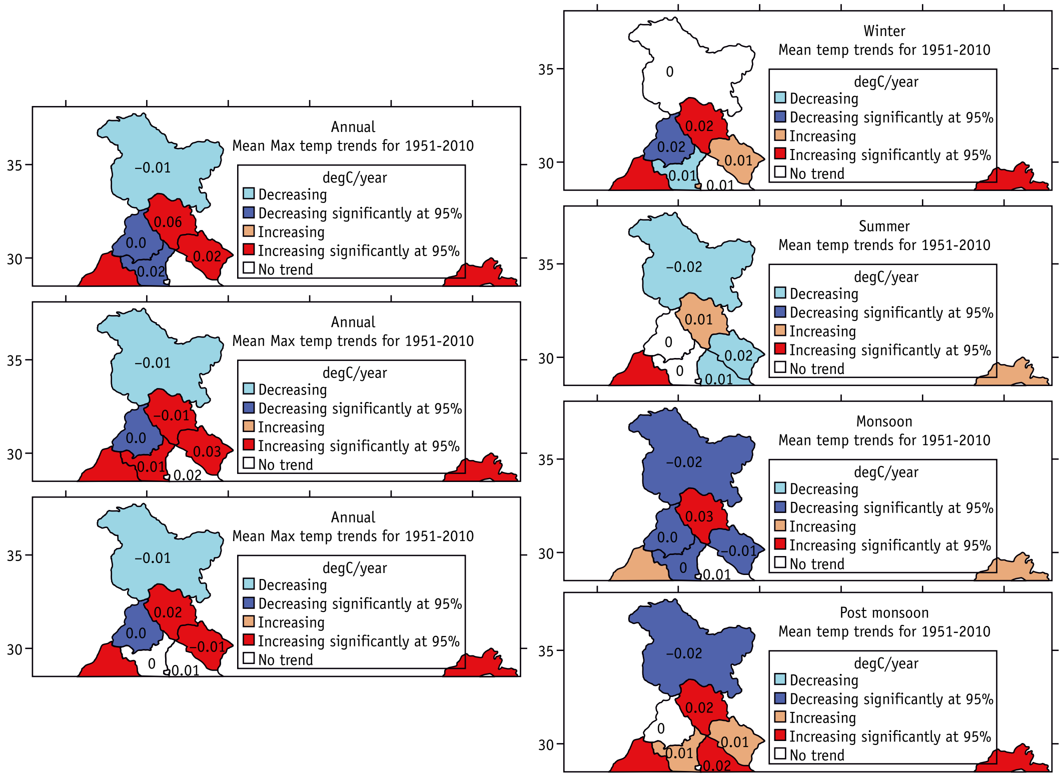

Figure 2.1: Trends in annual maximum, minimum, and mean temperatures (on left) and trends in seasonal mean temperatures (on right) for 1951–2010 period
Source: IMD monograph: ESSO/IMD/EMRC/02/2013

The city wide analysis over Amritsar shows that the annual average rainfall has increased by +150mm for the 1949–2000 period, indicating an increase of +3.7mm/yr. Seasonal rainfall shows an increasing trend for pre-monsoon (+1.7mm/yr), monsoon (+2.4mm/yr), and winter (+0.48mm/yr) seasons whereas a decreasing trend (-0.9mm/yr) for post-monsoon season. The analysis over Ludhiana indicates a significant increase in annual rainfall (+6.6mm/yr) for the 1970–2004 analysis period.

2.2.3 Drought

Punjab is enlisted under the frequent drought (10–20 per cent probability) prone areas as per the Indian Meteorological Department's (IMD) classification of drought incidences from 1875–2004 period (Figure 2.3). A total of 24 droughts[1] have occurred in the state, of which 20 were moderate and 4 have been severe over the 1879–2009 time period with drought probability of 18 per cent and with 5 instances of consecutive droughts over two years (Shewale and Kumar, 2005; Attri and Tyagi, 2010; IMD met monograph 21/2005 and 01/2010).

2.2.4 Cold Waves and Fog

De *et al.* 2005 documented the cold waves[2] for the state of Punjab and it was found that the epochs of 1901–99 have seen occurrences of 60 cold waves of which the 1978–99 epochs have seen 19 incidences. Fog, on the other hand, is not directly

[1] Drought: Meteorological drought over an area is defined as a situation when the monsoon seasonal (June–September) rainfall over the area is less than 75 per cent of its long-term average value. Moderate drought: if the rainfall deficit is 26–50 per cent and Severe drought: when the deficit exceeds 50 per cent of the normal. A year is considered as a 'drought year' when the area affected by moderate and severe drought either individually or together is 20–40 per cent of the total area of the country and seasonal rainfall deficiency during southwest monsoon season for the country as a whole is at least 10 per cent or more.

[2] Cold waves: Occurrences of extreme low temperature in association with incursion of dry cold winds from north into the subcontinent are known as cold waves. The northern parts of India specially the hilly regions and the adjoining plains are influenced by transient disturbances in the mid-latitude Westerlies which often have weak frontal characteristics and are known as Western Disturbances.

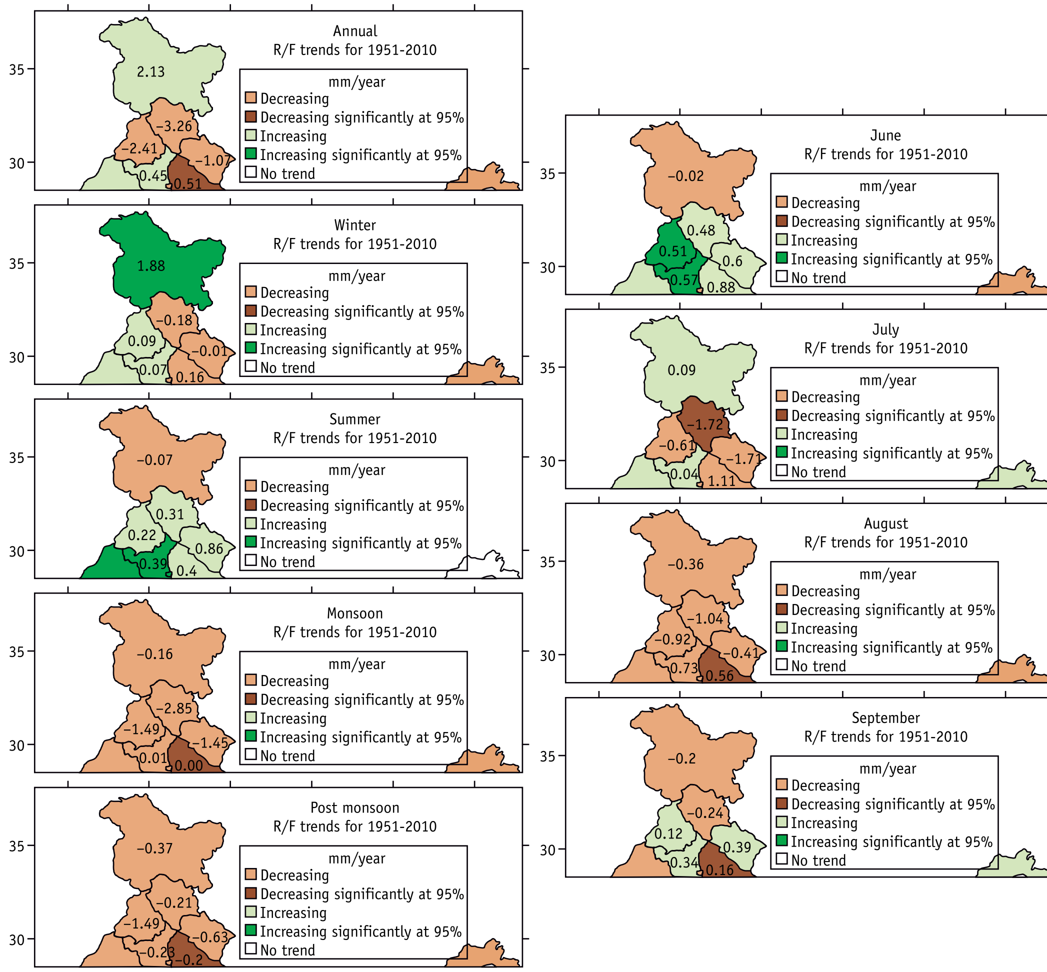

Figure 2.2: Trends in annual and seasonal rainfall (on left) and trends in monthly rainfall (on right) for 1951–2010 period
Source: IMD monograph: ESSO/IMD/EMRC/02/2013

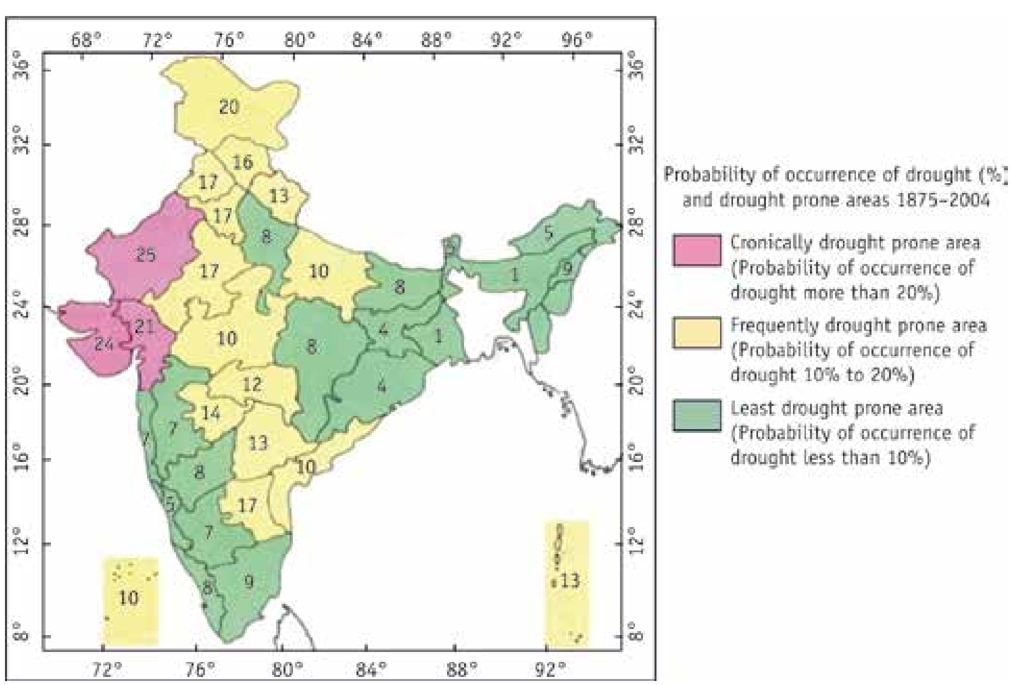

Figure 2.3: Probability of occurrence of drought (%) and drought prone areas 1875–2004
Source: IMD met monograph (2010)

related to the extreme weather events but has an effect in all of transport, especially aviation which indirectly affects the economy of aircraft operations and human inconvenience. The increasing trend in relative humidity and increased presence of aerosols of particulate matter (urbanization and automobiles) are the most likely causes of poor visibility. It has been seen that percentage frequencies of number of days with poor visibility have seen an increase for the city of Amritsar in the recent past (Figure 2.4).

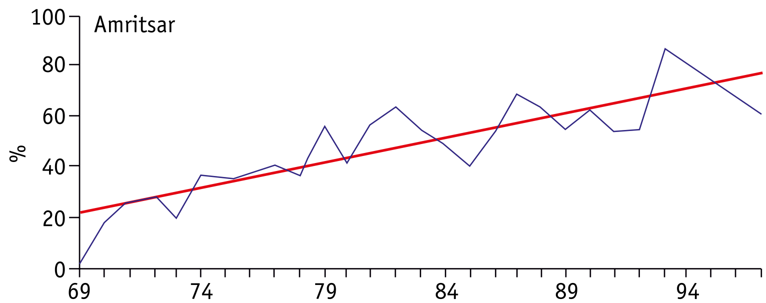

Figure 2.4 : Percentage frequencies of number of days with horizontal visibility < 2000 m at 03 UTC during winter season with significant trends at 99 per cent level
Source: De et al. (2005)

2.3 Approach

2.3.1 Climate Model

Objective: To analyse the future climate over the State, the regional model simulations at 25km × 25km resolution are being carried out. The model used in the study is PRECIS model.

Model setup: The model used in the study is PRECIS—Providing REgional Climates for Impacts Studies. It is developed at the UK Met Office Hadley Centre. PRECIS is an atmospheric and land surface model of limited area and high resolution. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all formulated, while the boundary conditions at the limits of the model's domain are required to be specified. It gives a comprehensive representation of physical processes in the atmosphere and on land in terms of:

1. dynamics - atmospheric circulations, cyclones, fronts
2. radiation - effects of greenhouse gases and aerosols
3. clouds - radiative effects, sulphate aerosol effects
4. precipitation - convection, large-scale condensation
5. land-surface - soil hydrology (4 levels), vegetation

The typical horizontal grid size is 50km which can be lowered as per the user. It has 19 levels in hybrid vertical coordinate (Simmons and Burridge, 1981; Simon *et al.*, 2004) with variable thickness. The sea surface boundary conditions would be taken directly from ocean component of the ECHAM05 model. The model has been tuned to simulate the baseline runs from 1970–2000 and future runs of 2030s (2020–2040) under the A1B SRES[3] scenario. A1B scenario assumed a balance emphasis on all energy sources under the A1 emission scenario characterised by rapid economic growth with quick spread of new and efficient technology. In other words, this scenario assumed a business as usual state in near future and hence has been taken as the optimum climate scenario for simulation. PRECIS is highly relevant for scientists involved in vulnerability and adaptation studies, particularly for national communication documents and has been extensively used throughout the world in numerous regional modelling experiments.

2.3.2 Sources of Uncertainty and Data Gaps

For building a climate profile over a region, studying historical trends and undertaking model validation, the long term

[3] SRES: Special report on emission scenarios, IPCC, 2000: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0 <last accessed on 2 November 2014>

observational data from the station or from an observational gridded dataset is essential. It is a direct relation between the number of station data used and the quality of the dataset. The IMD stations used in the 1951–2010 analysis as shown earlier are 2 for temperature and 20 for rainfall (Figure 2.5). Also, for the gridded dataset, the methodology is restricted over an area with less number of stations and hence, more approximations and interpolations are done to arrive at datasets. All these factors should be noted as the key factors for uncertainty in observational data and resulting model analysis. Figure 2.6 (below) shows the data gaps in the analysis for meteorological droughts.

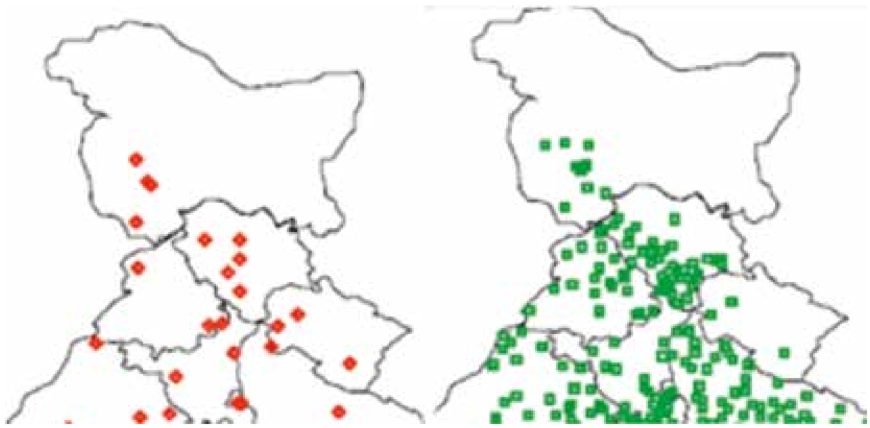

Figure 2.5: Distribution of met stations used for temperature trend analysis (left) and rainfall analysis (right)
Source: IMD meteorological monograph (2013)

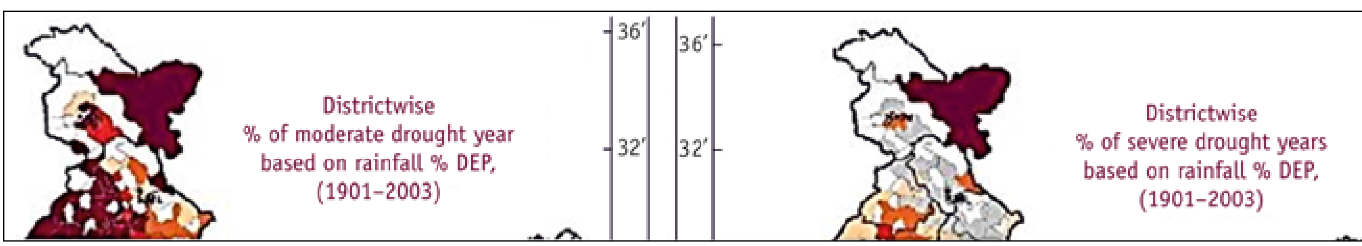

Figure 2.6: The white gaps show that the datasets were not available for the long-term drought intensity and frequency analysis
Source: IMD meteorological monograph (2010)

It may be noted that all the studies involving modelling assessments are probabilistic which provide us the best indicator on how the climate has been evolving in the past and will in the future. The degree of certainty depends on many factors like input data and the boundary forcings used, the parameter being modelled, the type of models used, resolution and domain utilized. Considering the recent studies around the world and scale of the present study area, it is advised to use a multi modal ensemble study and a much higher resolution to arrive at probabilistic climate projections over a district wide scale.

2.4 Trend Analysis

2.4.1 Rainfall

The long period 1901-2013 annual and monsoon accumulated rainfall over Punjab has been trendless. However, the rainfall variability have been very significant (Figure 2.7) in the past as well as in recent years. To analyze long period and the seasonal rainfall trends over the State, latest IMD high resolution gridded rainfall dataset (Pai *et al.*, 2014) have been utilized. The spatial resolution of these datasets is 0.25°x0.25° in the horizontal. The data has been extracted over the state and post-processed for the analysis. Since the dataset has square grids which do not necessarily match with the irregular state boundaries, this may result in some minor mismatch with station data analysis as reported earlier.

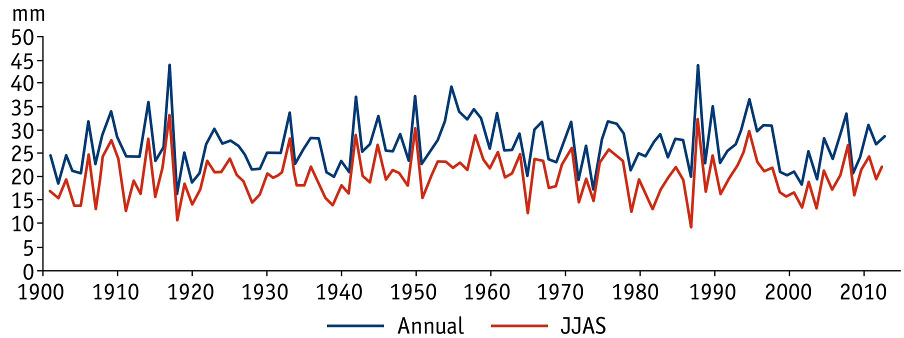

Figure 2.7: Annual and June, July, August, September (JJAS), accumulated rainfall over Punjab for the 1901–2013 period showing year to year variability
Source: TERI Analysis

As can be seen from Figure 2.8 (a,b,c) the seasonal climatologies for winter (December, January & February), pre-monsoon (March, April & May), and post-monsoon (October & November) season show an annual variability in rainfall. No significant trend can be seen in the mean seasonal rainfall in the recent past 30 year of dataset using the gridded rainfall dataset. A similar variability for monsoon season (June, July, August & September) is seen (Figure 2.9a) which shows a slight decreasing trend in rainfall relative to other seasons. As seen from anomalies (Figure 2.9b), the recent years have experienced more negative rainfall signifying poor monsoon than the long term normal.

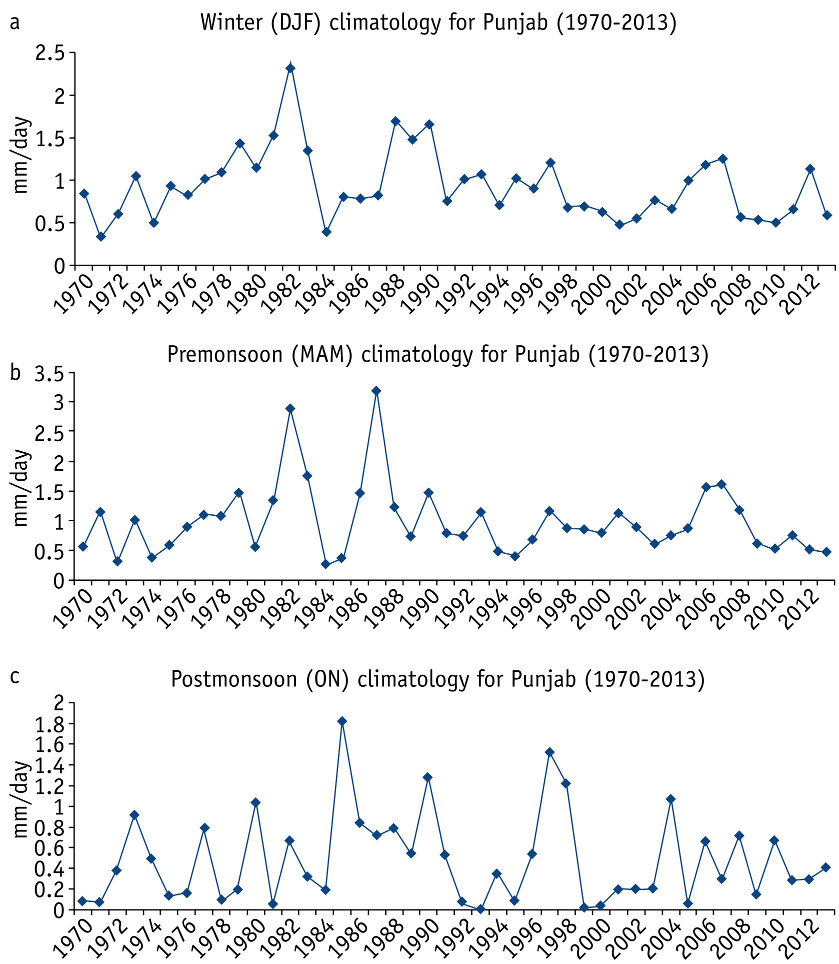

Figure 2.8: Seasonal rainfall climatology over Punjab for the 1970–2013 period for (a) winter (b) pre-monsoon and (c) post monsoon season
Source: TERI Analysis

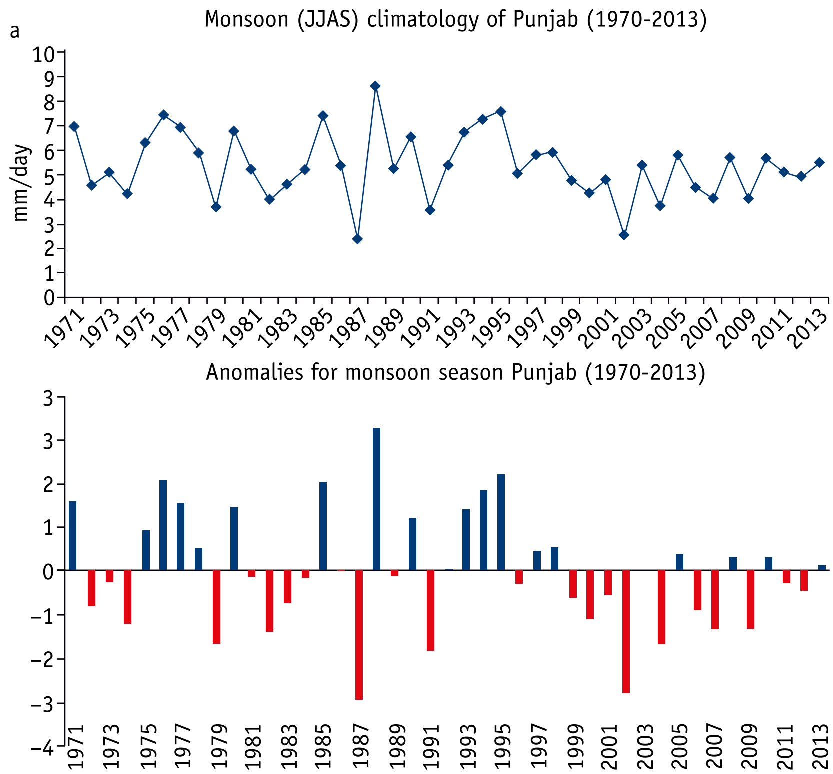

Figure 2.9: June, July, August, and September rainfall (a) climatology and (b) anomaly over Punjab for the 1970–2013 period
Source: TERI Analysis

The decrease of rainfall in the recent 30 years in past can be attributed to decadal to multi-decadal variability in atmospheric parameters, decadal variability in solar-sunspot cycle, and multi-decadal variability to external forcings like North Atlantic Oscillations (NAO), Atlantic multi-decadal oscillations, etc. Changes in rainfall are also affected by synoptic to planetary scale circulations like hurricanes, typhoons in western Pacific which cause shift in core of Somali jet southwards that result in subtropical westerlies in upper atmosphere to penetrate in tropics, resulting in downward currents thereby preventing convection and rains. It should be noted here that the data used in this assessment is a gridded high resolution IMD dataset which may differ from station dataset at few places owing to approximations in interpolation techniques. Spatially, the model simulated baseline shows that the rainfall bands over the state are east-west oriented with an easterly gradient (east having less value). Overall, the model is able to capture the observed rainfall spatially (Figure 2.10).

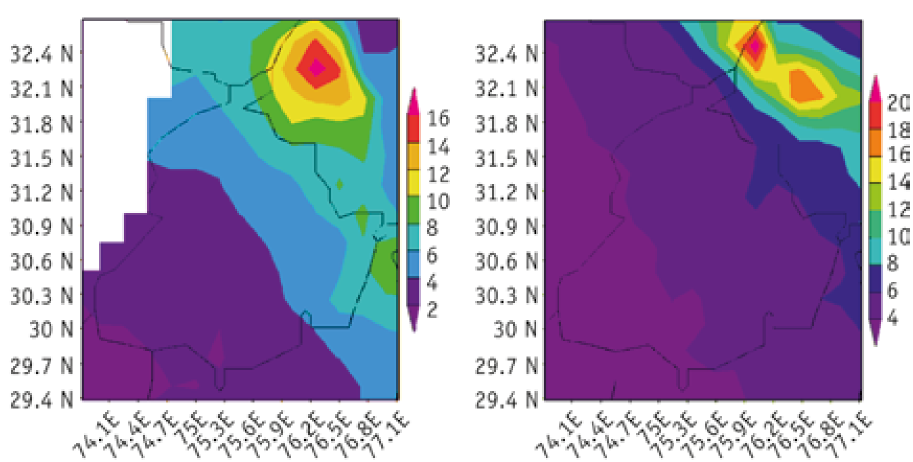

Figure 2.10: Monsoon (JJAS) rainfall climatology from IMD (left) and PRECIS (right) for the baseline period 1970–2000 both showing an eastward gradient
Source: TERI Analysis

2.4.2 Temperature

The annual maximum, minimum, and mean temperatures from the gridded IMD temperature datasets (Srivastava *et al.*, 2008) have been plotted (Figure 2.11) with the model baseline. It is observed that the model is able to capture the east-west temperature gradient but has a comparatively warmer bias over the State.

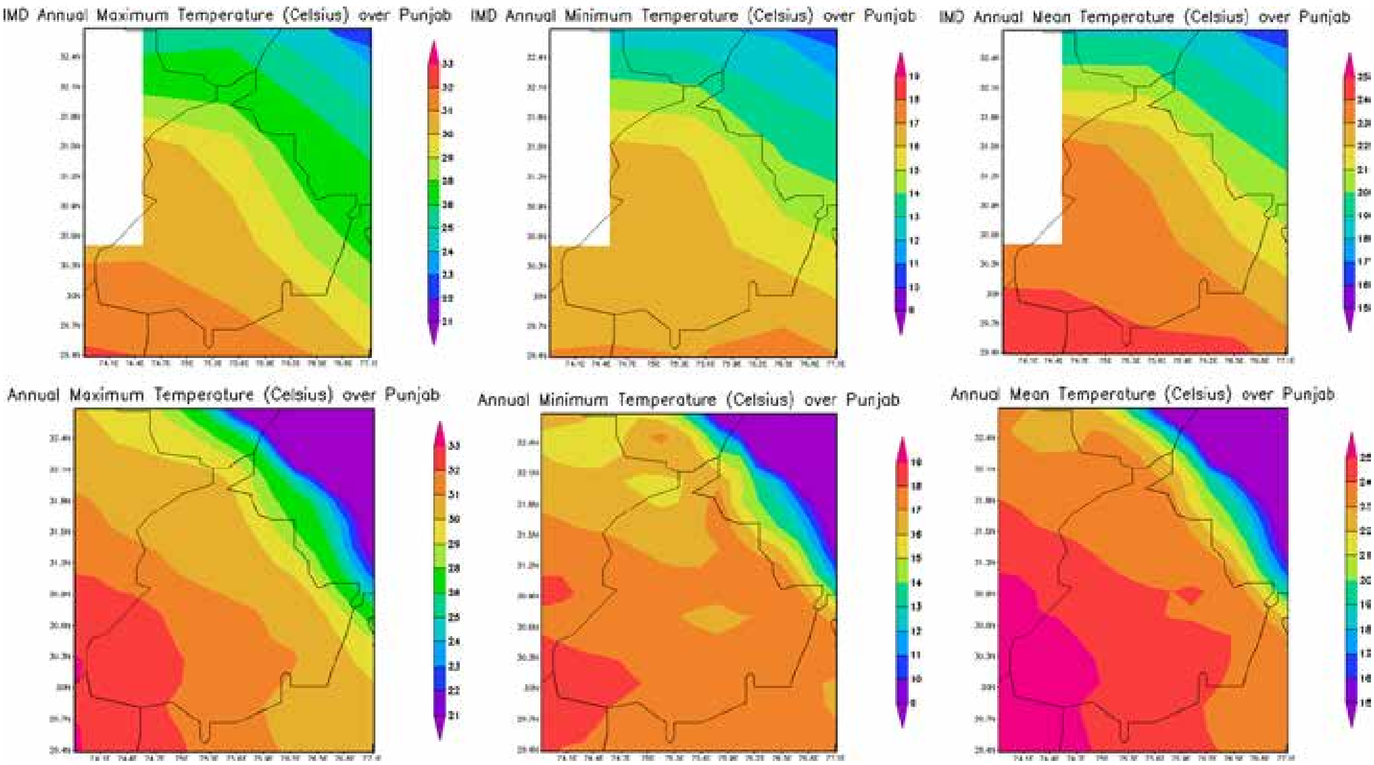

Figure 2.11: Annual maximum, minimum and mean temperatures from IMD (top panel) and model (bottom panel) for 1970-2000 baseline period over Punjab
Source: TERI Analysis

2.5 Climate Projections

2.5.2 Rainfall

The model simulates the spatial pattern of monsoon rainfall over the State considerably well and it closely matches with the observations. The analyses of baseline (1970–2000) and near future (2021–2050) climate simulations over the study area revealed an increase in summer monsoon (June–September) precipitation in the near future, relative to the baseline period (Figure 2.12 a,b,c). The model projections show an increase in the mean annual summer monsoon rainfall over the entire state of Punjab. The percentage change in rainfall is calculated and plotted (lower panel) to show the spatial distribution pattern change in the near future. The **increase** in mean annual summer monsoon rainfall is in the range of **0–20%** of the baseline rainfall. The increase in rainfall for future can be attributed to the increase in moisture availability and favourable conditions as simulated by the model.

2.5.2 Temperature

The model showed overall warming within the study domain area in the near future. Annual mean temperature projected to increase by **1.2–1.4°C** for 2021–2050 period relative to 1971–2000 (Figure 2.13).

2.5.3 Temperature extremes

Mean Annual Maximum temperature (**Tmax**) over the State is projected to increase by **0.5–1.25°C** (Figure 2.14). The Mean

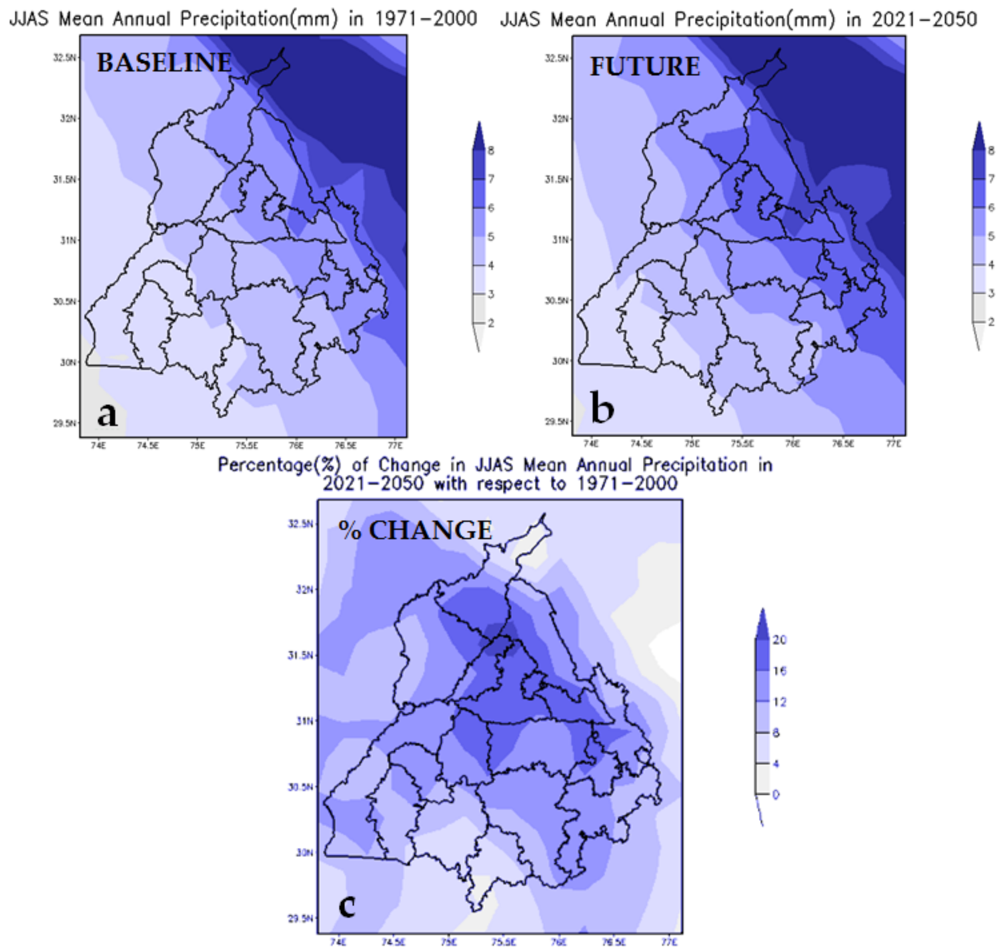

Figure 2.12: Mean annual summer monsoon precipitation for (a) baseline period (1970–2000), (b) near future (2020–2050) and (c) percentage change in near future relative to baseline period

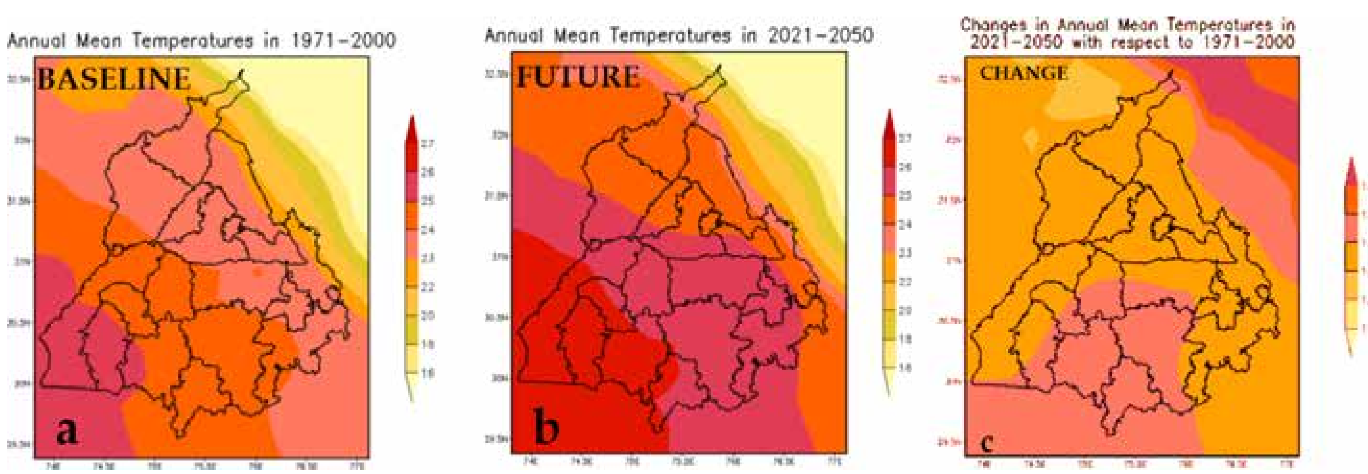

Figure 2.13: Mean annual temperature for (a) baseline period (1070-2000), (b) near future (2020–2050) and (c) absolute change in near future relative to baseline period.

Annual Minimum Temperature (**Tmin**) also is projected to increase over the study domain area in the range of **1.2–1.4°C** (Figure 2.15). Relatively larger changes are projected for minimum temperatures for the future. This corroborates with the historical trends over India, which have seen an increase in Minimum Temperature to contribute more than Maximum Temperature for the increase in Mean Temperature over the baseline period (1970–2000) (see INCCA report, MoEF, 2010).

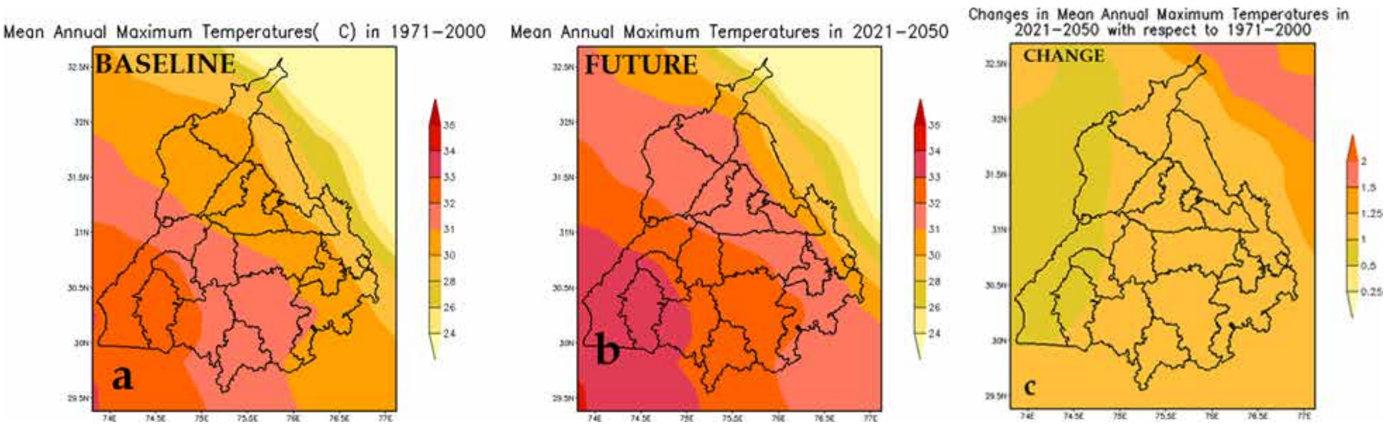

Figure 2.14: Mean annual maximum temperature for (a) baseline period (1970-2000), (b) near future (2020–2050) and (c) absolute change in near future relative to baseline period

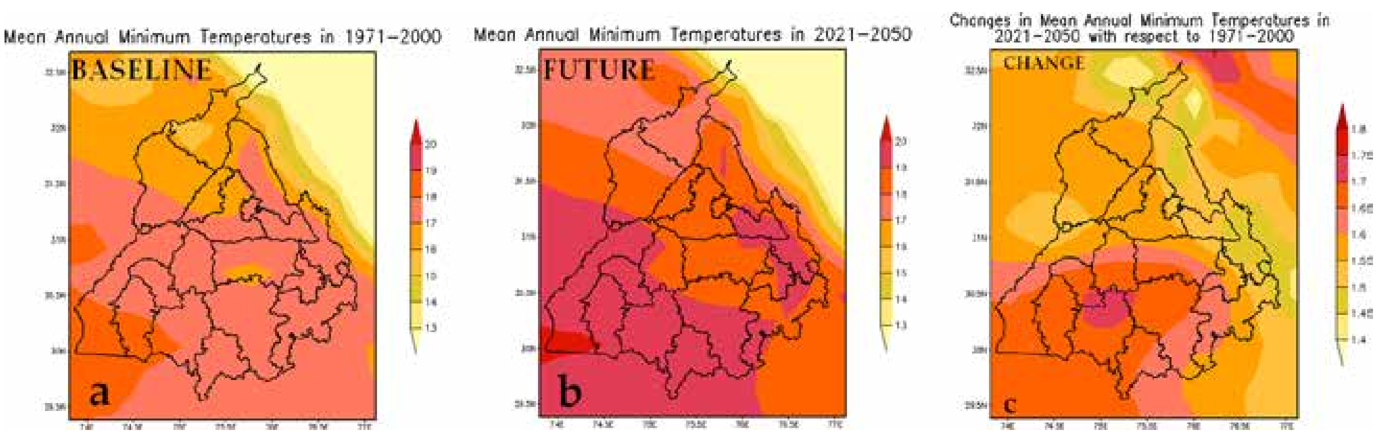

Figure 2.15: Mean annual minimum temperature for (a) baseline period (1970–2000), (b) near future (2020–2050) and (c) absolute change in near future relative to baseline period.

Increase in Minimum Temperature has many impacts not only over plants, crops but over human comfort as well. This also indicates that night time temperatures also will increase in the near future relative to the baseline period.

2.5.4 Rainfall Extremes

Extremely wet days were calculated as those days when the rainfall amounts exceed 99th percentile of the rainfall amounts in baseline period. This analysis provides us information on the contribution of extreme rainy days to the total rainfall in the near future. Figure 2.16 shows the precipitation amount (in percentage) of the total precipitation in future that is due to extremely wet days.

Figure 2.17 shows the percentage of wet days in future where the daily precipitation amount is greater than extremely wet days of the baseline period. Although the trend (indicatively increasing) doesn't seem significant, the 3-point moving average indicates that towards late 2030s and early 2040s, the State will experience higher number of extreme wet days. This implies that in the near future, in the summer monsoon season, there will be more break periods (in precipitation). The temporal distribution of rainfall will be different from that of the baseline period which will have implications on agriculture and transport sectors and other socio-economic activities of the State.

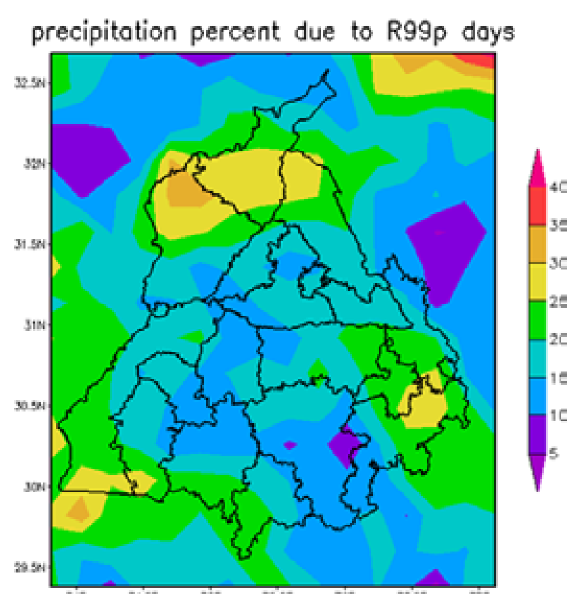

Figure 2.16: Extreme wet days contribution to the total rainfall in near future (2020–2050)

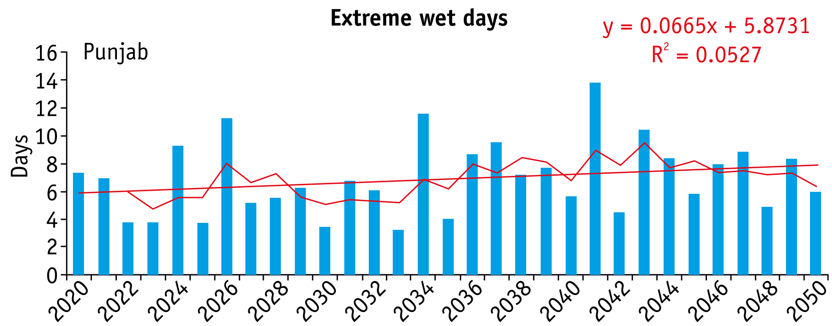

Figure 2.17: Extreme wet days in future relative to extreme rainfall in baseline

Analysis of other major climate variables such as Solar Flux, Relative Humidity, and Wind Speed were also performed (Figure 2.18) which also complemented the inferences drawn from precipitation and temperature analysis. The decrease in solar flux in the near future projections is due to increase in cloudiness (rainfall). Increase in Relative Humidity resulted from increased temperature all over the State. The increased wind speeds could bring more dust aerosols which subsequently causes decrease in solar flux.

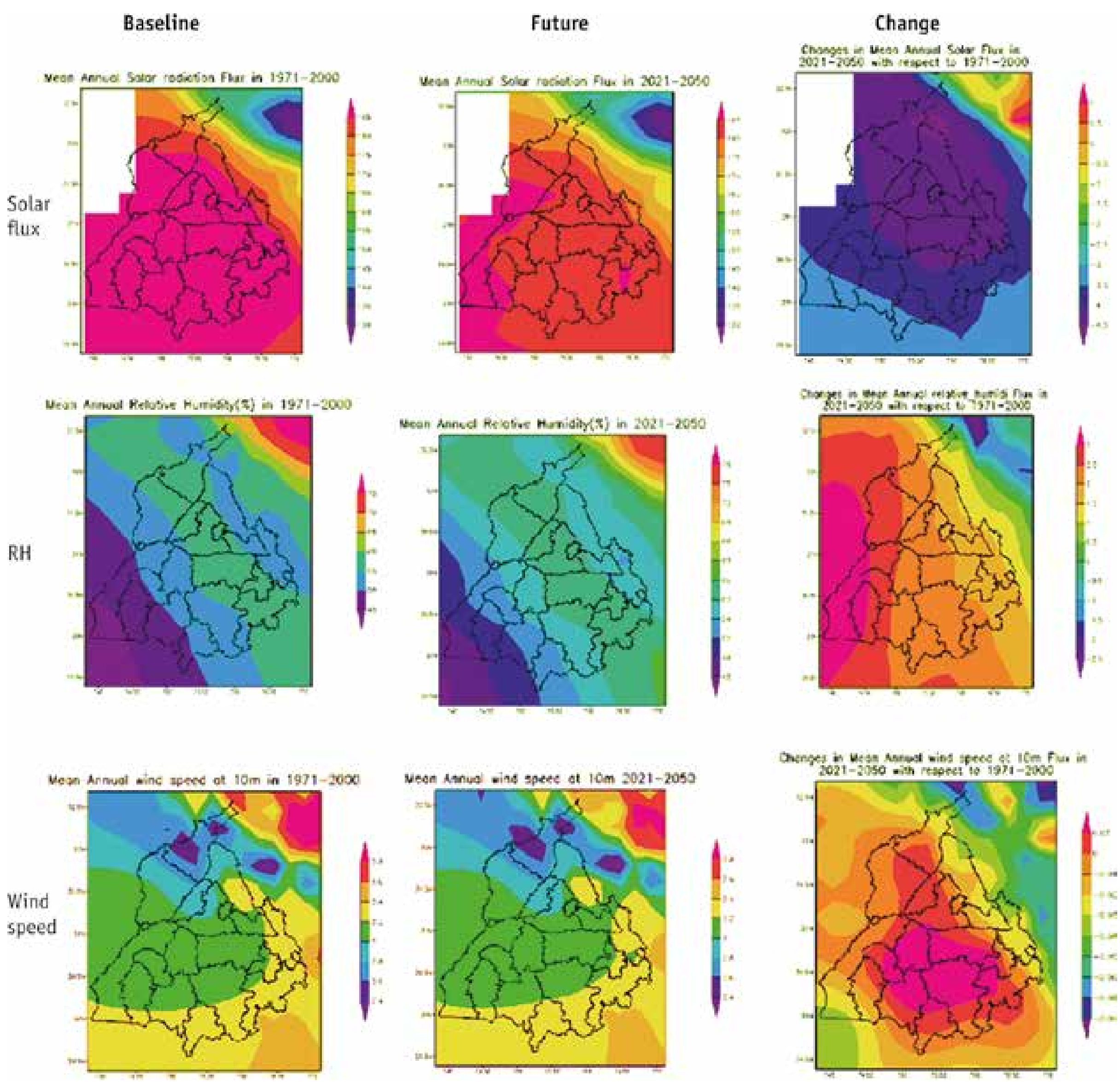

Figure 2.18: Spatial pattern of Solar Flux (top panel), Relative Humidity middle panel) and Wind speed (bottom panel) and the change in near future relative to the baseline period

Fundamental physics, approximated equations and empirical estimates of unresolvable sub-grid scale processes are fused together in climate models. So the models do have computational constraints. Hence, being probabilistic, the ranges in climate projections should be taken as indicative.

The above parameters are also taken as inputs for the Soil and Water Assessment component of the study that looks at the impact of future climate variability on soil and water parameters

2.6 Discussion

The following key points emerge:

- The study revealed an increase in future summer monsoon (June–September) precipitation in the near future (2030s) relative to the baseline period.
- Annual mean temperature projected to increase by 1.2–1.4°C.
- Relatively larger changes projected for minimum temperature (Tmin) which may adversely affect plants, crops, and human comfort.
- There will be more extreme rain events during the summer monsoon season in the near future than the baseline period. The temporal distribution of rainfall will be different.
- Higher levels of relative humidity are expected in the near future.
- The high resolution variables generated by this model can be applied for various types of impact modelling which in turn can inform policy-making.

2.7 References

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3

Soil and Water Assessment Tool for Punjab

3.1 Introduction

The state of Punjab covering an area of 50,362 sq km., is located in north-western India between latitudes 29.30 N to 32.32 N and longitudes 73.55 E to 76.50 E. The state is bordered by Jammu and Kashmir in north, Himachal Pradesh in northeast, Haryana in south, and Pakistan in west. The state is divided into 22 administrative districts—Amritsar, Pathankot, Barnala, Tarn Taran, Sangrur, Fazilka, Faridkot, Ferozepur, Fatehgarh Sahib, Mansa, Moga, Muktsar, Patiala, Jalandhar, Kapurthala, Ludhiana, Bhatinda, SBS Nagar, Hoshiarpur, SAS Nagar, and Rupnagar. These districts are further sub-divided into 138 blocks for administrative convenience.

Punjab can be divided into six major physiographic divisions—Shivalik hills, piedmont plain, alluvial plain, sand dunes, flood plains, and palaeochannels. The region covered by the Shivalik hills accounts for around 2.6 per cent area of the state and covers the districts of Pathankot, SBS Nagar, Hoshiarpur, SAS Nagar, and Rupnagar. Certain parts of the districts mentioned above also comprise the piedmont plains which act as a transitional zone between the Shivalik hills and the alluvial plains. The alluvial plains cover more than 75 per cent of the total geographic area of the state and are divided into three—upper-bari doab, bist doab, and Malwa plain. The sand dunes present as low ridges along the course of rivers and choes have been reduced to cover less than 1 per cent of the area of the state as an outcome of levelling and clearing by the farmers in recent years. The flood plains comprise almost 10 per cent of the total geographic area of the state. While the palaeochannels which are believed to be remnants of the old active channels are formed due to the recurrent changes in courses of rivers. The soils of Punjab can be classified into eight main types—flood plain or bet soils, loamy soils, sandy soils, desert soils, Kandi soils, sodic and saline soils, forest soils, and sierozems.

The state can also be classified into agro-climatic zones based on parameters such as the soil texture, homogeneity, cropping pattern, and rainfall pattern. These zones are sub-mountain undulating zone, undulating plain zone, central plain zone, western plain zone, and western zone. Out of these, central plain zone, western plain zone, and western zone fall under the trans-Gangetic plains region while sub mountain undulating zone and undulating plain zone fall under the western Himalayan region. Climate in Punjab is characterized by extreme hot or cold conditions. The annual temperatures in the state range from 1°C to 46°C, however, can reach 49°C during the summer months and 0°C during the winter months in different parts of the state. The northeast region in the state lying near the Shivalik foothills receives heavy rainfall while, the areas lying to the south and west receive less rainfall and experience higher temperatures.

Even after having just 1.5 per cent geographic area of the country, Punjab contributes 25–30 per cent of rice and 30–45 per cent of wheat to the central crop pool (GoP, 2013). Wheat and rice are the two major crops, which together comprises 85 per cent of the gross value of crop output (Figure 3.1). At present, the percentage of net area irrigated to net area sown in the state is 98.8 per cent (*ibid*). The main source of ground water extraction for irrigational purpose in Punjab is through tube-wells which were registered to be around 13.82 lakh units in 2010, while the total number of other agricultural machinery was registered to be around 17.91 lakhs in the year 2010 (DoA, 2012). The number of livestock and poultry animals has increased from 2.13 crores in 1997 (DADF, 1997) to 2.49 crores in 2012 (DADF, 2012).

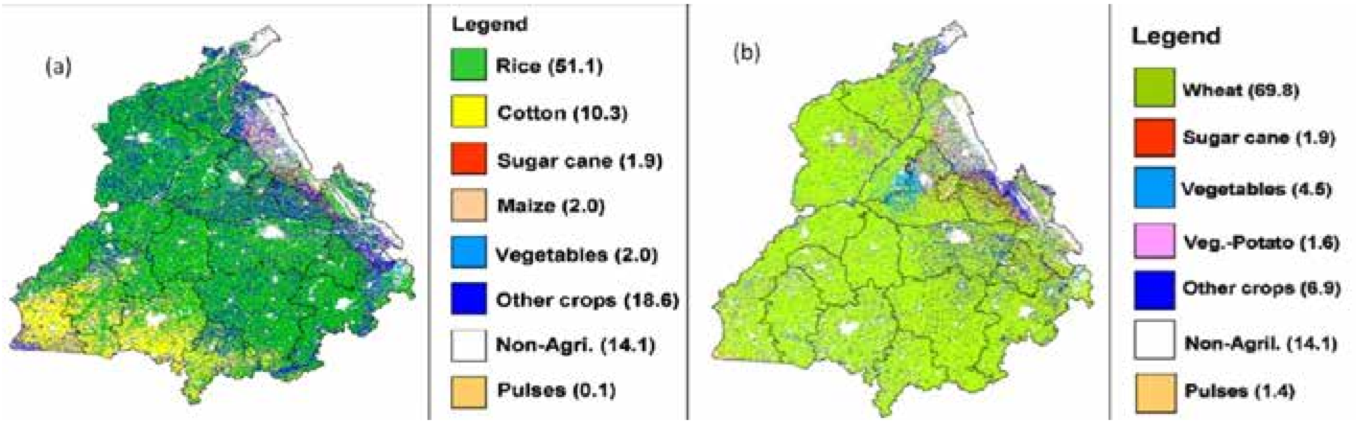
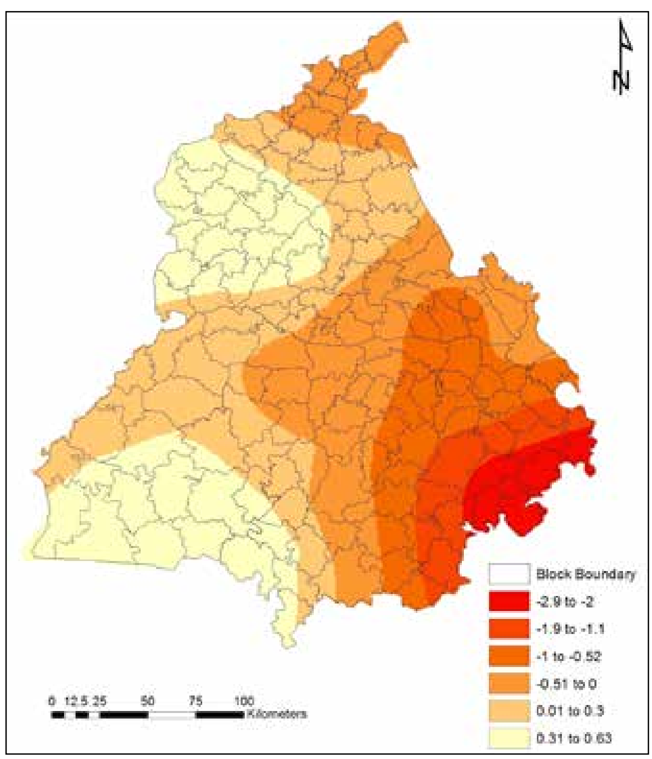


Figure 3.1: Cropping pattern in Punjab (a) Kharif and (b) Rabi. Figures in brackets represent percentage of area under each crop with respect to net sown area
Source: SAPCC (2014)

The rise in industrial water demand has been more than the domestic water requirement till the year 2010. In the future, there could be an increase in the number of industries but due to higher water usage and water use automation in industries, the water demand would more or less be the same. The domestic water requirement on the other hand would also keep on increasing.

The fluctuation in depth to groundwater varies across the districts. The blocks falling in the south-eastern districts show the maximum decline in the water level (Figure 3.2). Districts located in the south-west and those having the problem of water logging have had a slight increase in the groundwater level.



Average Ground Water Depth in Different Years for Punjab				
Year	1990	2000	2010	2014
Depth (mbgl)	6.52	7.02	9.03	15.13

Figure 3.2: Average decadal fluctuations in groundwater levels (2004–14)
Source: Analysis carried out at TERI using CGWB data

3.2 Methodology

The Soil and Water Assessment Tool (SWAT) model is applied to understand the status of water and soil parameters spatially. Outputs of the climate model, in terms of temperature and precipitation parameters is used as SWAT model inputs over two time periods (1970 to 2000 and 2020 to 2035). In addition, spatial inputs are provided to the SWAT model to understand the changes in water resources, and potential implications of climate variability and cropping patterns for Punjab's green growth and development.

The SWAT, a basin-scale distributed hydrologic model, allows basin to be divided into sub-basins, which can further be divided into hydrological response units (HRUs) which are a unique combination of soil and land cover. The SWAT model has its limitations when it comes to explicitly allowing for the inclusion of spatial data as model inputs. To overcome this limitation, ArcSWAT, a public domain graphical user interface programme, has been developed which aims at effective use of spatial data to enhance hydrological modelling. It has been designed such, that it links the hydrologic model SWAT (Soil and Water Assessment Tool) and the GIS package ARC/INFO.

This model has been used in various studies with a wide range of applications. A study conducted at the Mula and Mutha Rivers, Pune, India used the SWAT model to assess the impact of land use change on water resources (Wagner et al., 2013). In another study, the SWAT model was used for assessing the water yield in Dudhi micro watershed in Madhya Pradesh (Gosain et al., 2013). Using the Soil and Water Assessment Tool (SWAT) a 2014 study attempts to estimate the runoff of the Satluj basin by deriving the parameters necessary for runoff modelling with the help of a geospatial database for a period of thirty years from 1980 to 2010 (Panhalkar, 2014). A 2003 study established that the due to existing large areas under the long duration crops, including paddy and maize in conjunction with low forest cover seemed to be the a main cause for the high soil and water losses (Kaur, 2003).

Any increase or decrease in a land use class has an impact on the social and demographic layout of that particular place. This study would facilitate the policy makers in understanding the land use land cover dynamics and formulate policies in accordance with the current scenarios. The ArcSWAT model which simulates the quality and quantity of surface as well as ground water and predicts the environmental impact on land management practices, climate change, land use, etc., would facilitate the policy makers to formulate policies for land management and water management, in particular and resource management and environment management, in general. The study would look at how water management practices affect agricultural productivity.

The model takes inputs from the spatial analysis component as well as the climate model. This exercise will analyse both the past relationships between biophysical and economic factors, as well as forecasts of future trends. This in turn can feed into relevant sector-level models with potential links to the macro-economic modelling as well.

This model will be applied to the study area, i.e. Punjab (Figure 3.3)

- **Model to be used:** ArcSWAT for SWAT 2012
- **Modelling Unit:** River Basin (Watershed) – Sub-basin – HRU (Hydrologic Response Unit) – Administrative Boundary
- **Modelling Process:** Simulation Modelling
- **Climatic Data:** 1980 to 2000 and 2020 to 2030 (Projection)
- **Spatial Data:** 2000, 2010

The flow chart depicting the modelling approach for the ArcSWAT model is shown in Figure 3.4.

Government interventions and policies link different land-use to technology and management options for enhancing socio-economic conditions, livelihood, and ultimately, the standard of life. Hence to evaluate, reflect, and recommend on such policies; multifaceted, multidisciplinary, and compatible group of models gives added edge by facilitating decision making. ARCSWAT is one of the most useful tools. It has different modules like land use, surface and ground water, tree and crop growth module, and particle movement analysis. These tools can also be used with the following different combinations:

- Climate scenarios like climate projections using temperature rise or extreme events;
- Agriculture with different cropping patterns like using less water-intensive crops, growing vegetable crops, agricultural-horticulture mix;

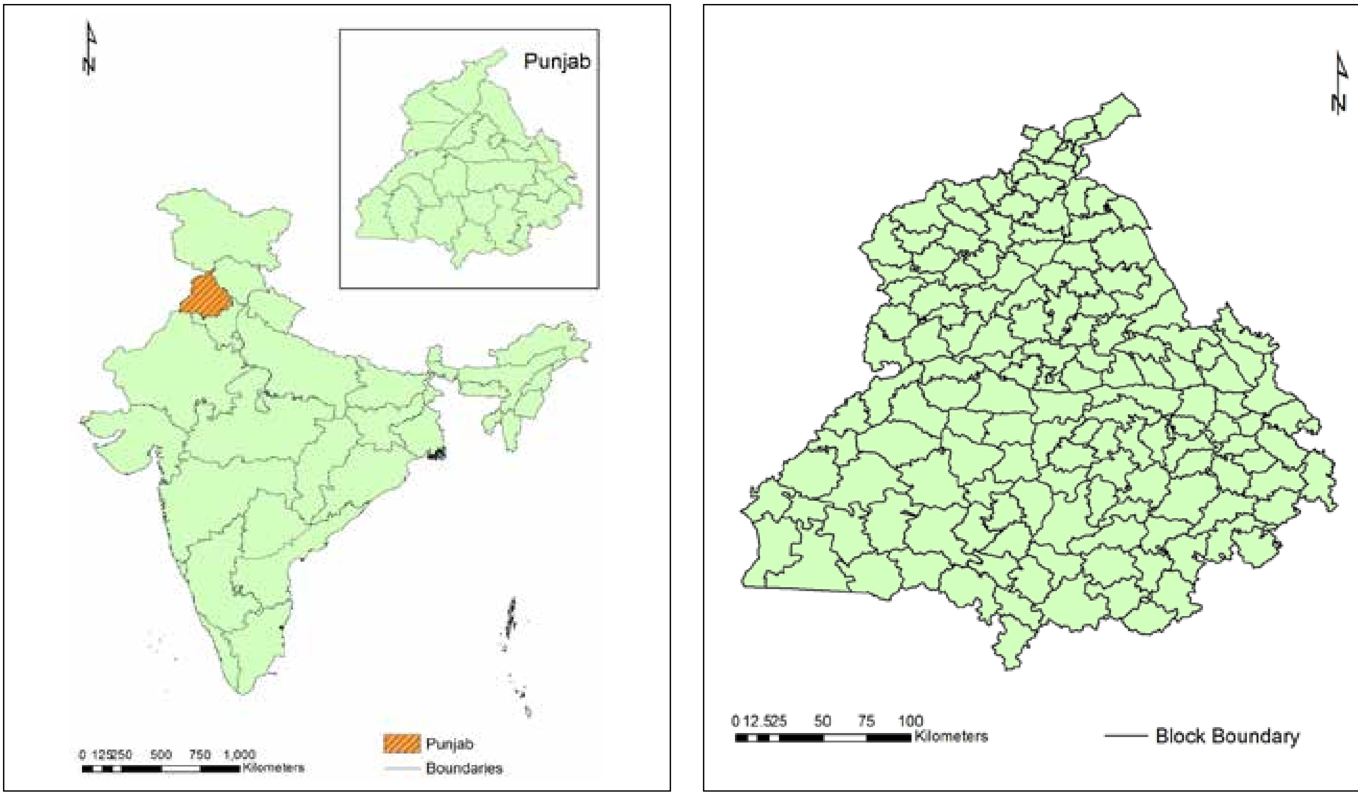


Figure 3.3: Administrative Divisions: Punjab, India

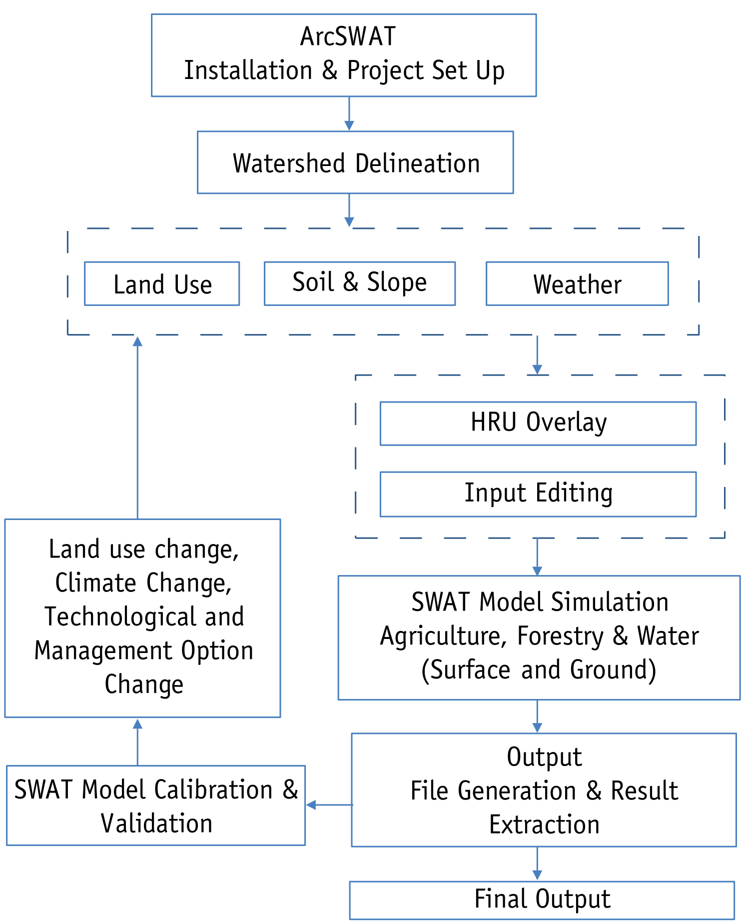


Figure 3.4: Modelling approach

- Change in technology—use of drips and sprinklers, laser land levellers, system of rice intensification;
- Change in input levels—less pesticide spraying, less fertilizer use, deficit irrigation technique;
- Regulatory and policy measures—area under forestry growth targets, area under particular crop like rice or sugarcane targets;
- Sensitivity (Shock) analysis—decrease in groundwater level and impact on water pollution, use of fertilizer on nitrogen leaching to groundwater;
- Change in management options—agriculture-livestock combination, special procurement prices, and facilities like grape purchase.

Each of these options can be applied to ARCSWAT model individually or in combination of other options to study quantifiable results of natural resources like different land use area, water quantities, pollution incidence, agriculture and forestry production, economic benefits, and environmental benefits in terms of quantities conserved. Details of the model are discussed in Annexure 3.1.

3.2.1 Data Used

A record of monthly and yearly flow data from Punjab state departments was obtained. Few locations also had daily stream flow data. The daily climatic parameters which include precipitation, temperature (min, max), relative humidity (min, max), wind speed and sun shine hours were acquired from the Indian Meteorological Department (IMD). Details of all major existing water resource infrastructures were obtained from Water Resource Information System (WRIS), India, and state government toposheets. Existing standard irrigation and the management practices were taken from a packages of practices in Kharif and Rabi season published by the state departments. Actual area, production and yield of major crops, vegetables and fruits were obtained from Ministry of Agriculture and Co-operation website and 'Statistics at a Glance – Various Issues'. Stream flow data of eleven locations (Karcham Wangtoo, Nathpa Jhakri, Rampur, Beas and Parbati in Himachal Pradesh and Ranjit Sagar, Madhopur Headwork, Pong Dam, Bhakra and Nangal Dam, Ropar Headwork and Harike Barrage in Punjab) was used for validation.

We started evaluation with validation of weather parameters. Data collected from National Data Centre, Indian Meteorological Department, for Shimla, Sundernagar, Bhuntar, Manali, and Nahan in Himachal Pradesh; and Amritsar and Patiala in Punjab, has been used for cross checking of predicted weather parameters. Then we used RECESS programme for calculating baseflow recession constant (α_{BF}) and this constant was then used for SWAT model. Thereafter SWAT model input-output was used for calibration and validation using stream flow data. This validated model predicted baseflow was then used for cross-checking with RECESS predicted baseflow. Then at the final stage, all existing management practices were simulated to match actual observed yield. Data used in the model is listed in Annexure 3.2.

3.2.2 Inputs for Model

The model takes in spatial as well as non-spatial datasets. Figure 3.5 shows the soil map of Punjab utilized in the study. Figure 3.6 shows the sub-basins in the state of Punjab. Table 3.1 shows a two key inputs utilized in the model.

3.2.3 Integration

Weather inputs for base period (1970–2000) and projected period (2020–35) were incorporated from the PRECIS model. Average, maximum, minimum and range of velocity of water flow for base period and projected period were given for 'hydrology-energy-economy' analysis. The outputs of the SWAT model were also given as inputs to the techno-economic model so as to examine the impacts of biophysical variability on hydropower generation.

3.2.4 Policy Relevance of SWAT model for State Development

Over the years Punjab has seen a rapid increase in the production of wheat and rice, especially after the Green Revolution. This has come with a cost to the environment in the state such as groundwater depletion, groundwater contamination, and

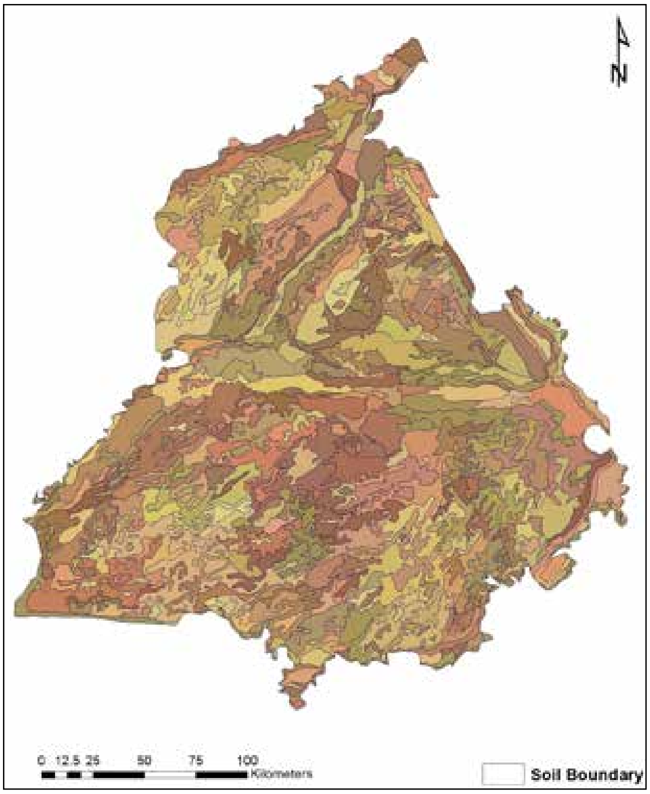


Figure 3.5: Soil types of Punjab

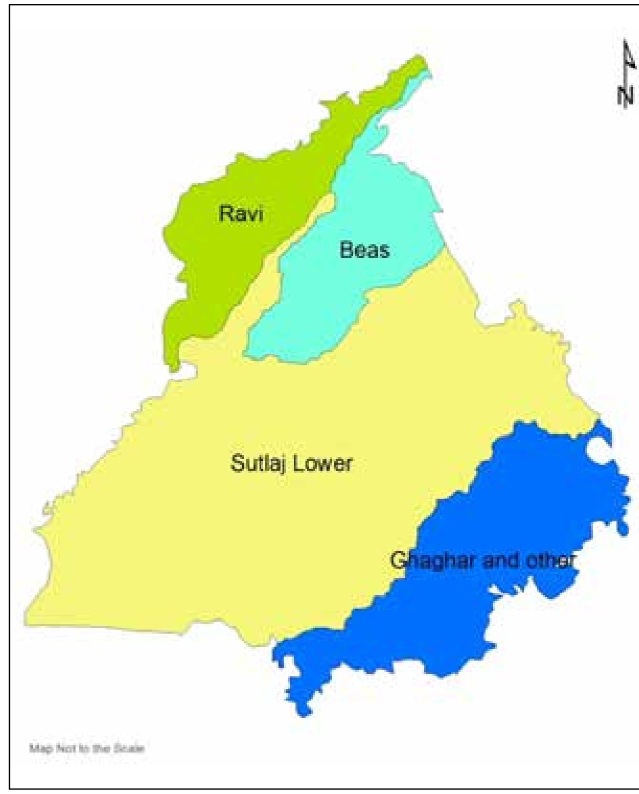


Figure 3.6: Sub-basins of Punjab

Table 3.1: ArcSWAT Input Files

File Extension	File Name	File Extension	File Name
	Watershed Level Files		**Sub-basin Level Files**
.cio	Master watershed file	.sub	Subbasin input file
.fig	Watershed configuration file	.wgn	Weather generator input file
.bsn	Basin input file	.pnd	Pond/wetland input file
.pcp	Precipitation input file	.wus	Water use input file
.tmp	Temperature input file	.rte	Main channel input file
.slr	Solar radiation input files		**HRU Level Files**
.wnd	Wind speed input file	.hru	HRU input file
.hmd	Relative humidity input file	.mgt	Management input file
.pet	Potential evapotranspiration input file	.sol	Soil input file
.cst	Weather forecast input file	.chm	Soil chemical input file
.cal	Auto-calibration input file	.gw	Groundwater input file
crop.dat	Land cover/plant growth database file		**Output Files**
till.dat	Tillage database file	input.std	Summary input file
pest.dat	Pesticide database file	output.std	Summary output file
fert.dat	Fertilizer database file	output.hru	HRU output file
urban.dat	Urban database file	output.sub	Subbasin output file
		output.rch	Reach output file

soil degradation. There is an urgent need for crop diversification and water conservation strategies to be implemented at priority level. Increasingly, natural resource management is gaining policy relevance in Punjab with the government stating clear intent on crop diversification, water conservation, and increasing tree and forest cover. Moreover, as stated in the Punjab State Action Plan on Climate Change, the state is showing clear policy intent for the need to factor climate change in sectoral policies.

SWAT model has been used for soil and water parameters for the base period (1970 to 2000) and for future period (2020 to 2035). The model results help in understanding the impact of climatic variability on the different aspects of land and water.

To assess the impact of different land use and management conditions on natural resources, the model was run with the different cropping patterns. The model has been calibrated and validated to simulate regional management conditions, following which the model has been run for reference, policy and ambitious scenarios.

3.2.5 Scenario Building and Stakeholder Consultation

Based on the trends observed in Punjab since the pre-Green Revolution era, three scenarios were proposed. In consultation with the Department of Agriculture, Punjab; Department of Horticulture, Punjab; Department of Forests and Wildlife Preservation, Punjab; Department of Soil and Water Conservation, Punjab; Department of Water Supply & Sanitation, Punjab; and the Punjab State Council for Science and Technology, the three scenarios developed are reference, policy, and ambitious. These scenarios are based on the changes in the cropping pattern in the near future. In the reference scenario, the current cropping pattern would continue to exist with the increase in rice cultivation. The policy is based on the assumption that in the future, rice cultivation can be brought down to almost half, which the government aims. The ambitious scenario is based on the assumption that a significant shift in the structural economy patterns of the state will lead to major changes in the cropping pattern, bringing down the area under rice cultivation to 2.8 lakh hectares. Table 3.2 describes the three scenarios and their assumptions.

Table 3.2: Assumptions under different Scenarios

	Assumptions
Reference	• The present cropping pattern trends will continue without any significant fluctuations. • The net sown area would reach an optimal stage and will be unwavering at 41 lakh ha. • The area under rice crop will reach a maximum 29 lakh ha by 2030–31 and stay at that level thereafter. • Area under maize will fall to 0.87 lakh ha. • Cash crops like cotton, sugarcane, and oilseeds which have been demonstrating a declining trend till now will continue to diminish. • Fodder crops also show a decreasing trend. • Current trends of area under vegetables will not change, having the same rate of increase and display a steady growth. • Pulses will show a stagnant trend with area under pulses being stable at 0.22 lakh ha. • With the growing need to increase the forest and tree cover in the state, more importance will be given to agro-forestry and horticulture. This rising importance will lead to an increase in the area under agro-forestry and fruit crops.
Policy	• A significant sectoral shift will lead to major changes in the cropping pattern. • The net sown area would reach an optimal stage and will be unwavering at 41 lakh ha. • The area under rice would be reduced to almost half by 2030–31 to about 15.5 lakh ha. • Area under maize will start increasing, owing to the diversifying cropping patterns and will reach 4.3 lakh ha. • Cash crops including cotton, sugarcane, and oilseeds will show an increasing trend. • Fodder crops will reflect an increase in area. • The area under vegetables will increase almost 3 times. • Pulses will have an increase of almost 7 times and will have around 2.9 lakh ha area. • Given that crop diversification is being promoted and emphasis is being given to agroforestry and horticulture crops, a sharp increase in area under agroforestry and fruit crops will be observed.

	Assumptions
Ambitious	• A significant shift in the sectoral pattern of the state will lead to major changes in the cropping pattern. • The net sown area would reach an optimal stage and will be unwavering at 41 lakh ha. • The area under rice will be considerably reduced to only 2.8 lakh ha. • Maize depicts a 10 times increase in the area. This increase in the area can be attributed to the crop diversification programme being promoted in the state. • Cash crops including cotton, sugarcane, and oilseeds will show a growing trend, with all of them having more than 3 times increase in their respective areas. • Fodder crops will show a 3 times increase in area. • The area under vegetables will increase almost 6 times to about 4.5 lakh ha. • Area under pulses will display a huge jump and increase about 14 times. • Area under agroforestry will increase more than 5 times to 3.7 lakh ha while area under fruit crops will increase more than 3 times to 2.5 lakh ha. • Overall, majority of crops show an increasing trend, with an exception being rice which has come down substantially.

3.3 Results and Discussion

This study, with the help of the ArcSWAT model measures the impact of climate change on the water availability in various sub-basins within the main Indus basin. The state of Punjab is mainly drained by the sub-basins formed by parts of Satluj, Ravi, Beas, Ghaggar, and other rivers. The model takes into consideration parameters like drainage network, land use cover pattern, soils, elevation, and climatic parameters for modelling water balance. The climate data used in ArcSWAT has been provided as an input from the PRECIS model. The simulations done using the ArcSWAT model have been performed for three future scenarios—reference, policy and ambitious—for the time horizon of 2020–35.

The model validation was done at various locations for which the stream flow data were accessible. For the entire validation process the details of all the major existing water resource infrastructure were obtained from the Water Resource Information System (WRIS), India and state government toposheets. The climatic parameters including precipitation, temperature (min, max, mean), relative humidity, wind speed, and solar flux were acquired from the Indian Meteorological Department (IMD). Incorporation of the existing irrigation levels and the current management practices has been done for modelling.

3.3.1 Water Balance in Different Sub-basins in Punjab

The **Beas** sub-basin partially covering the state of Punjab is projected to show an increase in the water yield from 377 mm to 476 mm by the year 2035. This increase in the water yield can be attributed to the increased precipitation projections of about 19 per cent. The surface water quantity and ground water quantity show an increasing trend with percentage changes of 44 per cent and 16 per cent, respectively. The evapotranspiration increases by 8 per cent (Figure 3.7).

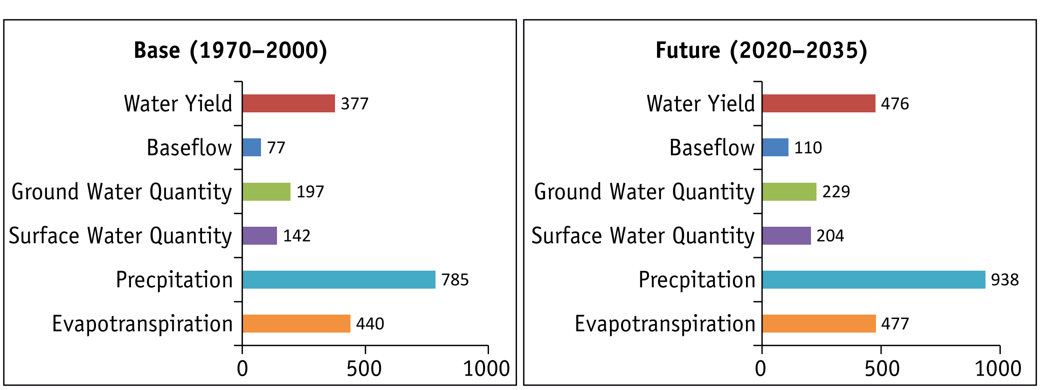


Figure 3.7: Water Balance Components (WBC) of Beas sub-basin

The **Ravi** sub-basin covering north-western Punjab is projected to experience an increase in the water yield to about 432 mm. Needless to say, a 23 per cent increase in the precipitation could be credited to the increased water yield in the 2020–35 time period. There is also an increase of 58 per cent and 22 per cent in the surface water quantity and ground water quantity, respectively. The evaporative losses show an 8 per cent increase (Figure 3.8).

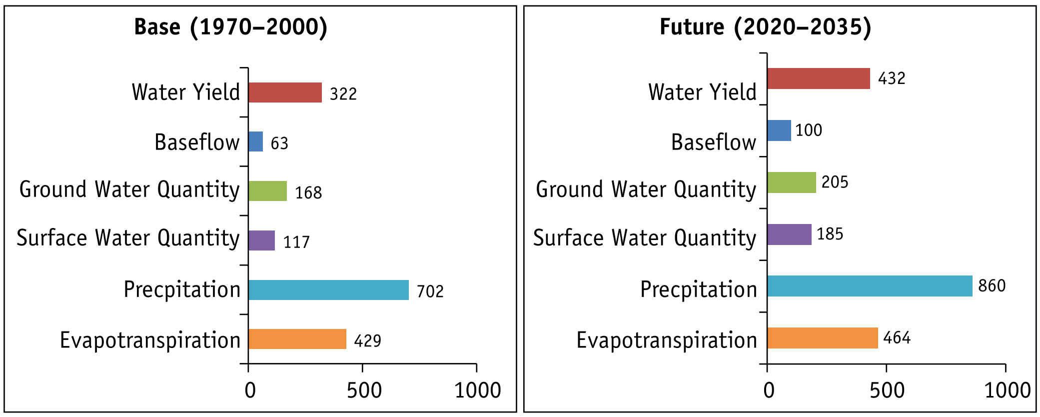


Figure 3.8: Water Balance Components (WBC) of Ravi sub-basin

The **Sutlej lower** sub-basin is projected to have an increased water yield by 2020–35 time period. This increase would be around 253 mm that is more than double of the water yield for the time period of 1970–2000. One of the factors behind an increased water yield could be the increase in precipitation, which is projected to rise to about 624 mm. The sub-basin will also experience an increase in the surface water quantity and the ground water quantity from 80 mm and 71 mm to about 130 mm and 111 mm, respectively. An increase in the surface and ground water quantities could be attributed to the changes in landuse/landcover patterns and increased precipitation. The evaporative losses would remain more or less the same with a minor increase from 447 mm to 475 mm (Figure 3.9).

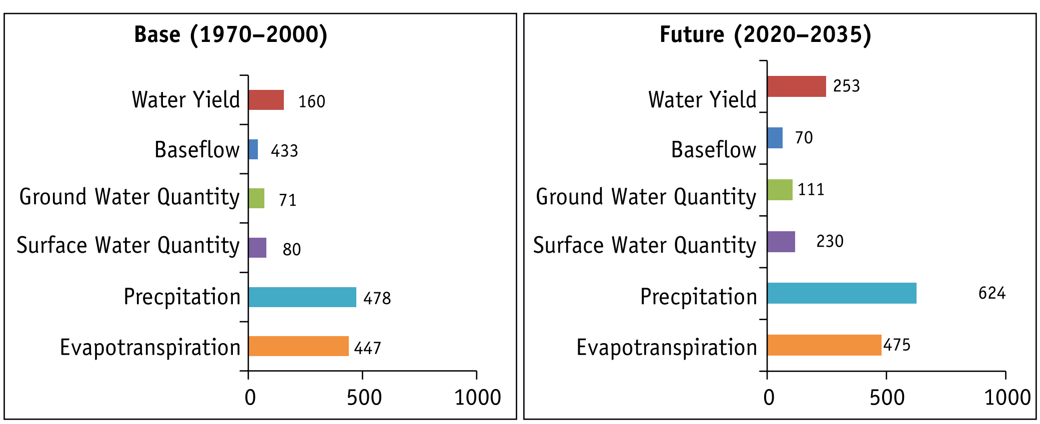


Figure 3.9: Water Balance Components (WBC) of Sutlej- Lower sub-basin in mm

The **Ghaggar** basin, including other minor sub-basins experiences an increase from 197 mm to 280 mm in the water yield by the time period 2020–35. The increase noted in the precipitation in the same time period is about 24 per cent. The surface water quantity and ground water quantity exhibit a somewhat similar increasing trend with percentage change of 45 per cent and 40 per cent, respectively. The evapotranspiration shows a minor increase of 6 per cent by 2020–35 (Figure 3.10).

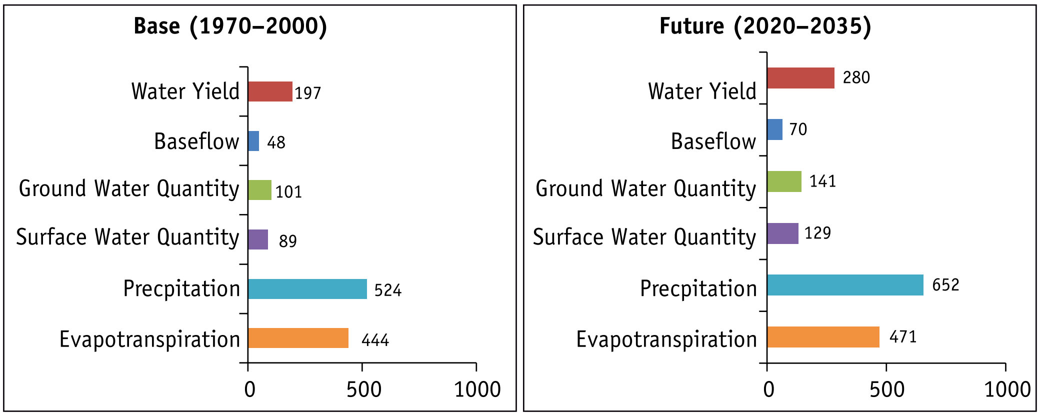
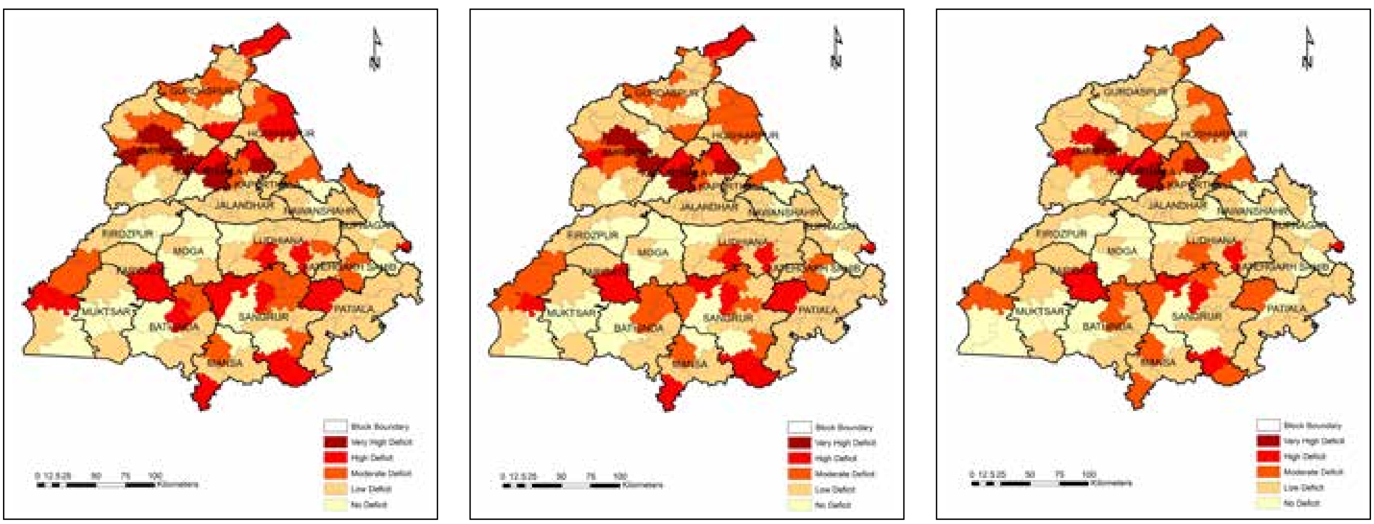


Figure 3.10: Water Balance Components (WBC) of Ghaggar and other sub-basin

3.3.2 Water Availability for Irrigation



(A) (B) (C)

Figure 3.11: Water Availability for Irrigation according to Different Scenarios

Agriculture production in the state of Punjab has immense importance for national food security and livelihood of farmers in the state. Agriculture in the state is very intensive and the gross cropped area during the 1980s which was around 6,763 thousand hectares, increased to 7,870 thousand hectares by 2012–13 (GoP, 2013). The agricultural growth of the state which is largely driven by the performance of wheat and rice production, is directly linked to the irrigation water availability. At present, the net irrigated area is 98.9 per cent of the net sown area in the state (GoP, 2013). Groundwater as well as surface water resources is being utilized to the fullest in the state and hence, it is very important to evaluate water availability for irrigation in the future.

Thoroughly calibrated and validated, the ArcSWAT model was applied to find out groundwater, surface water availability, and irrigation water demand according to scenarios described earlier (Section 3.6). Based on this, a block-wise analysis of total water availability (surface water and groundwater) and total water demand (domestic, industrial, and irrigation) was carried out to find out water availability status. Figure 3.11 shows the results of the analysis for reference future, policy, and ambitious scenarios, respectively. It is found out that out of total blocks of Punjab, about 85.5 per cent blocks are showing deficit compared to 14.5 per cent blocks showing no deficit in reference future scenario. Out of 85.5 per cent deficit blocks in this scenario, 40.4 per cent blocks showed moderate to very high deficit and 45.2 per cent blocks showed low deficit. As compared to reference future scenario, policy scenario brings about 66.3 per cent blocks to no deficit to low deficit category and still there will be 33.7 per cent blocks in moderate to very high deficit category. This scenario brings down many blocks from higher deficit to lower deficit. Likewise, in the ambitious scenario, 71.1 per cent blocks will be no deficit to low deficit blocks and 28.9 per cent blocks will be in the moderate to very high water deficit blocks category. This scenario brings major desired changes of bringing water deficit to the lowest level. Mainly, it brings down high deficit block number (30 blocks) of reference scenario to 13 blocks in ambitious scenario, as well as it also increases low deficit block numbers from 75 blocks in reference future scenario to 85 blocks in ambitious scenario.

It is also found that in future (2020–35), the total annual net water availability will be 4.074 million hectare (Mha) comprised of 1.9 Mha surface water and 2.084 Mha ground water. As compared to this, irrigation water demand would be 5.39, 5.11, and 4.52 Mha in reference, policy, and ambitious scenarios. Rice is the major crop responsible for huge irrigation water demand as well as groundwater depletion. The State is planning to bring area under rice crop cultivation to 16 lakh ha by 2020 (MoA, 2013). Considering this policy directive as well as the scenario of continuing observed trends and ambitious targets of bringing rice cultivation area to pre-Green Revolution level, the policy scenario was formulated as described in the previous section.

3.3.3 Impact of Cropping Pattern Change on Kharif Season Irrigation Water Requirement

Figure 3.12 gives Kharif season irrigation water requirement differentiated by total demand, rice crop demand, and non-rice crop demand under three different scenarios. According to Figure 3.12, rice crop water requirement is declining from 27.4 BCM (Reference) to 14.5 BCM (Policy), to 2.6 BCM (Ambitious). By moving from reference scenario to policy scenario, 12.89 BCM water can be saved and by moving to ambitious scenario, 24.78 BCM can be saved. We have considered many crops including water-intensive crops like cotton and sugarcane as replacement crops for rice. Non-rice crop water demand is increasing from 3.5 BCM (Reference) to 11.5 BCM (Policy), to 19.5 BCM (Ambitious). 8.8 BCM in ambitious scenario and 4.93 in policy scenario can be saved.

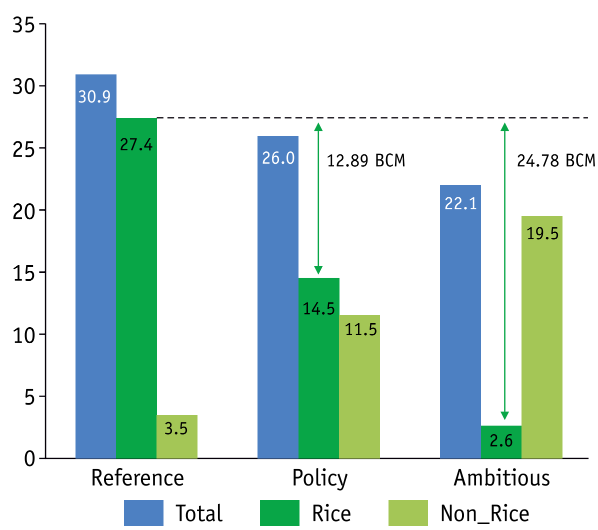


Figure 3.12: Kharif Season Irrigation water requirement in different scenarios (BCM)

3.3.4 Impact of Cropping Pattern Change on Annual Average Ground Water Depth

Presently, groundwater serves 73 per cent irrigated area while surface water resources serve only about 27 per cent of the irrigated area in the State. Agriculture sector is the largest consumer of water for irrigation purposes. The dominance of rice and wheat cropping pattern over the years has led to overexploitation of ground water. The water table has receded at an average annual rate of 0.70 metre all across the state, between 2008 to 2012, with a range of water table decline from 0.10 metre to 4 metres (SAPCC, 2014). The decadal pre-monsoon and post-monsoon groundwater level shows a decline from majority of area (around 85 per cent) from 2004–14. The decline is in the range of 1 to 3 meter while the remaining area shows a slight increase (0.6 meter) in groundwater level. By shifting from reference scenario to policy scenario; average annual groundwater depth will go up by 0.29 meter (Ravi sub-basin), 0.40 meter (Ghaggar & other sub-basins), 0.45 meter

(Beas sub-basin) to 0.46 meter (Sutlej Lower). Similarly, by shifting from reference scenario to ambitious scenario, the average annual groundwater depth will go up by 0.55 meter (Ravi sub-basin), 0.73 meter (Ghaggar & other sub-basin) 0.83 meter (Beas sub-basin) to 0.85 meter (Sutlej Lower).

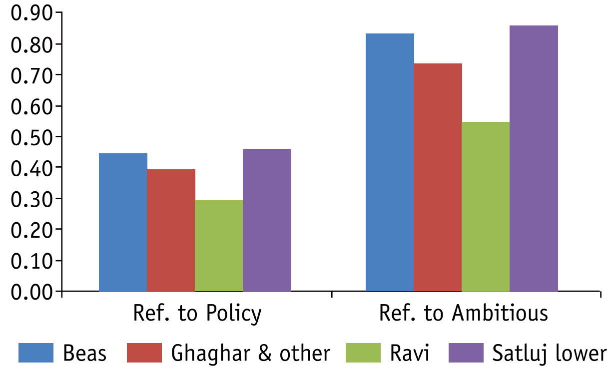


Figure 3.13: Impact of Cropping Pattern Change on Annual Average Ground Water Depth (meter)

3.3.5 Soil Erosion by Water

The National Mission on Sustainable Agriculture has major component of scheme for the soil health management. In Punjab state, the scheme entitled 'Up-gradation of Soil Health Labs under National Project on Management of Soil Health and Fertility' has been undertaken (GoP, 2014). Under this programme, Punjab aims to promote Integrated Nutrient Management and improve soil health and productivity.

As soil is an important part of the agricultural production system, loss of fertile soil is a major loss. The analysis finds basin-wise soil erosion values in Punjab for reference base (1970 to 2000) and reference future (2020–35). For reference base, Beas, Ravi, Ghaggar & other and Sutlej Lower basin has values of soil erosion as 4.2, 4.2, 1.7, and 3.1, t/ha/year, respectively. Likewise, for reference future, Beas, Ravi, Ghaggar & other and Sutlej Lower basin has values of soil erosion as 10.1, 10.4, 2.8, and 5.6, t/ha/year, respectively.

Change in soil erosion from base to future period is shown in Figure 3.14. It can be observed referring Figure 3.14 that Ravi and Beas sub-basins have very high changes in soil erosion. In reference base period all basin's soil erosion values were in slight erosion class (1 to 8 t/ha/year) and Ravi and Beas soil erosion values are going to moderate erosion class (8 to 24 t/ha/year). Soil formation is a very slow process. It takes about a thousand years for nature to make one centimetre layer of soil. Hence, even moderate soil erosion is not desired. Thus conservation agriculture should play major role in future.

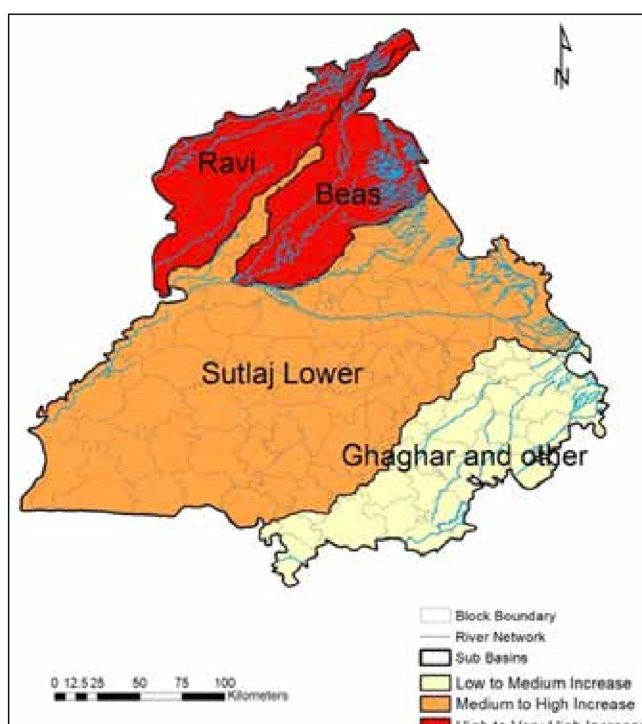


Figure 3.14: Change in soil erosion by water in Punjab (2020–35 w.r.t. 1970–2000)

When taking into consideration the policy or ambitious scenarios, the fertilizer consumption could increase, owing to the increased emphasis on crop diversification and a relative shift from the current cropping pattern. The NO_3 yield in surface and ground water would remain more or less similar to the current trends, not showing much variation in the reference, policy or ambitious scenarios as compared to the base scenario. The amount of NO_3 leached into the soil slightly decreases in the reference scenario but shows an increase in the policy and ambitious scenarios. These indicate that adequate and contextual measures need to be put into place on nutrient and pest management while going for crop diversification.

3.4 The Way Forward

Based on the above analysis, the following discussion points arise:

- Demand for drinking water in the State is continuously increasing as the population has increased from 1.35 crore in 1971 to 2.77 crore in 2011. Population is predicted to reach 3.24 crore by 2031. Domestic water requirement as compared to 981 million meter cube in 2011, will reach 1,617 million meter cube in 2031. Dwindling total water availability and deteriorating water quality are major concerns as drinking water supply is top priority.
- Rejuvenation of agriculture itself is crucially dependent on an industrial strategy in Punjab and it is building synergy between the two sectors. The industrial sector in the State is significantly changing with severe challenges and many new opportunities. The industry sector showed an increasing water demand mainly due to demand of small scale manufacturing sector till 2010. It is expected to grow sustainably with equal share of large- and medium-scale industry. Considering high growth as well as water conservation and automation strategy in industry, industrial water demand will increase from 1,428 million meter cube (2010) to 1,627 million meter cube (2030).
- Presently groundwater serves 73 per cent irrigated area while surface water resources serve only about 27 per cent of the irrigated area in the State. Agriculture sector is the largest consumer of water for irrigation purposes. The dominance of rice and wheat cropping pattern over the years has led to overexploitation of ground water. The water table has receded at an average annual rate of 0.70 metre all across the State between 2008–12 with a range of water table decline from 0.10 metre to 4.0 metres (SAPCC, 2014). Between 2004 and 2014, the pre-monsoon and post-monsoon groundwater level shows a decline from majority of area, around 85 per cent. Decline is in the range of 1 to 3 meter while remaining area shows slight increase (0.6 meter) in groundwater level.
- All the basins in the state show increased availability of surface and ground water, owing to increased rainfall and temperature. But, the actual water availability varies, depending upon the existing land use, domestic and industrial water use. Basin wise crop diversification and physiography of the region will play a major role in future water availability. Majority of rain is expected to fall within short duration.
- Sutlej lower and Ravi basins are expected to get benefits of increased total water availability as compared to Beas and Ghaggar & other sub-basins. But to take the advantage of increased water availability in the future, strategic planning is a must besides the role of growth rate of industrial sector and rate of crop diversification.
- It is expected to increase evapotranspiration of crops by 6 per cent to 8 per cent across all basins due to increase in temperature. Hence, the actual irrigation requirement will increase by 100 mm to 133 mm for a crop needing 500 mm irrigation water, considering the flood water irrigation method which is a dominant irrigation method in the state. Therefore, on-farm irrigation management, use of alternate irrigation methods, and conservation agriculture needs special attention.
- Industrial water requirement will increase by 10 per cent in 2020 and 15 per cent by 2030 as compared to the 2010 water requirement. Domestic water requirement will increase by 29.8 per cent in 2020 and 64.8 per cent by 2030 as compared to the 2010 water requirement. Increase in population, urbanization, and increase in standard of living will be responsible for this. Irrigation water demand is expected to stay around 56.1 BCM during 2020 and 2030 unless decisions of crop diversification are employed strongly. Considering this all, there will be a water deficit of 15.96 BCM by 2020 and 14.5 BCM by 2030 in the State.
- The agricultural growth of the State which is largely driven by the performance of wheat and rice production is directly linked to the irrigation water availability. It is estimated that in the future (2020–35), total annual net water availability will be 40.74 BCM comprised of 19.9 BCM surface water and 20.84 BCM ground water. To sustain with these water

resources, crop diversification is a must. Therefore, three crop diversification scenarios were formulated. Irrigation water demand for these scenarios will be 53.9, 51.1, and 45.2 BCM, respectively for reference, policy, and ambitious scenarios. These scenarios can bring down annual water deficit to 16 BCM (Reference), 13.26 BCM (Policy), and 7.66 BCM (Ambitious scenario).

- The high yielding varieties (HYV) of rice and wheat are the main consumers of water in agriculture sector. The cropping intensity (ratio of net sown area to gross cropped area) in the state has increased sharply from 126 per cent in 1960–61 to 190 per cent in 2012–13 with adoption of input intensive agricultural practices. Rice is the major crop responsible for huge irrigation water demand as well as groundwater depletion. If we bring down current rice cultivation area of 28 lakh ha to 16 lakh ha (policy scenario) to 2.8 lakh ha (ambitious scenario), then rice crop water requirement will decline from 27.4 BCM (reference) to 14.5 BCM (policy), to 2.6 BCM (Ambitious).
- As soil is an important part of agricultural production system, loss of fertile soil is a major loss. Soil formation is a very slow process and hence, even moderate soil erosion is not desired. It was observed that Ravi and Beas may have very high changes in soil erosion in future (2020–35). Therefore, emphasis on conservation agriculture should be given.
- It was seen that shift from reference scenario to the policy scenario or ambitious scenarios will increase the fertilizer consumption slightly. Hence, while giving increased emphasis on crop diversification, balanced use of fertilizer, use of bio-fertilizers, and use of farm yard manure should also be recommended.

3.5 References

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3.6 Annexures

Annexure 3.1: Note on ArcSWAT model

The Soil and Water Assessment Tool (SWAT) model simulates the quality and quantity of surface as well as ground water and predicts the environmental impact of land management practices, climate change, land use etc. An average ArcSWAT toolbar consists of six basic functions viz. SWAT Project Setup, Watershed Delineator, Hydrological Response Unit (HRU) Analysis, Write Input Tables, Edit SWAT Input and Swat Simulation.

The tool works in a series of steps starting with project set up, performing a series of analysis and finally coming up with an output (Exhibit 1). To begin with, a new Project needs to be setup or an already existing project can be loaded (Exhibit 2). The Project Setup will automatically create a project geodatabase, raster storage and a parameter geodatabase in the chosen directory. Once the project setup is done the Automatic Watershed Delineation command opens up a dialogue box with the help of which one can perform sub-basin delineation and evaluate the results (Exhibit 3). The interface generates topographic reports which can be accessed through the watershed reports command.

Exhibit 1: ArcSWAT Interface

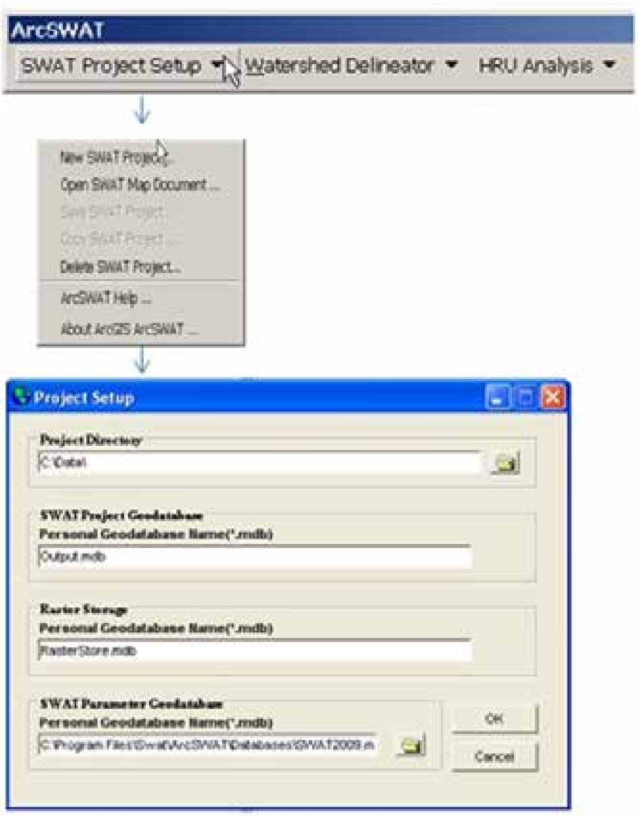


Exhibit 2: Project Setup

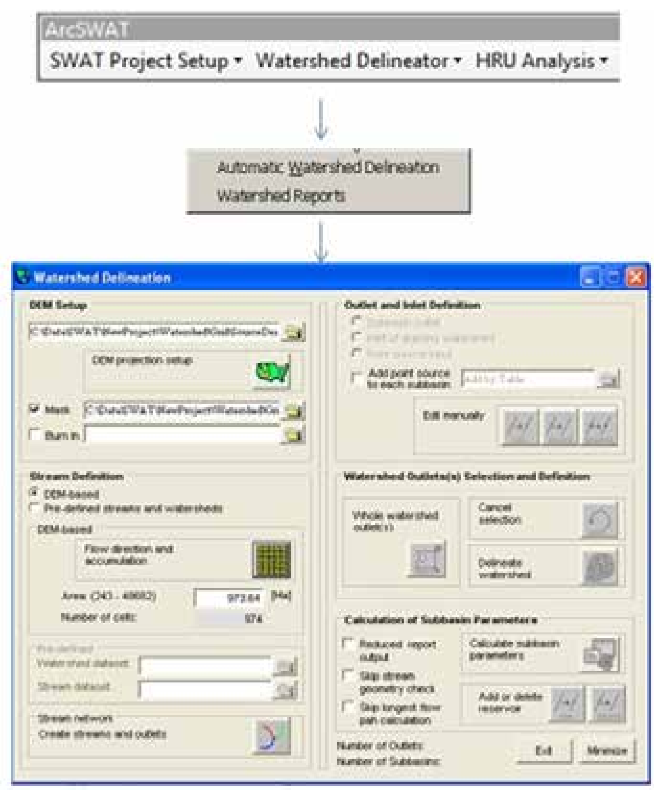


Exhibit 3: Watershed Delineation

With the help of the HRU Analysis tool the land use, soils, and slope analysis can be performed which are used to generate SWAT HRUs (Exhibit 4). The Land Use/Soils/Slope Definition command used to import land use and soil maps and perform overlay. Next to the HRU Analysis tab in the ArcSWAT toolbar is the Write Input Tables tab; the basic function of this tool is to generate the ArcSWAT geodatabase files which are used by the interface to store input values for the SWAT model (Exhibit 5). The Weather Stations command is used to load weather station locations and data for use.

The Edit SWAT Input tool allows to edit the SWAT model databases and the watershed database files containing the current inputs for the SWAT model (Exhibit 6). It contains various commands including Database, Point Source Discharges,

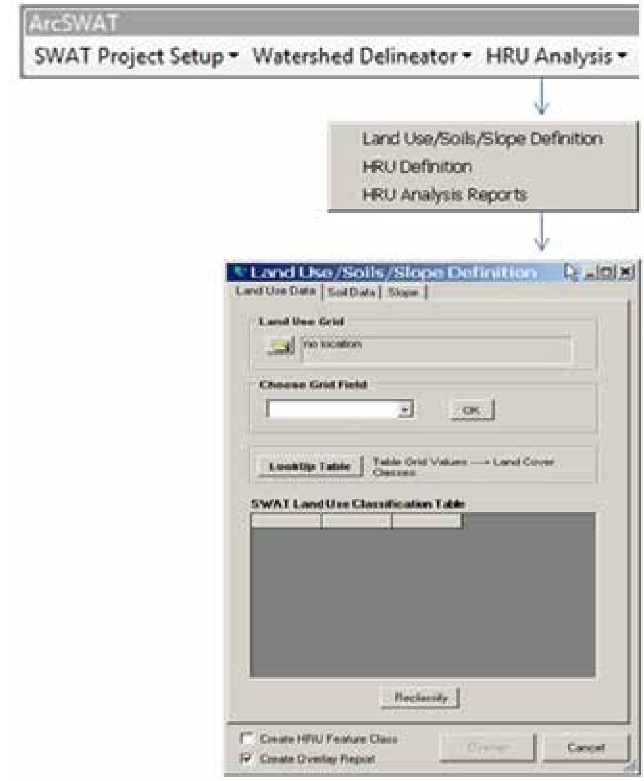


Exhibit 4: HRU Analysis

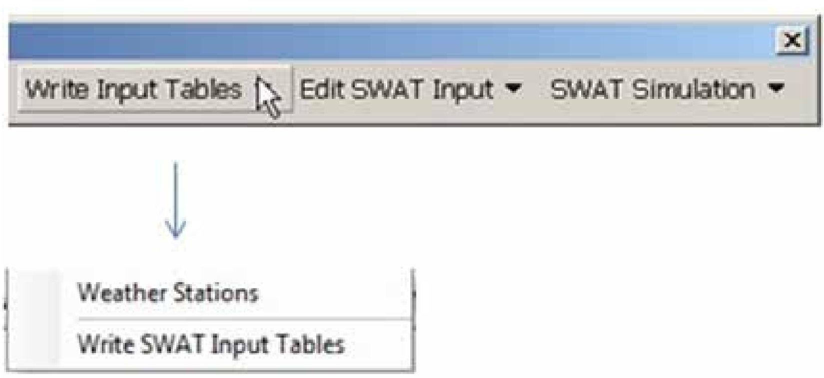


Exhibit 5: Write Input Tables

Inlet Discharges, Reservoirs, Watershed Data, Re-Write SWAT Input Files, Integrate APEX Model which facilitate the tool for the proper functioning. The last tab in the ArcSWAT toolbar is the SWAT Simulation tool which allows the user to run the SWAT model and perform sensitivity analysis and calibration (Exhibit 7). The Simulation tool supports four commands viz. Run SWAT, Read SWAT Output, Set Default Simulation and Manual Calibration Helper.

SWAT (Arnold *et al.*, 1998; Neitsch *et al.*, 2005) is a process-based distributed-parameter simulation model, operating on a daily time step. The model was originally developed to quantify the impact of land management practices in large, complex watersheds with varying soils, land use, and management conditions over a long period of time. SWAT uses readily available inputs and has the capability of routing runoff and chemicals through streams and reservoirs, and allows for the addition of flows and the inclusion of measured data from point sources. Moreover, SWAT has the capability to evaluate the relative effects of different management scenarios on water quality, sediment, and agricultural chemical yield in large, ungauged basins. Major components of the model include weather, surface runoff, return flow, percolation, evapotranspiration (ET), transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loads, and water transfer. For simulation purposes, SWAT partitions the watershed into subunits including

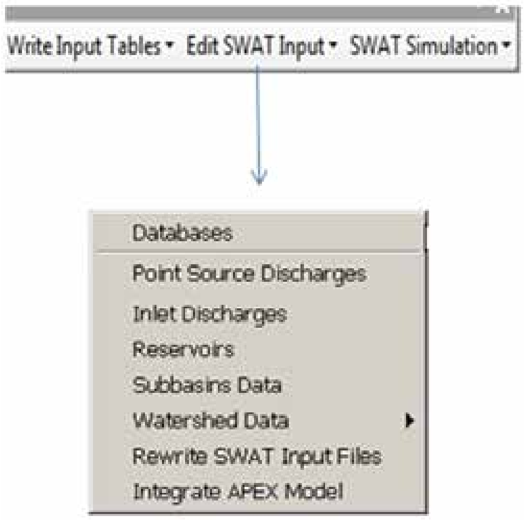


Exhibit 6: Edit SWAT Input

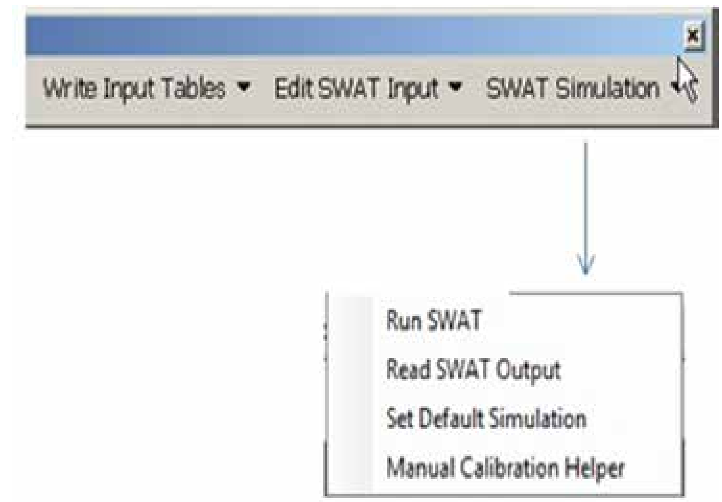


Exhibit 7: SWAT Simulation

subbasins, reach/main channel segments, impoundments on the main channel network, and point sources to set up a watershed. Subbasins are divided into hydrologic response units (HRUs) that are portions of subbasins with unique land use/management/soil attributes. The geographical information system (GIS) interface of the model (AvSWAT; Di Luzio *et al*., 2002) enables users to specify a critical source area (CSA) that controls the number of subbasins and the density of the channel network in the study area. This critical source area is the minimum area that is required for initiation of channel flow. The number of subbasins and the density of the channel network increase with decreased CSA (Di Luizo *et al*., 2002; Arabi *et al*., 2006).

Hydrologic component

SWAT uses a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) to compute surface runoff volume for each HRU. Peak runoff rate is estimated using a modification of the Rational Method. Daily or sub-daily rainfall data is used for calculations. Flow is routed through the channel using a variable storage coefficient method developed by

Williams (1969) or the Muskingum routing method. In this study, SCS curve number and Muskingum routing methods along with daily climate data, were used for surface runoff and streamflow computations.

Sediment component

Sheet erosion is estimated for each HRU using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975):

$$S = 11.8 \times (Q \times q \times A)^{0.56} \times K \times C \times P \times LS \times F$$

Where, S is the sheet erosion on a given day (metric tons), Q is the surface runoff volume (mm water), q is the peak runoff rate ($m3s^{-1}$), A is the area of the HRU (ha), K is the USLE soil erodibility factor, C is the USLE cover and management factor, P is the USLE support practice factor, *LS* is the USLE topographic factor, and F is the coarse fragment factor.

Nutrient and pesticide components

Movement and transformation of several forms of nitrogen and phosphorus and pesticides over the watershed are accounted for within the SWAT model. Nutrients are introduced into the main channel through surface runoff and lateral subsurface flow, and transported downstream with channel flow. Pesticides loadings from land areas to streams and water bodies are simulated in soluble or sorbed forms. Transport and transformation of pesticides in the channel network is modelled with a simple mass balance analysis.

Model evaluation

SWAT already has an established method for modelling hydrology along with several agricultural practices. The model also has the capacity to represent many other commonly used practices in agricultural fields through alteration of its input parameters. Crop yield one of the major outputs of the crop growth component of the model, accounts for both evapotranspiration and soil moisture required for vegetative growth. Therefore, crop yield can be used as an evaluation parameter. Groundwater is an integral part of hydrologic budget and it is always under attention. The description of recession of water in the ground can be used for the evaluation of aquifer properties and the sustainability of ground-water. In this regard, recession curves make a significant contribution to integrated river basin management by analyzing ground water and by separating baseflow from streamflow. The United States Geological Survey (USGS) developed RECESS model which develops the master-recession curve (MRC) method can enhance the accuracy of prediction. Considering this, the major parameters evaluated in this study are actual evapotranspiration (AET), streamflow, baseflow, baseflow recession constant (α_{BF}) and crop yield.

Annexure 3.2: Data Used for the Study

	Data Source	Time Period
Spatial Data		
Digital Elevation Model (DEM)	The National Aeronautics and Space Administration: ASTER	2009
Sub-basin boundaries	Water Resource Information System, GoI	2012
LULC map	Generated from LANDSAT remote sensing Image using ERDAS and ArcGIS	1980, 1990, 1998, 2014
Soil map	National Bureau of Soil Survey and Land Use Planning	1994, 1997
River Network and Drainage map	Ministry of Water Resources, GoI	2012
Non-Spatial Data		
Agricultural Area, production and yield of major crops, and fruit trees	Ministry of Agriculture & Co-operation, GoI	1950, 1960, 1970, 1980, 1990–2014
Climatic parameters (rainfall, temperature, wind speed, relative humidity, and sunshine hours)	National Data Centre, Indian Meteorological Department, GoI	1995–2000, 2009–2010
Fertilizer (NPK)	Fertiliser Association of India	1950, 1960, 1970, 1980, 1990–2013
Forestry	Forest Survey of India	1970, 1980, 1990, 2010, 2012
Ground water depth and observation well information	Central Ground Water Board, GoI	1990–2001, 2009–2010
Demographics (population, workers, medical, roads, power, etc.)	Census of India	1951, 1961, 1971, 1981, 1991, 2001, 2011
Number of Industries, Annual Production, etc.	Survey of Industries, Ministry of Statistics and Programme Implementation, GoI; Planning Commission Himachal Pradesh	1980–2013
Farm machinery and implements	Ministry of Agriculture & Co-operation, GoI and State Agricultural Departments	1970, 1980, 1990–2012

4

Stakeholder Perspectives on Natural Resource Management in Punjab: A Case Study Approach

4.1 Context

Punjab, at present, has more than 80 per cent of its total geographic area under agriculture with wheat and paddy being the dominant crops. The state produces 19 per cent of India's wheat while 11 per cent of India's paddy (CFAP, 2013). The wheat-paddy cropping pattern that has emerged in the state over the years, especially after the Green Revolution, has led to pressure on utilization of water and resulted in lowering of groundwater levels. The mono-cropping regime, deforestation, burning of farm residues, overuse of pesticides, herbicides, and fertilisers has gravely reduced the soil nutrient balance in large parts of cultivated Punjab soils and has caused groundwater pollution.

The trends in paddy cultivation show that the percentage of area under paddy has increased from 3.7 per cent in 1950–51 to 39.4 per cent in 2010–11, accounting for an almost 10 times increase in the past 60 years. In order to reduce the extensive paddy cultivation, the state has implemented a crop diversification programme, under which the area under paddy cultivation needs to be shifted to crops, including maize, cotton, sugarcane, vegetables, horticultural crops, pulses, and crops which come under agro-forestry (MoA 2013). The reach of this programme is still limited and much work has to be done in terms of educating farmers regarding the need and benefits of crop diversification.

Extensive paddy straw cultivation has also led to generation of huge quantities of paddy straw and the state is facing problems in terms of paddy straw management. Currently, Punjab produces approximately 17 million tonnes of paddy straw every year out of which around 15 million tonnes of paddy straw produced is being burnt in the fields (DSTE 2014), contributing to the high levels of air pollution and impacting health of the citizens due to increasing respiratory ailments. Lack of utilization options of paddy straw is the main thrust area in which initiatives are being taken up by the government. There is also lack of awareness amongst farmers regarding the alternative uses of paddy straw.

Having most of its area under agricultural cultivation has left Punjab with very limited land to increase forest and tree cover. The state at present has 1,772 sq. km area designated as forest cover and 1,499 sq. km area under tree cover, which together accounts for almost 6 per cent of forest and tree cover of the total geographic area in the state (FSI 2013). The state aims to bring the forest and tree cover to 15 per cent of the total geographic area by the year 2017 under State Forestry Action Programme (DoFWP 2008). To accomplish this task the state plans to increase tree cover along roadside plantation and promote agro-forestry.

The mono-cropping regime in the state has also had an adverse effect on the water resources in the state. Due to the excessive utilization of fertilizers and pesticides, owing to the increased cultivation intensity, the quality of groundwater has been deteriorating, making it unfit for domestic as well as to some extent agricultural use. Moreover, the groundwater depth in the state has been declining across districts except a few where the problem of waterlogging is prevalent. According to a 2011 Central Ground Water Board report, Punjab has 138 blocks out of which 116 fall in the category of over-exploited, semi-critical or critical.

4.2 Approach

To achieve the objective of the project, 'Initiative on Green Growth and Development in India', field analysis in the state of Punjab was undertaken by TERI researchers in four districts in the state in consultation with the Department of Science, Technology, and Environment (DSTE), Government of Punjab. The field visits included structured interviews and focused group discussions (FGDs) using nominal group technique and participatory-GIS tools with farmers along with key stakeholder interviews (KPIs) using semi-structured questionnaires.

The field visits allowed the researchers to understand the outlook of the community as a whole towards natural resource management (NRM) challenges in the state, including crop diversification, paddy straw management, green cover, and groundwater conservation. Documents and secondary information relevant to natural resource management in the state were collected from the respective government departments and reliable sources as per the scope of the study to enhance the understanding of the NRM challenges being faced by the state.

In relation to the study, the field visits to four districts, namely Amritsar, Faridkot, Rupnagar, and Sangrur[1] commenced in April 2014. During the said visits, an attempt was made to understand the perspective of farmers towards managing the natural resources and the challenges associated with their management. Some of the analysis of the findings from the structured questionnaire survey with the farmers has been shown in Annexure 4.1.

Based on the understanding from the field visit mentioned, focused group discussions were planned and conducted in each district. The framework of field visit approach is shown in Figure 4.1.

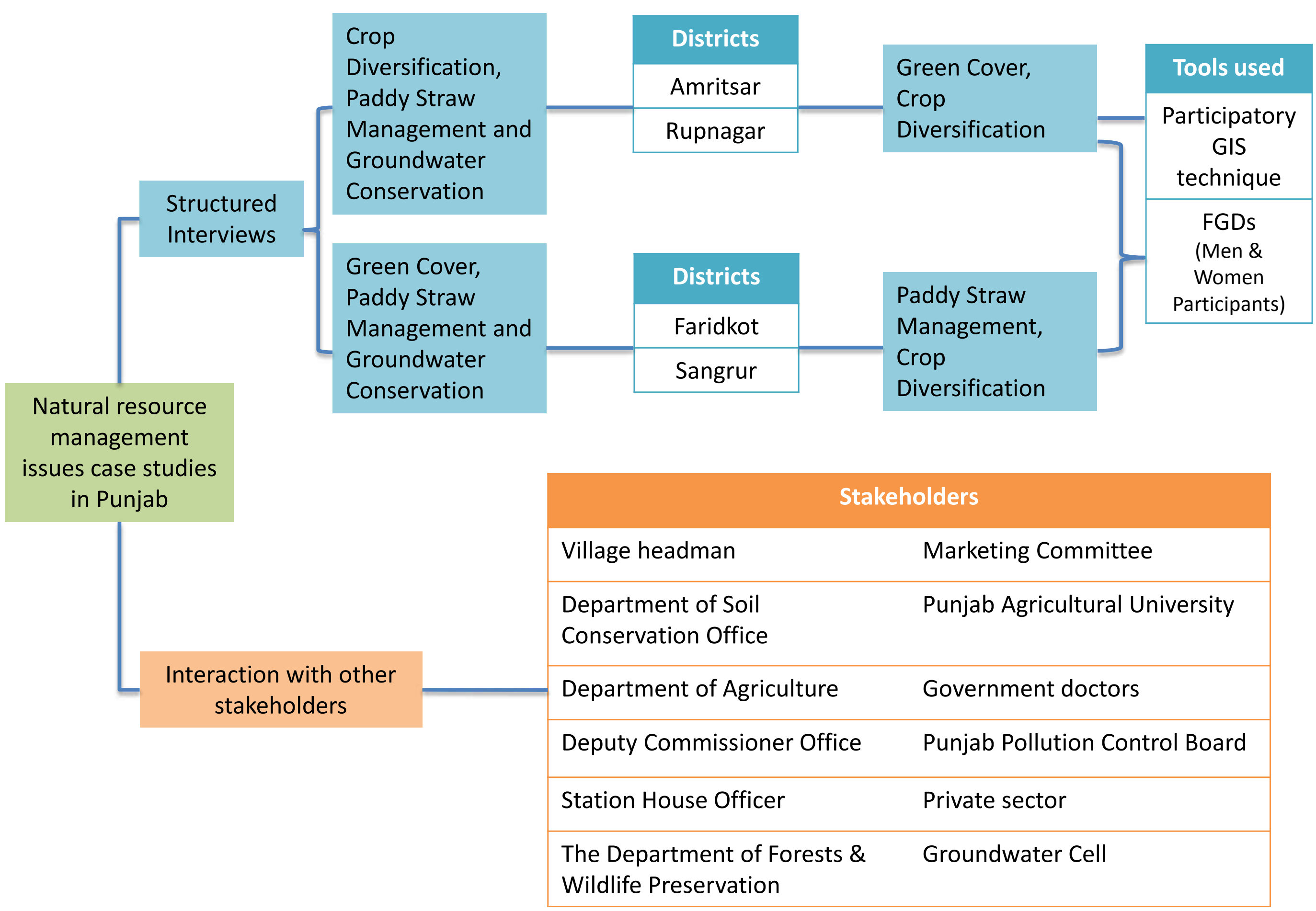


Figure 4.1: Stakeholders consulted during the study

[1] These districts were chosen after applying filtration technique to identify districts which performed contrastingly on parameters such as extent of crop diversification, paddy straw management, green cover, and state of groundwater conservation.

FGDs in Faridkot, Sangrur, Amritsar, and Rupnagar (Figure 4.2) were conducted during the months of October and December 2014 and January 2015. During the field visits, other stakeholders including government officials were also consulted to understand their perspective towards natural resource management and challenges associated with it in the State. Four case studies, one for each natural resource management issue, have been developed, based on the insights from field visits and interaction with the stakeholders.

The analysis takes into consideration four villages in Punjab, for assessing the land use land cover change in those villages over the years. These villages are spread across different districts in Punjab. Dadupura village is in Amritsar district, Jhampur village in Rupnagar, Rai Singh Wala village in Sangrur, and Virewala Kalan village in Faridkot district.

4.3 Spatial Profile of Study Villages

The study team sought to understand the land-use dynamics of the study villages. For this analysis, two time periods for four villages, one in each district, were taken. The time periods for Rai Singh Wala village were 2002 & 2014, for Virenwala Kalan village, 2003 & 2011 were chosen. While the time periods of 2003 & 2014 for Jhampur village and 2006 & 2013 for Dadupura village were selected.

All the high resolution images used for the study were Google Earth imagery, source CNES-Astrium and Digital globe. To process these images and to perform the LULC classification ArcGIS software was used. With use of the satellite imagery and ArcGIS software, digitization of different land use land cover classes was done. The four main classes include agriculture, built-up, tree cover, and water. With the help of this classification the change in the land use land cover classes was observed over the two different time periods.

Annexure 4.2 shows the LULC classification for the four villages.

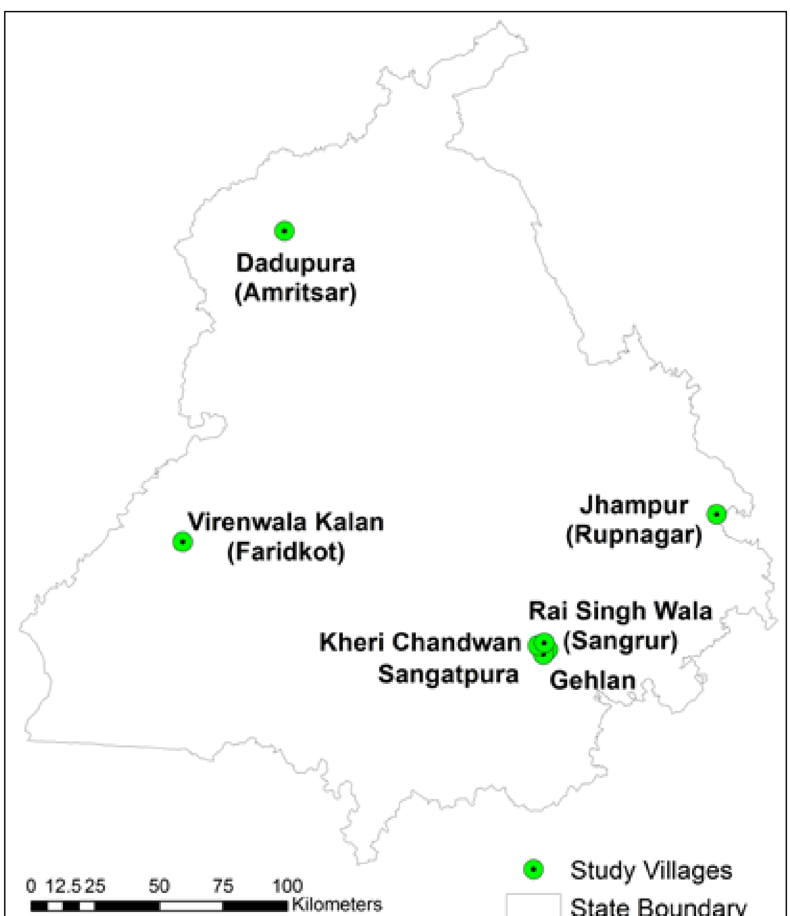


Figure 4.2: Map depicting villages considered for field visits
Source: Field Survey

From the analysis of Rai Singh Wala village in Sangrur district, it is evident that there has been an increase in area under built-up and tree cover, while the area under agriculture has declined from 9,23,373 sq. m in 2002 to 8,96,715 sq. m in 2014. There is a formation of water body that can be seen in the year 2014 which was absent in 2002. In the Virewala Kalan village, in Faridkot district, there has been a slight increase in the area under built-up while the area under tree cover has gone up considerably from 29,921 sq. m in 2003 to 46,002 sq. m in 2011. The Jhampur village, falling in Rupnagar district, records an increase in area under built-up, tree cover, and water while a decline in agriculture has been noted from 2003 to 2014. The village in Amritsar district, Dadupura, has seen an almost double increase in the tree cover from 5,029 sq. m in 2006 to 13,292 sq. m in 2013. The spatial analysis shows that there has been slight increase in built-up and a decline in agriculture.

Table 4.1: Area under different land use and land cover classification (in sq. m)

Class	Jhampur, Rupnagar		Dadupura, Amritsar		Rai Singh Wala, Sangrur		Virewala Kala, Faridkot	
	2003	2014	2006	2013	2002	2014	2003	2011
Agriculture	805111	783400	833111	822490	9,23,373	8,96,715	8,52,478	8,32,462
Built-up	59938	67728	84313	86434	75,502	95,086	1,43,812	1,47,008
Trees	51959	65995	5029	13292	12,285	16,492	29,921	46,002

Source: TERI Analysis

From the above findings, one important aspect that emerges clearly is that land-use dynamics in villages are changing over a short period of time with land under agriculture going down, increase in built area as well as increase in green cover. This presents the state policy-makers with an opportunity to put in place the right kind of policies that would incentivize sustainable land-use not only at the village level but beyond. These dynamics are also captured in the Soil and Water Assessment component of the project where ambitious scenarios consider an increase in green cover and farmer's openness for crop-diversification. The study now looks deeper into four policy relevant areas of Punjab—crop diversification, paddy straw management, ground-water conservation, and green cover increase.

4.4 Crop Diversification

The Green Revolution in Punjab and others regions in north India led to food grain surplus in the country. However, this lasted till the 1980s and there have been signs of stagnation since then. The intensive cultivation practices and package of technology in the wheat-paddy system has resulted in resource degradation. The wheat-paddy cropping pattern that emerged, however, led to pressure on utilization of water and since the 1980s the intensive usage of groundwater resources for cultivation of both the crops.

Environmental externalities such as depletion of groundwater and soil nutrient balance have impacted soil biodiversity and health, resulting in cascading economic, social, and environmental consequences. In addition to the existing pressures, climate change brings further stress with increasing temperatures, untimely and unpredictable amount of rainfall, and a factor of uncertainty. The State Action Plan on Climate Change (SAPCC) of Punjab narrates the projections that increasing temperatures are likely to decrease wheat and paddy productivity. The increasing trend of paddy and wheat cultivation has brought the crop diversification index down.

Figure 4.3 illustrates the trend of shift in cropping pattern in Punjab from 1950 to 2010. It is interesting to note that in 1950–51, the percentage of area under paddy cultivation was 3.7 per cent of the total area under principal crops in Punjab.[2] The area under wheat was 24.4 per cent, pulses 29.80 per cent, and coarse cereals 31.3 per cent. Remarkably, from 1950–51 to 2010–11, the percentage of area under paddy cultivation grew nearly ten times (from 3.7 per cent to 39.4 per cent) and

[2] In the graph, the categories; coarse cereals include, kharif cereals (bajra, maize) and rabi cereals (barley), pulses include gram, mash, moong, arhar, and massar, oilseeds include rapeseed and mustard, linseed, sunflower, and sesamum.

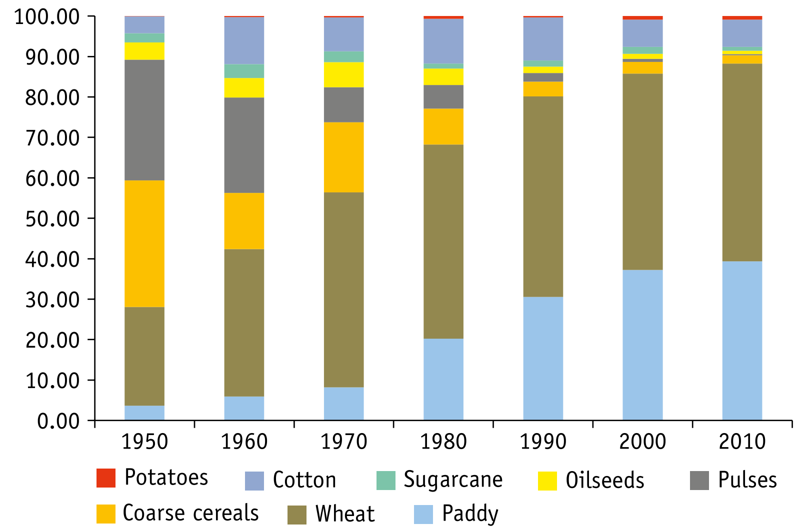


Figure 4.3: Percentage of area under principal crops in Punjab (1950–2010)
Source: Department of Land Records/ Agriculture, Punjab (various years)

under wheat doubled (from 24.4 per cent to 48.9 per cent). The area under pulses reduced by nearly 100 times (from 29.8 per cent to 0.3 per cent) from 1950 to 2010 and the area under coarse cereals decreased by about 15 times (31.3 per cent to 2.1 per cent) in this time period. The area under oilseeds and sugarcane has declined over the 1950–2010 time period. Cotton had a higher area in 2010 (4,83,000 ha) in comparison to 1950 (2,80,000). The area under potatoes has seen a marginal change, from 0.09 per cent of total area under crops to 0.89 per cent. Figure 4.4 provides information on the district level data on the cultivation of principal crops and paddy-wheat is the dominant cropping pattern in most districts of the state, while in ten districts, oilseeds have a prominent presence.

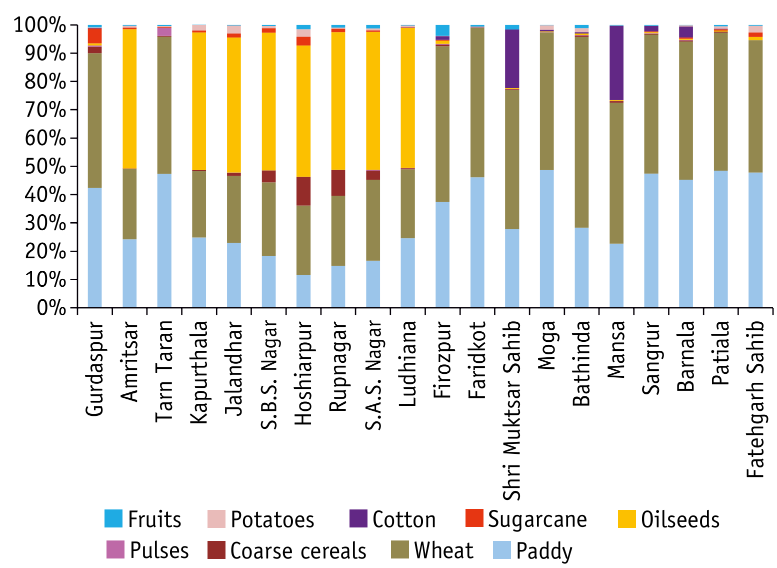


Figure 4.4: Percentage of area under principal crops in districts of Punjab in 2012–13
Source: Department of Land Records/ Agriculture, Punjab

The area sown more than once has increased by 250 per cent since the late sixties (Pandey 2014) and the intensification, especially in the wheat-paddy systems has resulted in resource degradation (Murgai, Ali and Byerlee 2001). The Green Revolution which sustained till the 1980s has shown signs of stagnation. According to Statistical Abstract of Punjab, 2013, the agriculture in the State has reached a plateau making it hard for further progress to be made under the available technologies and the natural resource base (GoP 2013a). The very sustainability of wheat-paddy production system is under threat and climate change is posing a new challenge on future agricultural growth.

It is interesting to note that in 1950–51, the percentage of area under paddy cultivation was 3.7 per cent of the total area under principal crops in Punjab, whereas that under wheat cultivation was 24.4 per cent. From 1950–51 to 2010–11, the percentage of area under paddy cultivation grew nearly ten times (from 3.7 per cent to 39.4 per cent) and that under wheat quite exactly doubled (from 24.4 per cent to 48.9 per cent). The area under pulses reduced by nearly 100 times (29.8 per cent to 0.3 per cent) from 1950 to 2010 and the area under coarse cereals decreased by about 15 times (31.3 per cent to 2.1 per cent) in this time period.

4.4.1 Policy Discussion

Crop Diversification Programme under RKVY

The objectives of the Crop Diversification Programme under the Rashtriya Krishi Vikas Yojana (RKVY) are, first, to demonstrate and promote the improved production technologies of alternate crops for diversion of paddy cultivation; and second, to restore the soil fertility through cultivation of leguminous crops that generates heavy biomass and consume less nutrient intake crops (GoI, 2014a). Under this programme in Punjab, the aim is to diversify the 1,40,000 hectares of paddy being cultivated to other crops. For this, INR 224.50 crores has been allocated to Punjab. While cluster demonstrations are given the maximum attention under this programme, a major focus of the proposed physical targets and financial allocations at the state level can be seen on farm mechanization and value added components.

For the year 2013–14, the revised targets under the programme suggested that about 20 different types of machine implements with a total machine count of 75,207 were targeted by the state. Out of which, 90 per cent of these were spray pumps/sprayers, 6 per cent of these were rotavators, 3 per cent were zero-till drills, and the rest 1 per cent were other machines. The machines being proposed under this programme are appropriate to either manage cropping operations or manage crop residue and there is no emphasis to shift farmers to other crops. Rotavators, happy seeders, and mulchers are specifically helpful for efficient handling of crop residue on the farmland. Zero-till drills have proven to be beneficial for resource-conserving practice for wheat cultivation. A debatable issue is whether there is a greater emphasis given on farm mechanization without due attention being given to issues related to storage (for example, cold storage for fruits and vegetables) and the marketing linkages for the alternative crops. The approved financial allocation for 2014–15 was INR 18,574.20 lakh as against the INR 25,000 lakh that was proposed by the state. In 2013–14, INR 22,450 lakh was the proposed as well as the approved amount of funds for crop diversification under the RKVY fund in Punjab. The information on the proposed crops for diversification is provided in Table 4.2.

4.4.2 Stakeholder perspectives

To understand the farmer's perspective, structured interviews (using interview schedules) were conducted with 102 farmers (men and women) in the two villages in Amritsar and Rupnagar districts. FGDs (using nominal group technique) were undertaken in Faridkot and Rupnagar districts to identify the criteria that would direct the farmers to diversify the cropping patterns.

The research team using the data from the previous interview schedule based consultation identified nine key criteria that are likely to play a crucial role in helping the farmers to diversify their cropping pattern. The farmers were divided in groups of men and women and during FGDs they were required to vote on the basis of the importance that they attach to each of the specified criteria (see Figure 4.5). An important insight from the graph is the gender dimension of criteria. Women farmers have higher preference for farm-level infrastructure, positive environmental externalities, and labour while the male farmers give higher weightage for economic drivers.

Minimum support price (MSP), market demand, and economic returns were ranked as the most important criteria (by both the men and women groups) in influencing the decision to diversify the cropping pattern. In essence, the interviews as well as the FGDs reflected the need for assured markets, for alternate crops, to motivate the farmers to diversify into alternate crops. Both the groups valued benefit to the environment as a legit factor for them to decide to diversify into alternate crops. The inference from our interactions with farmers reveals the need for strong set of positive incentives to be provided by the State to successfully achieve the policy targets regarding crop diversification.

Table 4.2: Proposed alternative crop choices for diversification as per Agriculture Policy of Punjab

Crop	Current area (lakh ha)	Potential area (lakh ha)	Districts
Rice	28.0	16.0	Amritsar, Gurdaspur, Tarn tarn, Ferozepur, Kapurthala
Maize	1.3	5.5	Traditional areas
Cotton	4.8	7.0	South-western districts
Sugarcane	0.7	2.6	Majha and Doaba regions
Guar (cluster bean)	-	0.3	South-western districts
Kharif Fodder	4.0	5.5	Throughout the State
Arhar (Pigeon pea)	Negligible	0.6	Central districts
Mungbean (Green gram)	0.2	0.6	Central districts
Kinnow	0.4	0.8	Traditional areas
Guava	0.1	0.2	Hoshiarpur, Ferozepur
Agroforestry	1.3	3.0	Kandi belt and Central districts (Poplar); South-western districts (Eucalyptus)
Groundnut		0.2	Hoshiarpur, Nawanshahar
Turmeric, chilli, tomato, garlic, capsicum, Kharif onion	0.2	0.5	Hoshiarpur, Kapurthala, Jalandhar, Amritsar

Source: Agriculture Policy of Punjab

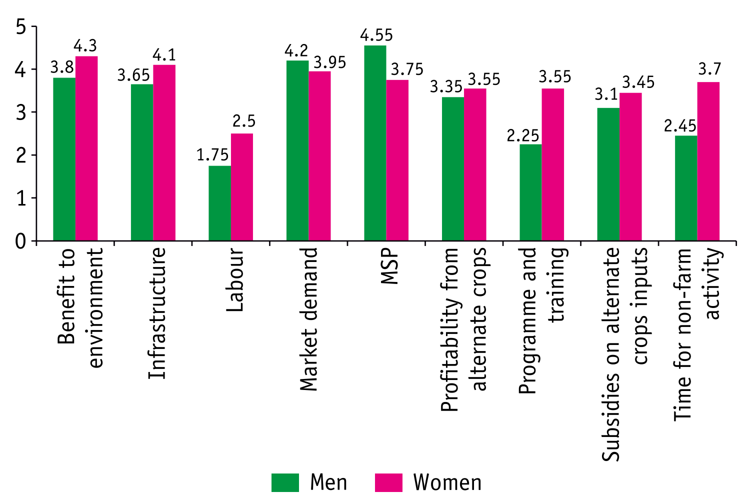


Figure 4.5: Factors influencing diversification of cropping pattern for men and women
Source: Field visits

Our survey reveals that farmers in Amritsar are more aware about the impacts of crop diversification (70 per cent as compared to Rupnagar (53 per cent). In both Amritsar and Rupnagar, depletion of groundwater, deterioration of soil health, and burning of crop residues were perceived as the most important impacts of the wheat-paddy cropping system (Table 4.4). In Amritsar, farmers want to diversify to either maize, vegetable cultivation or diversify into dairying activities, while in Rupnagar, farmers wanted to consider vegetable, maize and pulses (Table 4.5). In Amritsar the most important constraint to diversity was the lack of policy support—higher MSP or subsidy or state procurement (43 per cent), while in Rupnagar, the most important constraint is the availability of labour (56 per cent).

Table 4.7 captures the highlights from stakeholder interaction to understand their perspectives on taking crop diversification activities further ahead.

Table 4.3: Awareness of the impacts of Wheat-Paddy Cultivation

District	Yes	No
Amritsar	70	30
Rupnagar	53	47

Source: Field visits

Table 4.4: Three Most prominent perceived impacts of Cultivation of Wheat and Paddy

Impact	Amritsar District (%)	Rupnagar District (%)
Depletion of ground water table	55	44
Deterioration of soil health	37	10
Burning of crop residue leading to environmental problems	16	6

Source: Field visits

Table 4.5: Preferred crops to diversify/diversification to other activities

Crop	Amritsar District (%)	Rupnagar District (%)
Vegetable	31	50
Maize	45	34
Pulses	-	20
Shift to dairying activities	22	-

Source: Field visits

Table 4.6: Three most important challenges for crop diversification

Challenge	Amritsar District (%)	Rupnagar District (%)
Absence of market linkages	35	44
Labour requirement	43	
Lack of adequate policy support like higher MSP, subsidy or state procurement	43	-
Labour requirement	-	**56**
Lack of high quality or high yielding seed varieties	-	**28**

Source: Field visits

Table 4.7: Highlights from stakeholder interaction in Faridkot and Sangrur districts

Stakeholder	Highlights from stakeholder interaction
Village headman	Strong need for relevant and timely information relating to markets amongst farmers. If the number of agro-processing units around the villages and nearby towns grows much more, it could positively influence the crop diversification drive.
Department of Soil Conservation Office	Market demand, market linkages, and marketing knowledge needs to be strengthened for farmers to have a greater incentive to diversify their cropping pattern.
Department of Agriculture	Inter-crop (maize, pulses, oilseeds, sugarcane, poplar, and cotton), and farm diversification (fishery, dairy, agroforestry) would be beneficial and demonstrations/piloting of interventions are ongoing.
Deputy Commissioner Office	Sensitization of farmers for tree planting and silvi-horticulture Required and effective market infrastructure for crops has the potential to bring about crop diversification on a large scale. Extensive research must be done on varieties of other crops being sensitive to soil and water quality issues in Punjab. Community farming and organising farmers in functional groups to take crop diversification practices forward
Marketing Committee	Inadequate post-harvest support and incentives (like MSP, market linkages, presence in the market, labour availability, transportation of produce) for alternate crops are barriers preventing farmers to diversify to alternate crops. More attention needs to be given to the situation of small farmers who are devoid of alternate sources of income and the opportunity costs that crop diversification holds for them in current scenario.
Punjab Agricultural University	Extensive research must go into varieties of other suitable crops factoring in the soil and water quality issues in Punjab.

Source: Field visits

4.5 Paddy Straw Management and Utilization

4.5.1 Setting the context

Punjab produces around 17 million tonnes of paddy straw of which about 15 million tonnes of paddy straw, produced in the state, is being burnt in the fields every year (DSTE 2014). Burning of paddy straw emits particulate matter and other pollutants such as NOx and CH_4 into the atmosphere (Tiwana et al., 2007).

Open field burning of paddy straw is a common sight in Punjab especially during the months of October–November (Figure 4.6). This leads to dangerously high levels of air pollution in the State, leading to impacts on the health of the population at large. Health hazards such as respiratory diseases, skin disorders, irritation in eyes and throat have been believed to be triggered by paddy straw burning in the state (Kumar et al., 2015). The thick cloud of smog generated out of paddy straw burning causes reduced visibility, hampering the movement of vehicles on highways and roads (Tiwana et al., 2007).

Figure 4.6: Open field burning of paddy straw in Faridkot district, Punjab
Source: Field visits

The Government of Punjab has declared the state as an 'Air Pollution Control Area'. The notification by the Department of Science, Technology, and Environment in consultation with Punjab

State Pollution Control Board (dated 22 October, 2013) prohibits the indiscriminate burning of leftover paddy and wheat straw / stubble in the state of Punjab, under the exercise of power conferred under Section 19(5) of the Air (Prevention & Control of Pollution), Act, 1981, by the Governor of Punjab. However, in practice, given the large volume of paddy straw produced in the State, effective paddy straw management still remains a key concern.

Punjab is an agrarian state and has contributed significantly to ensure food self-sufficiency of the nation. Paddy is not native to Punjab. The crop requires tropical lowlands and a long warm growing season. Growth of paddy cultivation in Punjab is largely attributed to provisions of high yielding varieties of paddy, minimum support price (MSP), assured irrigation resources, and evolved markets for paddy crops (Sidhu et al., 2005).

With the provision of MSP for paddy, the opportunity cost of cultivating alternative crops has increased in Punjab. Farm mechanization has also played a crucial role in the growth of paddy productivity in the state. Combine harvesters allows farmers to harvest their paddy crop more quickly and efficiently. The number of self-propelled combine machines has gone up from 5,533 in 2000–01 to 10,363 in 2011–12. The number of tractor-drawn combine machines has risen from 4,922 in 2000–01 to 6,123 in 2011–12 (GoP 2012a). While mechanization of farm has helped in improving profitability of farms, the combine harvester machines has led to crop residues on the ground. Increase in adoption of these machines has resulted in large volumes of post-harvest paddy straw in the fields.

Paddy straw burning is widely prevalent in the state due to a number of reasons, including high labour costs required to remove paddy straw from fields, narrow window between harvesting of Kharif paddy, and sowing of the Rabi crop. Farmers believe that paddy straw is not a suitable animal fodder. In power plants, the increased silica content in paddy straw can lead to clinker formation in boilers.

Burning of paddy straw leads to emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide (Pathak et al 2006). Emissions from paddy fields burning in Punjab have been estimated to be 261 Gg of CO, 19.8 Gg of NOx, 3 Gg of CH_4, 30 Gg of PM10 and 28.3 Gg of PM2.5 during October 2005 (Badrinath et al 2006). These emissions are of serious concern to the state and demand immediate action, from both the government and citizens at large. The state may consider having wider pollution monitoring and source apportionment for continual improvement.

Paddy straw is rich in nitrogen, phosphorus, and potassium contents. Burning crop stubble can increase the temperature in the soil up to 33.8–42.2°C (Gupta et al., 2004). Paddy straw burning disturbs the carbon–nitrogen equilibrium in soil, and also kills beneficial microbes and organisms, thus deteriorating the fertility of soil (Tiwana et al., 2007).

4.5.2 Policy discussion

The Agriculture Policy for Punjab 2013 (Draft) advocates that the strategy for agriculture development has to address the sustainability concerns while achieving the overall growth objectives. The policy aims to make concerted efforts to reduce the area under paddy cultivation by 40 per cent from current levels in a span of 5–7 years. As per the policy, area under paddy should be restricted to 16 lakh hectares for maintaining the ground water balance. The policy promotes investment in research and development (R&D) as well as marketing infrastructure for alternative crops and suggests on having MSP for alternate crops. The policy proposes undertaking measures to recycle paddy straw to enhance soil fertility and promotion of farm machinery through custom hiring basis. The policy also suggests for enactment of legislation for management of crop residues.

The Policy for Management and Utilization of Paddy Straw in Punjab 2013 (Draft) provides information on alternative options for utilizing paddy straw and challenges witnessed in collection & storage of the straw (GoP 2013b). The Department of Science, Technology, and Environment (DSTE), Punjab, is the nodal department for implementation of this policy. The policy clearly states that the most preferable solution for the state is crop diversification. Cost effective mechanization, capacity building for disposal of paddy straw, and promotion of appropriate agricultural practices are discussed in the policy. This policy informs that the state aims to incentivize incorporation of at least 50 per cent of present generation of paddy straw in the fields by 2017 and suggests building capacities through awareness and extension education.

The New and Renewable Sources of Energy Policy – 2012, proposes to achieve a target of 600 MW power generation from biomass/agro residue by 2022 and also proposes to set up co-generation plants and achieve capacity addition of 500

MW by 2022 (GoP 2012b). The policy recognizes the potential for energy generation from agriculture residue like cotton stalks, paddy straw, and paddy husk. The policy incentivizes the development of power plants where at least 25 per cent of the biomass used is paddy straw. The policy mentions that the Punjab Energy Development Agency (PEDA) shall take up R&D projects in the biomass, especially paddy straw combustion for power generation through Rankin cycle/gasification in pilot mode.

Notification by Department of Science, Technology, and Environment (STE Branch) in consultation with the Punjab Pollution Control Board (dated 22 October 2013) directs prohibiting the indiscriminate burning of left over paddy and wheat straw with immediate effect under the exercise of power conferred under Section 19(5) of the Air (Prevention & Control of Pollution), Act, 1981 by Governor (DSTE [STE Branch] 2013).

In addition to this notification, district authorities are taking cognizance under Section 144 (imposed for preventing disturbance and maintaining law and order) of Criminal Procedure Code (CrPC) to register cases against farmers who burn stubble on their fields. The Punjab Pollution Control Board (PPCB) has also, through a notification, imposed a ban on burning of paddy straw in the State. Violators are supposed to be booked under Section 188 (disobedience to order duly promulgated by public servant) of the Indian Penal Code (IPC) and the Air (Prevention and Control of Pollution) Act. However, the issue of paddy straw burning is still pertinent in the State as there is little translation of these punitive actions and notifications into action. The state may consider revising their penalty mechanism to check paddy straw burning, enhancement of the enforcement system and set penalties in accordance with 'polluter pays principle'.

In 2014, the state of Punjab produced a Draft White Paper on management and utilization of paddy straw in Punjab (DSTE 2014). The document, while adopting a holistic perspective to paddy-straw management introduced the concept, 'Earn, Don't Burn', which advocated for an integrated approach to prevent loss of resources from paddy straw burning. In addition to making a strong case for reducing the area under paddy cultivation, the white paper also outlined an *in-situ* management strategy of paddy straw incorporation on fields.

As per the White Paper, the state government has an estimated target to use 5.73 million tonnes of paddy straw in 2016–17. Also, industries utilizing paddy straw as raw material can seek incentives under 'Fiscal Incentives for Industrial Promotion – 2013' scheme of the Government of Punjab.

The issue of paddy straw burning is well-acknowledged at the national level. National Policy for Management of Crop Residues (NPMCR) of 2014 envisages controlling of crop residue burning, adoption of technical measures, including diversified uses of crop residue, capacity building & training along with formulation of suitable laws/legislation (GoI 2014b) . The National Green Tribunal (NGT) had directed the centre and the states to come out with a draft national policy to curb the menace of paddy straw burning (National Green Tribunal 2014). The Ministry of Environment, Forest and Climate Change (MoEFCC) and Central Pollution Control Board (CPCB) in a joint workshop in January 2015 discussed various strategies to scientifically use and dispose of the paddy stubble and avoid open-field burning.

4.5.3 Stakeholder perspectives

As part of this project, questionnaire-based structured interviews were conducted with 208 farmers in 7 villages in Amritsar, Faridkot, Rupnagar, and Sangrur districts to understand their perspective on paddy straw management and challenges associated with it. These interviews were followed by FGDs using nominal group technique. The results are revealing in terms of challenges associated with paddy straw management faced by farmers and the factors that influence their decision of paddy straw burning. The study also mapped the views expressed by stakeholders on the paddy straw burning issue.

Figure 4.7: Farmers waiting in grain mandi in anticipation to earn a good price for their produce
Source: Field visits

Field interaction revealed that farmers are aware of the negative impacts exerted by paddy straw burning on their local environment and community. Further, imposition of restrictions by the state government making paddy straw burning an offence, has made farmers more open to accept alternative residue management practice. To address the issue of paddy straw burning, the paddy straw management needs to be made cost-effective to the farmers.

Traditional practices of using paddy straw for purposes like animal bedding and mulching have reduced in the state. Adoption of mechanized harvesting process using combine harvesters as against manual harvesting has made it tedious to collect left over stubble. Since most of the Punjab farmers prefer to employ migrant labour, it raises the labour cost. Therefore, any input cost in removing paddy straw from field makes the process economically unviable.

Farmers were found waiting for many days in the grain market to fetch a good price for their produce (Figure 4.7). Lack of timely access to market information for price discovery leaves them with a narrow window between harvesting of paddy and sowing of Rabi crop, thereby pushing farmers to burn paddy stubble.

Figure 4.8: Focus group discussion (FGD) being conducted by TERI team in Faridkot district, Punjab
Source: Field visits

Figure 4.9: Women participating in participatory focus group discussion and giving score to alternatives
Source: Field visits

Focus group discussions (FGDs) were conducted to identify the criteria that would encourage farmers to check paddy straw burning (Figures 4.8 and 4.9). Both men and women during FGDs felt that 'availability of labour' would aid them most in prohibiting paddy straw burning. 'Benefit to environment' as a criterion to prevent paddy straw burning received higher support from women participants, whereas 'cost and income' associated with paddy straw management received higher consideration by men participants. Figure 4.10 shows the score received by each criterion on a scale of 1 to 5.

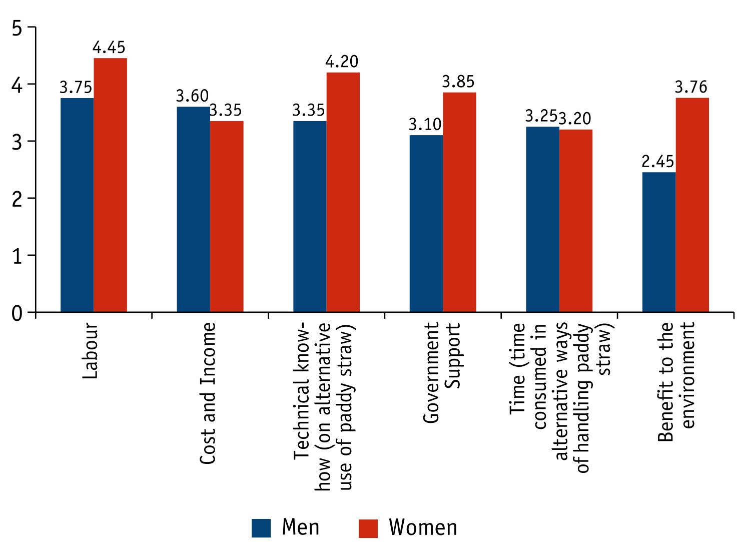


Figure 4.10: Average weightage given by men and women farmers
Source: Field visits

Other stakeholders were also consulted to understand their perspective on paddy straw burning issue in the State. Table 4.8 presents a snapshot of the views expressed by these stakeholders on the issue.

Interaction with stakeholders shows that paddy straw burning is believed to worsen, or in some cases, even cause health issues such as asthma, chronic obstructive pulmonary disease (COPD), bronchitis, acute respiratory infection, and can trigger tuberculosis, cold & flu, scabies, allergic conjunctivitis, and urticaria. Farmers and doctors opined that a number of respiratory disorders reported an increase during paddy straw burning period.

Table 4.8: Views expressed by stakeholder's during consultation sessions

Stakeholder	Views expressed
Deputy Commissioner	• Scale of paddy straw issue is large • MSP on alternative crops would promote crop diversification and thus help in reducing the paddy straw burning issues; and also reduce pressure on water resources.
Government doctors	• Incidence of respiratory disorders increases during paddy straw burning period. • Mostly, children and people in age group of 25-45 years are affected from paddy straw burning
Station House Officer (SHO)	• Considering the scale of paddy straw burning issue, resorting to section 144 of CrPC and section 188 of IPC, is not an appropriate solution • Potential business mechanism associated with alternative use of paddy straw has the potential to stop its burning
Punjab Pollution Control Board	• Need for more air pollution monitoring stations and awareness generation regarding paddy straw management • Private sector could play a significant role in managing paddy straw
Office of Chief Agriculture Officer	• In the long term, crop diversification is a solution for checking paddy straw burning • Biomass based power plants and cardboard factories should be encouraged, as they use paddy straw as raw material.
Farmers at Grain *Mandi*,	• Farmers wait for several days in *mandis* to fetch good price for their produce; leaving them with less time to clear the field of paddy straw and plan the sowing of next crop • Commission agents encourage paddy cultivation including basmati as it fetches better price and such circumstances
Private sector	• More R&D in paddy straw utilisation is required

Source: Field visits

4.5.4 Utilization options

Most of paddy harvesting in the State is carried out through machines. The machines after harvesting leave behind paddy straw on the field. Apart from burning paddy straw, the three major paddy straw disposal options for the farmers are incorporation of paddy straw into the soil, seeding next crop with standing stubble, and removal of the straw from farm.

Farmers can either engage in *in situ* or *ex situ* management of paddy straw. *In situ management* requires incorporation of straw into soil or seeding next crop without burning paddy stubble. This is achieved by shredding the straw and using machines such as rotavator for land preparation or using happy seeder to sow seeds with standing stubble. *Ex-situ management* requires utilization of paddy straw in non-farm activities. This is possible with combination of machines (baler, raker and cutter) which helps bale paddy straw, which are further transported for non-farm utilization.

An attempt was made to assess costs of paddy straw management options for *in-situ*[3] and *ex-situ*[4] management of paddy straw. The ownership and maintenance cost per annum[5] is estimated as highest for making bales from paddy straw followed

[3] Happy seeder and rotavator are the machines that were considered

[4] Baler, raker and cutter are the machines that were considered

[5] The assessment does not account for the number and cost of tractor involved in operation of individual agriculture implement

by seeding next crop with standing paddy stubble and incorporation of paddy straw into soil (Table 4.9). The operating cost per acre for these options has been presented in Table 4.10. Refer to Annexures 4.3 and 4.4 for detailed assessment of the costs presented in Table 4.9 and Table 4.10 respectively.

Table 4.9: Ownership and maintenance cost of different forms of paddy straw management options

Paddy straw management options	Total ownership plus maintenance cost per annum (INR)
Making bale from paddy straws	179955
Seeding for next crop with paddy stubble	31687
Incorporation into soil	22188

Source: Field visits

Table 4.10: Operating cost per acre of machines

Paddy straw management options	Operating cost per acre(INR)
Making bale from paddy straws	265
Seeding for next crop with paddy stubble	474
Incorporation into soil	393

Source: Field visits

An attempt was made to understand farmer's perception of the options available to manage paddy straw using these machine-based management options on human health (relatively less air pollution due to absence of paddy straw burning), crop productivity, and decrease in fertilizer input. It was observed that farmers perceive that making bales of paddy straw, seeding of next crop with standing paddy stubble, and incorporation of paddy straw into soil has a positive impact on human health (Table 4.11).

Farmers were uncertain of the impact of these options on crop productivity. Seeding next crop with standing paddy stubble was perceived to have a positive impact by decreasing the fertilizer input for the crop to be sowed whereas farmers were uncertain of the impact of the other two options on decrease in fertilizer input.

Table 4.11: Farmers' perception on the impacts of different forms of paddy straw management options

	Human Health	Crop Productivity	Decrease in Fertiliser Input
Making bale from paddy straws	Positive (green)	Uncertain (yellow)	Uncertain (yellow)
Seeding for next crop with paddy stubble	Positive (green)	Uncertain (yellow)	Positive (green)
Incorporation into soil	Positive (green)	Uncertain (yellow)	Uncertain (yellow)

(green)	Positive
(yellow)	Uncertain

Source: Field visits

Some good practices for paddy straw management, which were observed during field visits, have been discussed in Box 4.1.

Box 4.1: Practices for paddy straw utilization

Enterprising farmer involved in procuring and selling of paddy straw, Faridkot district

The study team interacted with an enterprising farmer in Faridkot district, who purchased baler machine from Zamindara Farm Solutions (Pvt.) Ltd, a Punjab based company offering agricultural equipment to farmers including baler machine used for clearing paddy straw from the farms. This farmer was involved in procuring and selling of paddy straw from the fields.

The farmer informed that since paddy straw has no use, the farm owner do not ask for any monetary or non-monetary return for taking the paddy straw away from their field. He also informed that presence of industries utilizing paddy straw as raw material makes procurement and selling of paddy straw a lucrative business with high profit.

Malwa Power Plan Limited (MPPL), Muktsar district

The study team visited the MPPL plant in Muktsar district, which is a 7.5 MW biomass based power plant. This plant procures agro-waste from farmers and generates about 400000 units per day with net production being about 230000 units per day.

The plant procurement of paddy straw for input is seasonal and also depends on the quantity it can procure considering its capacity. From the interaction with the officials it was found that the plant is able to produce about 150 units of electricity per quintal of paddy straw. The officials at the MPPL plant informed that paddy straw was being purchased from farmers at approximately INR 120 per quintal.

4.6 Green Cover

4.6.1 Setting the context

Punjab has 1,772 sq. km area designated as forest cover and 1,499 sq. km area under tree cover, which together accounts for almost 6 per cent of forest and tree cover of the total geographic area in the state (FSI 2013). According to the Forest Survey of India (FSI) classification, the State has no area under very dense forest cover (tree canopy density >70 per cent). The districts of Hoshiarpur, Gurdaspur, and Rupnagar have the main tract of dense forest (tree canopy density between 40–70 per cent) and alone account for almost 80 per cent of the total forest cover in the State. Hoshiarpur, Gurdaspur, Rupnagar, SBS Nagar, and Patiala together comprise around 80 per cent of the open forests (tree canopy density < 40 per cent) in the state (Figure 4.11).

Figure 4.11: Forest Cover Map of Punjab
100 sq.km

According to the Punjab State Forest Policy and Strategic Plan (2008–17) (Draft), the State aims to bring the forest and tree cover to 15 per cent of the total geographic area by the year 2017 under State Forestry Action Programme (DoFWP 2008). The Punjab State Action Plan on Climate Change 2014 Report provides forest cover projections, assuming a 'business-as-usual' scenario. Taking this scenario in consideration, if the current rate of increase in forest cover continues at the rate of 100 sq. km every 2 years, then the desired forest cover of 15 per cent can only be achieved by 2070 and forest cover of up to 10 per cent can be attained by 2045 (SAPCC, 2014) (Figure 4.12).

Punjab's main forest cover patches are concentrated near the Shivalik hills bordering Himachal Pradesh. Being largely an agrarian state, Punjab has a net sown area of 4,150 thousand hectare which is more than 80 per cent of the total geographic

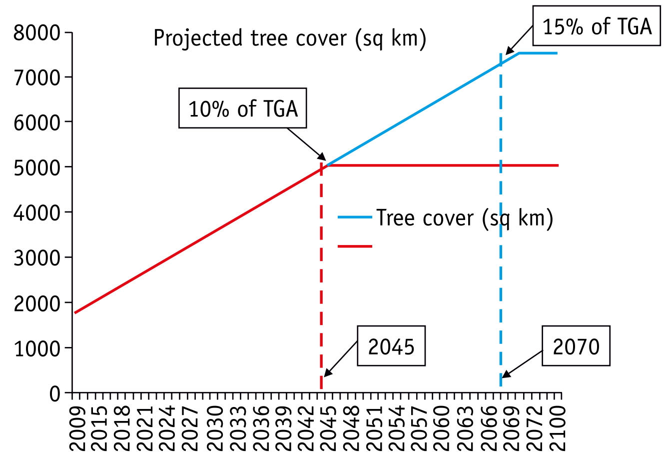


Figure 4.12: Projected Tree Cover for Punjab if growth rate is every two years. TGA= total geographical area of Punjab

area (GoP 2013a). Since most of the area in Punjab is under agriculture, there is unavailability of land for plantation of forests. The state has therefore, taken up the plantation of trees along roads and canals, in and around government schools, colleges and offices[6].

Looking at the trends for the last two decades, the recorded forest area in the state has increased from 2,842 sq. km in 1991 to 3,058 sq. km in 2011. While on the other hand, the forest and tree cover which increased from 1,343 sq. km in 1991 to 4,066 sq. km in 2001, saw a decline to 3,463 sq. km by 2011. Within the forest and tree cover category, a major decline has been in the forest cover which fell from 2,432 sq. km in 2001 to 1,772 sq. km in 2011, a decrease of 1.33 per cent (FSI 1991, 2001, 2011).

Interactions with stakeholders during the field visit also validate the decrease in the forest and tree cover. More recently, the tree cover in Punjab declined from 1,699 sq. km in 2011 to 1,499 sq. km in 2013; and the forest cover increased only marginally from 1,764 sq. km in 2011 to 1,772 sq. km in 2013.

Box 4.2: Definitions related to green cover

Forest Area

"The area recorded as a forest in the Government records. It is also referred to as 'recorded forest area'." – FSI, 2011

Forest Cover

"All lands, more than one hectare in area, with a tree canopy density of more than 10 percent irrespective of ownership and legal status. Such lands may not necessarily be a recorded forest area. It also includes orchards, bamboo and palm." – FSI, 2011

Tree Cover

"It comprises of tree patches outside the recorded forest area exclusive of forest cover and less than the minimum map-able area (1 ha)" – FSI, 2011

4.6.2 Policy Discussion

The National Forest Policy enforced in 1952 and amended in 1988, encompassing all Indian states, aims to preserve and restore the ecological balance while increasing forest and tree cover, increasing forest productivity and keeping a check on soil erosion.

The State is pursuing forestry and green cover with renewed vigour. The State in its Draft State Forest Policy and Strategic Plan (2008–17) envisions increasing area under forest and tree cover from 6.3 per cent to 15 per cent of the total geographic area by the year 2017 which is a highly ambitious target. Looking at the current state of increase and availability of land for forestry, this target might not be achievable by the year 2017.

The policy also highlights the role of agro-forestry on farm lands and by raising trees plantations on all kinds of land in the State. The state policy has underscored the role of 'trees outside forests' (TOF) as they have a major role in increasing the green cover of the state.

[6] Read more at http://www.pbforests.gov.in/Pdfs/may2010/YEARWISE AREA PLANTED UNDER VARIOUS SCHEMES.pdf, last accessed on 25 May 2015.

Table 4.12 indicates the cost implications for various green cover related strategies formulated by the government.

Table 4.12: Cost implications for various strategies formulated by the government (in crore)

Strategy	12th plan	13th plan	Total Cost
Increase area under forest and tree cover to 15%	1225.20	1304.80	2530.00
Enhance forest density in the Shivaliks	1563.60	1772.40	3336.00
Undertake capacity building activities for sustainable forest management	20.00	24.00	44.00
Strengthen biodiversity conservation measures	1.70	0.40	2.10
Total	**2810.50**	**3101.60**	**5912.10**

Source: Punjab State Action Plan on Climate Change, 2014

The Joint Forest Management Guidelines encourage active participation of people and local community to regenerate and manage degraded forests. Due to the lack of major forest tracts across the state of Punjab, these guidelines are left to mostly cater to the reserved and protected forest tracts in the Kandi area.

The Punjab Forest (Sale of Timber) Act, enforced since 1913, controls the sale and purchase of timber and establishment of sale depots. The Punjab Land Preservation Act of 1900 aims to regulate, prohibit and restrict cultivation, grazing, felling, burning, and quarrying in the protected and preserved parts of Punjab. The Act also undertakes responsibility for reforestation and soil conservation. Punjab has a number of policies, laws, and regulations for conservation, management, and restoration of the forest resources in the State but there is a need for stricter implementation.

The state, presently, has more than 80 per cent of its geographic area under agriculture[7], leaving very little open public space to pursue afforestation activities in order to increase the forest and tree cover in the State. The aforementioned policies aim for forest conservation, restoration, sustainable forestry as well as increasing forest cover. However, the State faces a major constraint in terms of limited availability of land for forestry. Thus, to address the issue of increasing the forest and tree cover, there is a need at this time to make modifications and amendments to these existing policies to incorporate the issue of land unavailability for forestry.

Some of the recent acts and policies have taken into consideration the issue of land unavailability and propose agro-forestry and horticulture as the avenues for increasing the tree cover. The National Agro-Forestry Policy of 2014 encourages farmers to venture into tree plantations and in turn, increase the tree cover in the state. On similar lines, the National Horticulture Mission, enforced in 2005–06, promotes holistic growth of the horticulture sector which would bring about considerable amount of land under tree cover if taken up on a large scale by the farmers. It will be important to strengthen the institutions at local level, and to improve the reporting and efficiency of operations by strengthening the management information systems (MIS). Punjab State Forest Policy and Strategic Plan (Draft) recommends an annual report stating records of trees outside forests (TOF), species-wise, by making it a part of the Revenue *Girdawari*[8] System. An intervention of this kind will be helpful in facilitating ground-truthing for satellite imagery and GIS-based assessments.

The State at present is far from its goal of achieving the 15 per cent forest and tree cover target. Innovations in the existing policies and strict implementation of the conservation measures would be required for the state to move in the direction of its set targets.

Figure 4.13 depicts government institutions involved in the conservation and management of forest and tree cover in Punjab and at the national level.

[7] More details at <http://lus.dacnet.nic.in/dt_lus.aspx>

[8] Girdawari - records of land cultivation

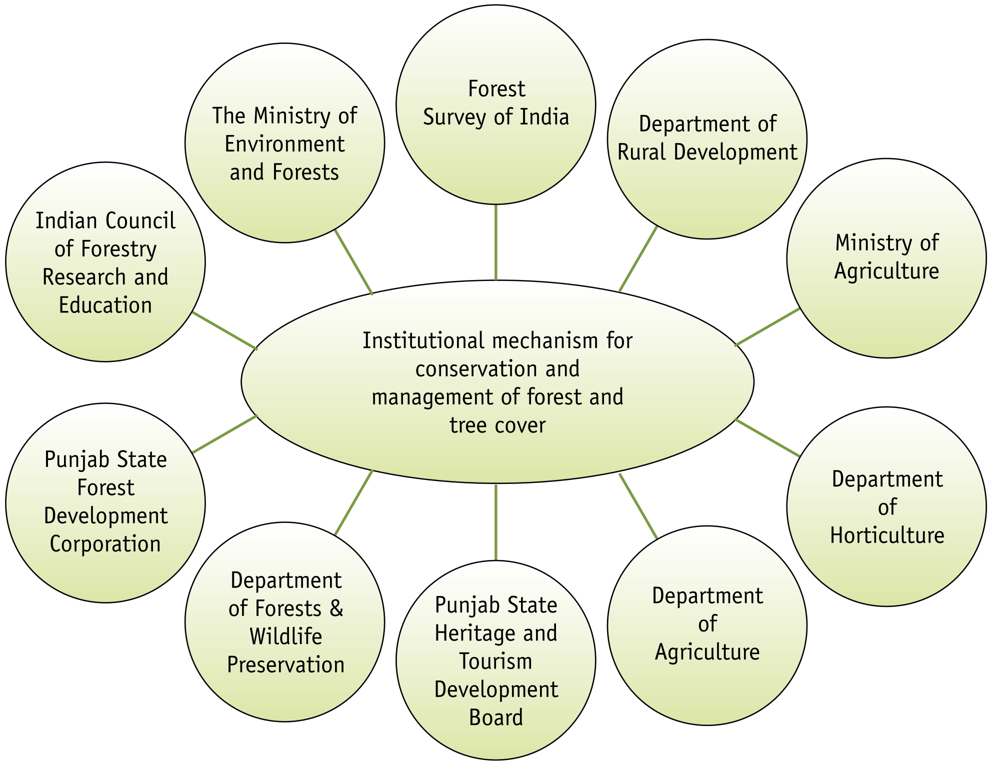


Figure 4.13: Government institutions for conservation and management of forest and tree cover

4.6.3 Stakeholder perspectives

As part of the project, questionnaire-based structured interview with farmers, focused group discussions using nominal group technique, and participatory-GIS tools, were carried out. The structured interview of 107 farmers was conducted in five villages in Faridkot and Sangrur districts to understand their perspective on green cover. These structured interviews were followed by FGDs and participatory spatial mapping technique to devise an easy-to-understand exercise to enable the farmers to participate. The results are revealing in terms of how farmers perceive the change in forest and tree cover surrounding them, as well as their viewpoints on what criteria would direct them to undertake tree plantation in and around the village. It also reveals the difference in priorities of the men and the women groups in selecting tree species.

Farmer interactions

Structured questionnaire-based interactions were carried out to help understand the farming community's viewpoints on the issue of forest and tree cover. Most farmers felt that the tree cover had declined over the last five years (Table 4.12). Farmer interactions highlighted that the government can play a major role in checking deforestation and maintaining records of the already existing tree tracts. At present, almost 63 per cent of the farmers are not involved in agro-forestry but do view it as an option for crop diversification which could help in increasing the tree cover in the State.

Participatory spatial mapping exercise

In order to understand the scenario of tree cover in the villages, an exercise of participatory spatial mapping was conducted wherein a group of participants were shown a satellite image of their village and were asked to recognize their houses and fields (Figure 4.13). Once they became well acquainted with the image, they were asked to identify and mark the places from where the tree cover has been removed in the past 5–10 years as well as places where more trees can be planted in the next 5–10 years. The farmers also informed that mostly all fields have one/two guava, *kinnow, jamun*, mango, and litchi plantations. Amongst these, *jamun* trees were considered best for farm boundaries. Speaking from their experience, farmers informed that Eucalyptus and Poplar extract a lot of water, shed leaves, and spoil crop yields.

The village headman (*Sarpanch*), officials from the forest office and agriculture office were consulted as part of the stakeholder consultations. Some of the highlights from these interactions are captured in Table 4.14.

(a)

(b)

Figure 4.14: (a) Participatory mapping exercise in progress; (b) Satellite image of Jhampur village (Rupnagar district) with green dots representing spots for future plantation of trees while yellow representing past plantations which were cut down.

Source: Field visits

Table 4.13: Farmers' perceptions on change in tree cover in the last five years

Districts	Farmers' perception (%)			
	Worsened	Improved	No change	Don't know
Amritsar	54.90	5.88	19.61	19.61
Rupnagar	50.00	14.00	28.00	8.00
Faridkot	20.00	60.00	20.00	0.00
Sangrur	59.62	21.15	13.46	5.77

Source: Field visits

Table 4.14: Highlights of stakeholder interaction

Stakeholder	Issues	Existing initiatives
Village headman	• Deforestation • Water scarcity • Lack of adequate awareness	• Sporadic awareness campaigns • Saplings distributed for free or at subsidized rates
Forest office	• Unavailability of land for forestry • Getting funding for forestry related projects (being a rich state Punjab not easily considered for funding) • Problems in implementation of on-going projects as most of them do not get a timely funding • Low survival rate of trees in water logged areas • Depleting levels of ground water	• Punjab Compensatory Afforestation Fund Management and Planning Authority) and Compensatory Afforestation Plan for afforestation activities in Punjab • For the past 10 years the departmental planting of eucalyptus taking place in which cremation grounds, schools, colleges, government offices and residences are targeted • Surveys conducted to understand the demand for trees and then free saps are handed out throughout villages. • Planting of bamboo, mulberry and *Khair* near Shivaliks; sesame, *neem* and *dek* being planted in the southern belt; while *babul* and *Acacia modesta* being planted in sandy areas across Punjab.

	• Illegal cutting of trees for if they are along an agriculture field causing hindrance in crop growth and for fuel purposes.	• Awareness campaigns regarding benefits of trees and knowledge dissemination camps teaching proper handling of various tree species so as to ensure their long survival, being held all across the state.
Agricultural office	• Most farmers not willing to venture into agro-forestry due to unassured market • Difficulty in growing any major crop once poplar becomes 3 yrs or older	• Establishment of wood *mandis* providing licenced wood at Ludhiana, Hoshiarpur and Jalandhar as these districts have more agro forestry as compared to other districts • Campaigns being held to propagate agro-forestry with poplar being the 1st choice of tree crop.

Source: Field visits

4.6.6 Roadmap Matrix

Table 4.15: Roadmap matrix

Areas	Any policy target	Current barriers	Policy/regulatory intervention needed	Technology needed
Short term	- 8% of the state area under forest and tree cover	- Encroachments - Forest fires - Unsustainable Forest Management - Invasion of Lantana	- Enactment of the Punjab Forest (sale of timber) Act, 1913 - Easing the transit and felling regulations for trees grown on private land within the state needed. - Provisions for the inclusion of sustainable forest management practices on the lines of Green India Mission and REDD+ in the working plan documents of the state could be made.	- Need for establishment of hi-tech nurseries throughout the state for producing quality germ plasms. - Enhancing productivity through clonal and tissue culture technologies. - Initiatives need to be taken in order to eradicate *Lanatana camara* especially in Gurdaspur, Rupnagar, and Hoshiarpur districts, where it is widely spread. - Launching productivity enhancement programmes for improving the quality and density of natural forests in the state. - Need for formation of Joint Forest Management Committees (JFMCs) and Forest Dependent Communities (FDCs) with the help of forest department for bringing in check forest fires through involving local communities. - Construction of fire lines and watches and ward towers in the forest fire sensitive areas. - Modern technologies like remote sensing & GIS tools should be used for proper management and scientific planning of forest resources assessment.
Medium term	- 10% of the state area under forest and tree cover	- Saline alkaline areas in plains of Patiala, Muktsar, Kapurthala and Amritsar districts.	- Since the National Forest Policy permits private sector to do plantation and conservation activities on degraded forest, there is a need for better implementation of such schemes.	- Soil and water management measures to control and balance the salinity and alkalinity of soils need to be undertaken

Areas	Any policy target	Current barriers	Policy/regulatory intervention needed	Technology needed
		- Waterlogged areas of various parts of Muktsar, Firozepur, Bathinda and Mansa districts - Demand of fuelwood, fodder, bamboo and minor forest produce.	- Forest corporation could establish minimum support price (MSP) for agro forestry species. - Inclusion of an additional chapter on assessment of forest carbon stock in the working plan documents of the state. - Develop carbon forestry projects such as Afforestation/ Reforestation (A/F) Clean Development Mechanism (CDM) and REDD+[9].	- Water logged areas are to be reclaimed through bio drainage process by planting tree species tolerant to water logging and submergence such as Eucalyptus, Willow, *Arjun, Jamun,* etc. - In the Shivalik region, enrichment planting with suitable species of trees, shrubs and grasses should be carried out on regular basis. In addition, construction of soil conservation measures should be carried out to check the soil erosion, conserve moisture and recharge ground water. - Awareness programs should be launched to promote Guniea grass, Oat and Sorghum which have been identified as suitable crops for block plantation.
Long term)	- 13% of the state area under forest and tree cover	- Population pressure on forest for livelihood - Only 0.37% (188 sq. km) of geographical area under agroforestry - Limitation of land for increasing forest cover as 82% of the geographical area of the state is under agriculture.	- Amendments could be made in the Indian Forest Act to relax transit regulations for the species grown on private land. - Need for better implementation of the National Agroforestry Policy. - The National Agroforestry Policy also suggests that the actual implementation may involve convergence and dovetailing with a number of programmes like MGNREGA, IWMP, NRLM, RKVY, CAMPA fund etc. - State forest department should enable environment for marketing on contract farming within the state. - Regulation for felling trees on private land and community holdings should be reviewed and rationalized to reflect the communities' interest in planting and protecting trees on their lands.	- Promotion of agroforestry species such as Poplar, Eucalyptus, *Sisham, Drek, Neem,* etc in the state. - Tree improvement programs consisting of clonal multiplication, grafting and raising seedlings by collecting seed from superior genotypes or certified sources should be undertaken. - Area under agro forestry species should be increased from 1.3 lakh ha to 3.0 lakh ha. - Bamboo cultivation could be encouraged as its cultivation ensures more than 25% of Internal rate of return (IRR) and returns are recurrent up to thirty years without recurring investment.

Source: TERI internal analysis compiled from various sources

[9] Reducing Emissions from Deforestation and Forest Degradation (REDD). "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks. http://www.un-redd.org/aboutredd

4.7 Groundwater Conservation

4.7.1 Setting the context

Punjab located in the north-western border of India is a small state occupying less than 2 per cent of the geographical area and inhabited by little more than 2 per cent of the total population in the country. The 'Green Revolution' introduced in Punjab was based on intensive irrigation, use of external chemical inputs, and hybrid varieties which led to a significant increase in crop productivity. The state produces about 19 per cent of India's wheat and 11 per cent of paddy (CFAP, 2013). Over the years, the increased reliance on groundwater resources for irrigation and its depletion have remained an arena of concern in the past three decades (Figure 4.15).

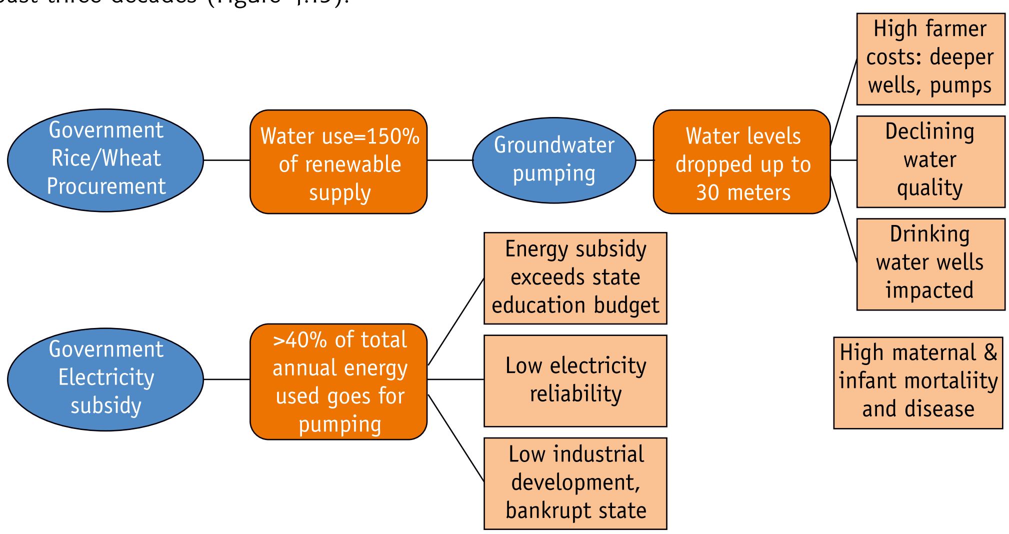


Figure 4.15: Impact of agricultural systems on resources and human well-being
Source: Perveen, et al., 2012, page 3

While Punjab's agricultural growth rate was the highest during 1960s to the middle of 1980s (Jodhka 2006), there has been a sectoral shift in the Punjab economy and the share of agriculture has fallen from 21.19 per cent in 2004–05 to 13.68 per cent in 2012–13, while the share of the tertiary sector has increased from 42.59 per cent to 48.68 per cent (Statistical Abstract of Punjab, various years).

Over the years, due to excessive utilization of fertilizers and pesticides the quality of ground water has been deteriorating making it unfit for mainly domestic consumption as well as to some extent for agricultural use. Study conducted by the Water Resources and Environment Directorate, Punjab revealed that districts like Muktsar, Mansa, Faridkot and Bhatinda are worse affected with more than 50 per cent area having unfit quality of drinking water. Districts like Hoshiarpur, Gurdaspur, SBS Nagar, and Rupnagar are doing fairly well with more than 90 per cent of their respective area having water under the fit category (Table 4.16) (Chopra et al., 2014).

Table 4.16: District wise classification of groundwater quality in Punjab State (2009–14)

District	Total Area (Sq. km)	Fit		Marginal		Unfit	
		Area	%	Area	%	Area	%
Amritsar	2647	2086	78.81	561	21.19	0	0
Barnala	1410	390	27.66	720	51.06	300	21.28
Bathinda	3385	84	2.48	1035	30.58	2266	66.94
Faridkot	1469	42	2.86	554	37.71	873	59.43
Fatehgarh Sahib	1180	872	73.9	308	26.1	0	0

District	Total Area (Sq. km)	Fit		Marginal		Unfit	
		Area	%	Area	%	Area	%
Ferozepur	5303	1444	27.23	1296	24.44	2563	48.33
Gurdaspur	3564	3549	99.59	15	0.41	0	0
Hoshiarpur	3365	3365	100	0	0	0	0
Jalandhar	2632	2331	88.56	276	10.49	25	0.95
Kapurthala	1632	1356	83.09	201	12.32	75	4.59
Ludhiana	3767	3340	88.66	401	10.65	26	0.69
Mansa	2171	88	4.05	499	22.99	1584	72.96
Moga	2216	665	30.01	1025	46.25	526	23.74
Muktsar	2615	0	0	114	4.36	2501	95.64
Patiala	3218	2063	64.11	880	27.35	275	8.54
Ropar	1369	1271	92.84	98	7.16	0	0
Sangrur	3610	1194	33.07	1456	40.34	960	26.59
SAS Nagar	1093	833	76.21	260	23.79	0	0
SBS Nagar	1267	1242	98.03	25	1.97	0	0
Tarn Taran	2449	632	25.81	1317	53.78	500	20.41
Area of State (Sq. Km)	**50362**	**26847**	**53.31**	**11041**	**21.92**	**12474**	**24.77**

Source: Water Resources and Environment Directorate, Punjab (2009–14)

Note: The water quality has been gauged on the basis of values obtained by testing Electrical Conductivity (EC) and Residual Sodium Carbonate (RSC) of collected samples.

Box 4.3: Artificial recharge structure: Success story

The concerns caused by high level of groundwater extractions exceeding the natural recharge in almost all block of Moga district in Punjab lead the Central Ground Water Board (CGWB) to initiate a pioneering project for augmenting the rapidly depleting aquifers with the help of artificial recharge in Bassian Drain in the district.

Under this initiative two trenches having 170 m length each were constructed with three recharge wells in each trench with 3 piezometers on both sides of the trench. Through this project a total quantity of 5.58 million cubic meter (MCM) water gets recharged annually through just these two trenches.

Such projects if implemented on large scale throughout the state may bring relief to the almost exhausted groundwater aquifers and restore the groundwater levels.

Source: Central Ground Water Board (2012)

The groundwater depth has gone down in most of the districts in Punjab, except a few where the problem of waterlogging is prevalent (Figure 4.16). Out of the total 138 blocks, there are 116 unsafe blocks in the state of which 110 are over exploited, 4 blocks are critical, and 2 blocks are classified as semi-critical, the rest fall in the category of safe blocks. The latest assessment by the Central Groundwater Board states that 80 per cent of the monitored wells are considered as overexploited (CGWB, 2012).

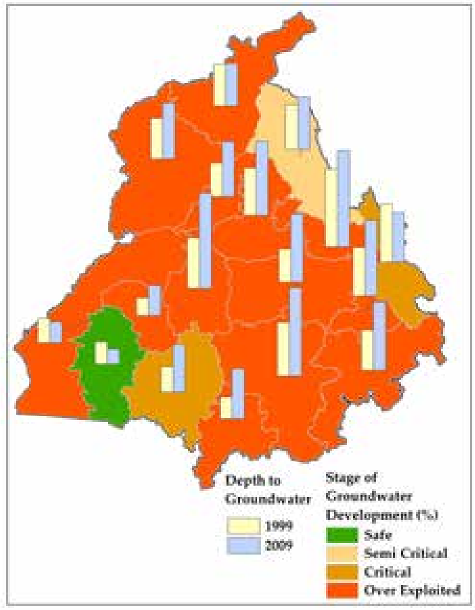
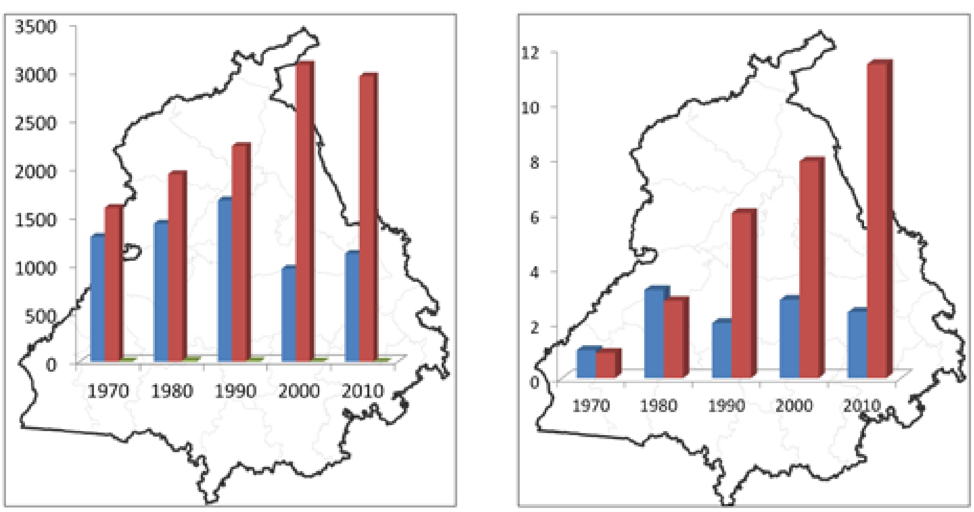


Figure 4.16: District-wise stage of groundwater development (%) and depth to groundwater (m) Punjab (1999 & 2009)
Source: Base-data from Statistical Abstracts of India (various years)

According to the latest assessment (CGWB 2012), net ground water resources of Punjab are 20.35 BCM, whereas net draft was 34.66 BCM, leading to ground water deficit of 14.31 BCM. As on March 2009, the stage groundwater development is 172 per cent. Irrespective of this huge groundwater deficit, the numbers of tube-wells are continuously increasing (Figure 4.17 (a)). The crucial benchmark year is 1997 when electricity provision for agriculture was made free (along with free canal water). Because of the unreliability factor surrounding canals, a major shift towards tubewell irrigation was witnessed 1990 onwards (Figure 4.17 (b)).



(a) Canals Tube wells Other sources (b) Diesel Operated Electric Operated

Figure 4.17: (a) Area irrigated by different sources in Punjab 1970-2010 (in '000 hectare); (b) Diesel & electric operated tubewells in Punjab 1970-2010 (in lakhs)
Source: Base-data from Statistical Abstract of Punjab, various years

Provision of free electricity to the farmers is thought to be one of the drivers for such high rates of groundwater depletion. The electricity subsidy for the agricultural sector has witnessed an increasing trend with the subsidy increasing from INR 3790 crores in 2008–09 to INR 6958 crores in 2013–14 (Table 4.17). The subsidy has progressively increased, with the subsidy for free electricity provision to farmers being INR 404 crores in 1996–97 (PSPCL 2011).

Table 4.17: Electricity subsidy (INR crores) across sectors in Punjab from 2008–09 to 2013–14

Gross Subsidy for different sectors	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Domestic	956	960	1266	903	1221	1612
Agri/Irrigation	3790	4485	4283	4919	6236	6958
Industry	210	-34	437	-74	-454	-106
Others	-445	43	67	-145	-130	-25
Net Subsidy	4511	5454	6053	5603	6873	8439

Source: NITI Aayog, various years

Note: Figures in negative indicate that the relevant sectors cross-subsidises another sector.

There have been many water conservation technologies developed to address the problem of depletion of groundwater resources in Punjab (Siddhu, Vatta and Dhaliwal, 2010). It was found that laser levelling in paddy cultivation brings down water use by 36.19 cm and an yield improvement of 0.78 tonne/ha and the total economic benefit from laser levelling was estimated atINR 8207 per ha (*ibid.*, p.417). A technology developed by the Punjab Agricultural University to reduce water usage in paddy cultivation is tensiometer. Experimental evidence has established that there could be a water saving of up to maximum 3.7 million litres per ha with the use of the tensiometer (Sidhu, Vatta and Dhaliwal 2010). A history of paddy-wheat cropping systems in the state has clearly put considerable stress on the state's water resources, and thus, crop diversification, as an alternative strategy has been well-acknowledged and included in development plans of the national and state governments.

4.7.2 Policy discussion

The Government of Punjab has acknowledged that groundwater exploitation is a serious issue and various interventions have been envisaged to address the increasing ground water scarcity. A significant initiative has been the formulation of The Punjab Preservation of Sub Soil Water Act in March 2009.[10] The Act mandates that no farmer can sow paddy before the 10th of May. One of the main reasons for the groundwater depletion recognized by The Punjab Farmer's Commission is the early transplanting of paddy (before mid-June), which leads to over extraction of groundwater, as monsoon is still far away, temperatures are very high, and the evapotranspiration rate (ETR) is maximum.

The Punjab Preservation of Subsoil Water Act, 2009, was intended as one of the key interventions to combat the persistent overexploitation of ground water in Punjab's paddy belt. However, research that explores the implementation, outcomes, and efficacy of this legal intervention are limited and demonstrate contrary findings. The Act has been successfully implemented throughout the state but there are still a few violators. The policy also needs to include appropriate disincentives to ensure that the farmers adhere to the rules set by the Act.

The National Water Policy (MoWR 2012) recommends demand side management of water resources, including water-use efficiency and volumetric pricing of water. The Draft Agriculture Policy for Punjab (2013) recommends setting up of Water Resources Regulatory Authority to promote and regulate the optimum use of surface and ground water, promoting cost-effective water saving technologies, construction of water harvesting structures, and metering and charging for power supply beyond a fixed level of free supply.

The Punjab State Water Policy of 1997 tries to encompass all major aspects of groundwater conservation. It aims to ensure unbiased distribution and effective use of the available water resources and upgradation and improvement of the existing hydrology infrastructure. Through this policy, the government encourages and promotes use of improved modern irrigation technologies and spreads awareness about the need for conservation of the limited water resources available, while also adopting appropriate mitigation measures to check water pollution. The Water (Prevention and Control of

[10] It was initially promulgated as an Ordinance in 2008.

Pollution) Act of 1974 with amendment in 1988, also aims, as the State Water Policy (1997), to prevent, regulate, and reduce water pollution and to maintain or restore the wholesomeness of water. There are various regulations for conserving and augmenting groundwater provided under the Punjab State Tube Well Act, 21, of 1954.

The Punjab Pollution Control Board addresses the issues pertaining to groundwater pollution with the National Environmental Laws and Acts such as the Water (Prevention and Control of Pollution) Act, 1974, Amended 1988; Water (Prevention & Control of Pollution) Cess Act, 1977; the Environment Protection Act, 1986 and the associated rules; Water (Prevention & Control of Pollution) Cess Rules 1978.[11]

The Water Mission, under the Punjab State Action Plan on Climate Change, also acknowledges the issue of groundwater exploitation and suggests innovative strategies to address the issue; and emphasizes on having an integrated approach for water resource management.

There is scope to encourage and promote construction of artificial recharge structures at village level. At present there are no large scale initiatives which assure groundwater recharge. There is a need to include and foster construction of groundwater recharging structures at the policy level so as to have a holistic development. Research studies and analytical insights from the exercise points to the opportunity to design a holistic Ground Water Demand-Supply Management (G-DSM) policy, capturing the unique challenges and opportunities for way forward.

4.7.3 Stakeholder perspectives

The TERI researchers conducted questionnaire-based structured interviews with farmers to understand their perspective on groundwater conservation. The results are revealing in terms of how farmers perceive the change in groundwater level and quality. A majority of farmers are of the opinion that the quality of groundwater has degraded over the last few years and that the availability has also become worse (Table 4.18).

Table 4.18: Farmers' perceptions on change in groundwater availability in the last five to ten years versus state government statistics

Districts	Farmers' Perception (%)				GoP Assessment (depth in meters)		
	Worsened	Improved	No Change	Don't know	2004	2014	Change
Amritsar	80.39	7.84	9.80	1.96	14.41	17.10	-2.69
Rupnagar	88.00	6.00	2.00	4.00	14.51	14.51	0.00
Faridkot	12.73	34.55	52.73	0.00	7.94	10.21	-2.28
Sangrur	90.38	0.00	3.85	5.77	18.38	25.28	-6.90

Source: Field visits and Statistical Abstract of Punjab, various years

Interaction with farmers revealed that on an average an electric pump-set needs to be changed in five to ten years (Figure 4.18) with a new pump costing around INR 1 lakh. While on an average the cost for maintenance of a pump-set comes around INR 7000–8000 annually. The expenditure on electricity for farm activities is zero as the government provides free electricity for agricultural use.

Field interactions revealed that while there was widespread compliance to the Punjab Preservation of Subsoil Water Act 2009, government officials at the district level stressed the need for emphasis on the awareness and education campaign on the need for groundwater savings. Highlights of the stakeholder consultation in February 2014 have been shown in Table 4.19.

[11] For more details, see http://www.ppcb.gov.in/environmental_acts_rules.php. Last accessed on 1 September 2015.

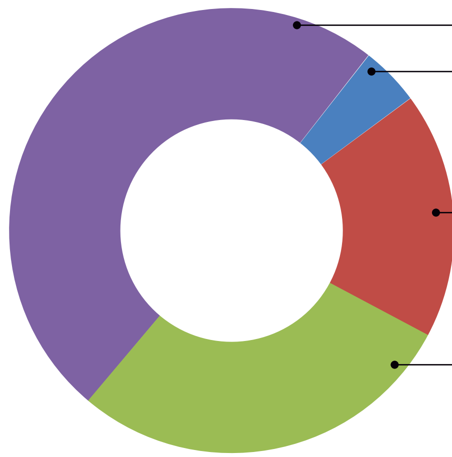


Figure 4.18: Time needed to change electric pump-set on average in Punjab
Source: Field Study

Table 4.19: Highlights of stakeholder interaction

Stakeholder	Issues	Existing initiatives
Village Headman	- Declining groundwater levels - Deteriorating groundwater quality - Water logging specially in the southwest regions of the state	- Awareness campaigns - Construction of water harvesting structures - Planting of eucalyptus in water logged areas
Soil and Water Conservation Office	- Declining groundwater levels - Deteriorating groundwater quality - Water pollution due to over utilization of fertilizer and pesticide by the farmers	- Construction of micro irrigation structures and renovation of ponds is being undertaken in various parts of the state for groundwater recharge - Awareness campaigns
Groundwater Cell	- Declining groundwater levels - Deteriorating groundwater quality - Lack of awareness amongst people regarding water conservation measures	- Promotion of water conservation measures and spread of awareness activities - Promotion and construction of water harvesting structures across the state.

Source: Field visits

4.7.4 Policy Level Vision

- Punjab is yet to **formulate a ground water policy.** It needs to develop an implementation framework for policies and mechanisms for operationalizing them. Given the over-exploited groundwater tables, deteriorating groundwater quality in most of the blocks in Punjab, there is a critical need to develop a comprehensive water conservation and management plan to rejuvenate water bodies and restore lakes and rivers that ensures the replenishment of water to the local aquifers and in general improves the water availability scenario in the state.
- An empowered institution dedicated for groundwater management is much needed along with funds for innovations to conserve ground water. **A dedicated fund for groundwater conservation** can be set up at the state level.
- The Electricity Act, 2003, made metering mandatory. These provisions will need to be enforced.
- Electricity subsidies are widely perceived to be one of the main causes of groundwater overexploitation. They encourage farmers to extract ground water at unsustainable rates which causes lowering of water tables, requiring more energy to extract groundwater.
- In the long term, there is an urgent need to bring about changes in cropping pattern by reducing area under paddy cultivation.

Institutional Innovations

- There is a need for **strengthening of groundwater authorities** in the state by providing more autonomy. This would help promote water conservation and recharge of ground water. Several watershed development projects are being implemented in the State, especially in the Kandi area. This needs to be sustained in the long term.
- Mechanisms for rational water pricing and sustainable financial performance of the local bodies.

Technology and Infrastructure

- **Water use efficiency needs to be increased** in the agriculture sector. The State of Environment Report of Punjab estimated that a 10 per cent increase in irrigation efficiency can help to bring additional 14 million ha area under irrigation. Punjab could learn from the experience of countries like Israel, which is based on the principle of 'More crop per drop'.
- The **ownership of expensive agriculture machinery** by individual farmers also **needs to be reduced**. These facilities should be provided by village cooperatives or private entrepreneurs on custom hiring basis so that groundwater is not exploited above sustainable levels affecting the water quality and availability.
- The development of infrastructure for feeder segregation for supply of power for agriculture needs to be implemented and monitored to curb misuse of electricity and thereby groundwater.
- Adopting demand driven approaches such as enhancing water use efficiency in all the three sectors, viz. agriculture, industries and domestic, would reduce unaccounted-for-water (UFW).

Information

- Developing water database and management using real time monitoring, linking billing with water supply network designs using Supervisory Control and Data Acquisition (SCADA) and cloud computing systems.

4.8 Ways Forward

Crop Diversification

1. **Sustained market procurement** of the crop produce is the primary driver which would induce farmers to decide to diversify their sown area from paddy to alternate crops. This could be ensured either by setting a MSP on the proposed alternate crops or by implementing an effective contract farming scheme or by strengthening market demand for Punjab's alternate crop produce within India and in international markets while establishing market linkages. Infrastructure facilities across the value chain need to be created.
2. **Convergence of activities and greater coordination** involving various national missions/programmes/policies that share a common vision like National Horticulture Mission, National Agroforestry Policy, National Mission for Sustainable Agriculture, National Food Security Mission with Crop Diversification Programme, could bear stronger and more resource-efficient results. This would require effective coordination between various intra-state departments and between central ministries and their state departmental counterparts. A special purpose vehicle, possibly under the mission mode could be conceived at the state level to carry forward the crop diversification programme. This institutional set up would ensure synergy in the implementation strategy across various stakeholders. There is a need for capacity building to operationalize crop diversification initiatives in a mission mode.
3. **There is need for an awareness and sensitization** programme among farmers and the rural community about the negative externalities due to the dominant wheat-paddy cropping pattern.
4. **Capacity building** and training of farmers for establishment of agro-based food processing units for value addition, for marketing new crops, and for land management should be another focus area of action for the state in the crop diversification drive.

Paddy Straw Management and Utilization

1. **Crop diversification** should be encouraged by the state by introducing support programmes and incentives for alternate crops. This would help divert area under paddy to other alternative crops in Punjab, leading to lesser paddy

straws and would also diversify the state's agriculture portfolio. Crop diversification if implemented well has the potential to manage the paddy straw burning issue.

2. **Accuracy and coverage of pollution monitoring systems** should be improved. This can play a significant role in managing the paddy straw burning issue. The ambient air of the entire state of Punjab is currently being monitored at 24 monitoring stations under National Ambient Air Quality Monitoring Programme (NAMP) that are set up in 11 cities (PPCB 2014). Building more monitoring stations will allow for continual improvement in monitoring and enable wider use of data for source apportionment and other scientific purposes. The state government should ensure that the monitors are well-calibrated and that the data is made available to public. Wider public release can both play role as a health advisory system and increase pressure on farmers who burn paddy straw from citizenry at large.
3. **Revisiting the incentive/disincentive mechanisms** around the popular 'polluter pays principle' for checking paddy straw burning may be considered by the state government. Imposing Section 188 of the Indian Penal Code or Section 144 of Criminal Procedure Code does not seem to be the answer to the problem of paddy straw burning because the scale of the issue is too large. It is suggested to set penalties, in accordance with the popular 'polluter pays principle' so that farmers are prohibited from burning paddy straw. The Government of Punjab has successfully enacted Punjab Preservation of Subsoil Water Act, 2009, which prohibits sowing nursery of paddy and transplanting paddy before the notified dates. The success of this Act can be attributed to the penalty mechanism which includes penalty of INR 10,000 for every month or part thereof, per hectare of the land till the period, such contravention continues, in addition to the recovery of the expenses incurred for destroying the nursery of paddy, or sown or transplanted paddy before the notified date. Environmental offences may be specifically recognized as criminal offences via a special legislation by the state government along with necessary safeguards. Such an offence, may be enforced effectively though principles of *malum in se*.[12]
4. **Private sector involvement** can contribute significantly in addressing the issue of paddy straw burning. The state should provide fiscal incentives to industries including Micro Small and Medium Enterprises (MSMEs) which use paddy straw as their raw material. Such industries should be promoted as these industries could source paddy straw from the fields and help curb the problem of paddy straw burning.
5. **Awareness campaigns** should be scaled up. Citizens in all age categories should be sensitized about the ill-effects of paddy straw burning and the potential ways of paddy straw management.
6. **Initiatives** by the state government addressing paddy straw management both directly and indirectly have common strands.The government may consider enhancing coordination between the statutes it has for paddy straw management and define a strategy to check paddy straw burning which enables the state to address sustainability concerns and also achieve agricultural growth.

Green Cover

1. **Tree species are recommended** for plantation along roadsides, agroforestry, and on farm plantation as the state of Punjab currently faces the problem of unavailability of land for forestry. Hence, the only way of increasing its green cover seems to be by increasing the tree cover outside forests. Different tree species recommended for different plantations include:
   - Roadside
     - Poplar *(Populus)*
     - Safeda *(Eucalyptus hybrid)*
     - *Dek (Melia azedarach)*
     - *Neem (Azadirachta indica)*

[12] *Malum in se* is a Latin phrase meaning 'wrong' or 'evil in itself'. The phrase is used to refer to conduct assessed as sinful or inherently wrong by nature, independent of regulations governing the conduct.

- Agroforestry
  - Poplar *(Populus)*
  - *Seesham (Dalbergia sissoo)*
  - Neem (Azadirachta *indica)*
- On farm
  - Mango *(Mangifera indica)*
  - Guava *(Psidium guajava)*
  - Lemon *(Citrus)*
  - *Neem (Azadirachta indica)*
- Horticulture
  - *Kinnow (Citrus)*
  - Lemon *(Citrus)*
  - Daisy Tangerine *(Citrus tangerine)*
  - *Amla (Phyllanthus emblica)*
  - Guava *(Psidium guajava)*
- In and around village common area
  - Litchi *(Litchi chinensis)*
  - *Chickoo (Manilkara zapota)*
  - *Kinnow (Citrus)*
  - Mango *(Mangifera indica)*
  - *Neem (Azadirachta indica)*
  - Guava *(Psidium guajava)*
  - Jamun (Syzygium cumini)
- Specific to waterlogged areas
  - *Safeda (Eucalyptus)*
  - Willow *(Salix)*
  - *Arjuna (Terminalia arjuna)*
  - *Jamun (Syzygium cumini)*

2. **Mandatory tree cover** provisions are required to increase tree cover outside forest. Enforcement of a mandatory minimum tree-cover requirement in agricultural fields, counter checked by necessary penalties, can help the state achieve the goal of 15% tree-cover.
3. **Alternative scenarios** for increasing tree cover can be considered. The present target of 15 per cent forest and tree cover by 2017 is highly ambitious. In order to increase the forest and tree cover in the state two scenarios are proposed, first scenario wherein 50 sq. km area under forest and tree cover is increased annually so as to reach a target of 9.9 per cent by 2047 and second scenario wherein 100 sq. km area under forest and tree cover is increased annually so as to reach a target of 13 per cent by 2047 (refer Figure 4.19).
4. **Promotion of agro-forestry** on a large scale by providing free or subsidized seeds, demonstrations, and training exercises is necessary. Also, there is a need for increasing the number of legal wood *mandis* where farmers can sell agro-forestry produced timber. Development of market-centric revenue models can help increase adoption of agro-forestry in the state.
5. **Building inventory of agroforestry related data** would be essential for evaluating the progress made in the field of agroforestry, and would also support research and development activities in the agriculture and forest sector.
6. **Promoting horticulture** would give the state long term tree cover as opposed to agroforestry. For this purpose the Kandi area in Punjab covering districts of Gurdaspur, Hoshiarpur, and Rupnagar would be suitable for fruit cultivation as it is situated at the foot hills of Shivaliks and has just the right amount of temperature required. There should be efforts

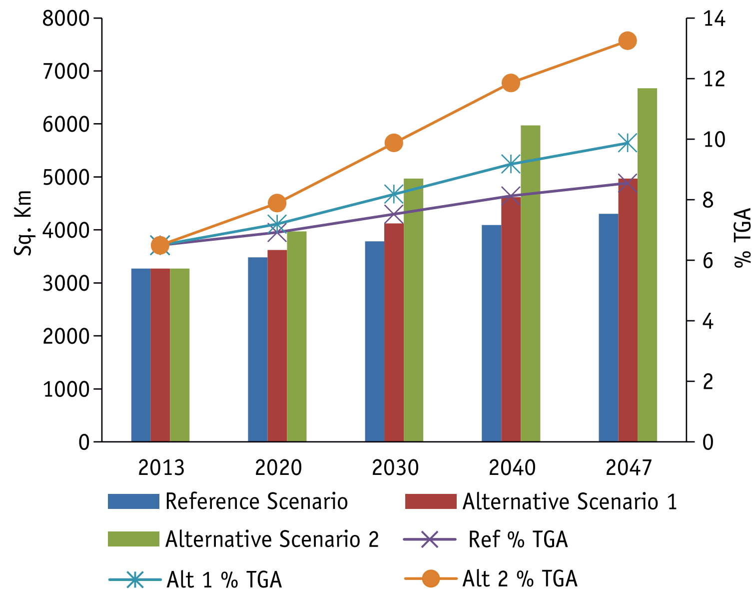


Figure 4.19: Probable scenarios for increasing forest and tree cover by 2047
(Note: *Reference scenario*- 30 sq. km annual increase assumed; *Alternate scenario - 1*- 50 sq. km annual increase assumed; *Alternate scenario - 2*- 100 sq. km annual increase assumed)
Source: TERI Analysis

to turn the Kandi area into a well-flourished horticulture belt. In addition to this, there is a need for establishment of proper market for selling the horticultural produce.

7. **Strengthening measures to check illegal deforestation** is essential for the state as people illegally cut down trees that are adjacent to their agricultural fields or for fuel purposes. There is a need for proper implementation of measures such as regular patrolling and penalizing violators in order to check illegal felling of trees.
8. **Conservation, restoration, and maintenance of wetlands** in the state is crucial to protect the bio diversity in these areas. The main tract of forest in the state is present near the Shivalik hills. In addition to this, the State has three major wetlands, viz. Harike, Kanjli and Ropar. Due to human interference, there is significant deterioration of these already existing forest tracts and wetlands.
9. **Introducing fiscal mechanisms to promote green cover:** The government could on a pilot scale look at mechanisms such as 'grain for green'. Under this mechanism the farmer could convert part of his land to green cover in return for the equitant monetary amount which the farmer would have got for growing grains. This has worked in countries like China.

Groundwater conservation

1. **Rationalization of electricity prices and gradual phasing out of subsidies** for irrigation, would contribute to both water conservation and economic gains. Interventions around metering and levying of tariffs are promising, provided the farmers are assured of quality power supply.
2. **Need for introduction of volumetric pricing of water**, to arrest the overexploitation of groundwater resources. There is also evidence that farmers are willing to pay for the electricity (Jain, 2006) and the government should initiate a discussion on this issue with the farmers and other stakeholders in the state.
3. **Feeder segregation** is suggested as a strategy for improving the quality and quantum of power supply to agriculture. This technique has particularly been successful in Gujarat.
4. **Crop diversification** is strongly recommended as a solution for shifting from water intensive to a less water consuming crop regime. This would also promote other sectors such as dairy farming, animal husbandry, horticulture, fisheries, and bee keeping. The state has to promote a progressive agricultural pricing and energy policy that will work together to incentivize adoption of less-water intensive crops and reduce groundwater draft.

5. **Further empirical research** on the existing knowledge gaps in understanding the efficacy of the technical solutions and the regulatory mechanism would also strengthen the policy discourse in the State.
6. **Construction of artificial recharge structures** to match the rate of extraction with rate of aquifer recharge is proposed. If creation of recharge structure were to be made compulsory for every few blocks and provisions for incentives and subsidies for aquifer recharge were made available, then the rapid fall in the water table could be arrested.
7. **Strengthening the canal network** in Punjab is crucial in order to reduce the dependence on tube wells. There is a need to maintain the already existing network, assuring availability of water throughout the year and hence, restoring the reliability factor. Along with this there is also a need to limit the number of tube wells so that the farmers shift their agricultural water usage to canals.
8. **Effective management and utilization of groundwater conservation fund** is recommended and continual emphasis needs to be laid on its improvement. This would ensure that the activities such as construction of groundwater recharging structures can be effectively supported and groundwater conservation awareness activities can be effectively propagated amongst masses.

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4.10 Annexures

Annexure 4.1: Analysis of the findings from the structured questionnaire survey

In the survey carried out, 208 farmers were interviewed in seven villages across four districts viz. Amritsar, Faridkot, Rupnagar and Sangrur. Interviews specific to the issue of crop diversification were done in Amritsar and Rupnagar, while those specific to the issue of green cover were done in Faridkot and Sangrur. The issue of paddy straw management and groundwater conservation was covered in all the four districts.

Crop Diversification (Total number of farmers interviewed 101)

Structured interview of farmers revealed that the main reasons behind the dominance of paddy-wheat cropping pattern can be attributed to the assured market availability and a fixed minimum support price (MSP). The field visit data shows that comparative economic advantage, stable productivity levels and stable price levels are also having an influence on the current paddy and wheat regime (Exhibit 1).

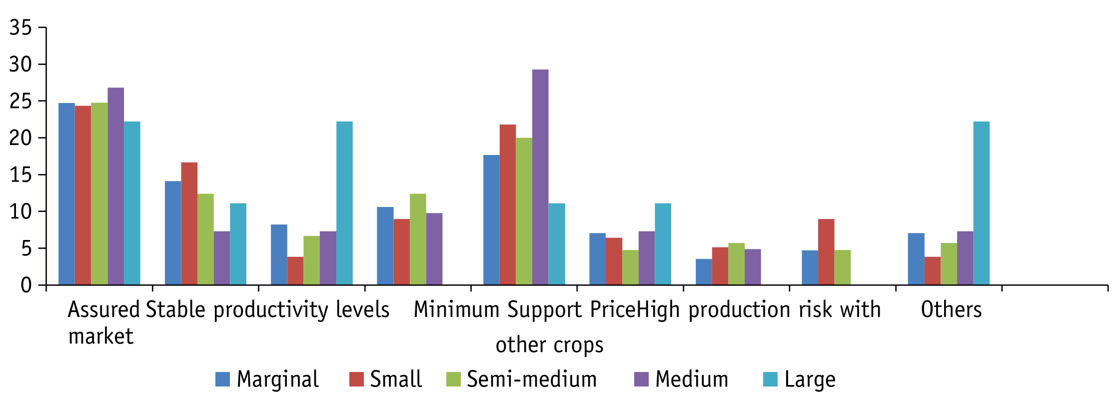


Exhibit 1: Reasons for cultivating wheat-paddy (percentage of total)

The field visit interactions showed that increased costs for inputs, increased cost of tubewell and availability of labour were the main challenges experienced in continuing with the paddy-wheat cropping pattern (Exhibit 2).

An analysis of the data collected shows that around 50% farmers in marginal, small, semi-medium and large categories are aware of the impacts of cultivating paddy-wheat. In the medium farmer category, a majority (79%) are unaware of these impacts. Amongst those who are aware, depletion of ground water, deterioration of soil health and danger of pest/insect attack as considered as main impacts.

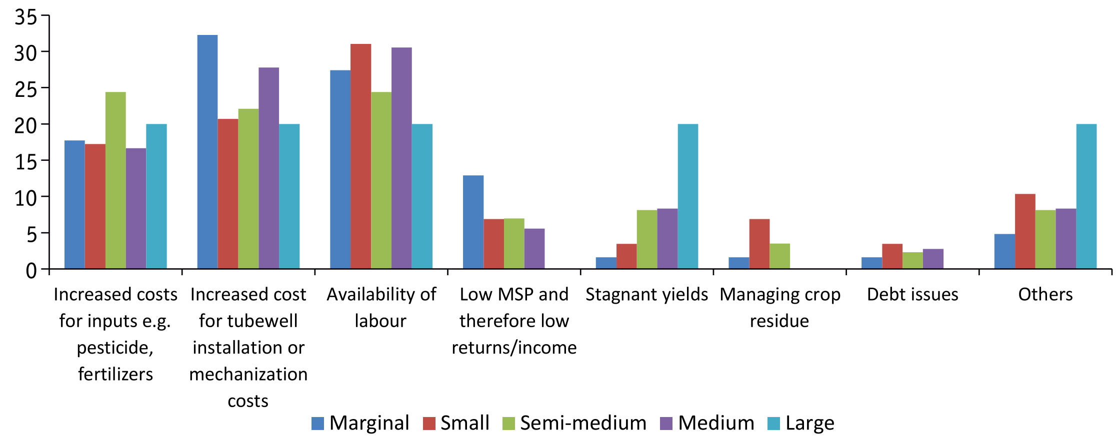


Exhibit 2: Current challenges experienced in continuing with the wheat-paddy system

Vegetables, Pulses, Maize and Sugarcane seem to be a popular choice for diversifying from current wheat and paddy regime across all farmer categories except large farmers, who are willing to adopt cultivation of fruits, vegetable and agro forestry (Exhibit 3).

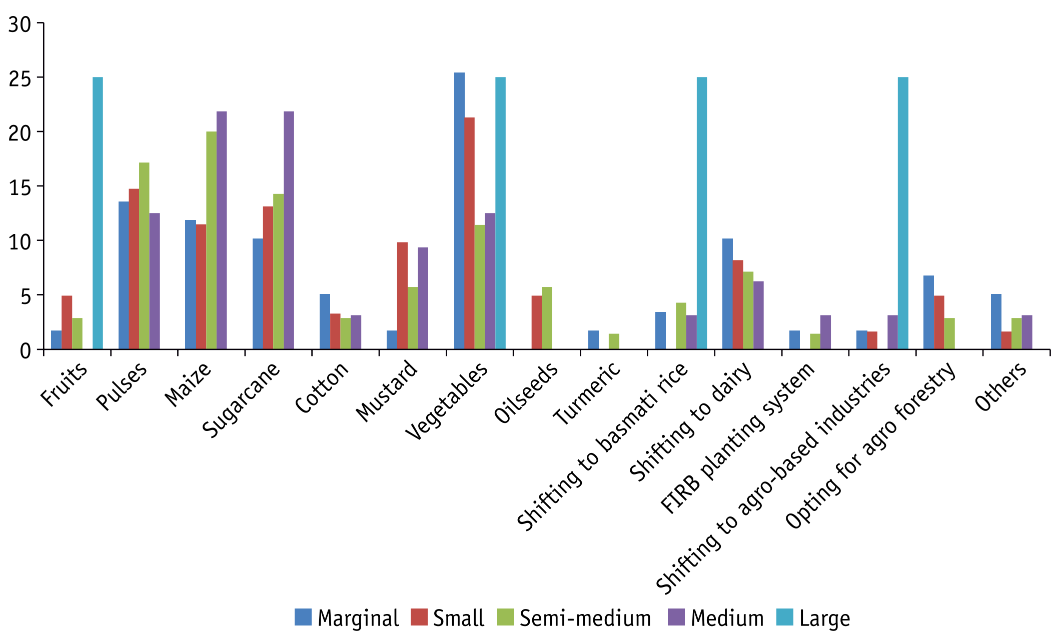


Exhibit: 3: Alternatives willing to adopt

Most of the farmers think that lower input use and cost, better soil health and improved returns are benefits that one can expect through crop diversification. A few of the large farmers see food and nutritional security as a benefit too. In terms of support from government, cold storage, collection and transport facilities, MSP for other crops, training and insurance against crop damage or failure seem to be popular choices amongst all categories of farmers.

Paddy straw (Total number of farmers interviewed 208)

On average wheat straw generated by marginal, small, semi-medium, medium and large farmers is 14.79, 17.68, 13.36, 18.81 and 29.12 quintals respectively. On average paddy straw generated by marginal, small, semi-medium, medium and large farmers is 16, 15.60, 25.13, 27.78 and 58 quintals respectively.

A majority of farmers in all the categories burn paddy straw. A significant proportion of marginal, small, semi-medium and medium farmers use paddy straw as cattle feed (Exhibit 4).

A majority of farmers in all the categories use wheat straw as cattle feed. A good proportion of marginal, small, semi-medium and medium farmers burn the wheat straw, while almost 35% of large farmers sell it instead of burning it (Exhibit 5).

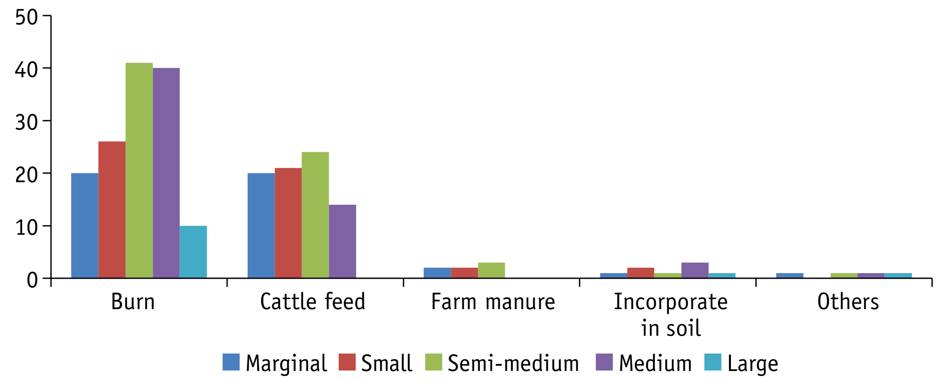


Exhibit 4: Paddy straw utilization

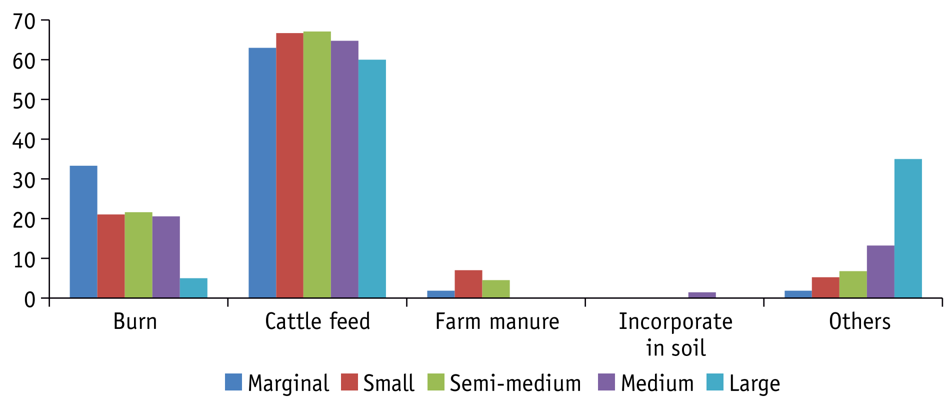


Exhibit 5: Wheat straw utilization

Green Cover (Total number of farmers interviewed 107)

There is lack of participation in agroforestry practice in the state. The field interview with farmers shows that more than 50 % of the farmers in all the categories are not practicing agroforestry (table A1). Maximum number of farmers (81.25 %) not practicing agroforestry falls in small farmer category. Maximum agroforestry is being practiced by medium farmers (45.71 %). Though many farmers don't practice agroforestry, they believe that agroforestry has the potential to increase forest cover. Plantation through public programme was appreciated only by semi-medium and medium farmers (Exhibit 6).

Table A 1: Farmer category wise percentage of farmers practicing agro forestry

Farmer Category	Yes	No
Marginal	36.36	63.64
Small	18.75	81.25
Semi-Medium	43.33	56.67
Medium	45.71	54.29
Large	33.33	66.67

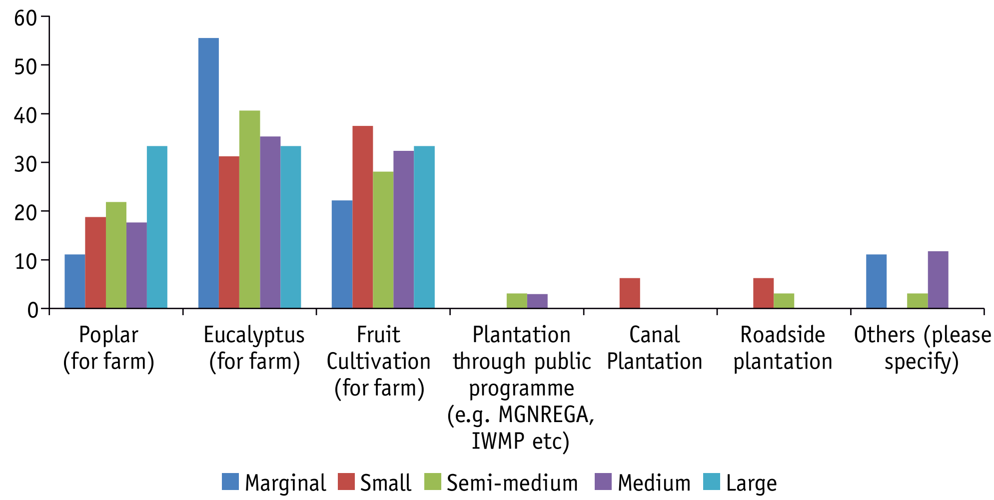


Exhibit 6: Options preferred for agroforestry

Table A 2: Options preferred by farmers for agroforestry

	Percentage of farmers under each landholding category				
	Marginal	**Small**	**Semi-Medium**	**Medium**	**Large**
Poplar (for farm)	11.11	18.75	21.88	17.65	33.33
Eucalyptus (for farm)	55.56	31.25	40.63	35.29	33.33
Fruit Cultivation (for farm)	22.22	37.5	28.13	32.35	33.33
Plantation through public programme (e.g. MGNREGA, IWMP etc.)	0	0	3.13	2.94	0
Canal Plantation	0	6.25	0	0	0
Roadside plantation	0	6.25	3.13	0	0
Others (please specify)	11.11	0	3.13	11.76	0
Sum	100	100	100	100	100

Annexure 4.2: Classified images of the villages where farmer interaction were conducted

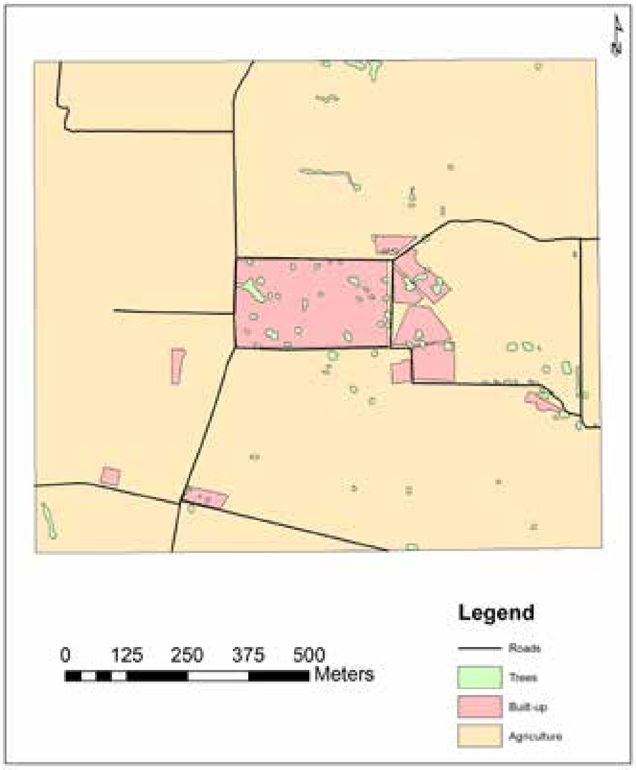


Exhibit 1: Rai Singh Wala (2002)

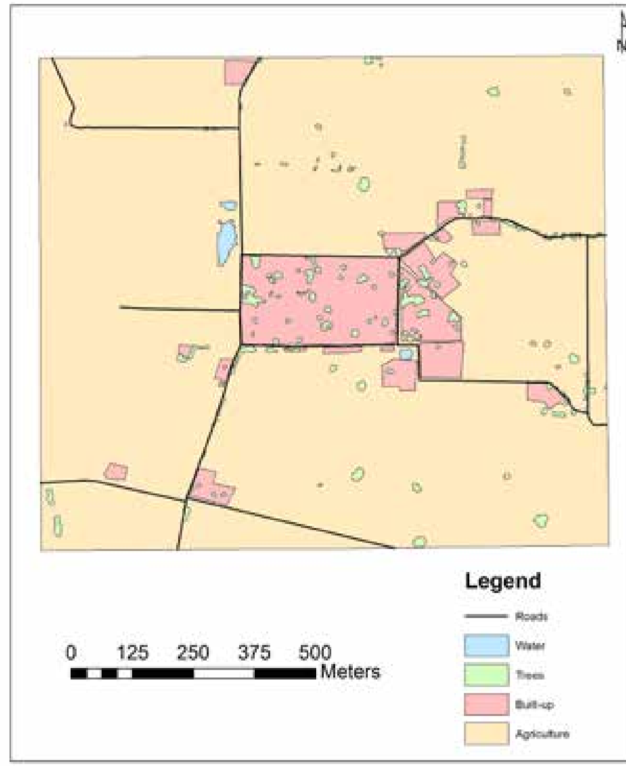


Exhibit 2: Rai Singh Wala (2014)

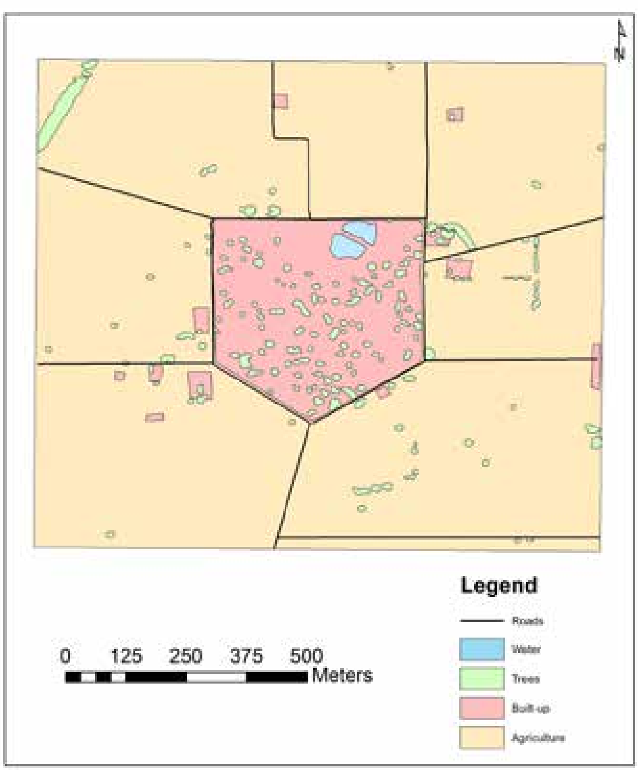


Exhibit 3: Virewala Kalan (2003)

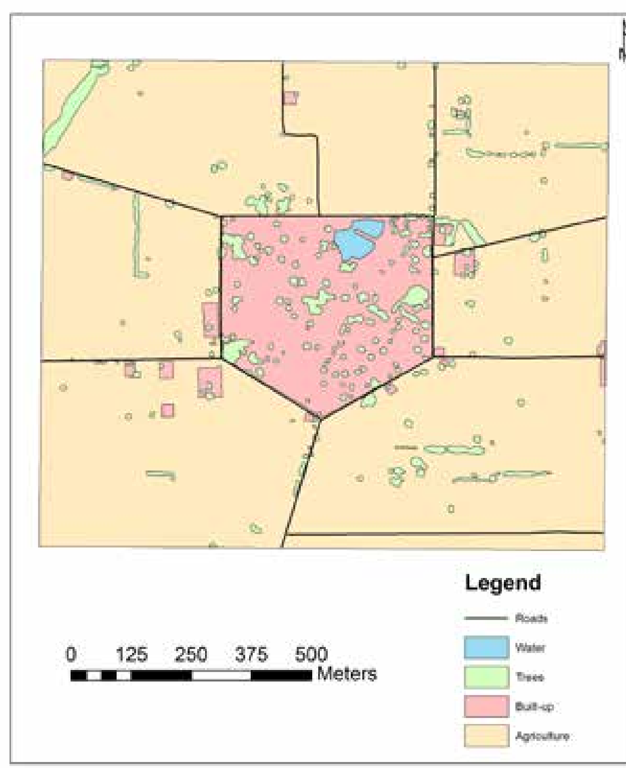


Exhibit 4: Virewala Kalan (2011)

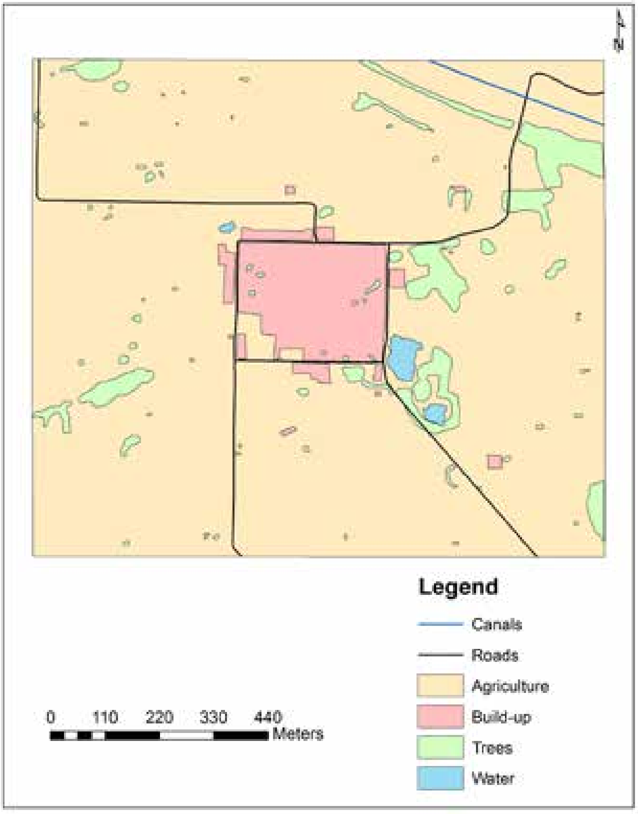


Exhibit 5: Jhampur (2003)

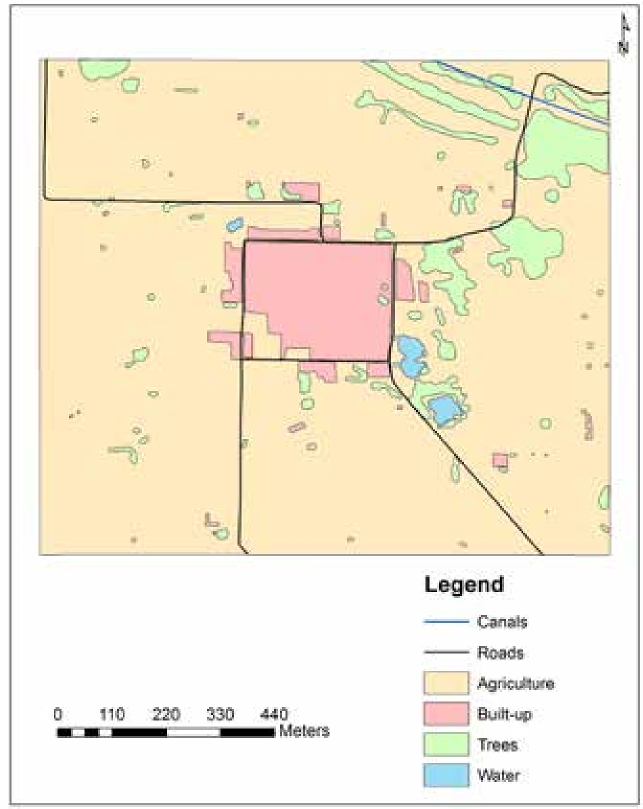


Exhibit 6: Jhampur (2014)

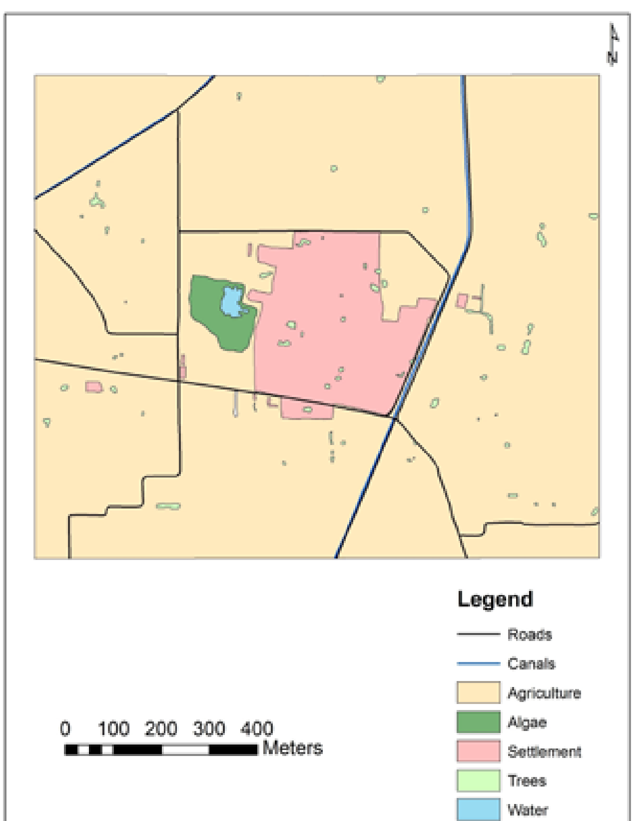


Exhibit 7: Dadupura (2006)

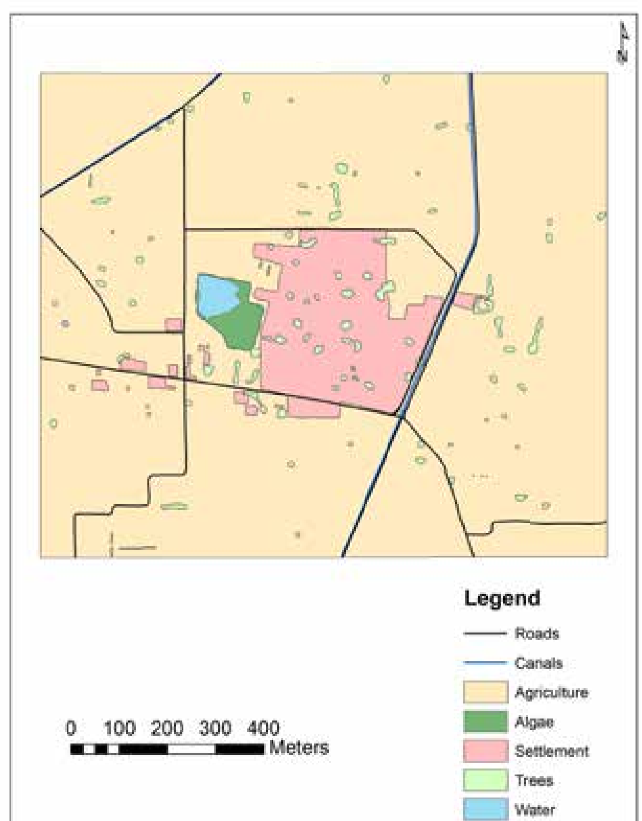


Exhibit 8: Dadupura (2013)

Annexure 4.3: Ownership cost and maintenance cost of machines

	Baler	Raker	Cutter	Happy seeder	Rotavator
Purchase price	875000	50000	25000	120000	83000
Years machine will be owned	10	10	10	6	6
Interest rate#	0.12	0.12	0.1075	0.12	0.12
Capital recovery (interest and depreciation)	154861.1	8849.2	4200.63	29187.09	20187.73
Total ownership cost (per annum)	154861.1	8849.2	4200.63	29187.09	20187.73
Maintenance cost (per annum)	10000	1000	1000	2500	2000
Total ownership plus maintenance cost (per annum in INR)	**164861.14**	**9849.21**	**5200.63**	**31687.09**	**22187.73**

Notes:

1. Based on Grain Truck Transportation Cost Calculator and Ag Decision Maker - Iowa State University Extension. For more details refer to http://www.extension.iastate.edu/agdm/crops/html/a3-29.html
2. #Interest rate is taken to be constant for the 10 year period and is in line with the interest rate on loans advanced by Punjab State Cooperative Agricultural Development Bank Ltd. For details refer to http://www.punjabcooperation.gov.in/html/pscadb.html
3. The primary data for operating and maintenance cost were obtained during field visits.

Annexure 4.4: Operating cost per acre

	Baler	Raker	Cutter	Happy seeder	Rotavator
Cost of diesel (INR/ litre)	49	49	49	49	49
Litres consumed per acre	1	1.5	1.5	7	7
Fuel cost/acre at INR 49	49	73.5	73.5	343	343
Number of hours machine take on one acre	0.5	0.3	0.3	1.5	1
Number of labour	1	1	1	2	1
Labour cost per day (in INR)	500##	500##	500##	700*	400
Labour costs per acre (INR)	31.25	18.74	18.74	131.25	50
Operating cost per acre (in INR)	**80.25**	**92.24**	**92.24**	**474.25**	**393**

Notes:

1. The primary data for operating cost calculation were collected during field visits.
2. In practice, baler, raker and cutter are used in combination and complement each other. The entire process of using these machines involves 4 tractors and minimum 5 human resources (4 drivers and 1 labour). The cost assessment does not include the cost of transporting bales away from field.
3. ##A labour supports the driver of Baler, raker and cutter therefore; INR 100 has been added in the labour cost per day for each of the machine over and above that of driver (INR 400).
4. *Happy seeder requires 1 labour costing INR 300 and 1 driver costing INR 400 and hence the total labour cost is INR 700 per day.

5

Energy Analysis for Punjab

5.1 Introduction

The state of Punjab has done well in terms of economic growth and per capita income. As can be seen from Figure 5.1, the state has shown an increasing trend in terms of the net state domestic product and per capita net state domestic product. Modelling projections show that the service sector will grow at a higher rate in comparison to the industry sector (Figure 5.2). Agriculture will have a stable growth rate though service and industry sector can move towards an incremental growth at a rising rate, impacting the per capita income of the State which can also experience an increasing pattern.

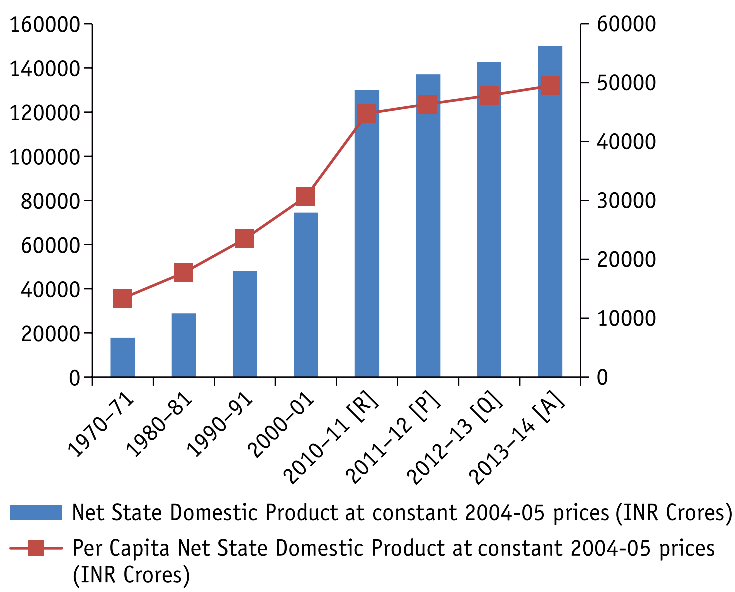


Figure 5.1: Historical pattern of the net state domestic product
Source: Economic Advisor, Government of Punjab

In terms of population projection, the rural and urban population growth rate is expected to gradually attain a stabilization pattern in future though it will continue to grow (Figure 5.3). The rural and urban population growth rate is based on a bottom up modelling exercise considering the Population Foundation of India (PFI), Scenario B.

While there will be a growing demand for industry, construction, and other value added services such as retail trade, hotels and restaurants, real estate, and community services and remittances, tourism and welfare expenditures (both by government and other social organisations), it has to be ensured that there is an increase in productive capacities, structural transformation, enhanced economic competitiveness, and improved institutions to sustain growth balancing the environmental and social sustainability.

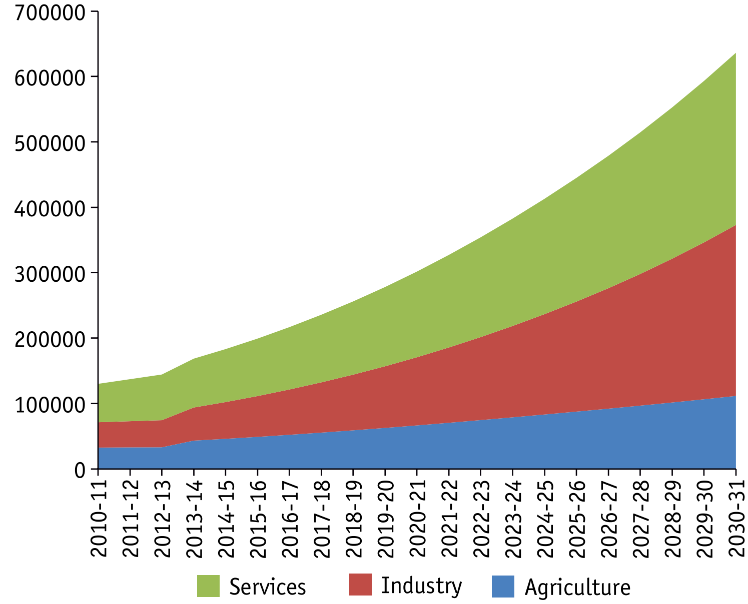


Figure 5.2: Projections for State NSDP Growth – Services, Industry, and Agriculture
Note: State NSDP has been calculated at 2004–05 constant prices (INR billion)

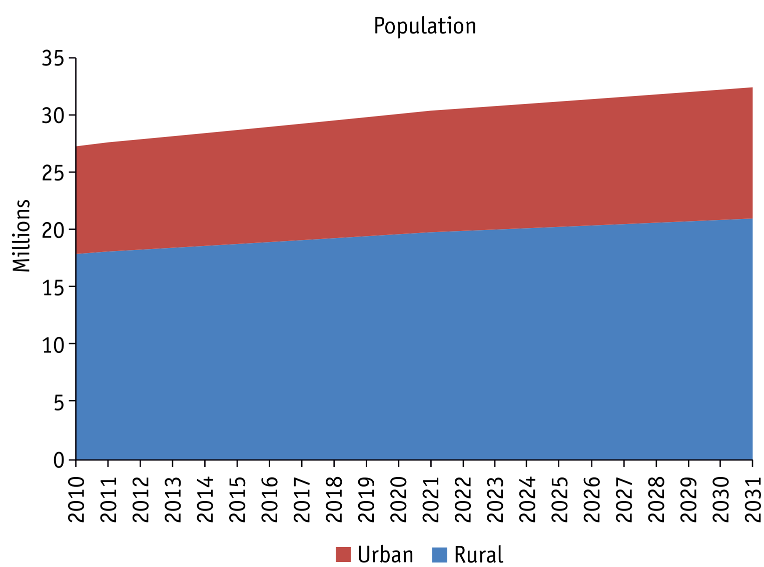


Figure 5.3: Population projection based on PFI Scenario B

In this regard, the state can create a perspective plan of green growth and development of Punjab involving strategic planning and including sectoral perspective plans with a focus on structural transformation, rural-urban dynamics as well as employment.

Rising per capita income, population, projected growth in the industry, and services sector is envisaged to create a demand for energy. However, the energy demand needs to be met from an energy mix which is diverse and includes a portfolio of renewable energy. This has to be also complemented by a set of energy demand management measures while the state economy grows. Energy supply and demand side is the focus of this analytical component.

5.2 Energy Situation in Punjab

Figure 5.4 shows the installed capacity and electricity generation in Punjab. As it can be inferred from the graph, the installed capacity has grown almost 8 times from 1970–71 to 2011–12. The generation has increased at a compound annual growth rate (CAGR) of 6.5 per cent from 1970–71 to 2011–12.

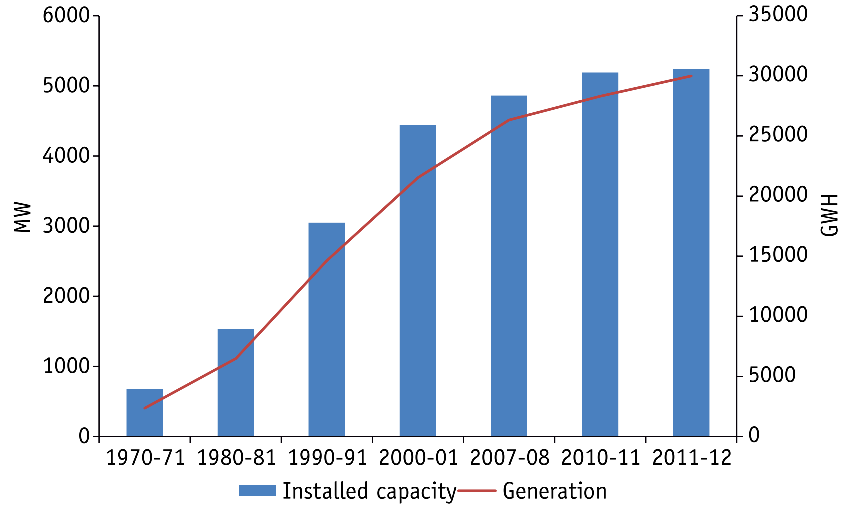


Figure 5.4: Installed Capacity and Electricity Generation in Punjab
Source: Statistical Abstract of Punjab 2012, CEA 2014

Punjab is the fourth most energy intensive state in the country (TEDDY 2015). The commercial energy supply is heavily dependent on fossil fuels in Punjab. In Punjab, the total installed capacity for electrical energy generation was 5,238.81 MW for 2011–12. The share of thermal energy (coal) in the total installed capacity was almost 50 per cent and was 2,655 MW in 2011–12. The share of hydro and renewable energy in the total installed capacity were 42.5 per cent and 7.5 per cent, respectively, for 2011–12. The share of renewables has increased from a mere 0.52 per cent in 2004–05 to 7.5 per cent in 2011–12. But the share of renewables in the installed capacity is still lower than the all-India average of 12 per cent. Coal-based electricity generation accounted for more than 65 per cent of the total electrical energy generation in Punjab, followed by hydro at 32 per cent and renewables at 3 per cent for 2011–12. Recently, the World Bank has rated Punjab's progress in this solar energy to be best of all states of India.

An energy balance for the state has been constructed to get the larger picture of energy demand and supply side. Data for 2010–11 is considered as these were available for the commercial energy supply and demand sectors. Total energy consumption in Punjab is the sum total of all petroleum products, coal, power, and renewables being consumed across agriculture, industrial, domestic, transport, and commercial sectors.

From an energy balance accounting conducted for the state model baseline situation, total energy demand was 9.68 Mtoe in 2010–11. Through the energy balance accounting, industrial sector contributed 32 per cent followed by transport at 25 per cent in 2010–11. More than 88 per cent of the coal was consumed in the power sector for electricity generation and the rest 12 per cent was consumed in the industrial sector for captive power generation in 2010–11.

Given the limited and unevenly distributed supply of non-renewable energy sources, it can become difficult to meet the demand relying on fossil fuels. Renewable energy sources can play an important role in this regard. Harvesting renewable energy is one of the options for reducing fossil fuel dependence of the state for a future green growth and development roadmap. This has to be attained through the existing policies and new ones, if required.

Policy changes are easier to analyse when impacts of various measures can be properly quantified. The distinct and diverse energy realities that characterize Punjab necessitate a more detailed examination of the state's future energy supply and demand situation. Therefore, a multi sector approach on the energy supply and demand side needs to be constructed for that purpose.

5.3 Approach

A multi-sector approach that takes cognizance of the various socio-economic, demographic and energy aspects of the state of Punjab is essential for projecting future energy supply and demand. Several macro level energy-economy modelling approaches have been used to analyse future trends of energy supply and demand mix. The Long-Range Energy Alternatives

Planning system (LEAP) is a bottom-up, scenario-based energy/economy/environment modelling tool which has been applied in the case of Punjab. With a flexible data structure, LEAP allows for an analysis rich in technological specifications and end-use details that allows the user many choices in setting parameters (UNFCCC, 2008). It is widely used to project energy supply and demand situations, in order to forecast future patterns, identify potential challenges, and assess the likely impacts of energy policies on various areas at the local, national, and global scales.

The diagram below gives a pictorial representation of the modelling process followed in the new modified LEAP model developed for the state of Punjab (Figure 5.5). Here energy demand comprises of primary and secondary energy demand. The various end-use sectors are—agriculture, industry, transport, residential, and commercial sectors. Energy efficiency aspects in all these sectors are considered while estimating total energy demand from these sectors.

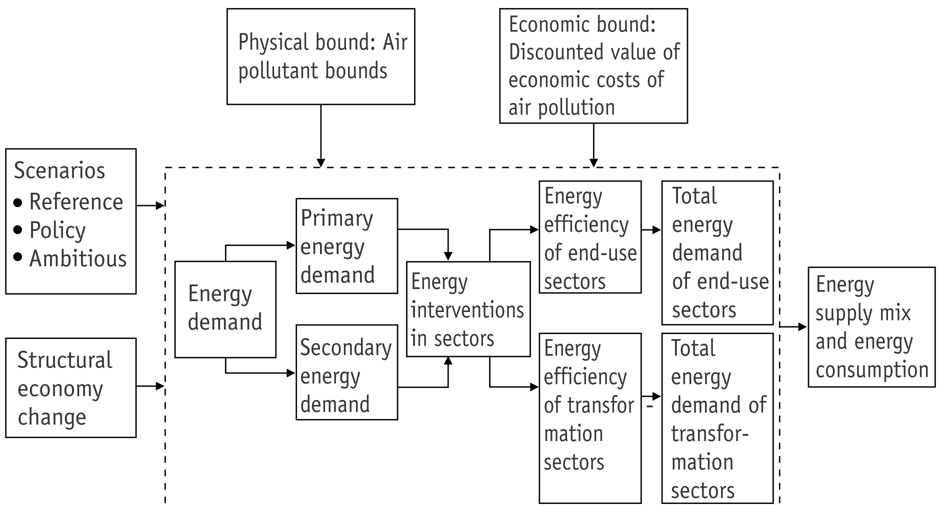


Figure 5.5: Modelling Framework

The energy model broadly considers gross state domestic product, population, sectoral shares (agriculture, industry, services), urbanization rate, rural, urban population growth rates, as major inputs that drives the demand for energy in the state. Demand for energy in the state increases with a rise in sectoral value added, per capita income. Per capita energy consumption increases as the industry and service sector of economy grows. Every sector of the economy experiences a growth in the demand for energy. However, the extent to which energy grows is different and depends on the inherent characteristics of the sector which are contextualized suiting the state situation.

The above mentioned modelling framework applies the following sectoral variables, parameters across the scenarios of the model before the equation context of the modelling is established. Basic assumptions of key variables, parameter patterns across scenarios are indicated in Table 5.1.

For green growth and development, constraints on pollutants like particulate matters (PM10, PM2.5) are also imposed on the model as while the state grows it also has to check the impacts of the growth on the pollutants. The annualized economic costs of these pollutants are to the tune of 2 per cent of the state Gross Domestic Product (GDP) every year and hence, it has been used as a constraint bound in the model. This modelling algorithm assumes certain bounds of economic costs due to air pollution.

Scenarios of the model

There are three scenarios considered in the model—Reference, Policy, and Ambitious.

- **Reference scenario** is the business-as-usual scenario which is structured to provide a baseline that shows how energy trajectory would evolve, provided current trends in energy demand and supply are not changed.
- **Policy scenario** considers the impact of state level policy changes and thus takes into account more efficient consumption, fuel substitution, and increased modern, clean energy access. The role of renewable energy supply sources is crucial here.

Table 5.1: Basic assumptions for key variables for the LEAP-Punjab model

Key variables	Observed (2014/15)	2021	2031	Source of observed data
Growth rate of GDP (%)	5.32	7.50	7.50	Economic and Statistical Organization, Government of Punjab
GDP (INR billion)	1841	3034	6399	State Statistical Abstract
Rural Population (millions)	18.64	19.82	21.02	Population Foundation of India, Scenario B, Census of India
Urban Population (millions)	9.81	10.58	11.42	Population Foundation of India, Scenario B, Census of India
Population growth rate (%)	0.76	0.73	0.73	Population Foundation of India, Scenario B, Census of India
GSDP -Agriculture (% total GSDP)	23	22	15	Economic and Statistical Organization, Government of Punjab
GSDP Industry (% total GSDP)	27	28	28	Economic and Statistical Organization, Government of Punjab
GSDP Services (% total GSDP)	50	50	57	Economic and Statistical Organization, Government of Punjab

- **Ambitious scenario** is ambitious in the sense because it entails faster implementation of energy and fuel efficiency measures, penetration of new technologies, fuel switching possibilities, and renewable energy-based supply provisions.

The assumptions for these three scenarios can be seen in Table 5.2. Data for these are listed in Annexure 5.1.

In addition to the above scenarios, a **structural change scenario** is also examined where the state economy maintains a stable share of agriculture sector in the future. In this scenario, the industry sector grows marginally, owing to growth of some of the small and medium industries and then the share of the industry sector stays stable. The service sector share faces an increase in future. Owing to this, any surplus power generated can be absorbed in the industry and service sector with an energy demand reduction in the agriculture sector.

In reference, policy, and ambitious scenarios, a series of policies and measures aimed at diversifying the energy supply and reducing total energy demand in Punjab state were assumed to have been implemented. The scenarios were developed in the LEAP-Punjab model under different sets of options—the clean energy substitution (CES) measure, the industrial energy efficiency (IEE) measure, energy conservation in buildings (ECB), other energy conservation measures (ECM), motor vehicle control (MVC) measure, renewable energy sources (RES) measures, capacity utilization measures (CUM), public transport measures (PTM), transport modal shift (TMS), motor fuel efficiency (MFE), and clean coal technology (CCT). The set of conditions is detailed in the respective measures, and the policy options and assumptions in the different measures, are given in Annexure 5.2.

Following the above state level modelling frame and activities, the analysis applies a Punjab specific LEAP model with energy system optimization techniques, complemented by constraints imposed on physical bounds and economic costs of air pollution for the state of Punjab.

Equation framework of the model: A Short Explanation

The study develops four green growth and development scenarios till 2051, using a bottom-up approach. However, given the policy decision making horizon of the State government, projections till 2031 are being indicated for relevant policy decision-making. These four scenarios are developed on the basis of demand and supply analysis, with low carbon and development

Table 5.2: Major Parameters Used in the LEAP-Punjab Model Scenario

Sector	Scenario fuel/technology		Observed data	2021			2031			Measures
				Ref	Pol	Amb	Ref	Pol	Amb	
Industry	Electricity	Intensity (kWh /INR)	0.0036	0.003	0.0015	0.0009	0.0028	0.0014	0.0009	IEE
	Coal	Industrial coal (%)	23	24.26	22.90	22.5	24.5	24.18	23.84	CCT/ CES
	Diesel	Diesel (%)	8.88	10.21	10.07	9.93	10.42	10.27	10.13	IEE/ CES
	LPG	LPG (%)	0	0	0	0	0	0	0	CES
	Fuel/ Furnace oil	Fuel oil (%)	4.69	4.76	4.69	4.62	4.82	4.75	4.7	CES
	LDO	Light Diesel Oil (%)	0.0008	0.0008	0.0008	0.00079	0.00082	0.00081	0.0008	CES
	Gasoline	Gasoline (%)	0	0	0	0	0	0	0	IEE
	LSHS/HHS	(%)	8.1	8.21	8.1	7.99	8.33	8.21	8.1	IEE
Transport	Bus	Bus (Modal Share Growth (%)	10	15	18	20	22	25	27	TMS/ MVC
		CNG bus (%)	0.5	0.7	1	1.2	1.5	1.7	1.9	CES
		Electricity bus (%)	0	0.25	0.33	0.41	0.32	0.43	0.45	CES
		Omni Bus (%)	2	2.1	3	3.5	3	3.2	3.7	TMS/ MVC
		Fuel efficiency (litre/ km)	0.0348	0.0308	0.0283	0.0263	0.024	0.022	0.021	MFE
	Truck	Growth (%)	30	29	28	26	28	27	25	TMS
	Car	Growth rate (%) (based on modal share)	20	23	22	21	25	24	23.5	MVC
		Gasoline (%)	58	56	53	51	54	52	50	CES

		CNG (%)	2	2.5	3	3.25	3.4	3.5	3.6	CES
		Electricity (%)	0	0	0	0	0	0	0	CES
	Two Wheeler vehicle	Modal Share Growth (%)	30	32	31	29	33	29	28	TMS
	Taxi	Modal Share Growth (%)	7	8	7.5	7	9.5	9.2	9	TMS
	Three wheeler	Modal Share Growth (%)	3	3.1	2.9	2.8	3.2	2.7	2.6	TMS, MVC
Commercial	Electricity	Intensity (kWh/INR)	0.0013	0.0117	0.00084	0.0005	0.0008	0.00065	0.000647	ECB
	Oil (Diesel)	Intensity (MTOE/INR)	0.000000197	0.00000021	0.000000208	0.000000194	0.000000224	0.000000219	0.000000205	ECB
Agriculture	Tractor	Diesel (%)	12.3	16.61	16.44	16.17	20.06	19.53	19.01	MFE
	Agri Implements	Diesel (%)	5.1	7.84	6.03	4.65	9.66	6.47	4.34	MFE
	Agri Pumpsets	Diesel (%)	41.96	41.96	37.96	35.96	34.94	32.94	30.94	MFE
		Electrical (%)	58	58	62	64	65	67	69	CES
		Decentralized solar (%)	0.04	0.04	0.04	0.04	0.06	0.06	0.06	CES
Transformation	Power plant	Coal (GW)	4.7	4.98	4.88	3.55	5.48	5.04	3.8	CCT/ CES /CUF
		Hydropower (GW)	0.11	0.1173	0.1242	0.1449	0.1311	0.1518	0.1587	CES
		Biomass (GW)	0.8	0.8	0.96	1	1.1	1.21	1.31	RES
		Solar (GW)	0.87	1.06	1.81	2.49	1.41	1.99	2.61	RES
		Waste (GW)	0.01	0.011	0.03	0.041	0.013	0.033	0.045	RES
		SHP (GW)	0.05	0.0527	0.0558	0.0651	0.0589	0.0682	0.0713	RES

Note: Data sources are listed in Annexure 5.1.

options on the energy supply and demand side for the period 2005 to 2051. The equation framework which is applied in the state model structure is given below.

$$ED_k = \sum\sum AL_{k,j,i} \times EI_{k,j,i} \qquad \text{Eq (1)}$$

Total energy consumption includes total final energy demand and energy transformation. Energy demand can be calculated by the above equation 1 (Eq 1) : where ED is the total energy demand, AL is the activity level, EI is the energy intensity, i is the sector, j is the end use technology , and k is the fuel type. Differing end use technology equipment and end use energy demand compositions in different scenarios will result in various AL and EI, thereby reflecting the changes in energy demand. Net energy consumption for transformation can be expressed as in Eq (2): where ET is the net energy consumption for transformation, ETP is the energy transformation product, m is the type of primary energy, n is the technology, t is the type of secondary energy, and $e_{m,n,t}$ is the energy consumption of fuel type m to produce unit secondary fuel type t in end use technology. Various technology choices in different scenarios will result in various ETP and $e_{m,n,t}$ which then reflect the changes in energy demand.

$$ET_m = \sum\sum ETP_{n,t} \times (e_{m,n,t} - 1) \qquad \text{Eq (2)}$$

5.4 Energy Supply Scenarios

Currently, there has been a large-scale coal-based thermal capacity addition in Punjab. Investments in these coal-based thermal power plants have to be utilized in future before any new large-scale capacity addition is implemented. Punjab is importing coal to run many of the thermal power plants, irrespective of its environmental cost and air pollution. On the other side, there is a growing economy which is demanding energy. A large part of it is satisfied by coal-based energy as of now.

Therefore, keeping the future of a green growth and development path of the state energy, environmental, social, and economic considerations have to be balanced. If the Punjab economy is allowed to grow and consume as it has been doing now, then the primary energy supply from coal in 2031 can reach 21.77 Mtoe (which is not sustainable considering the environment, ecology, and fiscal situation).

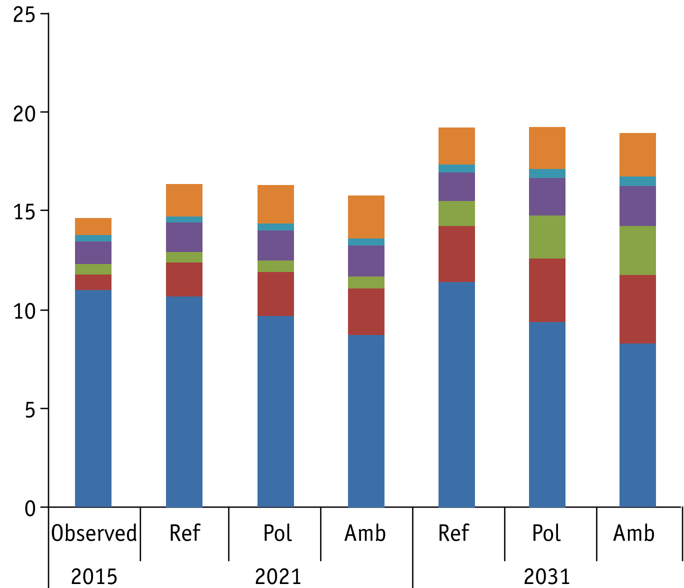
With the constraints of environmental degradation, economic cost of air pollution, loss of fiscal resources, Punjab economy's primary energy supply from coal needs to stabilize at 11.40 Mtoe in the reference scenario of 2031. This is arrived after conducting an energy optimization exercise for the entire economy with constraints on air pollutants.

For the state, in reference scenario, primary energy supply from coal increases from 10.68 Mtoe in 2016 to 11.40 Mtoe in 2031(Figure 5.6). Primary energy supply from coal cannot increase beyond this, given the current situation of thermal power plant utilization and the future costs to environment (through environmental degradation), human health, and loss of fiscal resources. A stabilization constraint is imposed on the emissions like PM10, PM2.5 that can be emitted with increase in coal usage. A green growth and development path has to balance these emissions and therefore the increase in the primary energy supply from coal should increase at a stable decreasing rate in the reference scenario.

Over the years, large-scale, coal-based thermal capacity addition in Punjab has happened. Investments made on thermal plants need to be fully utilized through capacity utilization of the plants in future. However, incremental coal-based thermal capacity addition can happen in the reference scenario. In policy and ambitious scenarios, the state will shift towards renewable sources of primary energy supply to a larger extent in comparison to the reference scenario.

Punjab is importing coal to run the thermal power plants which is adding to environmental cost, loss of fiscal resources, and also contributing to air pollution. By the time imported coal reaches Punjab from the port or the mining points, the delivery cost of coal goes up almost by three times. Import of coal also leads to loss of state financial resources. Moreover, burning more coal far away from its landed, mining points does not balance goals of environmental sustainability as it can cause damage to the environment on its way due to inefficient transportation infrastructure.

Air pollutants are emitted from coal-based thermal power plants. This pollution rate is higher for plants which use low grade domestic coal. Therefore, on one side there are environmental considerations and on the other hand, there is a growing economy which is demanding more coal to meet its increasing energy demand.



	Observed 2015	Ref 2021	Pol 2021	Amb 2021	Ref 2031	Pol 2031	Amb 2031
Bagasse	0.80	1.63	1.93	2.12	1.87	2.10	2.13
Waste to energy	0.28	0.32	0.34	0.35	0.36	0.42	0.50
Biomass and cogeneration	1.20	1.45	1.58	1.62	1.52	1.90	2.10
Solar	0.49	0.54	0.57	0.59	1.22	2.20	2.40
Hydro	0.80	1.71	2.17	2.38	2.87	3.20	3.50
Coal	11.00	10.68	9.70	8.70	11.40	9.40	8.30

Figure 5.6: Scenario-wise primary energy supply (Mtoe)

The Punjab economy's primary energy supply from coal needs to stabilize at most 11.40 Mtoe in the reference scenario of 2031, considering the constraints of environmental degradation, economic cost of air pollution, and loss of fiscal resources. This is arrived at after conducting an energy optimization exercise for the entire economy with constraints on pollutant emissions.

Modelling projections show that primary energy supply can increase more from solar, biomass and co-generation in Punjab. This will be followed by hydro and waste to energy. It can happen in future when the state will start relying more on renewable energy to meet the growing energy demand by balancing needs of economic growth and environmental sustainability.

Primary energy supply from solar can rise to 1.22 Mtoe in the reference scenario of 2031. In the ambitious scenario of 2031, this can go up further to 2.40 Mtoe. For biomass and co-generation together it can be 1.45 Mtoe (reference scenario of 2021) to 2.1Mtoe (in the ambitious scenario of 2031). Primary energy supply from hydro can rise from 1.71 Mtoe in reference scenario of 2021 to 3.50 Mtoe in the ambitious scenario of 2031. For waste to energy, it can rise from 0.32 Mtoe in reference scenario of 2021to 0.50 Mtoe in the ambitious scenario of 2031.

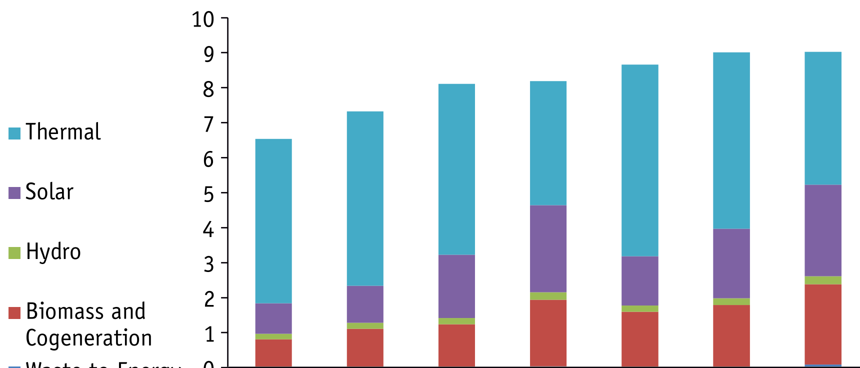
In the policy scenario, the state can achieve the target of adding a generation capacity of 1 GW by 2021 and the share of renewable energy can reach the level of 10 per cent of total installed capacity by 2022.[1] Figure 5.7 shows scenario-wise generation capacity.

Scenario-based analysis indicates that the coal-based thermal capacity addition in the reference scenario increases from 4.98 GW in 2021 to 5.48 GW in 2031 which in the policy scenario and ambitious scenario falls to 5.04 GW and 3.80 GW in 2031, respectively (Figure 5.7). Solar, Biomass and Co-generation, Hydro will also play a key role in the ambitious scenario in 2031. In Ambitious scenario, the state relies more on renewable energy resources to meet its energy demand and reduces its reliance on coal-based thermal power for reducing the CO_2 emissions and air-pollutants.

[1] http://www.peda.gov.in/main/images/policies_acts.pdf

The dependence on renewable energy sources like bagasse, biomass, solar, and waste to energy will increase by more than twice in the ambitious scenario of 2031 in comparison to reference scenario of 2021. This is because the state economy can strive for a high economic growth path by constraining pollutant emissions (PM10, PM2.5) and focussing on development indicators like employment generation, health benefits from reduced pollution in future. Due to that, the primary energy supply from coal can reduce as the state economy transits from a reference to a policy and ambitious scenario. The increase in renewable energy-based primary energy supply will also mean a rise in the capacity addition for renewable energy sources. Amongst the renewables, the generation capacity can increase as shown in Figure 5.7.

For solar, in the reference scenario, capacity addition increases from 1.06 GW in 2021 to 1.41 GW in 2031. In the policy scenario, this increases from 1.81 GW in 2021 to 1.99 GW in 2031. Within the ambitious scenario, the capacity addition increases from 2.49 GW in 2021 to 2.61 GW in 2031 (Figure 5.7).



	Observed	Ref	Pol	Amb	Ref	Pol	Amb
	2015		2021/22			2031/32	
Thermal	4.70	4.98	4.88	3.55	5.48	5.04	3.80
Solar	0.87	1.06	1.81	2.49	1.41	1.99	2.61
Hydro	0.16	0.17	0.18	0.21	0.18	0.19	0.23
Biomass & Cogeneration	0.80	1.10	1.21	1.90	1.58	1.76	2.30
Waste to Energy	0.01	0.01	0.03	0.04	0.01	0.03	0.09

Figure 5.7: Scenario-wise generation capacity (GW)

Note: Scenario based data projections validated with CEA Monthly Report – for data validation - currently in 2015 forecasted projection biomass is expected to have 1.1 GW, cogeneration - .013 GW, Small Hydro - .16 GW solar -.884 GW, waste to energy (not including agri residue or biomass) - .002 GW (however if agri residue waste is considered within waste to energy then a higher potential can be achieved)[2]

Other than solar, power from biomass and co-generation and wastes can also contribute to the generation capacity in future. Biomass and co-generation route-based power generation can increase from 1.10 GW in the reference scenario of 2021 to 1.58 GW in the reference scenario of 2031. In the ambitious scenario of 2031, biomass and cogeneration route-based power generation can increase to 2.30 GW. This indicates a compound annual growth rate (CAGR) of 7.65 per cent in the biomass and co-generation route-based capacity addition between reference scenario of 2021 and ambitious scenario of 2031. It suggests a CAGR of 4.81 per cent between reference scenario of 2021 and policy scenario of 2031.

In case of waste to energy sources, power generation capacity can increase from 0.01 GW in the reference scenario of 2021 to 0.01 GW in the reference scenario of 2031 (though there is a marginal change beyond two decimal points). In the policy scenario, the generation capacity increases to 0.03 GW in 2031 and in the ambitious scenario it goes till 0.09 GW. There is a potential of ten 2 MW waste to energy power plants in the state and already 8 clusters have been operational to address the potential. Therefore, the modelling projection indicates that in the future ambitious scenario of the state, agri residual waste, municipal wastes, and wastes from industry and service sector can be utilized more effectively to meet the domestic power demand.

[2] http://pserc.nic.in/pages/PSPCL-Tariff-Order-Vol-1.pdf, p. 182.

Therefore, in the ambitious scenario, the state can achieve more than the stated objectives of the New and Renewable Sources of Energy (NRSE) policy. In addition to solar, the state can also move towards other renewable energy options of power generation in policy and ambitious scenarios. The total renewable energy potential to be tapped has to be around 2 GW by 2022 which can increase further to more than 5 GW by 2031 in an ambitious scenario.

In the ambitious scenario, transformation towards a larger scale in terms of power generation from small/micro hydro projects, co-generation, power generation from biomass/agro residue and waste, and from urban, municipal, and industrial liquid/solid waste can take place. NRSE projects have already been set up in the state as well as within "Northern Regional Power System". However, in order to realize sale of power from these NRSE projects, the corresponding tariff structure from renewable energy-based power has to be more competitive to meet the current 2 per cent renewable energy purchase obligation of the state. The existing power tariff structure is discussed in Box 5.1.

Box 5.1: Power Tariff Structures and incentives

- Mini/Micro Hydel Projects – INR 4.82 per Kwh (base year 2014–15) Bagasse/ Biomass Cogeneration Projects-INR 5.85 per Kwh (base year 2014–15) with annual escalations @ 3% depending on the capacity utilization factor and PLF
- Biomass Power Projects – INR 7.80 per Kwh (base year 2014–15) with annual escalations @ 5% depending on the capacity utilization factor and plant load factor
- Biomass Gasifier – INR 6.93 per Kwh (base year 2014–15) with annual escalations @ 5% depending on the CUF and PLF
- Power Generation from Urban, Municipal and Industrial Liquid/ Solid Waste -
- - INR. 7.15 per Kwh (Base Year 2014–15) with annual escalations @ 5 per cent
- Power generation from Solar Energy (PV) - INR 6.95 per Kwh with annual escalations @ 5 per cent in real terms as in absolute terms the generation cost is expected to fall in future. However, the tariff will depend on CUF and PLF.
- Wind Power Projects- INR 3.74 per Kwh (as per CERC 2015 guidelines with capacity utilization factor (CUF) of 32 per cent) with annual escalations of @ 3% . If the CUF goes down to 20% the tariff can increase to INR 6/ kwh
- There can be an escalation of @ 5 per cent in real terms as in absolute terms the generation cost is expected to fall in future if the capacity utilization factor improves.

Source: Validated with CERC Guidelines at http://www.cercind.gov.in/2014/orders/SO354.pdf

Unless power tariff levels are brought down further by atleast more than 20 per cent, improvement in aggregate scale of capacity utilization of all renewable energy sources, the project realization might not happen to fulfill the renewable energy purchase obligations.

Within the ambitious scenario, the hydro potential depicted in Table 5.3 will also need to be tapped in Punjab.

Table 5.3: Scheme-wise generation

Scheme Type	No of sites	Potential (KW)
Irrigation Canal Falls	117	102738
Run-off-River Scheme	36	54250
Tail Race of Existing Hydel Channel	8	80000
Irrigation Dam Outlet Sites	11	510
Total	172	237498

Source: Based on data from Punjab Energy Development Agency

Till 2031, in the reference scenario, a potential of 510 KW of small hydro can be easily realized (through irrigation dam outlet sites). However, in the long run, small hydro capacity can be increased to more than 0.2 GW through implementation of small hydro projects in at least 172 sites. Majority of this potential can come from the irrigation canal fall-based schemes and can be dependent on the successful implementation of the initial schemes.

Decentralized power of around 1,500 MW can also come up in Punjab by 2031 using agri-residue and waste feeding to the biomass and co-generation-based power generation. A potential of more than 190 MW can be realized from biomass resources through the co-generation route from sugar, paper, fertilizer, chemical, textile, and other industries through larger push of favourable interventions in the policy and ambitious scenarios.

Almost 20 MW of power can be tapped from waste to energy projects using municipal, urban, and industrial solid waste in the ambitious scenario by 2025. This will facilitate the state to realize the potential target of 100 MW waste to energy by 2031 in the ambitious scenario.[3] From the perspective of a green growth and development path, by 2031 in the policy scenario, solar has a major role to play. However, in an ambitious scenario beyond 2031, along with solar, small hydro power, biomass, waste and bagasse-based power generation will also have a role to play to meet growing energy demand of the different economic sectors.

The power tariff from different renewable sources has to be competitive and within a range of INR 3.49–6.00 per unit to make the mandatory renewable purchase obligation target of 2 per cent viable. Given these intricacies of energy supply scenarios, it is critical to assess the nature of energy demand across three scenarios—viz., Reference, Policy, and Ambitious.

5.5 Energy Demand Scenarios

Majority of the energy demand caters to agriculture, industry and transport sector. Sectors like commercial sector (which includes commercial buildings) will also need to incorporate energy conservation measures for future energy demand reduction. Energy demand projection of the state for three scenarios is given in Figure 5.8.

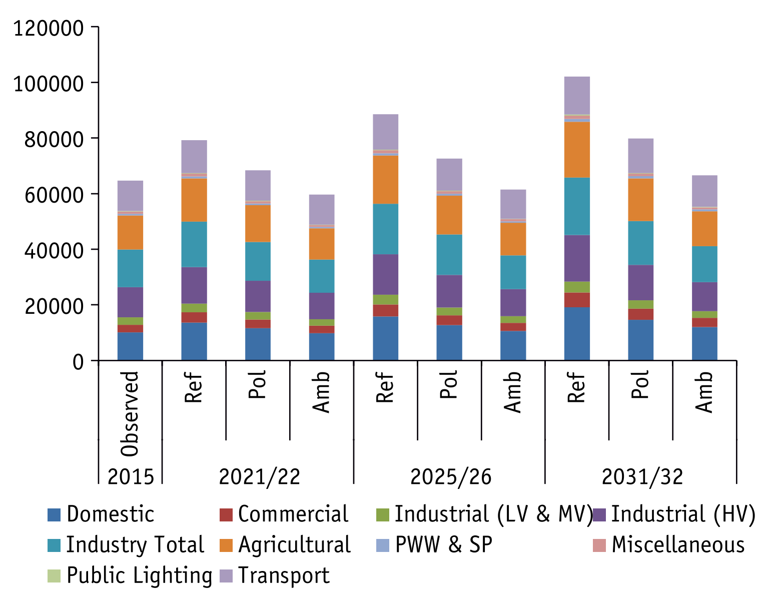


Figure 5.8: Scenario-wise energy demand across sectors (GWh)

For the year 2021–22, the transport sector energy demand can be reduced by 9.89 per cent by shifting to ambitious scenario from reference scenario. For the year 2031–32, the transport sector energy demand can be reduced by 20.75 per cent by shifting to ambitious scenario from reference scenario. For transport sector, in the ambitious scenario of 2031–32, an energy

[3] The state action plan on climate change posits a potential of 100 MW of waste to energy although the revised renewable energy target document of MNRE states a target of 45 MW.

demand reduction of 11.11 per cent can be achieved through fuel efficient (BS-IV&V) vehicles, larger fuel efficiency of buses, trucks, private vehicles, in comparison to the reference scenario of 2031–32.

For the year 2021–22, the industry sector energy demand can be reduced by 27.45 per cent by shifting to ambitious scenario from reference scenario. For the year 2031–32, the industry sector energy demand can be reduced by 37.49 per cent by shifting to ambitious scenario from reference scenario. Agriculture sector is also predicted to follow a similar pattern.

This sectoral energy demand reduction has to be in line with the broader policy goal or plan as envisaged by the state government which aims to incentivize all sectors of the economy to ensure conservation of energy to the extent of 20 per cent by the year 2020. It is important to attain this goal of conservation given that the absolute electricity consumption across all sectors of the state can rise by three times in 2031–32 (Figure 5.9).

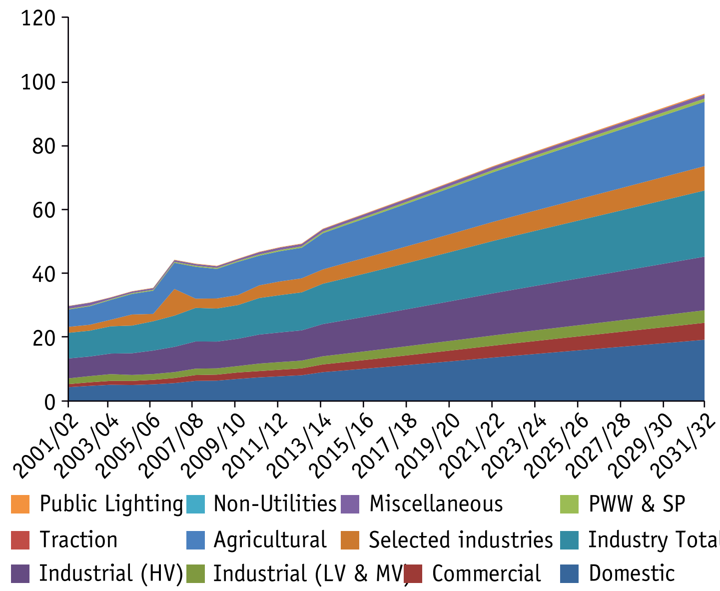


Figure 5.9: Sectoral electricity consumption (TWh)
Note: PWW&SP – Public Water Works and Sewerage Pipeline

As transport, industry, agriculture, and commercial buildings (as part of the commercial and service sector) will be major consumers of energy demand in future. A scenario wise modelling projection of energy demand for four key intervention sectors are addressed in the next sections.

5.5.1 Transport Sector

Owing to fuel efficiency-related measures, petrol consumption in cars goes down from 1,685 thousand tonnes in the reference scenario of 2031 to 1600 thousand tonnes and 1,516 thousand tonnes in policy and ambitious scenario of 2031/32 (Figure 5.10).

A similar pattern is observed even in the case of petrol consumption in utility vehicles which highlights that petrol consumption in 2031/32 for utility vehicles in the state can go upto 27.08 thousand tonnes in the reference scenario. In the policy scenario this can drop to 25.72 thousand tonnes and in the ambitious scenario it can be 24.37 thousand tonnes (Figure 5.11).

For two wheelers, petrol consumption increases to 1,214.27 thousand tonnes in the reference scenario of 2031. In the policy scenario, it becomes 1,153.56 thousand tonnes and in the ambitious scenario, it reduces to 1,092.85 thousand tonnes (Figure 5.12).

In the private car, commercial car, and SUV segment, the diesel consumption in the reference scenario of 2031/32 is 2,126 thousand tonnes which in the policy scenario reduces to 2,019 thousand tonnes and 1,913 thousand tonnes in the ambitious scenario (Figure 5.13).

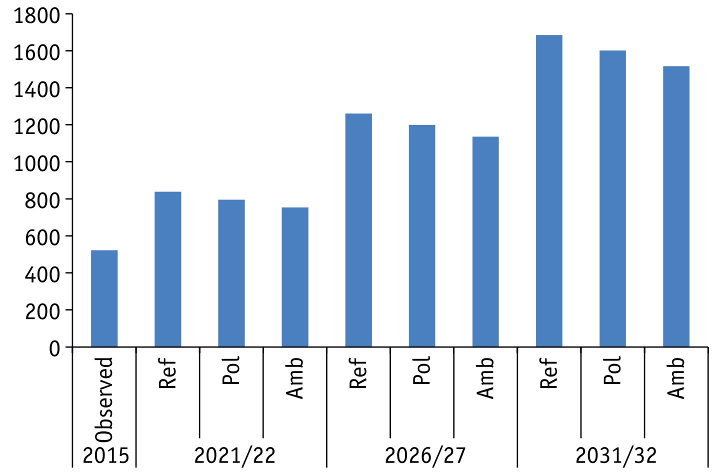


Figure 5.10: Petrol consumption cars ('000 tonnes)

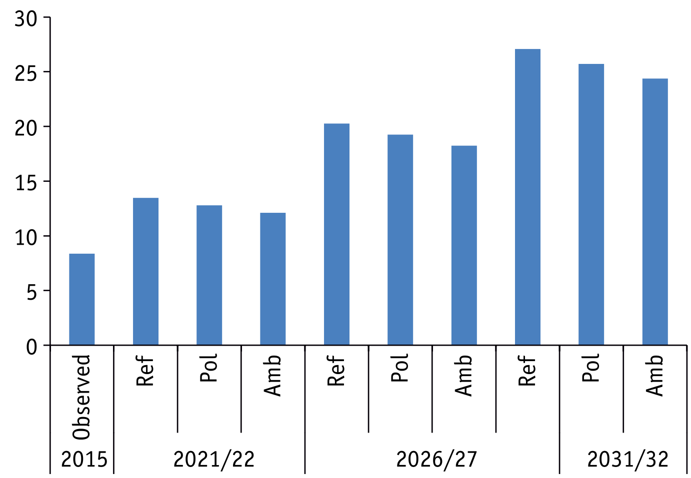


Figure 5.11: Petrol consumption in utility vehicles ('000 tonnes)

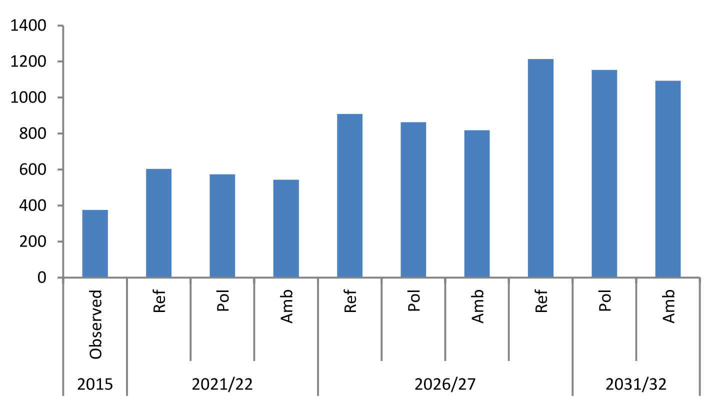


Figure 5.12: Petrol consumption in 2 wheelers ('000 tonnes)

In commercial cars and SUV segment, in the reference scenario of 2031/32, the diesel consumption becomes 1,465 thousand tonnes. In the policy scenario, it reduces to 1,391 thousand tonnes and in the ambitious scenario it drops to 1,318 thousand tonnes (Figure 5.14).

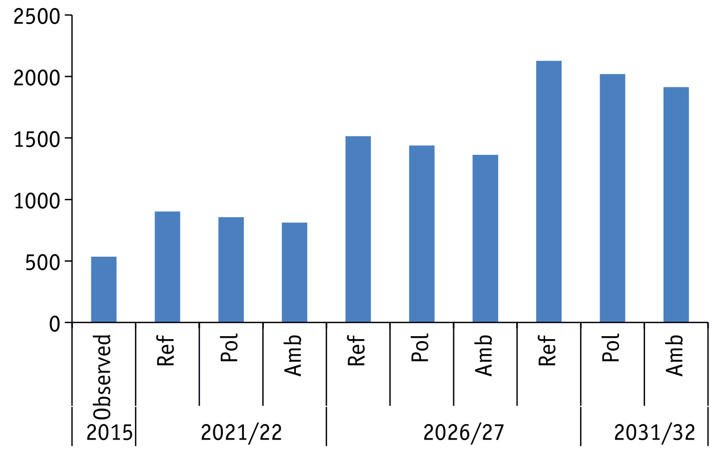


Figure 5.13: Diesel consumption in private car and SUV ('000 tonnes)

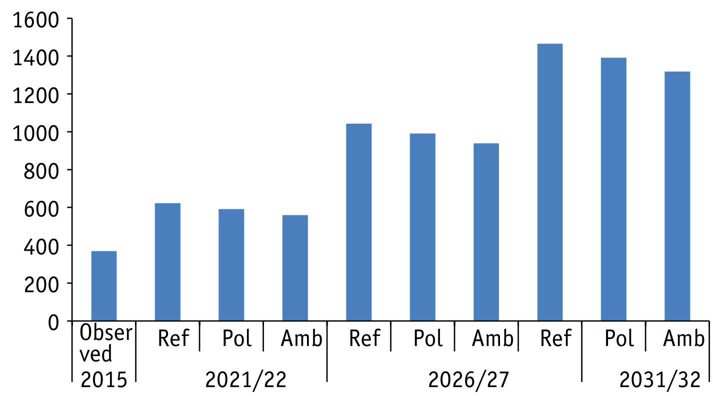


Figure 5.14: Diesel consumption in commercial cars (includes taxi) and SUV ('000 tonnes)

Diesel consumption in LCV/HCV in the reference scenario can reach 3,979 thousand tonnes in 2031/32. In the policy scenario, it reduces to 3,780 thousand tonnes and for the ambitious scenario, it drops down to 3,581 thousand tonnes (Figure 5.15).

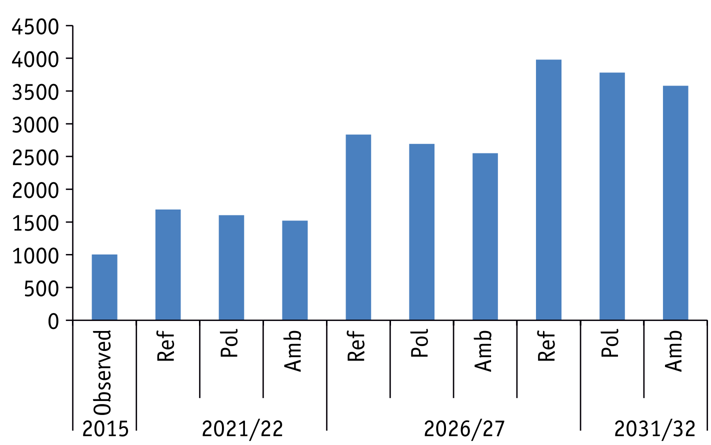


Figure 5.15: Diesel consumption in LCV, HCV ('000 tonnes)

Some specific measures to achieve the projected scale of reduction in petrol and diesel consumption within the transport sector are listed in Box 5.2.

Box 5.2: Transport sector measures

- Mandatory implementation of BS-IV&V measures in the transport sector enhancing fuel efficiency
- Introduction of BSIV, V compliant vehicles
- Tax incentives for using fuel efficient vehicles
- Enhancement of fuel efficient public, private buses, cars, private vehicles
- Promotion of fuel efficient last mile connectivity
- Scoping of undertaking the feasibility of introducing electric vehicles in the transport sector
- Promotion of public transport and utilization of alternative fuels like CNG in the transport sector
- Consideration of metro rail network by 2031 only after successful implementation of the plan for Ludhiana and Amritsar and consideration of a plan for Chandigarh after 2025
- Enhanced rail networks and increased mobility of passengers through rail networks

5.5.2 Industry

As the state grows, industrial sector energy consumption can increase in a reference scenario and from a policy perspective, it will be important to understand the response of different segments of industry sector to energy efficiency interventions in future.

Scenario-wise modelling projections highlight that textile, rubber, paper, chemicals segment of the industry will consume the largest amount of energy in future. Certain sections of these industries are unregistered and belong to unorganized small- and medium-scale enterprise (SME) clusters. Hence, through introduction of energy efficient practices, complemented by job creation policies in the policy scenario,[4] energy consumption in sectors like textile can go down in the policy scenario of 2031/32 from 2,840 GWh to 2,414 GWh. In the ambitious scenario, it further reduces to 2,173 GWh in 2031/32 (Figure 5.16).

Energy efficiency improvement measures in the policy and ambitious scenario of 2031–32 has a potential of 11.21 per cent and 13.23 per cent reduction of energy consumption as compared to reference scenario. Some of the sector specific measures to achieve this are highlighted in Box 5.3.

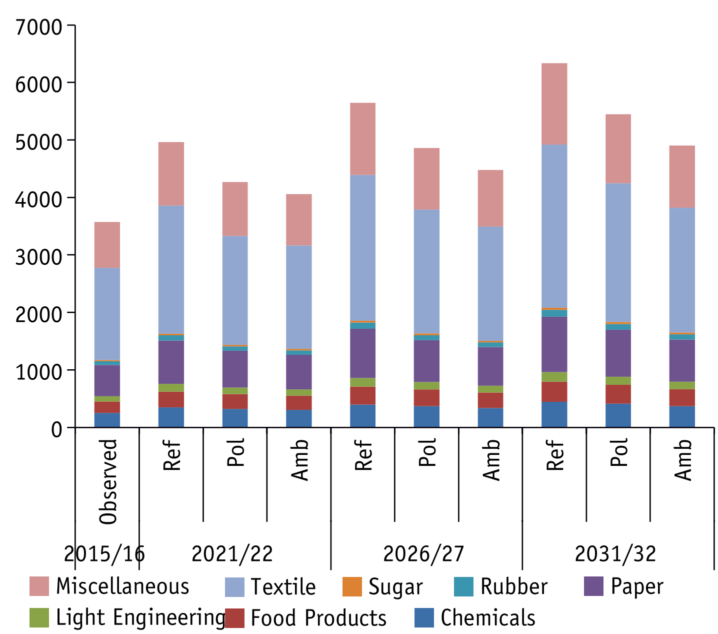


Figure 5.16: Scenario specific industry sector energy consumption (GWh)

[4] it is the scenario in which the energy efficiency potential of each of these sectors as per Bureau of Energy Efficiency Estimates are achieved with a specific focus to the SME sector.

Box 5.3: Industry Sector measures

- Implementation of BIS marked pump-sets and solar water heating systems in industries where hot water is required for processing purposes
- Increase in removal efficiency and control strategy of emissions in industries like cement, iron and steel products, textiles, fertilizers, paper, brick, aluminium products, glass industries and small, medium enterprises
- Improvement in the energy efficiency within the operational process of iron, aluminium and steel products
- Improvement in the energy efficiency of smelting and refining processes of glass industry with larger utilization of natural gas
- Increase in operational efficiency in the kiln systems, clinker coolers, and mills segments of the production process of Ordinary Portland Cement (OPC) and Portland Pozzolana Cement
- Enhanced, efficient utilization of the chemical pulp, recycled fibre and agro residues with reduction in residual waste in the paper industry
- Transition to tunnel kilns within the brick sector in the ambitious scenario
- New technological transition to Zig Zag Kilns in the policy scenario of the Brick Sector (from the current movable chimney, fixed chimney)
- Increased efforts in controlling emissions using efficient control systems like bag filter and ESP

5.5.4 Agriculture

Consumption of diesel in tractors and agricultural implements goes down from 3,128 thousand tonnes of the reference scenario to 2,972 thousand tonnes of the policy scenario and in the ambitious scenario it becomes 2,815 thousand tonnes (Figure 5.17). This reduction in the diesel consumption can be achieved through the state government policy of phasing out diesel-based agricultural pump-sets and traditional pump-sets with more efficient electric pump-sets.

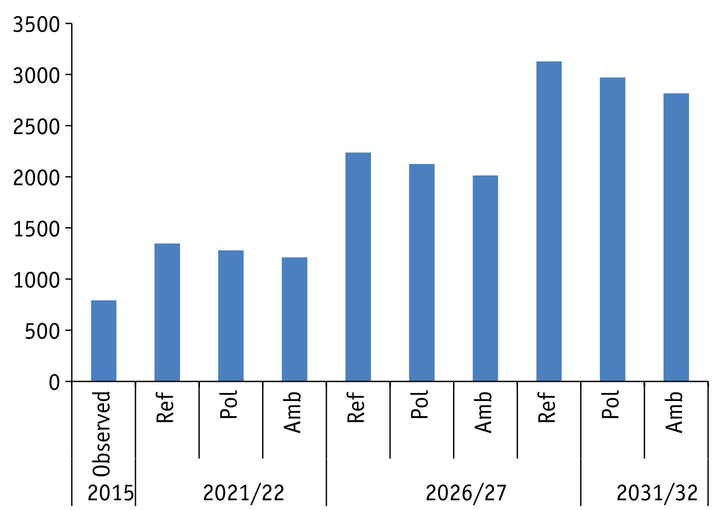


Figure 5.17: Diesel consumption in tractors and agricultural implements ('000 tonnes)

Consumption of diesel by agricultural pump-sets is also interlinked to the power subsidy regime. Therefore an interconnected analysis between energy consumption, power subsidies, and its impact on ground water level needs to be undertaken. However, some specific policy recommendation that emerges to achieve the above mentioned energy consumption reduction in the agriculture sector is indicated in Box 5.4.

Box 5.4: Agriculture sector specific measures

- Mandatory use of BEE 4 star labelled and ISI marked motor pump sets, power capacitors, foot/reflex valves in the agriculture sector, in all new tubewell connections in the climate smart villages of Punjab
- Crop diversification, energy productivity and yield improving agricultural policies and reduction in energy consumption of rice, maize, pulses, sugarcane (Kharif season crops), wheat,, fruits, vegetables (Rabi crops) by 2031

5.5.5 Buildings

For the final intervention sector, viz., commercial building component, three scenarios have been considered. These scenarios include—reference, policy, and ambitious. Within the policy and ambitious scenarios, reduction in EPI[5] happens.

An EPI reduction happens largely through demand side management measures and introduction of energy conservation practices of sustainable, resource efficient buildings into the commercial building sector of Punjab[6].

By bringing in energy efficiency measures to reduce energy consumption, almost more than 60 per cent of energy consumption in commercial buildings can be optimized across different scenarios (Box 5.5). At a macro level, for the entire commercial building sector, in the reference scenario of 2031–32, the energy consumption increases to 48.80 million Kwh. In the policy scenario of 2031–32, the energy consumption drops to 40.76 million Kwh and in the ambitious scenario it goes down to 34.41 million Kwh in 2031 (Figure 5.18).

For the state as a whole, the energy demand across the two scenarios (policy and ambitious) has to be reduced through the following set of policy actions (Box 5.5).

Box 5.5: Commercial Building sector specific measures

- Overall building sector can have an energy demand reduction of atleast 15 per cent which can go till 30%
- Optimization of HVAC loads can lead to a savings of 30 per cent in the modelling time period
- ESCO to be constructed for energy audits, ESPC for energy saving projects
- Optimization of energy systems, pumping and building energy systems
- Projects in the commercial building sector have to be financed by ESCO who will execute the project and recover the investment by getting a major share of savings
- Application of solar water heaters in hospitals, nursing homes, hotels, motels, banquet halls, jail barracks, canteens, residential buildings, schools, educational colleges, hostels, technical education centres, through a change in bye laws with the support of town and country planning department, urban development department, public works department, Punjab urban planning and development authority, public health and architecture department
- Inclusion of renewable energy technologies in all new buildings of the government sector
- Energy efficient building design concepts to be introduced in all new buildings and implementation of actions of Energy Conservation Act of 2001 through the Energy Conservation Action Plan Team and actions steered by the State Level Steering Committee for providing support to PEDA to implement energy conservation activities with the utilization of Punjab State Energy Conservation Fund, implementation of the energy conservation activities with the utilization of Punjab State Energy Conservation Funds along with a monitoring mechanism
- In the policy scenario, replacement of traditional light source of 40W can lead to an energy demand reduction of 32 per cent in the modelling time period between 2005–06 and 2031/32. Replacement of 70W traditional light source by light emitting diode (LED) creates an energy demand reduction of 34 per cent in the policy scenario.. For the replacement of the sodium 150 W and 250 W traditional light source by LED, the energy demand reduction potential till 2031 in the ambitious scenario is around 56 per cent in comparison to 2005/06. Heating, Ventilation and Air Conditioning (HVAC) load systems are also optimized to reduce the energy consumption in the policy and ambitious scenario. Lighting, heating, ventilation and air conditioning systems comprise of major part of the energy load in all commercial buildings.
- Larger implementation of energy conservation fund for awareness programmes of individual consumers, industries, commercial organizations, farmers, training of personnel, specialists by the state development agency, R&D in the field of energy conservation, testing and certification of energy consumption of equipment, appliances.

[5] Energy Performance Index (EPI) measured in terms of Kwh/million sq. m.

[6] Some of the reduction potential that is achieved through these measures include replacement of TL 40W by LED 16W, 70W by LED 30W, Sodium 150 W by 60W, Sodium 250 W by LED 120 W.

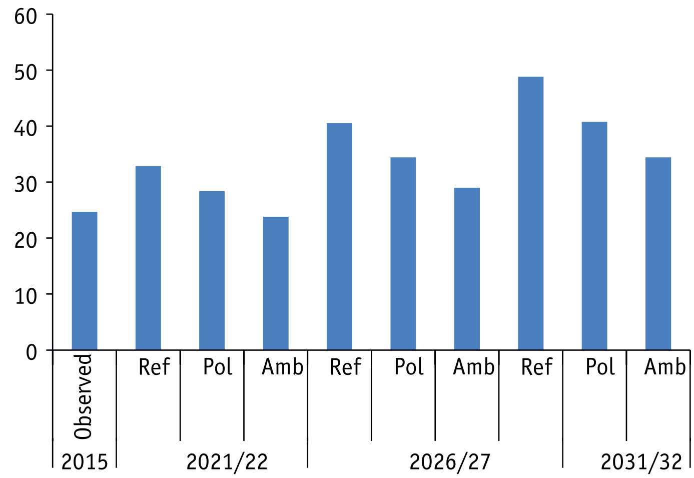


Figure 5.18: Scenario specific energy consumption in commercial buildings (million Kwh)

5.6 Structural Change and Implications on Energy Demand

As an additional scenario, an attempt through the energy optimization simulation with LEAP model is made to understand the nature of impact on energy demand for the state considering structural economy dynamics.

Structural change over here is defined as a stabilization in the falling share of agriculture in the state economy at 15 per cent in 2031 from 23 per cent in 2014. The share stays constant at 15 per cent after 2031.

Industry sector share as a part of the state GDP increases from 27 per cent in 2014 to 28 per cent in 2021 and stabilizes at this rate in future. The share of transport and service sector in the state economy increases from 49 per cent in 2014 to 57 per cent in 2031 and stays constant after 2031.

Structural change indicates a restructuring of an agrarian, industrial economy to a service oriented economy by maintaining stability in the share of agriculture and industry sector. Therefore, one of the key measures of this structural change is a shift to the service sector without creating any agrarian crisis or deindustrialization within the economy to balance the potential of job creation and employment generation from industry and agriculture sector along with a growing service sector. The sectoral share pattern is indicated in Table 5.4.

Table 5.4: Structural change through a shift in the sectoral shares of the economy

Sectors	2014*	2021	2031*	2041*	2051*
Agriculture	23%	22%	15%	15%	15%
Industry	27%	28%	28%	28%	28%
Services	49%	50%	57%	57%	57%

*(share of the sector as a percentage of state GDP)

Scenario-based state level energy optimization modelling exercise indicates that due to structural change along with demand-side energy efficiency measures, the energy demand of the state economy as a whole reduces from around 9.90 Mtoe in reference scenario to 6.64 Mtoe in structural economic change (Sec) scenario in 2031–32. The nature of reduction in the structural change scenario stabilizes as the economy moves onto 2031 from 2021 (Figure 5.19).

Broadly, for the state economy as a whole, owing to the structural change measures an energy demand reduction of 32.88 per cent can happen in structural economy change (Sec) scenario of 2031, in comparison to the reference scenario of 2031. The energy demand reduction can happen from efficient energy demand management practices in agriculture and industry. However, owing to a structural change there will be a marginal rise of energy demand in the service and transport sector.

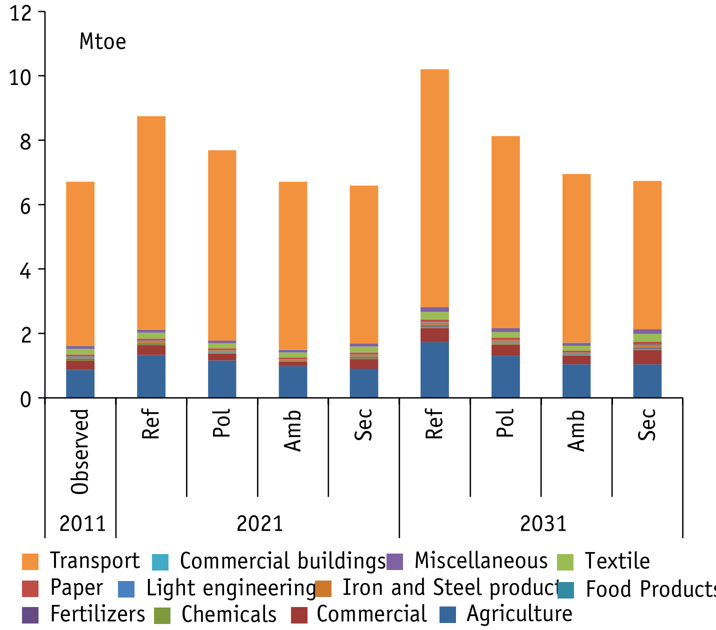


Figure 5.19: Impact of structural economy change in the energy demand (Mtoe)

5.7 Energy, agriculture, and water inter-linkages

The state of Punjab is historically known for its agrarian activities, especially in producing rice and wheat. The inter-linkages between energy consumed under different cropping regimes are now examined. Based on the trends observed in Punjab since the pre-Green Revolution era, three scenarios considered in the Soil and Water Assessment Tool are taken.

These scenarios are based on the changes in the cropping pattern in the near future. In the reference scenario the current cropping pattern would continue to exist with increase in rice cultivation. The policy is based on the assumption that in future, the rice cultivation can be brought down to 16 lakh ha (by 2021–22) from 28 lakh ha (2012–13), which the government is aiming. The ambitious scenario is based on the assumption that with a significant shift in the structural economy patterns, natural resource scarcity indicated by falling ground water table will lead to major changes in the cropping pattern, bringing down the area under rice cultivation to 2.8 lakh hectares (pre-Green Revolution level).

It emerges clearly from the Figure 5.20 that as part of crop diversification measures, for key crops which includes shift of area from rice to other less water intensive crops in Punjab, the energy consumption will go down in 2021s and 2031s (also see Annexure 5.3 and 5.4).

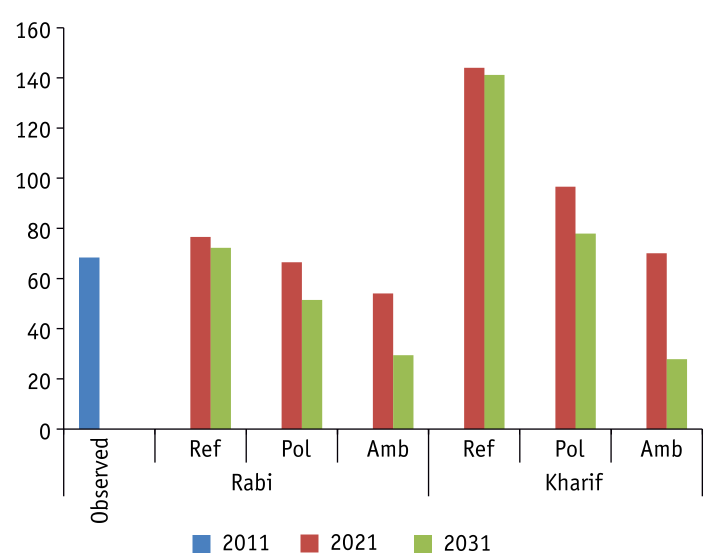


Figure 5.20: Energy consumption of Rabi and Kharif crops across scenarios (GWh)

The reduction in the energy consumption will progressively go down in these crops as one moves from reference to ambitious scenario. The reasons for that might be due to farmers' behaviour-based intense crop diversification measures, water management techniques, and other policy level interventions. Other factors might be improvement of crop and energy productivity while transitioning from the reference to the ambitious scenario. To realize this, current interventions in the state need to be complemented by economic incentives such as sustained price support for horticultural crops.

Agriculture in the State benefits from several fiscal supports, direct or indirect, from the State government. Among them, subsidized power holds special significance. Though free electricity might have spurred agricultural activities in the State, it has also created ramifications on the state fiscal deficit and on the ground water depth.

The current exercise attempts to evaluate the linkage between electricity consumption in agriculture and ground water depletion in terms of increase in water table depth (Box 5.6). The investigation has been undertaken for all major districts and also at the State level.

Box 5.6: Implications on groundwater

From the analysis it emerges, that if the current pattern of ground water withdrawal and energy consumption in the agriculture sector across the Kharif and Rabi crops continue, then the ground water table can decline at a rate of more than 1 metre a year. Consumption of water by agriculture sector can also be reduced by breeding early maturing rice varieties, recently released varieties like PR 121 and PR 123. Further, use of laser land leveller, which can save about atleast 15% of irrigation water and promotion of micro irrigation systems are also some of the ways of reducing the water consumption. These water saving interventions can thereafter create a diminishing impact on electricity demand and subsidy.

Hence, reduction of electricity subsidy can be an instrument to reduce electricity consumption and check this ground water depletion by 2031. Therefore crop diversification, energy productivity, and yield improvement of crops can assist in checking ground water depletion and improve the state fiscal situation by reducing the electricity subsidies (as a percentage of gross state fiscal deficit) which is largely allocated for the agriculture sector and cross subsidized by the industry segment of the economy. The scenario-wise analysis of the electricity subsidy reduction as a percentage of gross fiscal deficit is stated in Figure 5.21.

As shown in Figure 5.21, electricity subsidy as percentage of gross state fiscal deficit can be reduced from 30 per cent in 2031 (in reference scenario) to 10 per cent in the ambitious scenario of 2031.

Through the targeting of reduction in the electricity subsidy as a percentage of gross state fiscal deficit, a fiscal disciplining can be done. In a situation where states can face fiscal constraint in terms of restricted funding allocation from centre to states on issues pertaining to agriculture sector, this becomes more relevant to consider within the policy space of green growth and development road map.

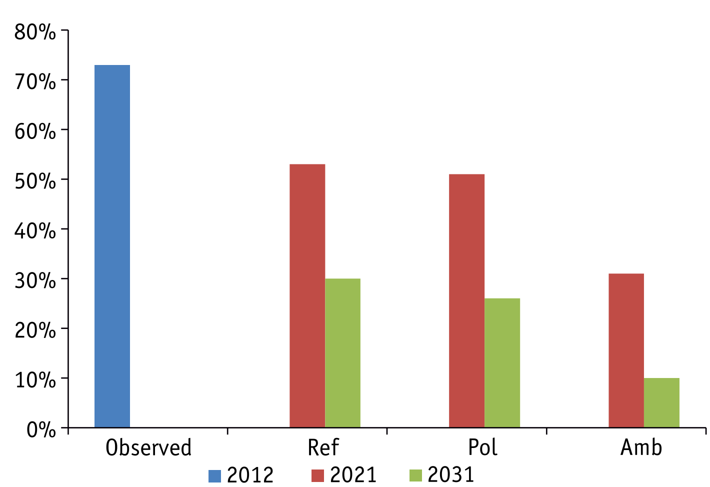


Figure 5.21: Scenario-wise electricity subsidy as a percentage of Gross State Fiscal Deficit for different cropping scenarios

5.8 Ways Forward

The following discussion points related to economy, energy supply, energy demand, and resource conservation need to be considered.

Economic Benefits

- Punjab state can lose out about 2 per cent of the state GDP every year till 2031 in the form of human health and environment-related measures if adequate measures are not taken constantly to check air pollutants from power, industry, transport, and agriculture sector when the state is making rapid economic growth. Air pollution can impact human health and working life span of the exposed population, ultimately affecting their income earning capabilities. In the absence of measures to check pollutant emissions from power, industry, transport, and agriculture sectors, the number of respiratory diseases owing to exposure to air pollution can become 17 per 1000 exposed people in the state.
- Multi-sectoral, multifaceted integrated analysis carried out for the state of Punjab reveals that the state needs to create perspective plan with strategic thinking for industry, construction, tourism, retail trade, welfare expenditures, and other value added services by the involvement of both government and social organizations. Focus should be laid on livelihood generation, climate smart agriculture, horticulture, and agro-forestry, locally contextualized agrarian practices, and on farm water management. There is a need for strengthening of rural and urban health centres to address and mitigate the respiratory diseases from exposure to air pollution.
- To promote adoption and deployment of energy efficiency in industry, there is a need for job creation in energy efficient small and medium enterprises.
- A roadmap for environmentally sustainable service sector with emphasis on low energy intensive services, and modern infrastructure sector needs to be chalked out. This in turn will require detailed understanding of structural economy dynamics, urbanization and employment opportunities.
- Investment in environment and low energy and emission sectors needs a boost.
- The state can think of an economic restructuring where the agriculture sector share drops and stays stable at 15 per cent and industry sector grows marginally to 28 per cent from 27 per cent and stays constant. The structural change will imply a constant share of 57 per cent for the service sector in future. In such a situation, an energy demand reduction of 32.88 per cent can happen in the entire economy in 2031. However, owing to a rise in the service sector share, a rise in commercial sector energy demand can happen. A marginal rise in the industry sector share can lead to a rise in energy consumption in new industries like food processing and other SME sector industries with employment opportunities. However, this rise will be overweighed by a drop in energy consumption in the agriculture sector. This structural change has to come through a perspective plan of the state.
- The state might like to create a perspective plan for agriculture, industry, construction and other value added services such as retail trade, hotel and restaurants, real estate, and community services and remittances, tourism and welfare expenditures (both by government and other social organisations). A key component of this plan will involve strategic planning and sectoral perspective plans with a focus on health, education, agriculture, livestock, forestry, fishery, industry, tourism and ICT, urbanization, infrastructure, energy, and water. An integral component of the plan will need to have components like a livelihood generation implementation plan emanating from climate smart agricultural practices, horticulture, with innovative locally contextualized agrarian practices applying efficient irrigation and agriculture practices along with energy and employment opportunity-related interventions in the industry and service sector.

Energy Supply

- From the viewpoint of fiscal prudence and environmental sustainability, it is considered rational not to add excess thermal power generation capacity in the state, even if the energy demand grows with a growing economy. The state needs to recover the investments made in the existing thermal power capacity by running existing thermal power plants with their fullest capacities. It can meet the growing future energy demand through renewable sources of energy where other than solar, biomass and cogeneration can be thought of as alternate options.

- Energy policy analysis and climate change mitigation assessment carried out for Punjab state using "Long Range Energy Alternatives Planning System (LEAP)" model envisage that more than 14 per cent of the new renewable energy based capacity can come from solar in 2031 according to policy scenario. This capacity might enhance further according to ambitious scenario considerations.
- The state needs to rely more on solar, biomass and co-generation route of renewable energy supply followed by hydro and waste to fulfill the 2 per cent renewable energy purchase obligation. However, this will happen only when there is more than 20 per cent improvement in the capacity utilization factor of solar, biomass followed by reduction of power tariff within the range of INR 3 .00–6.00 per unit.
- A policy push should be given for reducing the wheeling charges of biomass based-energy to the grid from the current 2 per cent to boost grid interactive biomass based-power generation.
- Around 220 MW of power supply can be realized from biomass through the co-generation route from sugar, paper, fertilizer, chemical, textile, and other industries by 2031 in Punjab. Decentralized power of more than 1,500 MW can also come up in Punjab by 2031 using agri-residue and waste for power generation. Almost 100 MW of power can come up from waste to energy projects using municipal, urban and industrial solid waste in the ambitious scenario by 2031 depending on the successful implementation of the cluster based projects.
- The state has to rely more on renewable energy sources in future with stabilization and reduction in coal-based capacity addition in reference and ambitious scenario.

Energy Demand

- For the year 2021–22, the transport sector energy demand can be reduced by 9.89 per cent by shifting to ambitious scenario from reference scenario which in 2031–32 can be reduced by 20.75 per cent by shifting to ambitious scenario from reference scenario.
- Energy efficiency improvement measures for the industry sector in the policy and ambitious scenario of 2031–32 has potential of 11.21 per cent and 13.23 per cent reduction of energy consumption as compared to reference scenario of 2031–32.
- Major energy demand reduction potential exists in agriculture, industry, and transport sectors. Within the agriculture sector, this can be achieved through aggressive penetration of electric pumpsets, mandatory use of BEE 4 star labelled and ISI marked motor pump sets, power capacitors, foot/reflex valves in all new tubewell connections in the climate smart villages of Punjab. Uptake of solar pumpsets has to increase. Within the industry sector, ambitious energy conservation measures in paper and pulp, chemicals, small and medium scale industries, textile, rubber, iron and steel derived industries in 2031–32 holds a potential of energy consumption reduction of 37.49%. In the industry sector this can be achieved through removal efficiency and control strategy of emissions in industries like cement, fertilizers, paper, brick, glass industries, and small, medium enterprises.
- In the policy scenario, replacement of traditional light source of 40W can lead to an energy demand reduction of 32 per cent in the modelling time period by 2031–32. Replacement of 70W traditional light source by light emitting diode (LED) creates an energy demand reduction of 34 per cent in the policy scenario by 2031–32. For the replacement of the sodium 150W and 250W traditional source of light by LED, the energy demand reduction potential till 2031 in the ambitious scenario is around 56 per cent in comparison to 2005/06. Heating, Ventilation and Air Conditioning (HVAC) load systems are also optimized to reduce the energy consumption in the policy and ambitious scenario. .
- Commercial building sector can have the potential of achieving a cumulative energy demand reduction band of 15–30 per cent by 2030 in comparison to 2015 through implementation of measures like optimization of HVAC loads, energy systems, pumping and building energy systems, application of solar water heaters in hospitals, nursing homes, government hospitals, hotels, motels, banquet halls, jail barracks, canteens, housing complexes, residential buildings, schools, educational colleges, hostels, technical education centres, through a change in bye laws with the support of town and country planning department, urban development department, public works department, Punjab urban planning and development authority, public health and architecture department.

- Broadly, for the state economy as a whole, owing to the structural change measures, an energy demand reduction of 32.88 per cent can happen in structural economy change (Sec) scenario of 2031 in comparison to the reference scenario of 2031.

Resource conservation

- With green growth and development interventions like crop diversification, yield enhancement and energy productivity improvement measures in the Punjab state, electricity subsidy as percentage of GSFD (gross state fiscal deficit) can be reduced to 10 per cent in the ambitious scenario of 2031 from the 73 per cent in 2012–13.
- Metering of the power, implementation of feeder separation, peak power use based tariff system can also reduce excess electricity consumption and can reduce ground water depletion rates.
- Use of efficient micro-irrigation techniques along with the farmer behavioural change can reduce ground water depletion rates. .
- Energy conservation in the commercial building sector can happen through projects financed by energy service companies who can execute the energy conservation projects in the commercial building sector and recover the investment by getting a major share of savings from the project implementation.
- Energy efficient building design concepts need to be introduced in all new buildings. Implementation of actions of Energy Conservation Act of 2001 through the Energy Conservation Action Plan Team can be brought out by 2031. Policy actions steered by the State Level Steering Committee for providing support to PEDA to implement energy conservation activities with the utilization of Punjab State Energy Conservation Fund for awareness programmes of individual consumers, industries, commercial organizations, farmers, training of personnel, specialists by the state development agency, R&D in the field of energy conservation, testing and certification of energy consumption of equipment, appliances need to be implemented gradually by 2025 along with a monitoring mechanism.
- Another key area of intervention for energy demand management in the agriculture sector pertains to mandatory use of BEE 4 star labelled and ISI, BIS marked motor pump sets, power capacitors, foot/reflex valves in the agriculture sector, in all tube-well connections. Through crop diversification, energy productivity, and yield improving agricultural policies, a reduction in energy consumption of rice, maize, pulses, sugarcane (Kharif season crops), wheat, fruits, and vegetables (Rabi crops) can happen by 2031.

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5.10 Annexures

Annexure 5.1: Data Sources Used in the Model

Sector	Parameter	Data source used for calculation
Industry	Electricity	State Statistical Abstract, Economic and Statistical Org. , Economic Advisor of Punjab, Govt. Of Punjab Government of Punjab , Various Volumes
	Coal	Observed data for 2011 - CEA General Review, TEDDY
	Diesel	Observed data for 2011 - CEA General Review, TEDDY
	LPG	Observed data for 2011 - CEA General Review, TEDDY
	Fuel/ Furnace oil	Observed data for 2011 - CEA General Review, TEDDY
	LDO	Observed data for 2011 - CEA General Review, TEDDY
	Gasoline	Observed data for 2011 - CEA General Review, TEDDY
	LSHS/HHS	Observed data for 2011 - CEA General Review, TEDDY
Transport	Bus	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
	Truck	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
	Car	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
		City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)
	Two Wheeler vehicle	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development
	Taxi	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development
	Three wheeler	City Mobility Plans, Punjab Transport Department Data and syndication, Ministry of Urban Development (2010)

Sector	Parameter	Data source used for calculation
Commercial	Electricity	Department of Economics, Statistics, Economic Advisor of Punjab (2014)
	Oil (Diesel)	Department of Economics, Statistics, Economic Advisor of Punjab (2014)
Agriculture	Tractor	Economic Survey, Punjab, Survey conducted by Petroleum Planning and Analysis Cell, MOPNG (2013)
	Agri Implements	Economic Survey, Punjab, Survey conducted by Petroleum Planning and Analysis Cell, MOPNG (2013)
	Agri-pumpsets	Economic Survey, Punjab, Survey conducted by Petroleum Planning and Analysis Cell, MOPNG (2013)
		Economic Survey, Punjab (2014)
		State Agriculture Department, IWMI Statistics on Punjab (2015)
Transformation	Power plant	CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL
		CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL, CERC, MNRE
		CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL, CERC, MNRE
		CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL, CERC, MNRE
		CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL, CERC, MNRE
		CEA Annual General Review of Thermal Power Plants, CEA Load Generation Report, MOSPI Energy Statistics, PSERC, PEDA, PSPCL, CERC, MNRE

Annexure 5.2: Sector wise polices and interventions

Sector	Measures	Policies and interventions
Agriculture	CES, MFE, ECM	**Draft Agriculture Policy for Punjab, 2013***:* The draft agriculture policy seeks to enhance agricultural productivity and farmers' incomes keeping in mind the sustainable use of natural resources through focus on crop diversification and value addition and integrated farming. **Punjab State Electricity Regulatory Commission (Demand Side Management) Regulations, 2012:** Draft regulations for DSM have been developed by PSERC and comments have been invited for the same. The Commission will enforce DSM activities for energy efficiency in a variety of sectors. The focus in the agriculture sector is on the use of star rated energy efficient pump sets. **Scheme for "Supplying, Commissioning and Maintaining Solar Photovoltaic (SPV) Pump sets at Farmers fields at in Punjab", Department of Soil and Water Conservation:** The DSWC is currently running a scheme that provides farmers having micro-irrigation system on their field the opportunity to procure SPV at 75% of the cost, subject to a maximum . The farmer would need to choose from an empanelled contractor and deposit his share as a beneficiary to avail the subsidy. **Feeder Segregation:** Feeder segregation for separation of general and agricultural load has largely been completed for all feeders as part of the Urban Pattern Supply Scheme.

		However, in the Kandi tract, owing to the presence of a hilly zone feeder segregation challenges are being faced which is also expected to be sorted out soon. Conversion of agriculture load feeders from Low Voltage Distribution System (LVDS) to HVDS has been undertaken in part and continues in the state. The annual plan also specifies that in the agriculture sector, the state proposes to convert (LVDS) to HVDS in agriculture sector. **SPV Water Pumping Programme under Jawaharlal Nehru National Solar Mission:** As part of this scheme, installation of 500 SPV water pumping systems is envisaged in the state. A 30% subsidy is provided on installation of solar projects that also includes solar water pumping systems of capacities ranging between 0.5 KWp to 5 KWp. As of recent past, approximately 1900 solar power pumps have been installed. **Pilot Agricultural Demand Side Management (Ag- DSM) Project at Muktsar & Tarn Taran, Punjab, 2010:** The Ag-DSM scheme is implemented by the Ministry of Power through BEE. This pilot in Punjab by a private agency is meant to provide an insights for energy agencies/ state distribution utility interested in investing and undertaking projects through PPP mode, for the replacement of old pumpsets with energy efficient ones. In this sector, energy conservation measures through demand management is crucial. Demonstration and pilots for solar power based agricultural pump-sets is needed.
Transport	MFE, MVC, PTM, TMS	**National Mission on Sustainable Habitats – Developing sustainable Transport systems** The state aims to attain a **modal shift** in its transportation sector under this mission. **National Transport Policy, 2006:** Following interventions in Punjab are being planned • Extend Metro to 4 cities (Amritsar, Jalandhar, Ludhiana and Mohali) and provide integrated feeder bus services to and from the proposed metro stations • DPR of metro for one city has already been prepared • Enhance density of public bus transport system • Create additional parking spaces based on projected passenger vehicle density by 2030s • Decongest roads by building separate tracks for non motorised transport. **Operational efficiency and traffic management:** The state is working to reduce congestion, improve operational efficiency, reduce noise and air pollution by Introducing intelligent traffic management systems. Developing real time passenger information systems is being worked out. Installation of dynamic traffic lights that can operate on the basis of level of congestion on the roads at different times of the day and hence can divert traffic in advance and can adjust times for stopping traffic at signals according to the traffic flow. **Promote low carbon transport infrastructure:** The state is working on the following interventions • Develop a fast moving freight corridor between the industrial towns of Punjab (Amritsar, Ludhiana and Jalandhar) to connect to the dedicated rail freight corridor being constructed linking Ludhiana to Kolkata in the east and Mumbai in the west. • Introduce battery operated/SPV operated/ alternate fuel operated small bus services to travel small distances **Awareness related interventions:** The state is thinking of the following measures. • Raise awareness about better driving practices and maintenance of trucks to enhance fuel efficiency • Promote car free days in different zones • Declare markets and heritage areas as no fossil fuel driven vehicle zones. **Enhance fuel efficiency:** The following interventions can reduce emissions from transport sector • Replace 700 old buses of Punjab Roadways with engines that can accept fuel with latest EURO—IV norms

		• Conduct training on Bus Simulator and other infrastructure in all workshops • Raise awareness of better driving practices and maintenance of buses to enhance fuel efficiency. • Introduction of BS IV and BS V vehicles in the state from 2017 Apart from the above measures, the state will need to start thinking about motor control measures.
Buildings	ECB, CES	**Punjab Energy Conservation Building Code**: Punjab Energy Development Agency (PEDA) has amended ECBC as per composite climate zone applicable for the state of Punjab and called as The Punjab ECBC. Provision of renewable energy systems and use of Punjab ECBC in building byelaws vide notification issued by Dept. of Housing & Urban Development, Govt. of Punjab are some of the key recent achievements in this regard. **GRIHA Incentives/mandates:** The Department of Housing and Urban Development, Government of Punjab has notified that an additional 5% floor area ratio free of charges shall be permissible to buildings that provide relevant certificates from the Bureau of Energy Efficiency or from GRIHA (Green Rating for Integrated Habitat Assessment). **Bachat Lamp Yojana in Punjab:** To save electricity, Punjab has introduced a "Bachat Lamp Yojna" in seven circles, Gurdaspur, Hoshiarpur, Nawanshahr, Ludhiana Suburban, Khanna, Sangrur and Faridkot. The distribution of CFLs started in May 2011, to replace the incandescent lamps. Compact Fluorescent Lamps (CFLs) are being provided to the consumers at subsidized rates. It is being implemented through the Punjab State Power Corporation Limited (PSPCL). The state will need to integrate the above measure in by-laws across the state.
Industries	IEE, CES	**PAT scheme in Punjab:** It is a nationally implementable market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded. The scheme is being used to unlock energy efficiency opportunities in the country, estimated to be about Rs. 74,000 crores. The state aims to achieve industrial energy efficiency through the PAT scheme. Out of the 60 units notified in Northern India, 22 units are in Punjab. They are 2 chlor alkali making units, 2 fertilizer plants, 3 power plants, 3 pulp and paper units, 11 textile units and 1 cement unit. These units have energy consumption exceeding 30,000 MT of oil equivalent and have been identified under the Phase-I of PAT scheme and governed by the Energy Conservation Act, 2001 with amendment in 2010. The scheme is being implemented from April 1, 2011. Industries which exceed their energy efficiency improvement targets will receive Energy Saving Certificates (ESCs) equivalent to their excess savings and industries which fail to meet their targets may either face penalties or purchase ESCs. Clean energy substitution in industries needs a major boost in the state.
Renewable Energy	RES, CES	**New and Renewable Sources of Energy (NRSE) Policy, 2012:** This policy promotes the application of **renewable energy technolog**ies to maximize their share to 10% of the total installed power capacity in the state by the year 2022. A major rooftop programme for solar photovoltaic power project has been launched in the state under which the rooftop SPV power projects are being setup at various important govt., institutional, and religious buildings namely Punjab Raj Bhawan, Punjab Civil Secretariat, Golden Temple, Wagah Border, Punjab Agricultural University, Ludhiana and Pushpa Gujral Science City, Kapurthala. PEDA is undertaking a solar rooftop programme in the state for the domestic and commercial sectors through grid interconnectivity by deploying net metering in consultation with MNRE. Punjab has issued notifications for mandatory use of CFL, Solar Water Heating Systems, BIS approved & minimum 4 Star Labelled pump sets and promotion of energy efficient buildings. Demo projects have been initiated for development of energy efficiency in municipal street lighting & water pumping in existing govt. buildings. Use of BEE star labelled electrical appliances in all government organizations has also been mandated.

		Currently, 28.5 MW of biomass power is being generated in the state and another 245 MW is in the pipeline. Almost 220 MW of renewable energy through cogeneration is already deployed in the state. 30 MW of small hydro power plants are in place and 40 MW of biogas plants are under construction. Eight clusters have been crested to facilitate conversion of energy from Municipal Solid Waste. There is a potential of 10 waste to energy power plants with each having a 2 MW capacity in future. There is need for attracting private sector investment in NRSE projects along with broader participation by public community/civil society. Support research and development, demonstration and commercialization of new and emerging technologies in renewable energy sector. Encourage solar power generation and promote Stand Alone, Rooftop and integrated power projects to achieve installed capacity of 1000 MW with net-metering agreement between consumers and Discoms. RPO compliance also needs to be looked at.
Thermal energy	CUM, CCT, CES	The demand for power in the state is rising sharply on account of rapidly increasing use of electrical energy for agricultural operations, progressive industrialization, increasing service sector growth and high living standard of residents and intensive rural electrification programme. With a view to make the state self-reliant, four thermal plants namely Talwandi Sabo 1980 MW, Rajpura 1400 MW, Govindwal Sahib 540 MW and Gidderbaha 2640 MW have been undertaken. The state has also proposed to set up 1000 MW gas based power plant at Ropar. Recently, 3 new coal based IPPs have been sanctioned. Out of this the IPP in Rajpura has started running. The capacity of the Rajpura unit is 660 MW and two of the units are running. The state has been experiencing surplus thermal power generation in the recent past since last two years and is aiming to explore how the surplus power can be utilized efficiently in future for a growing SME and service sector. The state has been contemplating to reduce coal imports in the future as it adds to the environmental pollution, economic costs of air pollution and emissions. Moreover, the imported, delivered coal is approximately three times costly in comparison to the landed and mining points which add to the cost of generation and loss of fiscal resources. Clean coals applications are yet find place and large scale application in this area. Also capacity utilization factor of thermal plants needs to be further increased.
Hydropower	CES	The state is generating 4353 MU from hydro-power. The state is importing 4321 MU of hydro-power from Bhakra Beas Management Board. The potential power generation capacity of the state from its extensive canal systems is about 250 MW at Canal falls, out of which 133 MW capacity projects are in operation. Another 23 MW capacities are under execution including hydel projects undertaken by Punjab State Power Corporation Limited (PSPCL). The State Government is committed to exploit the total potential by the year 2022. In addition to the sites already identified by PEDA in association with Punjab Irrigation Department (PID) and PSPCL, private investors can also apply for self-identified sites in case of small / mini hydel projects, which are not included in the list of projects identified by PEDA. The state may need to continue to buy hydro-power in the near future to meet it energy needs.

Annexure 5.3: Energy consumption of Kharif crops across scenarios

Kharif Crops										
Energy consumption (million Kwh)	Rice	Maize	Total Pulses	Sugarcane	Total Fruits	Total Vegetables	Total Oilseeds	Cotton	Fodder Crops	Agro forestry
Reference										
2020	87.22	4.99	0.46	22.84	11.50	1.20	0.15	8.50	5.20	2.00
2030	88.75	3.91	0.30	24.38	10.20	0.50	0.11	6.20	5.30	1.50
Policy										
2020	60.85	3.61	0.43	7.03	10.37	0.70	0.34	6.61	4.80	1.90
2030	46.99	3.39	0.42	4.78	9.94	0.10	0.27	5.84	4.90	1.30
Ambitious										
2020	47.04	2.61	0.28	5.23	6.33	0.66	0.13	1.21	4.69	1.89
2030	10.82	2.39	0.14	3.44	4.16	0.09	0.03	1.05	4.48	1.21

Annexure 5.4: Energy consumption of Rabi crops across scenarios

Rabi crops								
Energy consumption (million kwh)	Wheat	Total Pulses	Sugarcane	Total Fruits	Total Vegetables	Total Oilseeds	Fodder Crops	Agro forestry
Reference								
2021	61.67	2.17	3.48	0.95	1.88	0.91	3.60	1.89
2031	60.41	1.72	3.19	0.71	1.57	0.50	2.35	1.82
Policy								
2021	53.93	**0.42**	3.46	0.83	1.18	0.75	4.50	1.42
2031	44.23	**0.27**	2.82	0.52	0.33	0.46	1.58	1.21
Ambitious								
2021	44.69	0.21	3.16	0.61	0.26	0.50	3.58	1.01
2031	24.85	0.16	1.27	0.44	0.05	0.39	1.57	0.68

Climate Resilient Green Growth Strategies for Punjab

Towards an Inclusive Development Agenda

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