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NITI Aayog

भारत 2023 INDIA

INDIA ENERGY SECURITY SCENARIOS (IESS) 2047

VERSION 3.0

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Suggested Citation

NITI Aayog (2023), India Energy Security Scenarios (IESS) 2047 V3.0, Government of India.

Available at: https://www.iess2047.gov.in

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NITI Aayog welcomes user's feedback/suggestions for continuous upgradation and improvement of IESS 2047.

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CONTENTS

LIST OF ABBREVIATIONS

AEEE	Alliance for an Energy Efficient Economy
AFRM	Alternative Fuels and Raw Materials
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
APDRP	Accelerated Power Development and Reforms Programme
AT&C	Aggregate Technical & Commercial Losses
AUSC	Advanced Ultra Supercritical
BAU	Business As Usual
BCM	Billion Cubic Meters
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
BPKM	Billion Passenger Kilo Meter
BTKM	Billion Tonne Kilo Meter
BWR	Boiling Water Reactor
CAGR	Compound Annual Growth Rate
CCS	Carbon Capture and Storage
CEA	Central Electricity Authority
CNG	Compressed Natural Gas
COP	Conference of the Parties
CPP	Captive Power Plant
CSP	Concentrated Solar Power
CUF	Capacity Utilization Factor
CV	Calorific Value
DFC	Dedicated Freight Corridor
E&P	Exploration and Production
ECBC	Energy Conservation Building Code
eMARC	Monitoring and Analysis of Residential Electricity Consumption
EOR	Enhanced Oil Recovery
EPI	Energy Performance Index
EV	Electric vehicle
EWS	Economically Weaker Section
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FBR	Fast Breeder Reactors

LIST OF ABBREVIATIONS	
FCV	Fuel Cell Vehicle
FID	Final Investment Decision
FMCG	Fast Moving Consumer Goods
GDP	Gross Domestic Product
GWh	Gigawatt hour
HELP	Hydrocarbon Exploration and Licensing Policy
HEP	Hydro Electric Power
HSR	High Speed Rail
HYBRIT	Hydrogen Breakthrough Ironmaking Technology
IOR	Improved Oil Recovery
IPDS	Integrated Power Development Scheme
IRENA	The International Renewable Energy Agency
JNNSM	Jawaharlal Nehru National Solar Mission
KG-D6	Krishna Godavari Dhirubhai 6
kWh	kilo Watt hour
LE	Life Extension
LIG	Low-Income Group
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
lph	liters per hour
MFBR	Metal Fuelled Fast Breeder Reactors
MIG+	Middle-Income Group and Above
MMSCMD	Million Metric Standard Cubic Meters per Day
MMT	Million Metric Tonne
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MoSPI	Ministry of Statistics and Programme Implementation
MoUD	Ministry of Urban Development
MSW	Municipal Solid Waste
MT	Million Tonnes
Mtoe	Million Tonnes of Oil Equivalent
NAPCC	National Action Plan on Climate Change

LIST OF ABBREVIATIONS

NDC	Nationally Determined Contribution
NEP	National Electricity Plan
NIWE	National Institute of Wind Energy
NPP	Nuclear Power Plant
NSM	National Solar Mission
NSSO	National Sample Survey Office
OALP	Open Acreage Licensing Programme
PAHAL	Pratyaksh Hanstantrit Labh
PAT	Perform, Achieve, Trade
PHP	Pumped Hydro Plants
PHWR	Pressurized Heavy Water Reactor
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
PWR	Pressurized Water Reactor
R&D	Research and Development
R&M	Renovation and Modernisation
R/P	Reserves-to-Production
RPO	Renewable Purchase Obligation
SAARC	South Asian Association for Regional Cooperation
SC	Super-Critical
SEC	Specific Energy Consumption
SFC	Specific Fuel Consumption
SubC	Sub-Critical
T&D	Transmission and Distribution
TAPS	Tarapur Atomic Power Station
TKM	Tonne Kilometer
TPP	Thermal Power Plant
TWh	TeraWatt hour
ULBs	Urban Local Bodies
USC	Ultra Super-Critical
WHR	Waste Heat Recovery
WtE	Waste to Energy

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Foreword

India is now the fifth largest economy in the world and aspires to be the third largest by 2027. The country's growth will be facilitated by an expansion of urban, industrial and infrastructural services. Energy is required in multiple areas for social development, to support India's demographic transition and consequent job creation, its agrarian and urban transition, and critical energy infrastructure development. Achieving economic growth in a sustainable manner is a key priority of the Indian Government.

In the last few years, India has made significant policy choices with respect to transitioning towards a more inclusive and sustainable energy system. Enabled by these choices, India has achieved the 2015 Nationally Determined Contributions (NDC) goals 9 years ahead of schedule. The Climate Change Performance Index (CCPI 2023) has also listed India among the top 5 countries and the best performing among G-20 nations. India has historically followed the path of low-carbon growth. India's share in total cumulative emissions from 1850-2021 is less than 5% compared to 24% in the US and 14% in China. India's growth is now being driven by green initiatives. The share of non-fossil in the total installed power capacity has increased to 43%. This is expected to rise further in the future as India's economic growth decouples from emissions.

India's energy transition story can be viewed from the lens of i) increasing share of electricity in the overall economy; ii) increasing share of clean energy in total electricity generation; iii) increasing application of energy efficiency; and iv) application of circular economy principles. Digitalisation and behavioral changes are complementing these efforts. These four shifts are taking place alongside the increase in availability of modern energy for fulfilling the developmental needs of the country.

NITI Aayog as the apex policy think tank of the Government of India has undertaken this important exercise of revamping the India Energy Security Scenarios (IESS) 2047 tool to explore future scenarios of plausible demand electrification, share of non-fossil in the total installed electricity capacity, role of energy efficiency, share of alternative clean fuels such as Green Hydrogen, electric vehicles, biofuels and the role of renewable technologies including energy storage. With the updated IESS 2047 tool, we aim to encourage informed policy discussions on issues affecting the energy transition in the country.

(Suman Bery)

New Delhi
14th July, 2023

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MESSAGE

India Energy Security Scenarios (IESS) 2047 is an accounting based tool to model energy scenarios using bottom-up approach. Given the rapid developments that have taken place in the last decade especially with emergence of new technologies such as Green Hydrogen, Energy storage alternatives and increased penetration of renewables, NITI Aayog has undertaken an exercise to revamp the IESS tool to align with these latest developments and the Panchamrit targets announced by the Hon'ble Prime Minister at COP-26.

Given the projected energy demand in various sectors, the user can choose a different combination of energy supply options to satisfy the demand. Seventeen supply sectors are identified for primary energy use namely coal, coal with carbon capture storage (CCS), oil, gas, large hydro, small hydro, nuclear, solar photovoltaic (PV), concentrated solar power (CSP), distributed solar, onshore wind, offshore wind, biomass based electricity, 2G biofuels, 3G biofuels, waste to energy and imports and exports. The energy demand and supply are balanced using an accounting principle wherein unmet energy demand is met from imports while in-case of electricity, unmet electricity demand is met from coal generation.

The updating of sectoral sheets of the IESS 2047 has been undertaken in detailed consultation with all relevant stakeholders of demand and supply side. The sectoral linkages are also established with socio-economic indicators such as GDP, sectoral share of GDP, rate of urbanization and population growth. As seen in the earlier version, the tool can generate energy demand and supply scenarios for India leading up-to year 2047. The tool also provides for implications on water, land, cost besides emissions and energy indicating the richness of the tool.

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एक कदम स्वच्छता की ओर

I hope that line ministries/departments, sector experts, think-tanks and academic institutions benefit from this updated tool to develop realistic energy models for the country. If we succeed in persuading more users to engage with this tool, we will consider our efforts have been successful.

I congratulate the team led by Shri Rajnath Ram, Advisor (Energy/Natural Resource and Environment) and his team members Shri Venugopal Mothkoor, Sr. Specialist and others for their contributions towards building an updated version of the tool.

(DR. VK SARASWAT)

NEW DELHI
13.07.2023

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भारत 2023 INDIA

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MESSAGE

India has clearly articulated its climate ambitions with the announcement of its updated Nationally Determined Contributions (NDC) and the submission of its "Long-Term Low Carbon Development Strategy" laying down the path for achieving the "Panchamrit" goals announced by the Hon'ble Prime Minister at COP-26. The updated quantified NDC targets announced by the Government include: i) 50% of total installed power capacity from non-fossil sources; ii) 45% reduction in emission intensity over 2005 levels; and iii) creation of additional carbon sink of 2.5 to 3 billion tons of CO2 equivalent through additional forest and tree cover.

Besides these NDC commitments, there are several other policies announced by various central government ministries/departments related to energy transition. It is for NITI Aayog to assess the integrated impact of these announced policies and understand the implications therein. **India Energy Security Scenarios** (IESS) 2047 is a tool developed by NITI Aayog in collaboration with IIT Bombay to fulfill this objective wherein a user can generate energy demand and supply numbers till 2047 under various scenarios. The tool has been revised after extensive consultations and inputs from a large number of stakeholders and sectoral experts.

The strength of the tool lies in its open nature through which a user can generate an infinite number of scenarios. The web version of the tool offers user-friendly graphical representations of energy demand and supply scenarios for the country based on user choices. It works on accounting principles and provides implications for energy, emissions, land and water for a chosen scenario.

For meeting the energy needs of the country sustainably, there needs to be a greater understanding of the choices involved and the aim of this tool is to develop this rich understanding. I compliment the Energy Team of NITI Aayog for their efforts in bringing this tool in the public domain.

13/7

[B.V.R. Subrahmanyam]

New Delhi
13th July, 2023

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एक कदम स्वच्छता की ओर

ABOUT IESS 2047

India Energy Security Scenarios (IESS) 2047 Version-3.0 is a scenario based accounting tool developed by NITI Aayog in collaboration with IIT Bombay to model supply and demand sectors for India leading up to the year 2047 incorporating the latest developments and policy announcements of green hydrogen mission, carbon capture-storage, emergence of energy storage alternatives, increased penetration of renewables and nuclear energy. The tool provides options for developing different scenarios based on different assumptions of GDP growth, share of industry, services and agriculture in the economy, population growth, rate of urbanization, end use energy demand, penetration of different technologies and energy efficiency, etc. The tool provides implications on water, land, cost besides emissions and energy transition. The views of various stakeholders have been suitably incorporated after due consultations.

Each sector in IESS is modelled using different levers. Further, each lever has four levels defined in terms of future trajectory as explained below:

1. **Level 1- Pessimistic Scenario:** This assumes that little or no efforts are made in terms of interventions on the demand and supply side.
2. **Level 2- Business-As-Usual (BAU) Scenario**: This describes the level of efforts which is deemed practically achievable based on historical trends as well as recent progress.
3. **Level 3- Optimistic Scenario:** This describes the level of efforts that is ambitious and targets to achieve various climate commitments of the government efforts.
4. **Level 4- Heroic Scenario**: This considers extremely aggressive and ambitious options depending upon on technical limits and capabilities.

The IESS 2047 Version 3.0 also allows users to define values outside the level definition for each lever using a user defined trajectory option. As a result, user will be able to generate infinite number of scenarios. The web version of the tool offers user-friendly graphic representations of the energy demand and supply scenarios for the country based on user choices.

This booklet provides short one page summary of various assumptions used in building IESS 2047 Version 3.0 across both demand and supply sectors. It also provides hypothetically generated pathways representing scenarios of Net Zero and Aatmanirbhar. These pathways are simply indicative and should not be considered as prescriptive by NITI Aayog. The aim of the tool is to encourage informed policy discussions on issues affecting energy transition using different kinds of permutation and combinations of the scenarios. Finally, the document also summarizes the results of few scenarios modeled using IESS 2047 Version-3.0.

For information on how to develop your own pathway and detailed documentation for each sector, please log on to our website: www.iess2047.gov.in

DEMAND SECTORS

CHAPTER-I
INDUSTRY

IA: ENERGY CONSUMPTION OF INDUSTRIES

The industry sector is not homogeneous in nature. It comprises several manufacturing industries which engage in different energy-consuming activities. However, a few industries are more energy-intensive than others and contribute heavily to the total energy consumption in the industry sector. Perform, Achieve, Trade (PAT) scheme Phase-I included seven energy-intensive industries - cement, textile, iron & steel, aluminium, fertilizer, pulp & paper and chlor-alkali production. These seven industries have been considered in the IESS model. The rest of the industries have been clubbed together and denoted as 'others'.

Energy consumption of the industry sector is estimated as:

*Energy consumption= Σ(Sectoral production*sectoral Specific Energy Consumption (SEC))*

Further, the energy consumption of each industry is disaggregated into fuel-wise energy consumption with fuel mix assumptions.

Table IA.1 gives a description of the fuel mix of industries as of 2020, as reported by the Bureau of Energy Efficiency (BEE). Four trajectories have been developed in terms of the change in the fuel mix in future. Green Hydrogen has been added as another alternative fuel in the future energy mix. To achieve a low carbon future, change in the fuel mix of the industry sector is crucial. Figure 1A.1 show the impact of change in fuel mix on energy-related emissions from industries.

Table 1A.1: Fuel mix in various industries as of 2020.

Sector	Coal	Oil	Gas	Grid Electricity	Bioenergy
Aluminium	94.0%	4.5%	0.5%	1.0%	0%
Cement	97.0%	1.0%	0.0%	2.0%	0%
Chlor-alkali	75.0%	2.0%	13.0%	10.0%	0%
Fertilizer	8.0%	0.0%	90.0%	2.0%	0%
Iron & Steel	83.5%	1.5%	2.0%	13.0%	0%
Pulp & Paper	80.0%	5.0%	0.0%	15.0%	0%
Textile	71%	1%	2%	25%	0%
Others	33.5%	40.0%	6.0%	9.3%	11.3%

LEVEL 1

Level 1 is a pessimistic trajectory. It assumes that the current situation will not change in future. The fuel mix of all sector remains constant throughout the timeline of the model.

LEVEL 2

Level 2 assumes that the fuel mix gradually changes over time. The share of grid electricity, gas and green hydrogen (for sectors where it can be used) increases slowly and the share of coal and biomass in the mix decreases accordingly. Oil products are largely used for non-energy purposes in the industry sector. Hence, the share of oil products has been kept constant, not only for this trajectory but for all trajectories.

LEVEL 3

Level 3 is an optimistic trajectory where the fuel substitution takes place quickly and to a greater extent as compared to level 2. Penetration of grid electricity and gas increases in the mix, especially in cement, steel, aluminium and pulp and paper industries, which results in lower emissions from industry sector.

LEVEL 4

Level 4 considers extremely aggressive trajectory which assumes a high amount of electrification in the industry sector along with penetration of green hydrogen in the sectors where it is feasible, such as fertilizers, steel, etc.

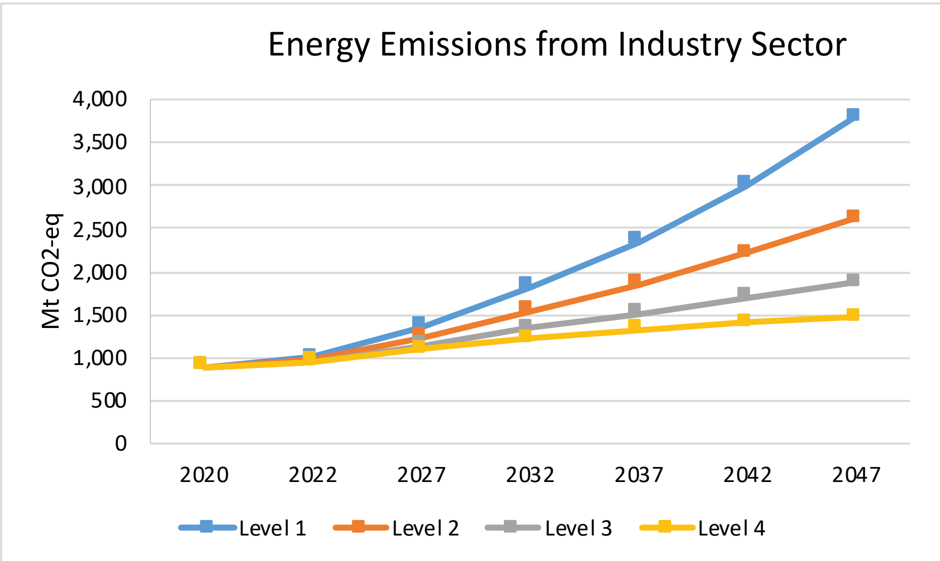


Figure IA.1: Energy Emissions from Industry Sector

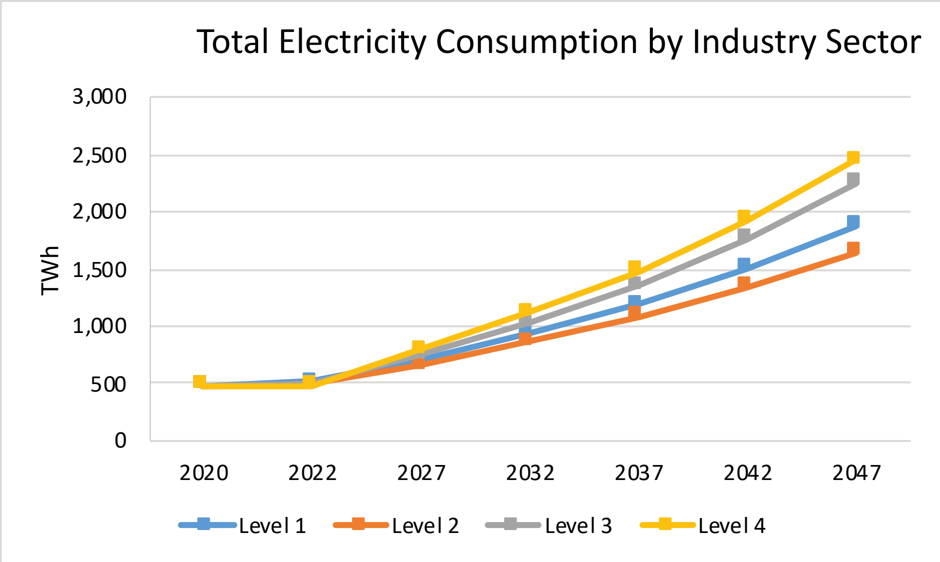


Figure IA.2 Total Electricity Consumption by Industry Sector

IB: FUEL SAVINGS IN CEMENT SECTOR

The energy demand for the cement industry has also been modelled on the basis of improvement in technology process. The lever of Specific Energy Consumption (SEC) has already been adopted, now the users may choose one among the available fuel saving options. Cement sector is one of the two major energy-consuming industrial sectors, the other being the steel industry. Different technology options are modelled in the cement sector for additional fuel savings. In general, the default technology option is Level-1 and other options are denoted by succeeding numbers. Each succeeding option indicates a reduction in energy demand from the cement sector but this does not necessarily imply a reduction in emissions from the sector. Additional SEC improvement of 0.2% per year is assumed in Level 2, 0.8% in Level 3 and 1% in Level 4.

LEVEL 1

In this level, no extra efforts have been made for additional fuel savings or SEC reduction other than SEC improvements.

LEVEL 2

This option characterizes the additional impact of a concerted drive to increase the penetration of Waste Heat Recovery (WHR) technologies in cement plants. Such technologies are available globally, but in India, the current penetration is low. Under this technology option a large penetration of such technologies is assumed with a corresponding reduction in thermal and electrical energy used in the process. This level assumes additional fuel saving or additional reduction in SEC of 10% by 2047.

LEVEL 3

In this option, a major switch in the sourcing of electric power in the cement sector is modelled. Currently, the plants prefer to produce most of their electric power through Captive Power Plants (CPPs) which are largely coal-powered. This option provides insights into the impact of a switch to procuring most of the electric power from the grid. This assumes that reliable grid power would be available. Such a switch provides an improvement in the energy efficiency of the specific plant since the inefficiency of the CPP is now outside the plant boundary. This level assumes additional fuel saving or additional reduction in SEC of 25% by 2047.

LEVEL 4

Option 4 is a major driver for reduction of thermal energy consumption in cement plants. European and Japanese plants are reportedly running with more that 30-50% coal being substituted by alternate fuels such as domestic, industrial and agricultural waste and used rubber tyres. The penetration of Alternative Fuels and Raw Materials (AFRM) in India is probably less than 1% and thus a large potential seems to exist if the enabling infrastructure and incentives can be provided along with policy-based support. This level assumes additional fuel saving or additional reduction in SEC of 30% by 2047.

IC: FUEL SAVINGS IN STEEL SECTOR

Steel sector is one of the two major energy-consuming industrial sectors. The energy demand for steel sector has been modelled on the basis of improvement in technology options. Users may choose one of the four available options which are modelled in the steel sector. The default technology option is level 1, and other options are denoted by succeeding numbers. Each succeeding option indicates a reduction in energy demand from the steel sector but this does not necessarily imply a reduction in emissions from the sector. Additional SEC improvement of 0.2% per year is assumed in Level 2, 0.8% in Level 3 and 1% in Level 4.

LEVEL 1

In this level, no extra efforts have been made for additional fuel savings or SEC reduction other than SEC improvements.

LEVEL 2

The Level 2 considers the impact of a major shift to electric furnace than traditional oxygen furnace which is a default option. This level assumes additional fuel saving or additional reduction in SEC of 10% by 2047.

LEVEL 3	LEVEL 4

LEVEL 3

This technology option models a major switch in the sourcing of electric power in the iron and steel sector. Current trends show that plants are preferring to produce most of their electric power through the use of Captive Power Plants (CPP). This tech option provides insights into the impact of a switch to procuring most of the electric power from the grid. Such a switch provides a major improvement in the energy efficiency of the specific plant since the inefficiency of the CPP now goes outside the plant boundary. This level assumes additional fuel saving or additional reduction in SEC of 25% by 2047. This level assumes additional fuel savings or additional reduction in SEC of 25% by 2040.

LEVEL 4

This technology option is a major driver for the reduction of thermal energy consumption in iron and steel plants. Plants in USA, Europe and Japan are continuously increasing scrap based steel production. The utilization of scrap in steel plants in India is probably less than 3-5%. Increased scrap utilization has the potential to significantly reduce the thermal energy consumption in steel plants since typically 60% of the total energy is used for producing iron and this can be saved through the increased use of scrap in the downstream steel-making process. This level assumes additional fuel savings or additional reduction in SEC of 30% by 2047.

CHAPTER-II
PASSENGER TRANSPORT

IIA: PASSENGER TRANSPORT DEMAND

The passenger transport sector is characterized by the passenger mobility demand of the country, measured in passenger-kilometers. The passenger transport demand is linked to the growth and development activities of the economy and hence linked with the Gross Domestic Product (GDP) of the country. With increased economic development, there is expected to be an increase in mobility and demand for both inter-city and intracity passenger transport in India over the next few decades. A correlation between per capita mobility (i.e. passenger-km per capita) and GDP per capita has been developed. This correlation occurs from the assumption that as the per capita GDP of a country increases, passenger mobility also increases until it reaches a certain level and then saturates. The saturation of passenger mobility demand has been observed in developed countries such as the UK and the US.

The correlation is mathematically expressed as,

$$\frac{pkm}{capita} = \frac{(Saturation\ level)}{1+a*e^{(b*\frac{GDP}{capita})}}$$

Where, a and b are coefficients of correlation

The average distance travelled annually per person in India in 2020 was 6,900 km. The correlation between GDP and passenger transport demand is used to create projections of future transport demand.

LEVEL 1

Level 1 assumes a steady increase in the per capita demand for transport over the next three decades. From current levels of 6900 km, the distance travelled annually per person is expected to increase and saturates at 16,929 km by 2047. Improved access to transport infrastructure, accompanied by increasing demand for mobility due to increased economic activity would lead to an increase in total passenger transport demand.

LEVEL 2

Level 2 envisions a rise in the number of activity centres across the country, thereby reducing the demand for inter-city travel of people migrating for employment opportunities. Better planning and improved urban designs would also lessen intra-city travel distances. This Level would see a drop in the overall annual demand for mobility per capita of 15,290 km by 2047.

LEVEL 3	LEVEL 4
Level 3 visualizes a world where all new cities that come up in the country in the next four decades plan for Transit Oriented Development, and there is a conscious effort to incorporate similar best practices in pre-existing urban centres. Smart, IT-enabled transport infrastructure enabling better route optimization for commute trips further helps in reducing the transport demand per person. The distance travelled per person saturates at 13,579 km by 2047.	Level 4 assumes that the growth of passenger transport demand would be moderated by policy initiatives on urbanization patterns and transport management. Development in the rural sector will reduce the demand for transport of migrant workers seeking employment in urban centres. The measures for Transit Oriented Development would get strengthened, with a focus on minimizing the need for commute trips. All these initiatives will reduce the annual per capita passenger transport demand which would saturate at 11,793 km by 2047.

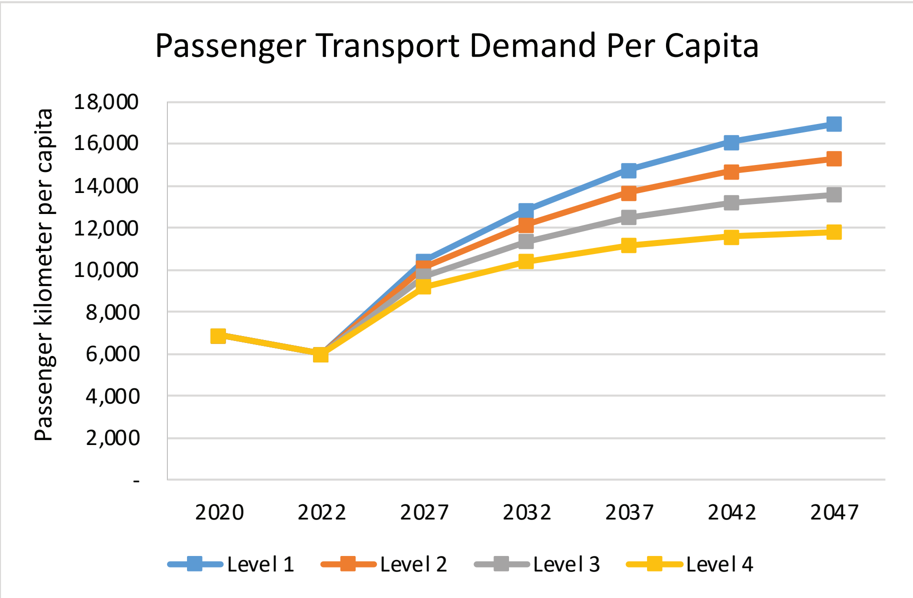


Figure IIA.1: Passenger Transport Demand Per Capita

IIB: PASSENGER TRANSPORT MODAL SHARES

Passenger transport is divided into three modes of travel - road, rail, and air travel. In 2020, estimated travel by road accounted for 87.24% and rail accounted for 11.29% of total passenger traffic. The remaining 1.47% of traffic was catered to by air travel. Electric vehicles witnessed a limited penetration in the market, the prominent share of which, around 0.9%, was mainly in the two-wheeler segment. With improved road transport infrastructure and increased penetration of private modes of road transport, railways have been consistently losing share in the overall passenger traffic volumes in India.

Four future trajectories have been defined in the tool to analyze the effect of changing the modal mix of passenger transport on the fuel-wise energy demand of the transport sector.

LEVEL 1

In the level 1 trajectory, it is assumed that the share of rail keeps declining as per current trends and reduces to 10% in 2047 from the current 11.29%. The share of air transport also drops to 1% in 2047. The remaining demand is met through road transport.

LEVEL 2

In level 2, i.e. BAU trajectory, it is assumed that the share of rail in passenger transport increases marginally to 12%, and that of air travel increases to 1.5%. Road transport fulfils 86.5% of demand.

LEVEL 3

In the level 3 trajectory, it is assumed that rail transport remains favourable due to the construction of metro and High-Speed Rail connecting major metropolitan cities, due to which the share of railways increases to 13% in 2047. The share of air transport increases to 4% in 2047.

LEVEL 4

Level 4 trajectory assumes that aggressive efforts are made to increase the share of railways in transport, resulting in a 15% share in 2047 due to increasing usage of metro and HSR services in a lot of cities. The share of air transport is assumed to further increase to 5% with an assumed increase in the growth of domestic airports.

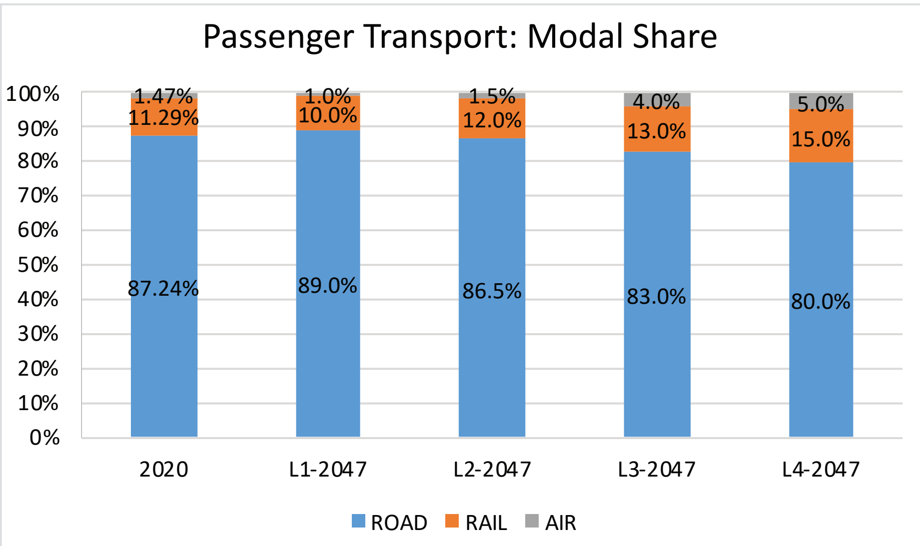


Figure IIB.1: Modal Share in Passenger Transport

IIC: MASS TRANSIT IN ROAD TRANSPORT

The passenger road transport is further disaggregated into mass transit and personalized transport. Mass transit includes passenger travel via buses and omnibuses, whereas personalized transport includes transit through cars, taxis, 3-wheelers and 2-wheelers. The share of mass transit (buses and omnibuses) within road transport was about 60% in 2020.

Mass transit is an effective means to achieve the same amount of passenger transport with less energy and consequently fewer emissions than private transport. Thus, it can play a vital role in reducing transport energy consumption and emissions. Four trajectories have been developed to analyse the effect of the varying shares of mass transit in the system. Table IIC.1 describes the four trajectories for the share of mass transit.

Table IIC.1: Share of Mass Transit and Private Transport in Road Transport

Mode	2019-20	2047			
		Level 1	Level 2	Level 3	Level 4
Mass Transit	60%	40%	58%	60%	70%
Private	40%	60%	42%	40%	30%

LEVEL 1

Level 1 assumes a decline in share of public transportation compared to the current levels. The mass transit share reduces to 40% by 2047 as compared to 60% in 2020. This decline is the result of reduced bus usage of 40% in 2047 as compared to 60% in 2020.

LEVEL 2

Level 2 assumes a slight decrease in use of public transportation as compared to 2020 levels. The mass transit share reduces very slightly to 58% by 2047 as compared to 60% in 2020.

LEVEL 3

Level 3 assumes the current share of public transportation to remain same until 2047. The share of bus usage remain almost same until 2047.

LEVEL 4

Level 4 assumes a healthy increase in share of public transportation compared to the current levels. The mass transit share increases to 70% by 2047 as compared to 60% in 2020.

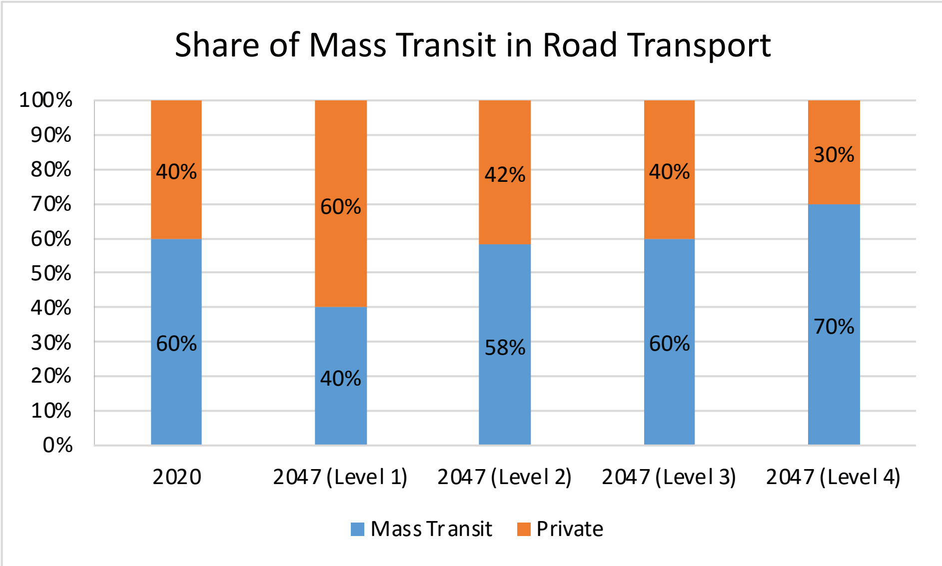


Figure IIC.1: Share of Mass Transit in Road Transport

IID: SHARE OF EVS, FCVS, CNG AND HYBRID VEHICLE

Passenger transport is divided into three modes of travel - road, rail, and air travel. While rail transport is on the way to getting completely electrified soon, road transport is still mainly dependent on high emission fuels. The oil product requirements for the transport sector form a key part of India's import needs. Alternative technologies such as Electric Vehicles (EVs), Fuel Cell Vehicles (FCVs), Hybrid Vehicles and CNG Vehicles are emerging technologies which could help reduce the import dependence of the country, as well as curb the tailpipe emissions from on-road vehicles.

The government of India launched the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme to encourage the adoption of electric and hybrid vehicles in India. Ambitious targets have also been set for sales of electric vehicles. Active efforts are being taken to develop and launch fuel cell-based vehicles for Indian climate and terrain conditions.

To understand the impact of these alternative technologies, share of EVs/FCVs/CNG/ Hybrid vehicles has been introduced as parameter in the model. Four trajectories have been created for the penetration of electric vehicles, fuel-cell vehicles in future, for multiple vehicle categories. Trajectories have been described in Tables IID.1 to IID.4. Table IID.1 shows the penetration of fuel cell-based vehicles in road transport in different levels.

Table IID.1: Penetration of Fuel Cell-based Vehicles in Road Transport

Mode	2020	2047			
		Level 1	Level 2	Level 3	Level 4
FCV Car	0%	0%	5%	7%	9%
FCV Bus	0%	0%	1%	2.5%	3.75%

Table IID.2: Penetration of EVs in Road Transport

Mode	2020	2047			
		Level 1	Level 2	Level 3	Level 4
Electric Car	0.5%	10%	20%	40%	50%
Electric 2W	0.9%	50%	60%	80%	100%
Electric 3W	0.3%	50%	60%	80%	100%
Electric Taxi	0.1%	15%	25%	40%	60%
Electric Bus	0.2%	10%	20%	40%	60%

Table IID.3: Penetration of Hybrid Vehicles in Road Transport

Mode	2020	2047			
		Level 1	Level 2	Level 3	Level 4
Hybrid	0%	0%	5%	10%	15%

Table IID.4: Penetration of CNG Vehicles in Road Transport

Mode	2020	2047			
		Level 1	Level 2	Level 3	Level 4
CNG Car	2.0%	3%	10%	15%	20%
CNG 3Ws	15.0%	10%	15%	20%	-
CNG Taxis	4.0%	3%	5%	10%	10%
CNG Buses	1.6%	2%	10%	15%	20%
CNG Omni-Bus	1.6%	2%	10%	15%	20%

LEVEL 1

Level 1 assumes a slower adoption of EVs, FCVs, CNG and hybrid based vehicles. Hybrid and FCVs share remain zero from 2020. Electric car share increase to 10% in 2047 compared to 0.5% in 2020. Electric 2Ws and 3Ws show a healthy increase to 50% in 2047. CNG based vehicles show an increase in every type of vehicles except for 3Ws and CNG Taxis.

LEVEL 2

Level 2 assumes a slightly faster adoption of EVs and CNG based vehicles. FCV cars and hybrid vehicles share increase to 5% in 2047 compared to 0% in 2020. Electric car share increase to 20% in 2047 compared to 0.5% in 2020. Electric 2Ws and 3Ws show a healthy increase to 60% in 2047 compared to 0.9% and 0.3% in 2020 respectively.

LEVEL 3

Level 3 assumes fast adoption of EVs, FCVs, CNG and hybrid based vehicles. Electrification of private and mass transit vehicles reach 40% and in 2W and 3W sector it reaches to 80% in 2047. Hybrid and CNG vehicles assume a share in the range of 10–20% in 2047. Fuel-cell based car reach 7% and buses share account for 2.5% in 2047 compared to 0% in both cases.

LEVEL 4

Level 4 assumes complete electrification in 2W and 3W sector. Electric car accounts for 50% share in 2047 compared to 0.5% in 2020. Hybrid and CNG vehicles assume a share in the range of 10–20% in 2047. Fuel-cell cars get a share of 9% in 2047 compared to 0% in 2020.

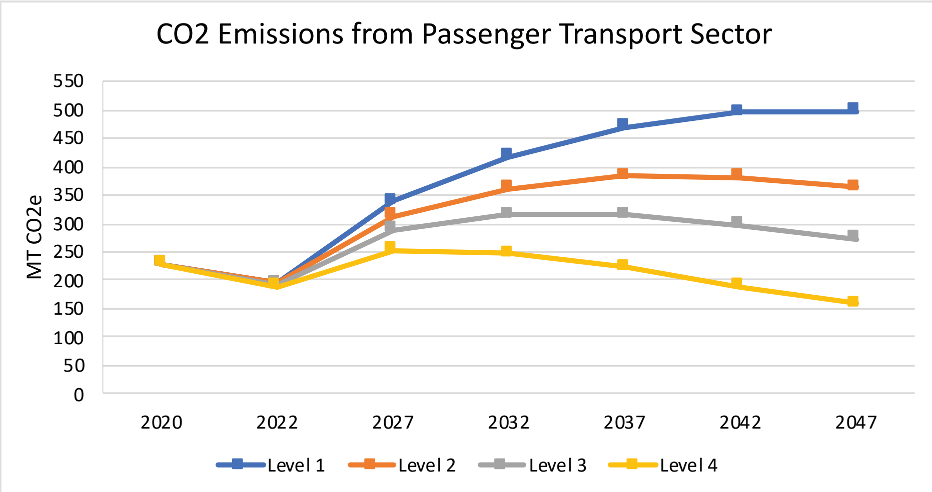


Figure IID.1: CO_2 Emissions from Passenger Transport Sector

CHAPTER-III

FREIGHT TRANSPORT

IIIA: FREIGHT TRANSPORT DEMAND

Freight transport demand is dependent on the nature of economic activity in the country and is linked to the growth in the agricultural, industrial, mining, manufacturing, and service sectors. It is measured in terms of Tonne Kilo Meters (TKMs) moved. The demand for freight transport has grown at a very fast rate in the first decade of the twenty-first century. Given India's economic growth potential, the demand for freight movement is set to significantly increase in the future from the level of 2639 billion tonne-kilometers (BTKMs) in 2020.

Per capita freight demand (TKM/person) has been associated with GDP growth using a saturation function.

$$Ln\left(\frac{S}{S_o - S}\right) = Ln\left(\frac{GDP}{capita}\right) * a + b$$

Where, S is per capita freight transport demand and S_o is the saturation limit considered

LEVEL 1

With increasing growth in industrial activity, Level 1 sees a continuous rise in freight demand, with no logistical planning. Sectors such as power, cement and minerals are expected to continue to see an increasing transport demand. Additionally, with improved standards of living, the demand for white goods is also expected to grow, adding to the overall freight demand. With all these assumptions it is expected that freight transport requirement will increase from 2,639 BTKMs in 2020 to 13,067 BTKMs by 2047.

LEVEL 2

Level 2 assumes that as the demand for freight transportation grows, there is a slight moderation in the distances of cargo transportation, as economic activities get more organized through formation of logistics hubs and industrial clusters. Further, with better planned markets and points of production, the freight traffic volumes are expected to reduce by around 5% from Level 1 by 2047, to reach 12,561 BTKMs by 2047 in this level from 2,639 BTKMs in 2020.

LEVEL 3

Level 3 envisages an improved scenario with organized logistics assisted by better information technology solutions to optimize route planning and more efficient movement of goods across the country. Planned industrial clusters along with optimized transport logistics serving commercial and industrial needs is assumed to help in reducing the total volume of freight traffic by about 10% from Level 1 by 2047, to reach 11,961 BTKMs by 2047 in this level from 2,639 BTKMs in 2020.

LEVEL 4

Level 4 envisions India with significantly improved logistic planning along with a movement towards local production and local consumption. Concentrated economic activity in the form of logistics parks, industrial clusters, and industrial centres is assumed to result in a reduction in the average leads for freight transport on both rail and road. This would imply a reduction in the volume of freight traffic by about 15% over Level 1 by 2047, to reach 11,239 BTKMs by 2047 from 2,639 BTKMs in 2020.

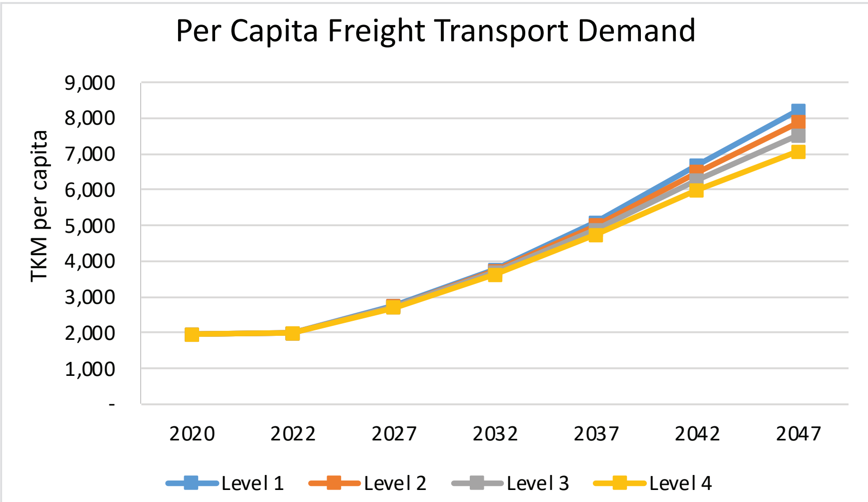


Figure IIIA.1: Per Capita Freight Transport Demand

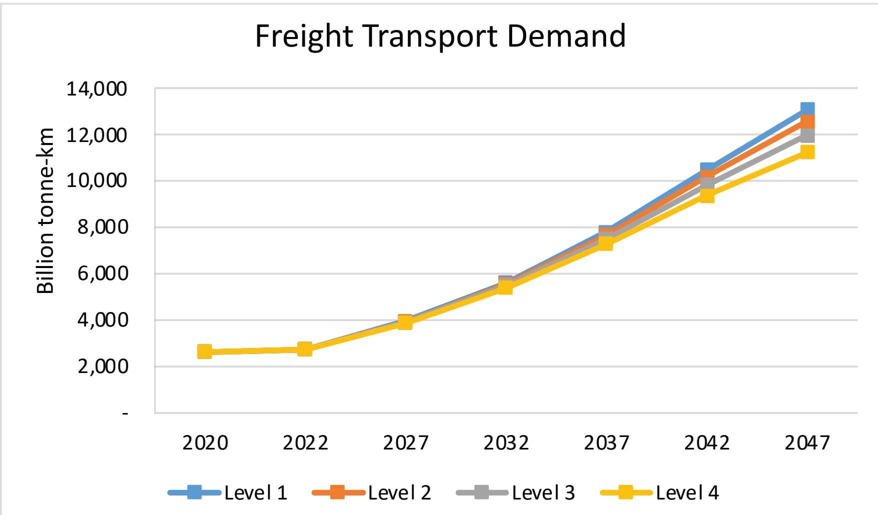


Figure IIIA.2: Freight Transport Demand (BTKMs)

IIIB: FREIGHT TRANSPORT MODE

Freight transport is divided into 4 modes of travel - road, rail, air and water. Railways accounted for about 25% and roadways for about 74% of India's total freight traffic in 2020. The trend in the last few decades has seen an increase in the share of traffic on roads in the total share of surface freight transportation. This is partly linked to an increase in the share of manufactured goods like white goods, Fast-Moving Consumer Goods (FMCG) etc. These cargos move over shorter distances and are time-sensitive. The share of road has also increased due to the highly competitive nature of road transport, convenience and flexibility in tariffs and the capability of roads to handle diverse loads. The share of inland waterways which is an energy-efficient mode of transport is relatively low.

Four trajectories have been developed for future modal shares of freight transport.

LEVEL 1

In the level 1 trajectory, it is assumed that the share of rail keeps declining by around 0.85% p.a., as per past trend and will reduce to 20% in 2047 from the current 25%. The share of road transport increases to 78.9%. The share of air transport is assumed to remain constant at 0.1% and the share of water transport increases from 0.35% to 1%.

LEVEL 2

In the level 2 (BAU) trajectory, it is assumed that the share of rail will increase and reach 35% in 2047, and the share of air freight increases to 0.2%. Share of water transport increases to 2%. As a result, road transport share declines to 62.8% by 2047.

LEVEL 3

Level 3 is an optimistic trajectory, which assumes that rail transport remains favourable due to the construction of Dedicated Freight Corridors (DFCs), due to which the share of railways increases to 45% in 2047. This is in alignment with the ambitious National Rail Plan. The share of air transport increases to 0.3% in 2047 while the share of water transport increases to 3.5% in 2047.

LEVEL 4

Level 4 scenario assumes that very aggressive efforts are made to increase the share of railways in transport, resulting in a 50% share in 2047 due to an increase in usage of DFCs. The share of air transport is assumed to further increase to 0.4%, while that of water transport increases to 5%. Share of road transport in this trajectory declines to 44.6%.

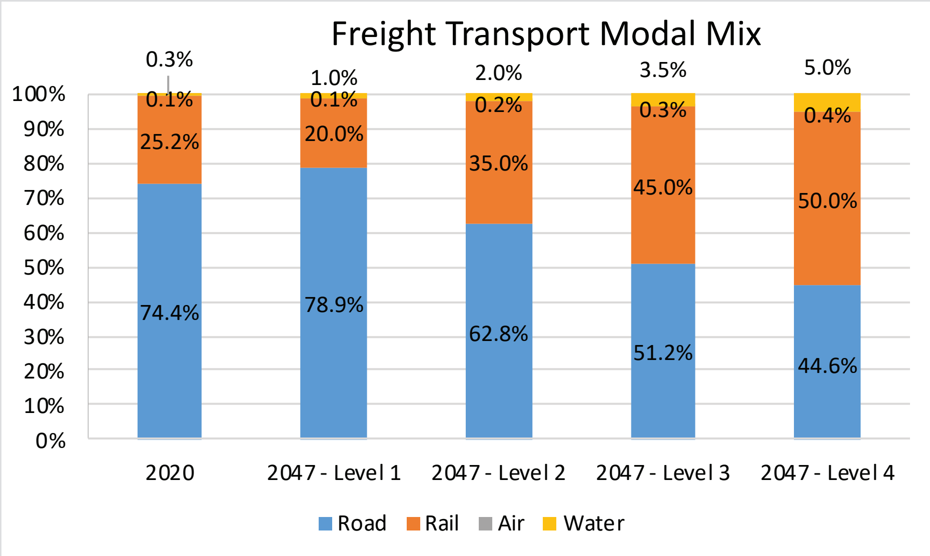


Figure IIIB.1: Freight Transport Modal Mix

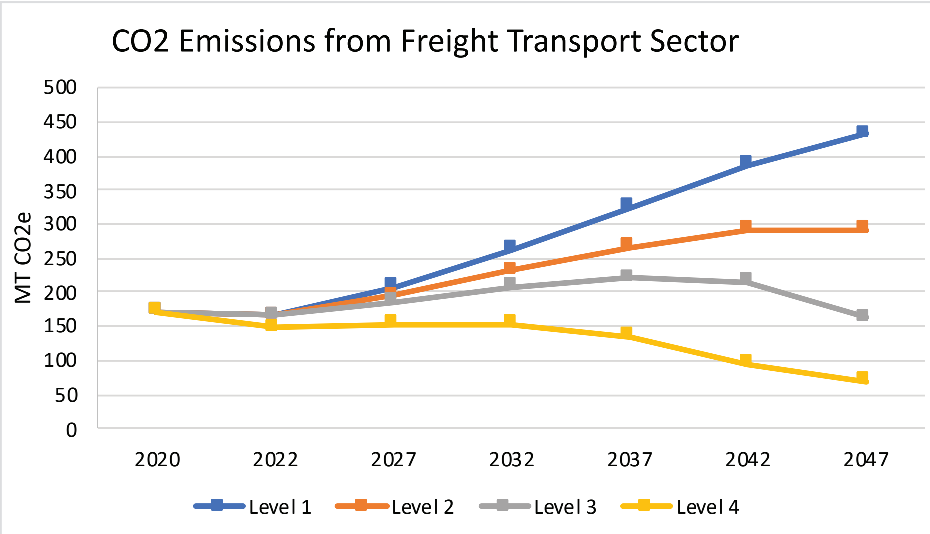


Figure IIIB.2: CO2 Emissions from Freight Transport Sector

CHAPTER-IV

COMMERCIAL BUILDINGS

IVA: COMMERCIAL BUILDING FLOOR SPACE

Floor space area for the different types of commercial buildings have different growth rates. The data for floor space area in 2017 as estimated by Alliance for an Energy Efficient Economy (AEEE) is considered as the reference data. Assuming the different growth rates for each of the three trajectories, the projections for 2047 have been developed.

Table IVA.1: Category-wise growth rates for commercial buildings floor space

Categories	Level 1	Level 2	Level 3
Hospitals	2.71%	2.58%	2.45%
Hotels	3.81%	3.63%	3.45%
Retail	1.95%	1.86%	1.77%
Office space	2.17%	2.07%	1.97%
Educational	3.72%	3.55%	3.37%
Assembly places	0.60%	0.57%	0.54%
Transit	1.77%	1.68%	1.60%
Warehouse	7.59%	7.23%	6.87%

LEVEL 1

Level 1 assumes the maximum growth rate of commercial floor space for all the categories of commercial buildings. The projected floor space area for 2047 is 2797.2 million sq. m. Building category-wise growth rates have been described in Table IVA.1.

LEVEL 2

Level 2 assumes a growth rate lower than the level one, implying more efficient utilization of floor space. The projected floor space area for 2047 is 2667.3 million sq. m.

LEVEL 3

Level 3 assumes the least growth rate with most heroic efforts in floor utilization. The projected floor space area for 2047 is 2545.1 million sq. m.

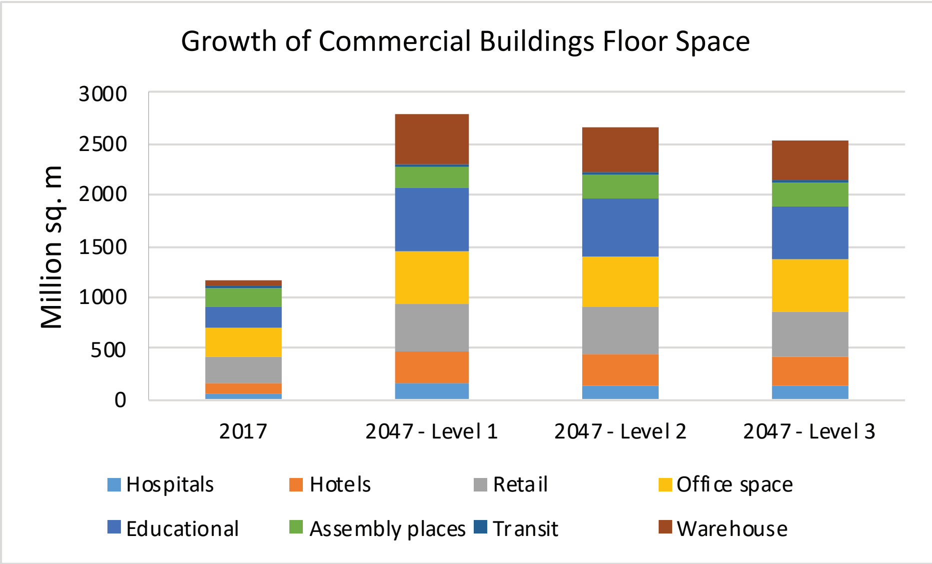


Figure IVA.1: Growth of Commercial Buildings Floor Space

IVB: SHARE OF AIR CONDITIONED SPACE

For a commercial building, Energy Performance Index (EPI) is the measure of units of energy used per unit area. The EPI value will be larger for the Air-Conditioned (AC) space as compared to the non-Air-Conditioned (non-AC) space. Using the share of AC space, the energy consumed can be calculated for buildings with AC and non-AC space.

The 2017 data from a publication by Alliance for an Energy Efficient Economy (AEEE) has been considered as the reference. Further, the 2047 estimates of the share of AC space for different categories of buildings are tabulated in Table IVB 1.

Table IVB.1: Share of Air-conditioned Space in Commercial Buildings

Categories	2017	2047: Level 1	2047: Level 2	2047: Level 3	2047: Level 4
Hospitals	34.3%	80%	65%	55%	50%
Hotels	49.57%	90%	75%	60%	50%
Retail	19.21%	60%	50%	40%	30%
Office space	35.32%	85%	75%	65%	55%
Educational	14.10%	70%	60%	45%	35%
Assembly places	6.89%	30%	25%	20%	15%
Transit	41.86%	45%	35%	30%	25%
Warehouse	22.84%	60%	50%	40%	35%

LEVEL 1

In level 1, commercial buildings will have low natural ventilation and will rely on the mechanical ventilation. The AC share is maximum in this level, which implies a higher energy consumption.

LEVEL 2

Level 2 considers slightly higher amount of natural ventilation and air flow circulation, thereby having a lower share of air-conditioned space than Level 1.

LEVEL 3

Level 3 assumes even further reduction of air-conditioned space, leading to a lower EPI of commercial buildings.

LEVEL 4

Level 4 assumes the least amount of increase in air-conditioned space as compared to 2017 levels. Thus, this trajectory has the lowest increase in EPI amongst four trajectories.

IVC: ECBC COMPLIANCE IN COMMERCIAL BUILDINGS

Energy Performance Index (EPI), measured in kWh/sq.m/year, is a parameter often used to characterize the energy performance of commercial buildings. Bureau of Energy Efficiency (BEE) published Energy Conservation Building Code (ECBC) in 2007 for commercial buildings and updated it in 2017. ECBC sets minimum energy efficiency levels for different types of commercial buildings.

In the IESS2047 model for commercial buildings, energy consumption is estimated as follows:

Energy consumption of buildings = EPI x Floor space

There are three levels of energy performance standards in the updated Energy Conservation Building Code (ECBC) i.e. ECBC, ECBC+, and Super ECBC. In ascending order of efficiency, ECBC-compliant buildings shall demonstrate approximately 25% savings, ECBC+ buildings 35% savings and Super ECBC buildings will show 50% or more energy savings as compared to conventional buildings. With these definitions of levels, trajectories have been created for the possible penetration of different types of buildings. Table IVC.1 describes levels for penetration of ECBC-compliant buildings. Figure IVC.1 depicts the effect of ECBC compliance in commercial buildings when all other parameters are kept constant.

Table IVC.1: Share of ECBC-compliant Buildings (Penetration%)

	ECBC	ECBC+	Super-ECBC
Level 1	5%	1%	0%
Level 2	10%	5%	2%
Level 3	15%	10%	5%
Level 4	20%	15%	10%

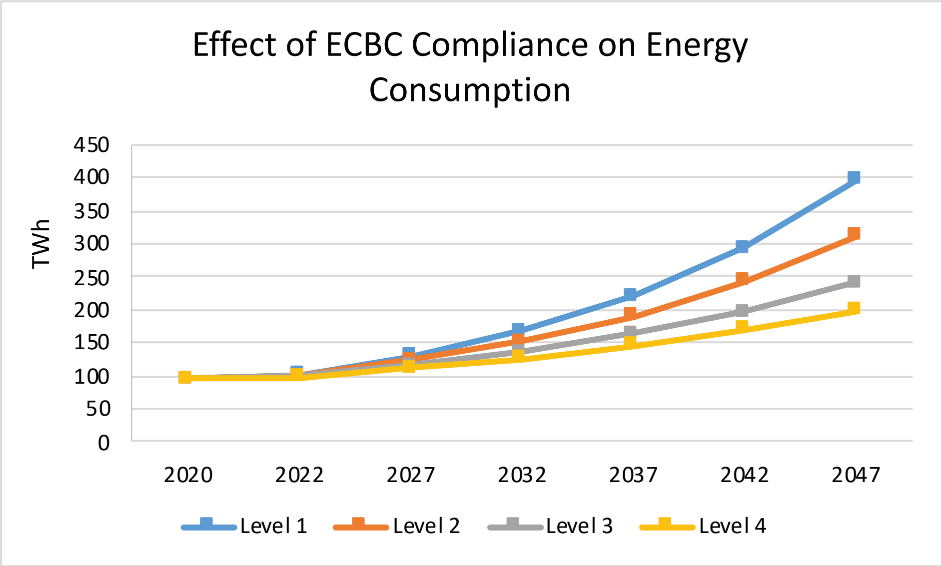


Figure IVC.1: Effect of ECBC Compliance on Energy Consumption of Commercial Buildings

CHAPTER-V

RESIDENTIAL BUILDINGS

VA: NUMBER OF HOUSEHOLDS

Using the Household Data from Ministry of Statistics and Programme Implementation (MoSPI) and census, estimated number of households in India in 2012 was 215 million. The growth rate of the number of households in India has constantly been decreasing. With the latest available data, i.e., for 2011-12, the growth rate is 2.2%. This growth rate has been assumed to continue between 2012 and 2022. Thus, estimated number of households in India is 268 million in 2022. This estimate is also closer to estimate from recent NSS surveys.

Four trajectories have been created for the growth of households in country using different growth rates.

LEVEL 1

Level 1 assumes that the number of households growing in the country is at the same rate of 2.2% per year till 2047. No saturation has been assumed to occur until 2047.

LEVEL 2

Level 2 assumes that the growth rate of households in the country will start declining, eventually reaching 1.5% p.a. in 2047 from 2.2% p.a. in 2022. This shift is assumed to be linear.

LEVEL 3

Level 3 assumes that the growth rate of households drops to 1% in 2047, signifying that the country's population will be gradually moving towards saturation by 2050.

LEVEL 4

Level 4 assumes that the growth rate of households keeps declining and reaches 0.5% p.a. in 2047 from 2.2% p.a. in 2022.

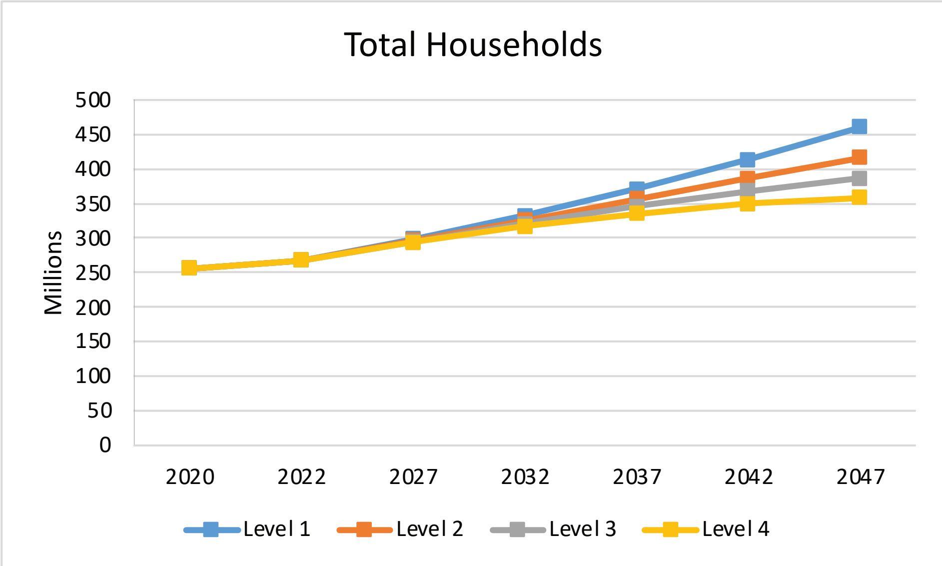


Figure VA.1: Total Households

VB: SHARE OF ECONOMIC CATEGORIES

Population in different economic categories resides in different types of houses. Therefore, the total housing stock in the country is divided based on the economic categories. To characterize the residential buildings' energy consumption, the share of economic categories has been considered as a parameter. Three categories have been defined for both urban and rural settings separately:

1) Economically Weaker Section (EWS)
2) Low-Income Group (LIG)
3) Middle-Income Group and above (MIG+)

This categorization has been done using the Monthly Per Capita Expenditure (MPCE) as a variable to signify the economic status of a household. Decile-wise per capita expenditure data is obtained from 76th round of the National Sample Survey Office (NSSO) surveys on drinking water, sanitation, hygiene and housing by Govt. of India. The estimated break-up of Indian households into different categories for 2020 is as follows:.

Table VB.1: Share of economic categories for urban and rural households

Economic category	Rural	Urban
EWS	59.8%	8.8%
LIG	36.7%	69.9%
MIG+	3.6%	21.3%

Four trajectories have been created for the change in the share of economic categories.

LEVEL 1

Level 1 assumes no change or improvement in the share of economic categories in the country. Thus, the category-wise share in housing space (share of EWS, LIG, MIG+) remains constant throughout the model's timeline.

LEVEL 2

Category-wise share in housing space does not remain constant in level 2. It is assumed that as the country develops, some population migrates to a better economic category, and the share of the population in the EWS category reduces. A slight increase has been assumed in the share of other categories (LIG, MIG+) for both rural and urban populations. Share of EWS in rural area reduces to 50% in 2047 from 59.8% in 2020, whereas in urban areas it reduces to 5% in 2047 from 8.8% in 2020. Accordingly, there is a slight increase in other categories.

LEVEL 3

Level 3 assumes the share of EWS further reduces to 40% and 2.5% in rural and urban areas respectively by 2047. Share of MIG+ households increase to 7.5% and 30% in rural and urban areas respectively. The share of LIG is adjusted accordingly.

LEVEL 4

Level 4 assumes that the share of EWS in rural households drops to 30%. A major portion of this population is assumed to have been shifted to LIG category by 2047. Hence the share of LIG category will rise to 60% in the case of rural households by 2047. For urban households, share of MIG+ increases to 34% by 2047 implying a massive change in the lifestyle of the urban population.

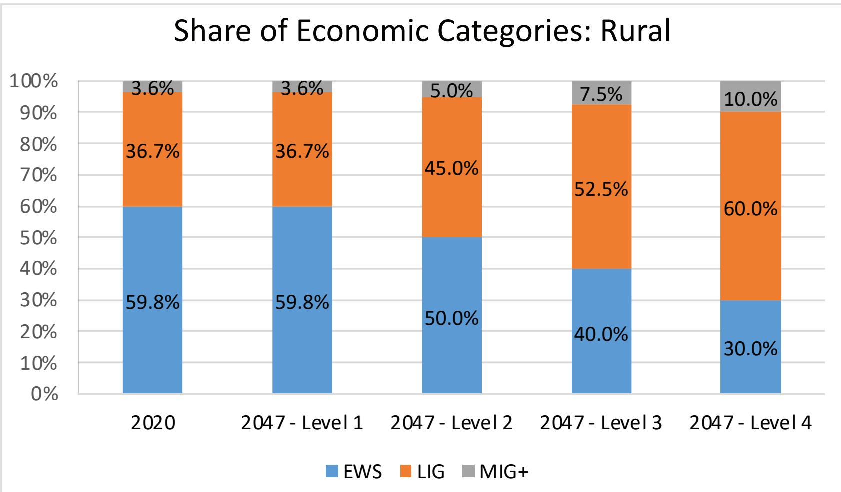


Figure VB.1: Share of Economic Categories in Rural Households

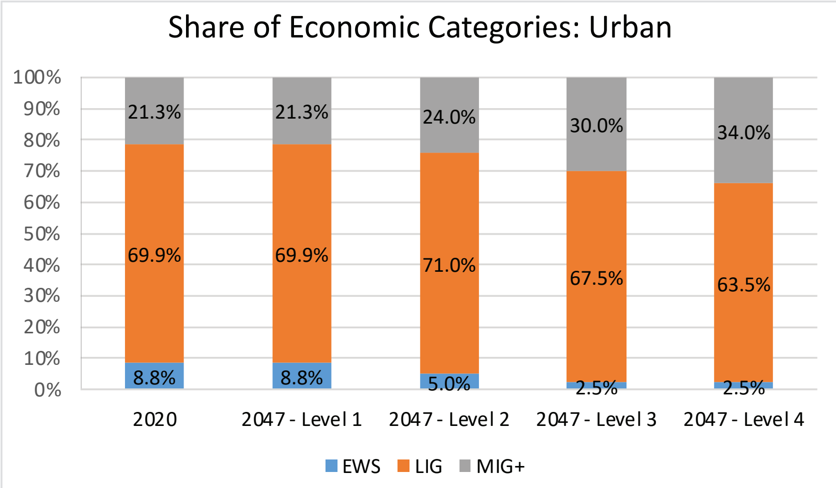


Figure VB.2: Share of Economic Categories in Urban Households

VC: GROWTH OF RESIDENTIAL EPI

The average floor space area, as well as average electricity consumption per household data, is obtained through a systematic review of literature on residential energy use, using which energy per unit area (energy footprint/ residential EPI) is calculated. Overall electricity consumption in the residential sector is then calculated by using floor space area estimates and residential EPI values.

The past data shows that residential electricity consumption has been growing at an average Compound Annual Growth Rate (CAGR) of 7.8% between 2012–20. There is an average growth of 5.48% for the energy footprint of residential buildings. These two growth rates have been considered while estimating the numbers of households in 2020, as well as defining future trajectories.

LEVEL 1

In Level 1, Energy footprint for all economic categories is assumed to grow at 5.5% p.a. till 2022, and the growth rate declines to 5.2% p.a. by 2037.

LEVEL 2

In Level 2, Energy footprint for all economic categories is assumed to grow at 5.5% p.a. till 2022, and the growth rate declines to 4.6% p.a. by 2037. After 2037, it is assumed to decline further to 4% p.a. by 2047

LEVEL 3

In level 3, energy-efficient measures such as energy-efficient appliances will be adopted in the country on a larger scale; thus, the growth of energy footprint is arrested. Growth rates assumed for energy footprint are: 5.5% p.a. up to 2022, 4% p.a. by 2037, and 3% p.a. by 2047.

LEVEL 4

For Level 4, the energy footprint of residential buildings will be near the saturation value in 2047. Hence the growth rate in 2047 is very low at 2% p.a. for all the economic categories. EPI growth rates considered are: 3.2% p.a. by 2037 and 2% p.a. by 2047.

CHAPTER-VI

COOKING

A comprehensive literature survey of studies published on cooking energy requirements suggests that an urban household consumes 10.7 MJ of useful energy in a day whereas a rural household consumes 8.6 MJ of useful energy. The overall energy requirement depends on the cookstove technology used. The final energy needed for cooking depends on the fuel used, the energy conversion efficiency of the fuel, population growth, economic growth, government policies and urbanization. Data suggests that on average a household in India consumes around 8 to 10 Liquefied Petroleum Gas (LPG) cylinders annually.

Penetration of LPG as a cooking fuel has increased in India after the launch of the Pratyaksh Hanstantrit Labh (PAHAL) and Pradhan Mantri Ujjwala Yojana (PMUY) schemes. According to the National Family Health Survey 2021, around 83% of urban households and 42% of rural households use LPG as primary cooking fuel. 57% of rural households still use traditional biomass as the primary cooking fuel. The government is putting efforts into moving towards cleaner cooking fuels such as PNG, electric cooking, biogas, etc. PNG has a penetration of about 5.8% in urban households, while electric and biogas cooking have a total share of around 1% in urban households. The use of PNG and electricity for the cooking purpose has two advantages:

i) These fuels are cleaner than the existing alternatives

ii) The efficiency of PNG cookstoves as well as electric cookstoves is also higher. Thus, it takes less amount of energy to cook the food.

LEVEL 1

Level 1 assumes that the share of PNG increases to 20% and 5% in urban and rural households by 2047. Similarly, the share of electricity increases to 15% and 5% in urban and rural households by 2047. Penetration of LPG increases to 70% in rural households. Traditional biomass is eliminated from urban areas and declines to 14% in rural areas by 2047.

LEVEL 2

Level 2 assumes that the share of PNG increases to 30% and 8% by 2047 in urban and rural households from 5.8% and 0% in 2022. Similarly, the share of electricity increases to 18% and 10% in urban and rural households by 2047. Traditional biomass is eliminated from urban areas and declines to a mere 3% in rural areas by 2047. LPG share in rural households increases from 42% in 2020 to 72% in 2047.

LEVEL 3

In level 3, the share of PNG increases to 40% and 12% in urban and rural households by 2047. The share of electricity increases to 20% and 15% in urban and rural households by 2047. Use of traditional biomass is completely eliminated in this trajectory from both urban and rural households.

LEVEL 4

Level 4 assumes aggressive efforts being put into fuel switching. The share of PNG increases to 50% and 15% in urban and rural households by 2047 respectively. The share of electric cooking also rises to 25% and 20% in urban and rural areas respectively.

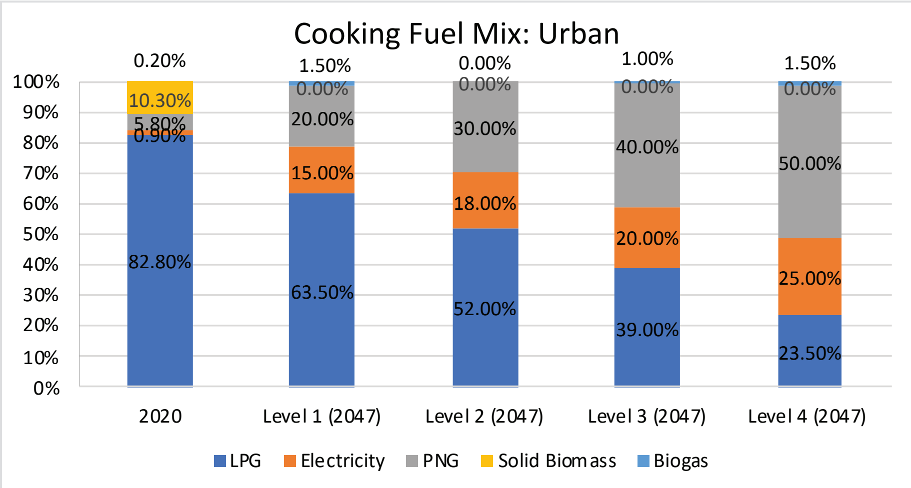


Figure VI.1: Cooking Fuel Mix for Urban Households

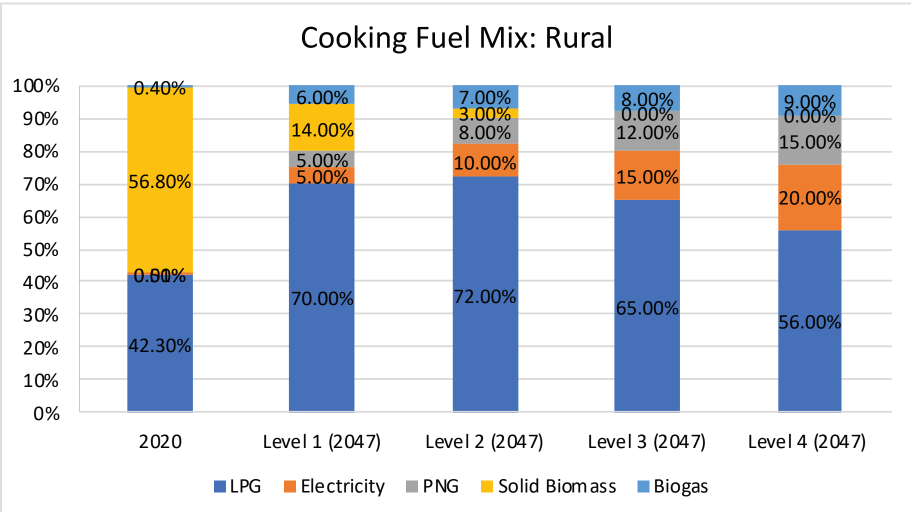


Figure VI.2: Cooking Fuel Mix for Rural Households

CHAPTER-VII

AGRICULTURE

VIIA: ENERGY DEMAND FOR TRACTORS

Agriculture is the largest sector in India in terms of the working population involved. The agriculture sector contributed to 17.7% of the total electricity consumed in India and 12% of the total diesel consumed in India in 2019–20. Most of the energy consumption in the agriculture sector comes from pumping required for irrigation purposes, and farm machinery (mainly tractors). The average land holding size of an Indian farmer is less than two hectares. The level of farm mechanization, i.e. use of tractors, power tillers and other machinery for farming was relatively low in India as compared to the other countries until the last decade. In recent years, mechanization has increased rapidly in the agriculture sector and India is now the largest manufacturer of tractors in the world. Almost 900,000 tractors were manufactured in India in 2018-19. And the market is expected to grow in the coming years.

In the model, both diesel and electric tractors are considered for farm mechanization. The total diesel consumption is calculated using - the number of tractors, diesel consumption per hour, and annual hours of operation. Based on the literature survey, the model uses 500 hours for annual usage across all scenarios and years. On the other hand the values of diesel consumption per hour varies across levels and years, starting from 4.5 litres in 2047 (Level 1) to 3.75 litres in 2047 (Level 4). Through stakeholder consultations, it is also found that the number of tractors in India would saturate around 16.5 million. Trajectories have been created to reach the saturation level from 2032-2047.

LEVEL 1

In this level, it is assumed that there is no improvement in the fuel efficiency of tractors. Tractors continue to use 4.5 lph of diesel until 2047 and percentage of electric tractor grows to 8% in 2047. The number of tractors in India grows with a CAGR of 5.9%.

LEVEL 2

Level 2 assumes that fuel efficiency improves and only 4.25 litres of diesel is needed to run a tractor for an hour in 2047. Electric tractors grow to 12% by 2047. Tractor number grows with an annual growth rate of 6.2%.

LEVEL 3

Level 3 assumes that fuel efficiency improves further with only 4 litres of diesel needed to run a tractor for an hour in 2047 and the number of tractors grows with a CAGR of 6.5%. The percentage of electric tractors reach 18% by 2047. The ceiling for maximum Specific Fuel Consumption (SFC) as tightened by the Bureau of Indian Standards (BIS) will be achieved.

LEVEL 4

Level 4 assumes that fuel efficiency improves with only 3.75 litres of diesel needed to run a tractor for an hour. BIS restricts the penetration of inefficient tractors with fuel consumption above specified SFC norms. Deregulation of diesel prices for the agriculture sector also pushes up the sale of fuel-efficient tractors, hence the tractors use 3.75 lph of diesel in 2047. The percentage of electric tractors reach 24% by 2047 and total tractors grows at an CAGR of 6.8%.

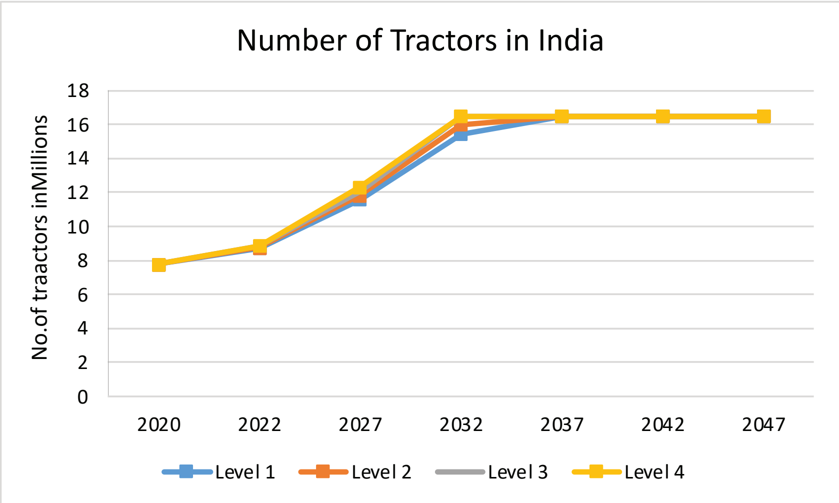


Figure VIIA.1: Number of Tractors in India

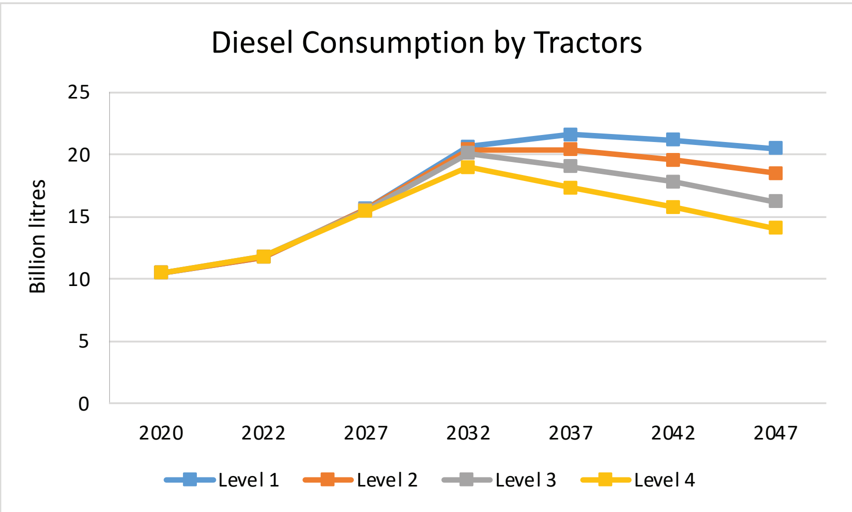


Figure VIIA.2: Diesel Consumption by Tractors

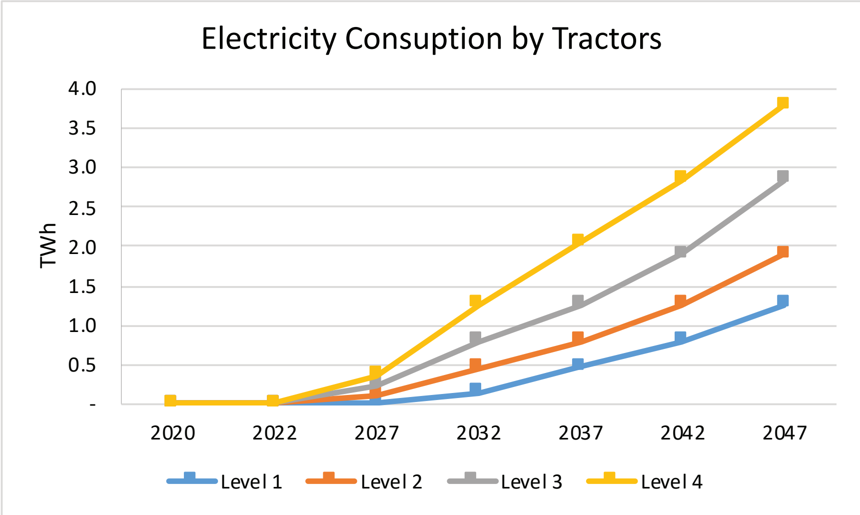


Figure VIIA.3: Electricity Consumption by Tractors

VIIB: ENERGY DEMAND FOR AGRICULTURAL PUMPS

Agricultural pumping sector has a lot of potential for efficiency improvement. Power quality issues, improper maintenance, and improper sizing of pumps are major reasons for prevailing low efficiency in the agricultural sector. This results in huge financial loss to the economy. The Government of India has launched Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyaan (PM-KUSUM) Yojana in 2019 to improve the penetration of solar PV pumps and to solarize grid-connected pumps. The scheme is expected to achieve the installation of 17.5 lakh standalone solar PV pumps.

Pumping energy demand has been modelled using parameters such as gross irrigated area, pumpset intensity, annual energy consumption per pumpset and pumpset efficiency. To analyse the effect of technology substitution, a parameter has been introduced in the IESS2047 model which will mirror the shift toward solar pumps as announced by the government. As of 2020, the share of diesel, electric and PV-based pumps in the mix are 29.2%, 70.2%, and 0.6% respectively. Four trajectories have been created to capture the effect of changing fuel mix on energy consumption and emissions from agricultural pumping. The efficiency of Electric pumps is assumed to remain at a constant level of 36% in level 1. Whereas in all other levels, the efficiency increases with time and reaches 40%, 45%, 50% by 2047 in level 2, level 3 and level 4 respectively

LEVEL 1

This trajectory assumes a large dependency on electric-grid based pumps with share of 80% by 2047. Share of diesel pumps decreases to 15% and share of solar pumps increases to 5%. The average efficiency values of electricity-based and diesel-based pumps are assumed to remain the same up to 2047.

LEVEL 2

The scenario assumes that 70% of the total pumps run on grid electricity, 15% run on solar energy, and 15% run on diesel in 2047. The efficiency of electricity-based pumps and diesel pumps increase to 40% and 36% in 2047 respectively from the estimated 36% and 33% in 2020.

LEVEL 3

It considers aggressive efforts toward the elimination of diesel-based pumps. It assumes that 75% of total pumps run on grid electricity and 25% run on solar PV in 2047. The efficiency of electricity-based pumps is assumed to improve to 45% in 2047 from 36% in 2020.

LEVEL 4

In this scenario, it is assumed that 60% of total pumps will run on grid electricity, and 40% on solar energy. The efficiency of electricity-based pumps is assumed to improve to 50% in 2047 from 36% in 2020.

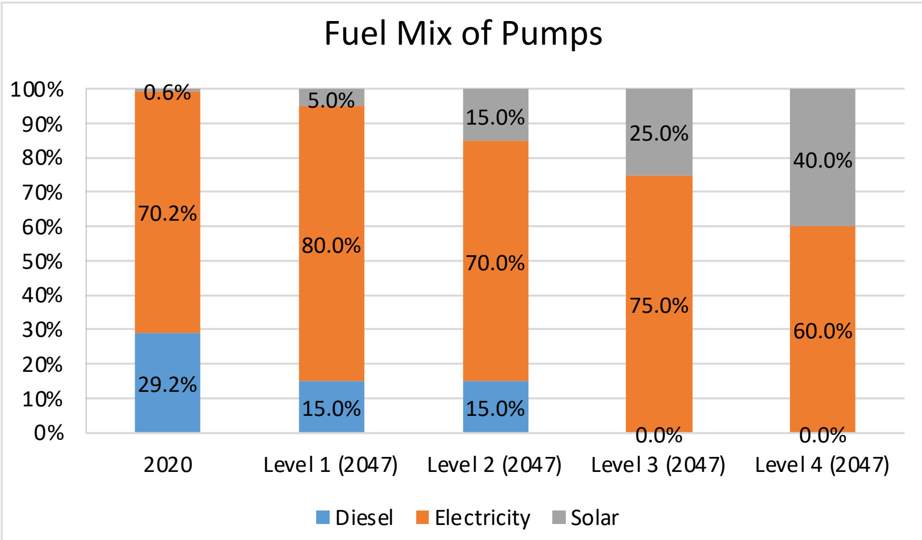


Figure VIIB.1: Fuel Mix of Pumps

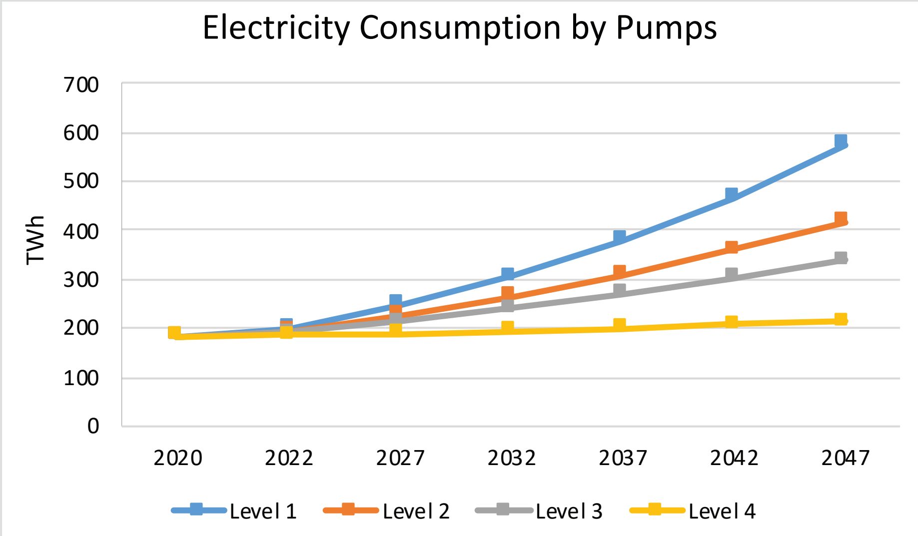


Figure VIIB.2: Electricity Consumption by Pumps

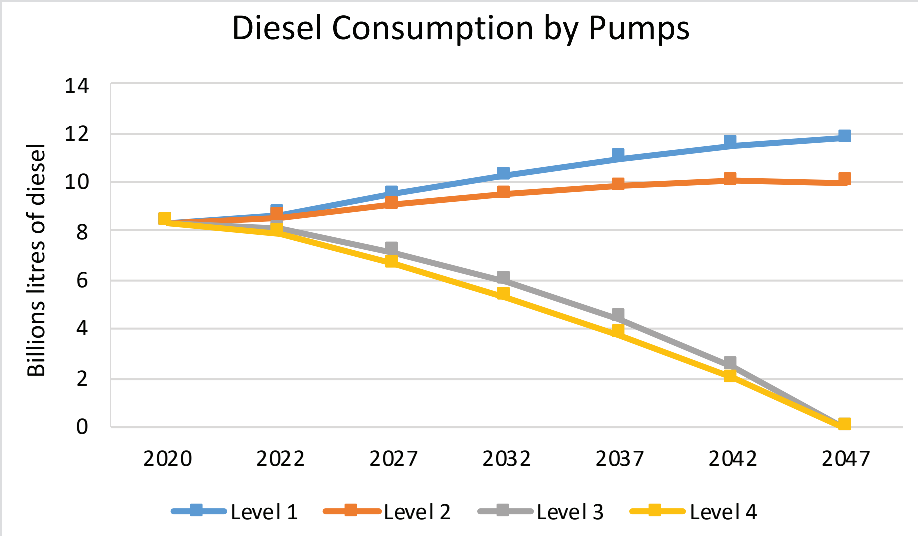


Figure VIIB.3: Diesel Consumption by Pumps

CHAPTER-VIII
TELECOM

REPLACEMENT OF DIESEL IN TELECOM SECTOR

The Indian telecom sector is the second largest in the world. As of November 30th, 2020 India had 1.17 billion telephone connections, including 1.16 billion wireless telephone connections which form the backbone of its telecom market. Overall teledensity in the country is 86.55% whereas urban teledensity is 139% and rural teledensity is 59.08%. The number of Broadband connections is 734.82 million at the end of October 2020 (Ministry of Communications, 2020). 55% of the total telecom towers are located in urban areas whereas the rest are situated in rural or semi-urban areas. This ratio is assumed to be constant over the years. Presently, telecom towers run on grid electricity and use mainly diesel generators as the backup power source. Due to the unavailability of 24-hours electricity to telecom towers, a significant amount of diesel is consumed in the telecom sector. This analysis factors in the rate of conversion of telecom towers from diesel support to electricity/clean energy solutions, with a similar number of towers in all four levels. Clean energy solutions considered in the model are: rooftop PV plants, wind power plants, biogas to electricity and hydrogen-based fuel-cell solutions.

LEVEL 1

Level 1 assumes that no regulations have been enforced and the present energy consumption scenario continues. Here, only solar solutions are considered feasible for the urban area while for rural areas, solar and wind solutions are considered feasible. By 2047, the penetration of off-grid solar and wind solutions in rural areas is expected to become 10% and 1% from 7% and 1% in 2020 respectively. Whereas in urban areas 10 % of rooftop solar tower is expected to be installed by 2047.

LEVEL 2

A higher proportion of solar PV solutions (40% in both rural and urban areas) is expected by 2047 from 7% and 3% in 2020 respectively. Wind energy solutions penetration is expected to increase from 1% assumed in 2020 to 3% in rural areas and from 0% to 3% in urban areas. Bioenergy solutions contribute 3% to rural and urban telecom towers and hydrogen-based solutions replace 3% of diesel usage in urban areas only.

LEVEL 3	LEVEL 4
The penetration of off-grid solar plants is expected to increase to 60% in rural areas and 50% in urban areas by 2047 from 7% in rural areas and 3% in urban areas assumed in 2020. Whereas wind power solutions are expected to increase up to 5% in both areas by 2047. Bioenergy solutions contribute to the replacement of 6% in rural and 5% in urban telecom towers. Hydrogen kicks in rural areas after 2030 and is expected to replace 3% for rural and 5% for urban telecom towers by 2047.	This level assumes that all government regulations are met. Telecom towers run on grid supply and clean energy solutions, both in urban and rural areas. The percentage of diesel-operated telecom towers replaced by off-grid solar by 2047 is expected to be 75% in rural areas and 50% in urban areas. whereas wind power solutions is expected to increase up to 10% in rural areas and 7% in urban areas by 2047. Bioenergy solutions contribute to the replacement of 10% in rural and 7% in urban telecom towers' diesel requirements while hydrogen replaces 5% of rural and 10% of urban requirement.

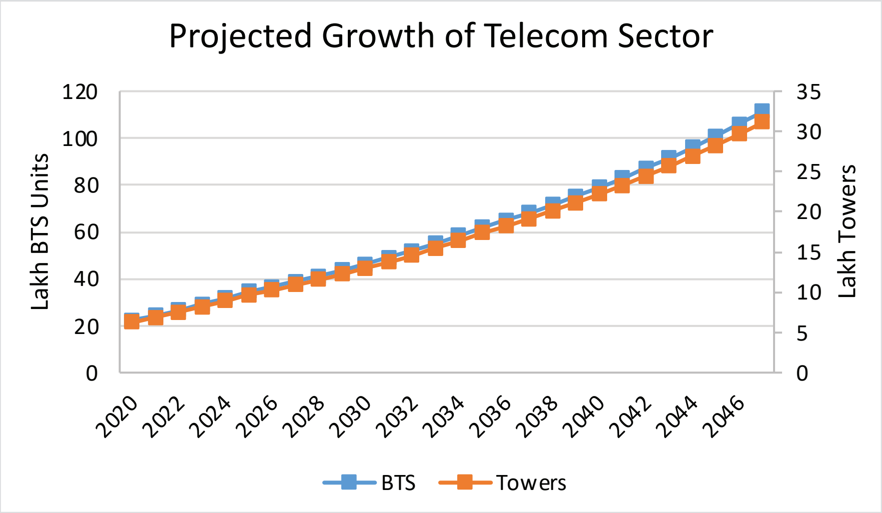


Figure VIII.1: Projected Growth of Telecom Sector

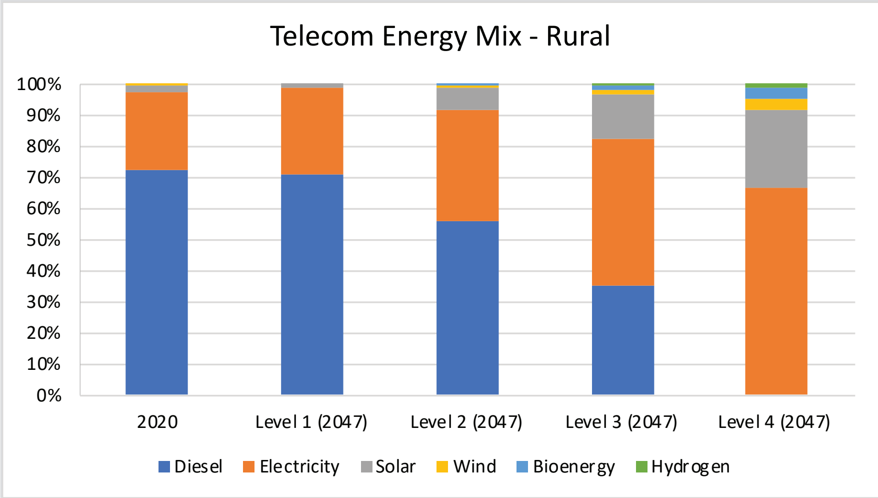


Figure VIII.2: Telecom Energy Mix - Rural

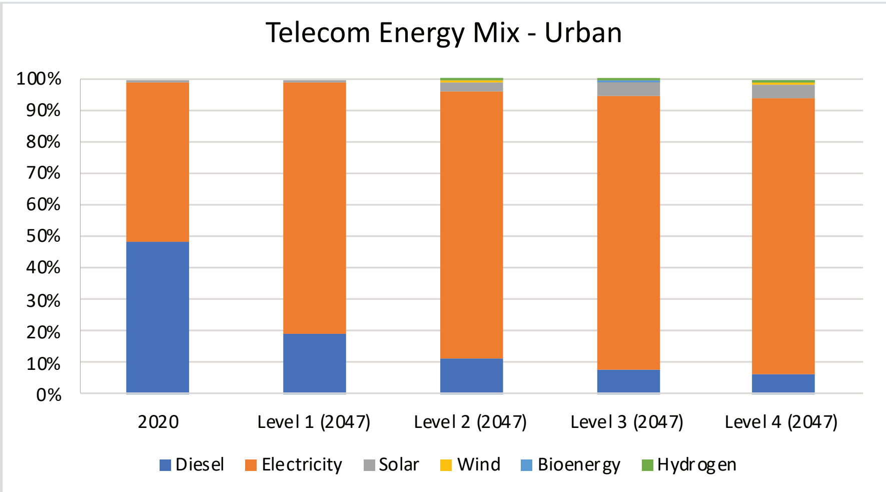


Figure VIII.3: Telecom Energy Mix - Urban

FOSSIL FUEL PRODUCTION

SUPPLY SECTORS

POWER SECTOR

BIOENERGY

CHAPTER-IX

FOSSIL FUEL PRODUCTION

IXA: DOMESTIC COAL PRODUCTION

The coal sector in India is an integral part of the economy and will continue to play an important role in ensuring energy access to people and energy security in the country, at least for a decade. India is the 2nd largest producer and consumer of coal in the world. As of March 2020, India has 20,000 million tonnes (MT) of coking coal reserves, 143,000 MT of non-coking coal reserves, and 7,000 MT of lignite reserves, whereas the estimated production was in 2020 was 53 MT, 678 MT and 42 MT for coking coal, non-coking coal and lignite respectively.

Past trends show that production of coking coal is stagnated due to quality constraints and lignite production has witnessed a decline in India. Whereas, non-coking coal production has witnessed a continuous rise. The Reserves-to-Production (R/P) ratio estimates suggest that India has enough resources to provide for 100+ years of coal requirement. However, the role of coal in future energy systems will be determined by balancing the priorities of energy access and security along with sustainability and climate change needs. The requirement for non-coking coal and lignite may see a decline in future with the adoption of alternative technologies by the power sector and industries. Coking coal requirement is expected to increase with growing steel demand. However, the coal demand will also be impacted on account of green steel demand.

Trajectories have been created for the domestic production of these three types of coal. If the projected quantity of domestic coal production does not fulfill the demand of coal from power and industry sectors, the balance amount of the coal demand is imported. If the projected quantity is sufficient to fulfil the demand, the production is capped to the demand value, as overproduction and thereby export of coal from India is not an envisaged future scenario considering the current climate and energy situation of the world.

LEVEL 1

Level 1 assumes that the mineability of the reserves will remain at the present level and proven coal reserves will increase from the current status. In this trajectory, it is assumed that coking coal production remains at the 2020 level, i.e., 53 MT. Production of non-coking coal increases slowly with a CAGR of 1% and reaches 815 MT by 2047. Lignite production has been assumed to follow the past trend of decline. Lignite production decreases from 42 MT in 2020 to 20 MT by 2047.

LEVEL 2

Level 2 assumes that proven reserves of coal will follow the past trend of linear increase up to 2047. Coking coal production witnesses a gradual growth of 1% p.a. and the production rises from 53 MT in 2020 to 69 MT in 2047. Non-coking coal production increases at a rate of 2.17% with an expectation of declining demand in the future. Non-coking coal production reaches 1,010 MT by 2047. Lignite production has been assumed to stay constant in this trajectory at 42 MT per year.

LEVEL 3

The rate of coal production is assumed to increase due to increased mineability and technological advancement. Coking coal production rises at 2% p.a. and reaches 90 MT by 2047. Non-coking coal production follows the decadal growth observed between 2010 and 2020, and rises at 3.35% p.a. By 2047, non-coking coal production reaches 1,250 MT. Lignite production is assumed to witness a rise of 1.07% p.a. and reaches 56 MT by 2047.

LEVEL 4

The level assumes a reduction in exploration costs along with technological progress. Coking coal production rises sharply and reaches 134 MT by 2047 - more than double the production in 2020. Non-coking coal production increases at a 4% CAGR and reaches 1,405 MT by 2047. Lignite production also experiences high growth and reaches 75 MT by 2047 from 42 MT in 2020.

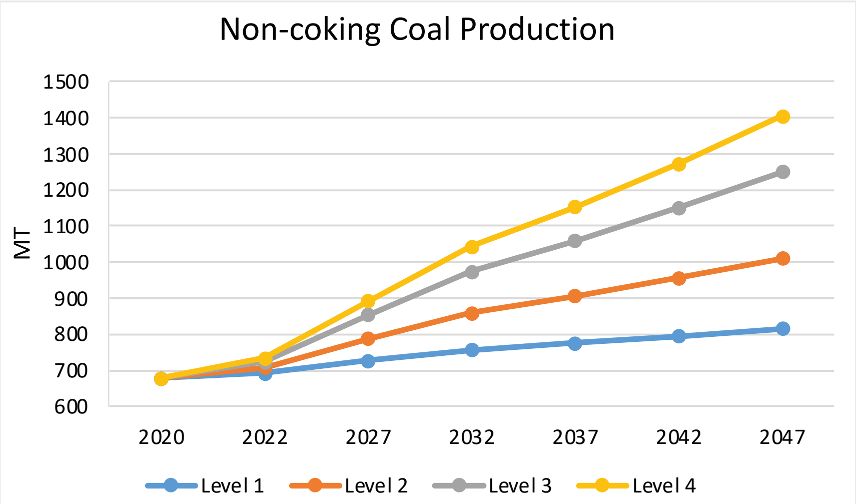


Figure IXA.1: Production of Non-coking Coal

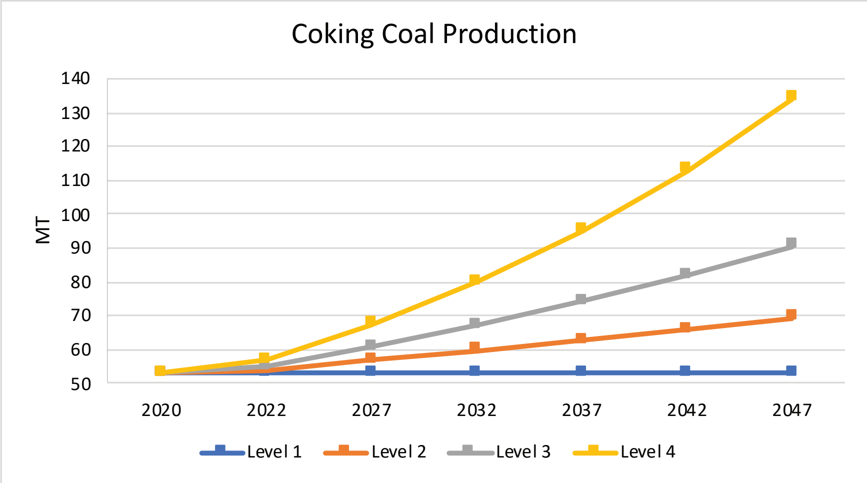


Figure IXA.2: Production of Coking Coal

IXB: DOMESTIC GAS PRODUCTION

India has 26 sedimentary basins covering an area of 3.36 million sq. km spread over onland, shallow water and deep water. An area of about 1.71 million sq. km i.e. 51 % of the total sedimentary basin area does not have adequate geo-scientific data. As a base to launch future Exploration and Production (E&P) activities, appraisal of all un-appraised areas has been considered an important task. The prognosticated conventional hydrocarbon resources in 26 sedimentary basins of the country are of the order of 41.87 billion tonnes (oil and oil equivalent of gas), which is about 49% increase as compared to an earlier estimate of 28.08 billion tonnes.

The advent of the Hydrocarbon Exploration and Licensing Policy (HELP) promulgated in March 2016, brought about paradigm changes in the way exploratory blocks are auctioned in India. The Open Acreage Licensing Programme (OALP) offered the potential investors the freedom to carve out blocks of their choice through submission of Expression of Interest.

The analysis of India's exploratory successes and production trends offers an interesting revelation. While we have been reporting the discovery of new resources, our production has been stagnant. India's In-place reserves of natural gas have grown at an average rate of 3.1%. The in-place reserves are rising but the ultimate reserves and production are static. This signifies that the recovery factor and production factor both have a declining trajectory. Gas production is estimated as follows:

Gas production=in place gas reserves X recovery factor X production factor

It has been assumed that the in-pace reserves will keep increasing at 3.1% in future. The actual exploitation rate (production factor) for 2020 and 2022 is 1.36%, which has been assumed to increase upto 1.76% (Average of last 15 years) in 2047. Four trajectories have been created to examine possible future scenarios. The Gas recovery factor is currently in the range of 55-60%. The four Levels of likely gas production leading up to 2047 are based on rising recovery factors.

LEVEL 1

Level 1 assumes that the production is based on current reserve estimates. The domestic gas supply is expected to reach about 85.63 BCM by 2047 in this level. This Level assumes a constant recovery factor of 50%. Since level 1 is a pessimistic scenario, production is based on current reserve estimates.

LEVEL 2

Level 2 assumes a growth in the recovery factor. Level 2 assumes an improvement in existing policies in the gas pipeline sector as well. With a recovery factor of 55% assumed, domestic gas production rises to 94.19 BCM by 2047 in this trajectory.

LEVEL 3

Level 3 will require additional policy inputs to spur the growth of the natural gas sector. Improved data availability de-risks E&P activities taking place are assumed. Level 3 assumes R/F of 60% from the existing fields, which results in a domestic gas production of 102.75 BCM by 2047.

LEVEL 4

Level 4 assumes a highly favourable upstream regime wherein IOCs find it attractive to come to India, gas pricing/ utilization provisions have been done away with and free market pricing has set in. This level opens up a market for power and fertilizer sectors to address the accessibility issuein line with Govt. ambitions Level-4 assumes R/F of 65%, which results in domestic gas production of 111.31 BCM by 2047.

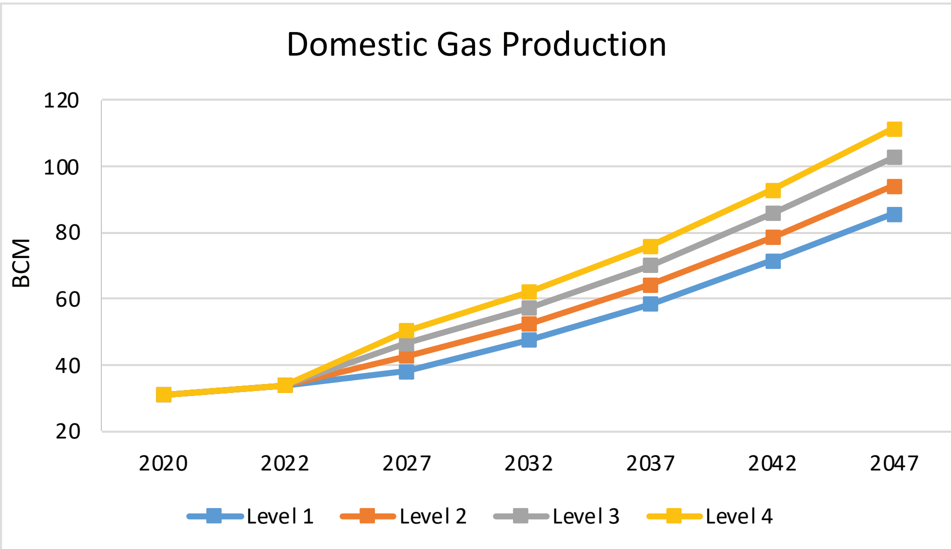


Figure IXB.1: Domestic Gas Production

IXC: DOMESTIC OIL PRODUCTION

India has been continuously reporting the discovery of new resources for oil, however, the production has been stagnant. There is definitely a time lag between discovery and production. India's In-place reserves of crude oil have been constantly growing at an average rate of 1.3%. However, the recovery factor seems to be stagnated at 28%. Lastly, the exploitation rate is also constant (or marginally falling since the last decade) at around 1.5% to 2%. These three factors have been utilized to model the future production of crude oil in India.

Crude oil production = in – place reserves x recovery factor x exploitation rate

It has been assumed that the in-place reserves will keep increasing at 1.33% in future. The average exploitation rate between 2005 and 2020 is 1.9%, which has been assumed to be constant until 2047. The user is offered the choice to play upon recovery factor (R/F) lever. Four trajectories have been created to examine possible future scenarios.

LEVEL 1

Level 1 assumes no improvement in recovery factor, and no new fields come into production barring the ones for which Final Investment Decision (FID) has been taken. This is a hypothetical construct to establish the lower extremity of the production band under the modelling exercise. The Ultimate reserves (which can be technically extracted) have been calculated by applying an R/F of 28% to initial in-place reserves.

LEVEL 2

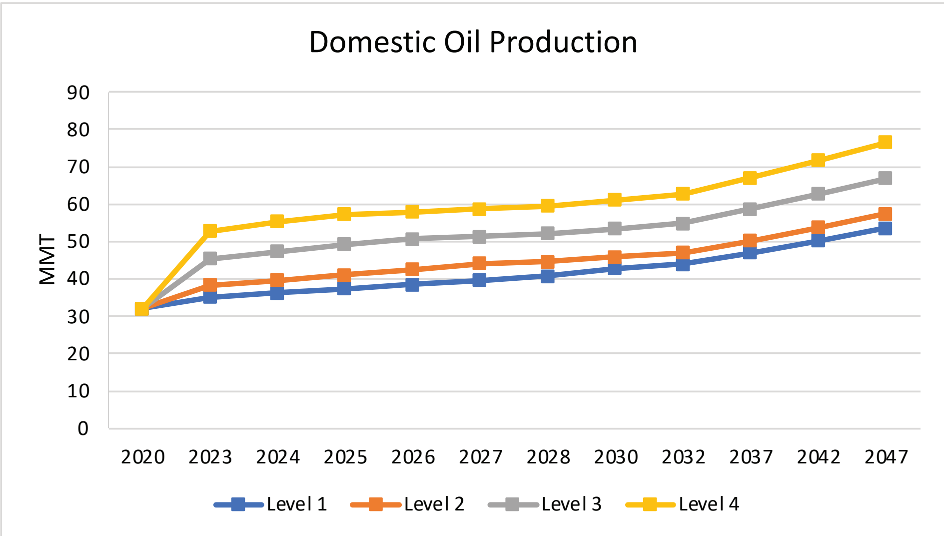
In level 2, the Government continues to make efforts to improve the oil/gas production landscape. New policies to help monetize discoveries continue to be launched but there is no dramatic change in the policy framework. Level 2 assumes that the recovery factor of 30% would be maintained till 2047, based on the investment plan of the companies.

LEVEL 3

In level 3, new fields envisaged come into production. It may be noted that there are a number of oil discoveries that are awaiting appraisal and development as of now. This level envisages that a number of them are found to be commercial and they come into production. Marginal fields would supplement the production. Enhanced Oil Recovery/Improved Oil Recovery (EOR/IOR) schemes would be taken up aggressively. Level 3 assumes that a recovery factor of 35% would be maintained till 2047.

LEVEL 4

Level 4 assumes the availability of new technologies for hydrocarbon exploration and development along with the large-scale implementation of the existing ones. This trajectory assumes the best technological alliance of NOCs with major players, better recovery factors, deep-water exploitation of reserves and no rig unavailability problems for deep-water development. In-house capabilities have been assumed to be developed as an enabling factor. Level 4 assumes that a recovery factor of 40% would be maintained till 2047.



IXC.1: Domestic Oil Production

CHAPTER-X
BIOENERGY

XA: FIRST AND SECOND-GENERATION BIOFUELS

The Government of India initiated mandated biofuel blending programs in 2003 under the National Biofuels Mission. These programs specify the blending of biofuels (5%, 10% and 20%) with fossil fuels in a time-bound and phased manner across India. Feedstocks identified were molasses for the production of ethanol and tree-borne non-edible oil seed crops like Jatropha and Pongamia for the production of biodiesel from marginal lands. To increase biofuel production that has a larger scope, lignocellulosic liquid fuels from agri-residue and biodiesel from extensive Jatropha/Pongamia cultivation from wastelands are being pursued. As of now, majority of ethanol production is through sugarcane molasses. Other crops like sweet sorghum and sugar beet can also be used for bioethanol production. A demand-side approach that focuses on blending targets as one of the drivers has been adopted. Combining the fuel requirement from the transport sector and the blending share considered in the trajectory, the amount of biofuel required is calculated assuming its enough availability.

Bioethanol requirement = estimated petrol demand x ethanol blending

Biodiesel requirement = estimated diesel demand x biodiesel blending

LEVEL 1

Level 1 is a pessimistic trajectory which assumes a lack of effort in achieving the targets for bioethanol blending. The total 5.1% blending (including ethanol and biodiesel) was achieved in 2020, and this increased to 10.2% in 2022. This slightly increases to 11% by 2047.

LEVEL 2

The Government of India has a target of achieving 20% ethanol blending in petrol by 2025. However, the past trend shows that the blending share is linearly increasing by 0.56% every year. The same trend has been projected in future for level 2. Bioethanol blending reaches 20% in 2047. The total blending (including ethanol and biodiesel) percentage reaches 25% by 2047.

LEVEL 3

Level 3 is an optimistic trajectory which assumes extra efforts being put into bioethanol blending. This level assumes that the 20% ethanol blending is achieved in 2030 which saturates and remains at 20%.

Level 3 assumes an even faster pace of growth for the blending of biodiesel. Total blending share reaches 30% in 2047.

LEVEL 4

Level 4 is heroic effort trajectory which assumes that the policy target of ethanol blending 20% is achieved early (by 2024) compared to level 3. This saturates and remains at 20% until 2047. The total blending percentage reaches 35% by 2047.

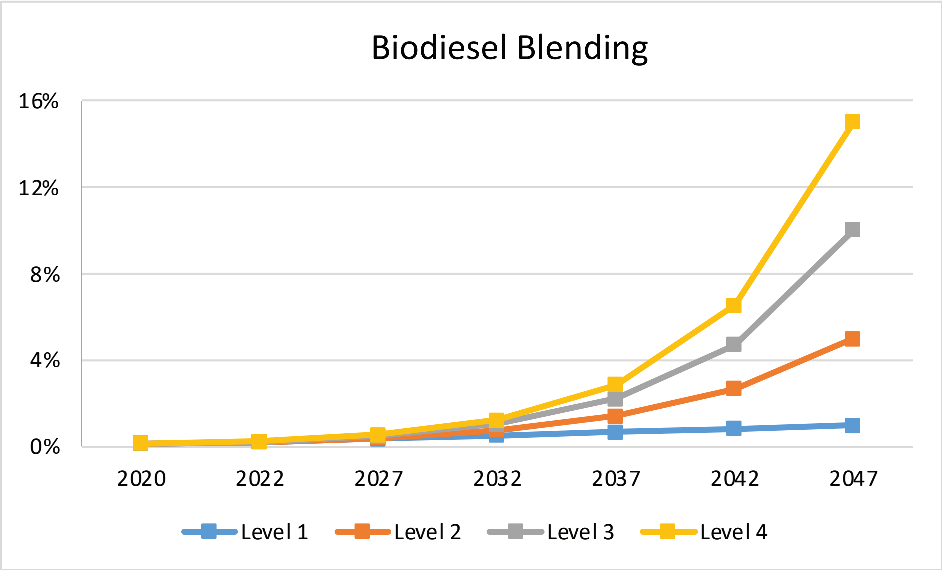


Figure XA.1: Biodiesel Blending

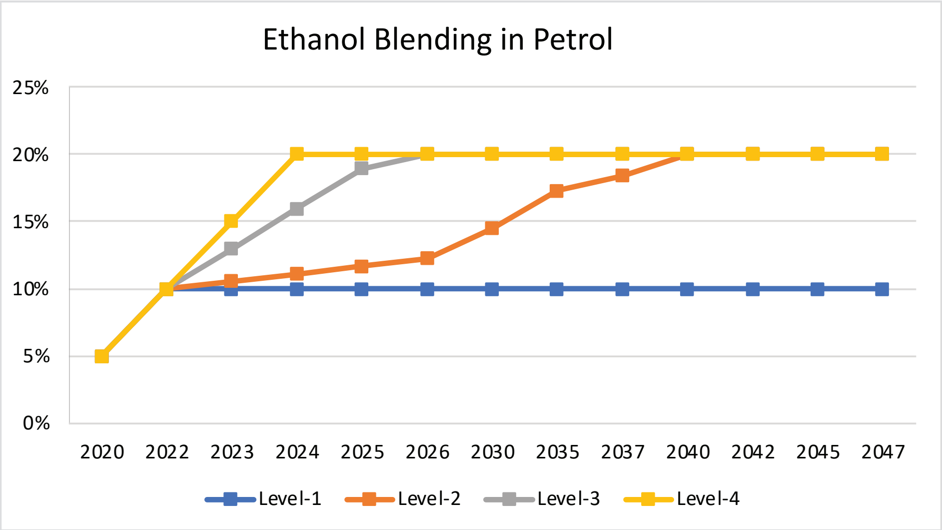


Figure XA.2: Ethanol Blending in Petrol

XB: ADVANCED BIOFUELS

Advanced biofuels (beyond 1st & 2nd generation) have been considered as they present a large scope for use as transportation fuel. Microalgal biofuels and macroalgal (seaweed) fuels (offshore) have been considered under this scenario. They are still in the Research and Development (R&D) stage and are considered to be in a relatively earlier stage of development compared to lignocellulosic (1st and 2nd generation) biofuels. Sea water has been considered to be the appropriate water source. Of the two applications, the model considers atleast one to be commercially viable while other contributes only marginally with technology not maturing. The numbers may be used interchangeably depending on whichever technology (or a combination thereof) matures better. This analysis captures future scenarios of this emerging technology incorporating the area of sea for macroalgae and area onland allocated for micro-algae farming.

LEVEL 1

In this level, microalgal technology expects barely any development. Area productivity of 2.9 TWh/M ha/day and lipid content of 18% has been considered to be achieved by 2047. The expected cultivation land area extends to 400 ha while 160 ha sea area is used by 2047. Offshore macro algae expect negligible development with energy production reaching just 0.1 PJ/year by 2047 while onland micro-algae energy production is expected to reach 0.23 PJ/year by 2047.

LEVEL 2

In level 2, the microalgal fuel development is still slow with commercial production expected to start by 2027. Area productivity of 4.18 TWh/M ha/day has been considered in 2047. Lipid content is taken to be 23%. The expected sea area farmed is expected to be 1875 ha and the land area extends to 3750 ha by 2047. This leads to microalgal biofuel production of 3.8 PJ/year by 2047.

LEVEL 3	LEVEL 4
Microalgal fuel development is assumed to be promising with commercial production starting from 2022. Area productivity of 6.6 TWh/M ha/day has been considered and Lipid content is envisaged at 28%. Microalgae cultivation land area is expected to increase up to 0.26 M ha by 2047. This relates to microalgal biofuel production of 516 PJ/year by 2047. It is assumed that offshore macro algae also pick up with commercial production starting from 2022. The fuel conversion efficiency reaches 52% by 2047 from the present 20% as in lignocellulose liquid fuels. Liquid fuel production from macroalgae is expected to go up to 30 PJ/year by 2047.	Microalgal fuel development is assumed to become commercially viable by 2027. Area productivity of 8.9 TWh/M ha/day has been considered and Lipid content is envisaged at 38%. Microalgae cultivation land area is expected to increase up to 0.48 M ha by 2047. This relates to microalgal biofuel production of 1774 PJ/year by 2047. The fuel conversion efficiency reaches 60% by 2047 from the present 20% as in lignocellulose liquid fuels. Liquid fuel production from macroalgae is expected to go up to 96 PJ/year by 2047.

XC: MUNICIPAL SOLID WASTE (MSW) BASED WASTE TO ENERGY (WTE)

The total Installed capacity of Waste to Energy (WtE) projects based on Municipal Solid Waste (MSW) as on 31st March 2021 was 200 MW (Government of India, Ministry of New and Renewable Energy 2021).

MSW is a heterogeneous mix of combustibles, organic matter, inert and moisture. Energy generation through biochemical conversion or combustion will depend on the levels of segregation and collection efficiency of MSW. This is a key focus area of Ministry of Urban Development as well as Urban Local Bodies (ULBs) across the country as per guidelines under AMRUT (Atal Mission for Rejuvenation and Urban Transformation). It is assumed under all scenarios that by 2047:

- Urban areas will have MSW collection efficiency of approx. 100% and segregation levels of approx. 90%.
- Rural areas will have MSW collection efficiency of approx. 100% and segregation levels of approx. 70%.

With improving segregation levels and Government's focus on Waste to energy:

1) CERC has revised NTP-16 directing tariff structure and mandatory purchase of power from Waste to energy.

2) Swacch Bharat Mission launched in 2014 by Ministry of Urban Development (MoUD) for MSW management aims at:
   a) Elimination of open defecation,
   b) Waste Collection (100%),
   c) Transportation of Waste (100%).
   d) Scientific Disposal (100%).
   e) Implementation of 5 new projects by MNRE.

LEVEL 1

Level 1 assumes that waste to energy capacity will grow slowly primarily due to lack of inter-agency coordination and favourable policies. Other key adverse factor will be limited understanding of technical issues involved in construction, operational and environmental aspects of MSW based WtE projects. Once these projects have lived their life, there will be no MSW based WtE projects till 2037. In this scenario, MSW based waste to energy capacity is expected to increase up to 230 MW by 2032 and 300 MW by 2047 from 171.08 in 2017 with an annual growth rate of 2% over the period of 30 years.

LEVEL 2

Level 2 assumes that the development of waste to energy plants in India is higher than the level 1. The capacity addition happens in line with the targets due to improved technology, government subsidies, improve quality of MSW etc. The waste to electricity generation capacity is expected to increase up to 550 MW by 2032 from 147 MW in 2020. Thereafter it is expected to go up to 1500 MW by 2047 with annual growth rate of 7.5%.

LEVEL 3

Level 3 assumes that Government and ULBs emphasize on MSW based Waste to energy as a key resource recovery option. The policies and incentives get aligned. Rural areas adopt organic MSW based gas as a key energy option. However, in urban areas, evolving technologies like combined heat and power still does not get any traction. In this scenario, it is expected that the present estimated waste to electricity potential of 2556 MW (Central Statistics Office 2017) will be achieved by 2047.

LEVEL 4

In this scenario, there are absolutely no barrier (economic, social or technical) to the growth of MSW based Waste to energy. Inter-agency conflicts are also resolved. Waste to energy gets enhanced attention coupled with technology advancement, quality of MSW, reduction in generation cost etc. Energy security is consciously factored in energy planning. The MSW based waste to energy capacity is expected to increase up to 772 MW by 2032 and 5.85 GW by 2047 from 200 MW in 2022.

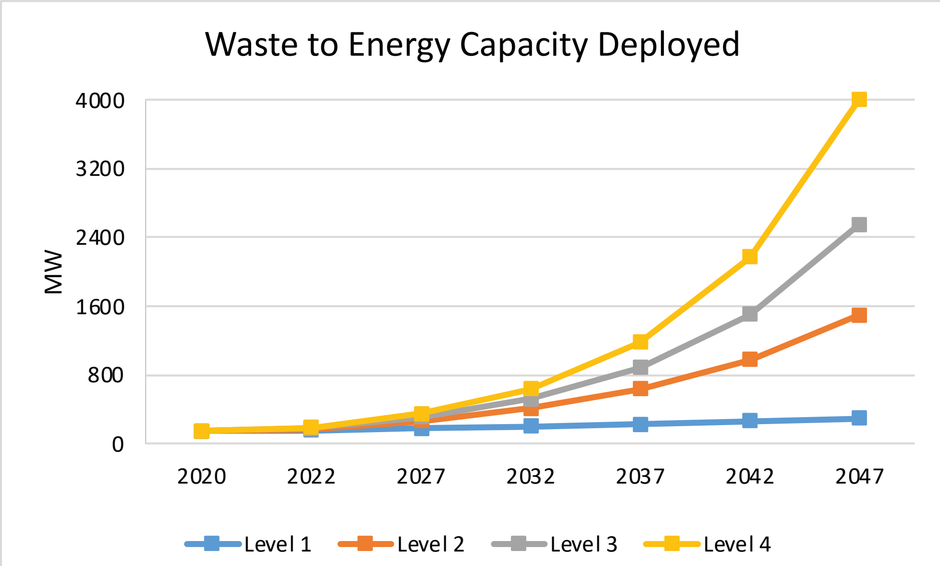


Figure XC.1: Waste to Energy Capacity Deployed

CHAPTER-XI

POWER SECTOR

XIA: GAS POWER

The Indian power sector is heavily dominated by thermal power plants. Coal power is the major contributor to electricity generation, with more than 70% share in the total generation in 2020. Apart from coal, gas-based power is the other contributor to power generation in India. The share of natural gas in the primary energy supply in India has remained steady at around 6% in recent years. The majority of the gas is used in the industrial sector and power sector. Natural gas is a relatively cleaner fuel with a high Calorific Value (CV). It is also easy to transport and easy to use. Hence, natural gas is becoming a desirable substitute for coal and oil in many sectors. However, even if the demand has been steeply increasing in all sectors, domestic supply has not grown as much. Therefore, it has been facing a lot of challenges recently.

The natural gas requirement for gas-based power plants in India is more than 100 MMSCMD, if they are to work at a load factor of 90%. However, the actual gas supplied to the power sector is stagnated at around 30 MMSCMD in the past few years. Therefore, the average PLF of gas-based plants drastically reduced from 67% in 2010 to 22% in 2020.

Four possible future trajectories have been considered for the gas power sector in the model considering the challenges for the sector and policies implemented by the government.

LEVEL 1

Due to the sustained shortage of gas, no new plants will be added in the future. Hydropower plants are used for achieving the required flexibility in generation, hence there are no efforts made to increase the generation from gas power. The installed capacity remains at 25 GW and the net electricity generation from gas power plant reaches around 54 TWh in the year 2047.`

LEVEL 2

Due to the recent discovery of gas in KG-D6 basin, domestic gas production will increase. It is assumed that the share of gas allotted to power still remains around 20%, but overall gas allotment will increase. As a result, the installed capacity increases with an average CAGR of 0.5%. Total capacity increases to 28.5 GW by 2047 from 25 GW in 2020. Electricity generation from gas power rises to 73.6 TWh by 2047 from 48 TWh in 2020.

LEVEL 3

Level 3 assumes that gas production in the country will increase, thereby increasing the allotment of natural gas to the power sector which shall revitalize the interest of gas power producers in India. Installed capacity grows at a rate of 1% till 2047, and the total installed capacity becomes 32.6 GW. As a result, electricity generation from gas power sector rises to 98.2 TWh by 2047.

LEVEL 4

It is assumed that the government puts aggressive efforts into increasing the share of gas in the primary energy mix. With the improved infrastructure of LNG terminals and reduced prices of imported gas, the availability of gas no longer remains a problem for the power sector. The capacity increases at a rate of 1.5%. The total installed capacity reaches 37.3 GW in 2047. Electricity generation rises from 48 TWh in 2020 to 128 TWh by 2047.

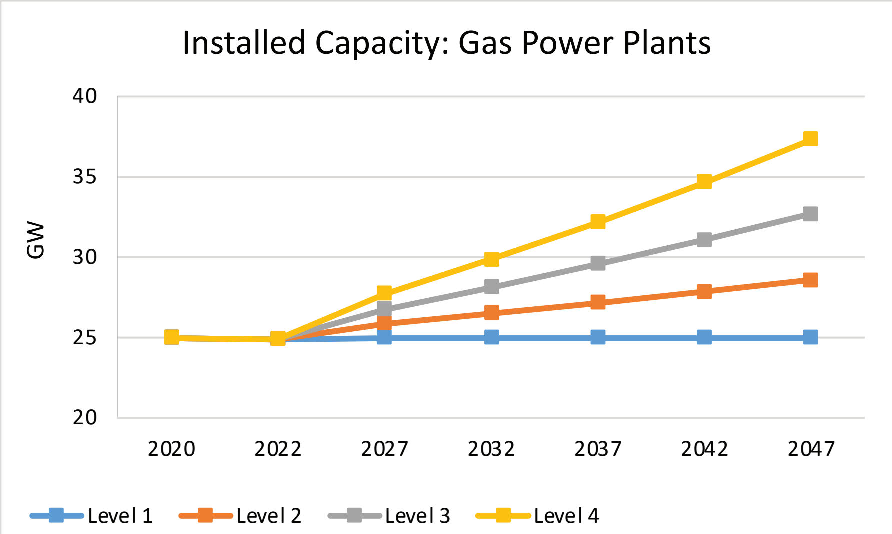


Figure XIA.1: Installed Capacity of Gas Power Plants

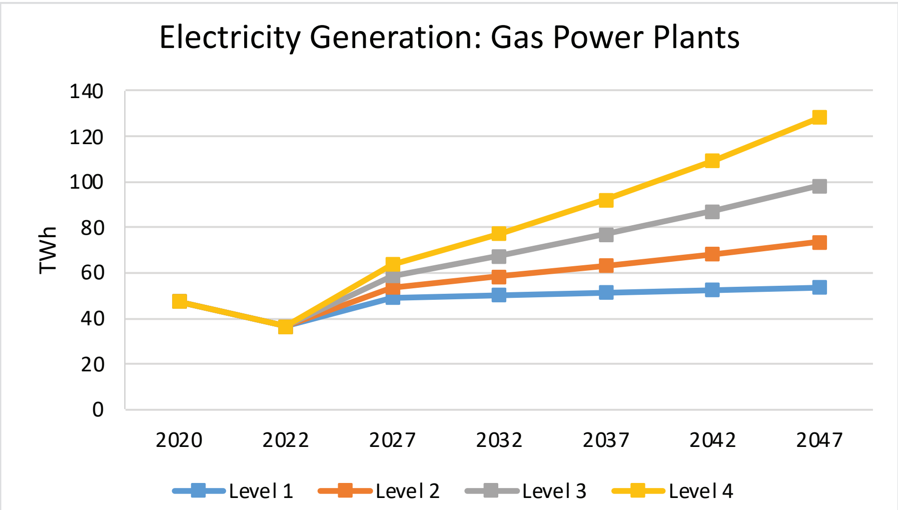


Figure XIA.2: Electricity Generation from Gas Power Plants

XIB: COAL POWER PLANTS

India's existing Thermal Power Plants (TPPs) are mostly based on inefficient subcritical technology, though efforts are now being made to adopt new efficient technologies like super-critical, ultra-supercritical etc. From 2012 to 2017 capacity addition from supercritical technology contributed around 42% of the total capacity addition from coal-based plants. However, the development and deployment of these efficient technologies is sluggish due to Indian coal having high ash content and low calorific value. This analysis models the penetration levels of efficient technology in coal-based TPPs till 2047. Based on the above, the user of this tool can estimate the quantity of coal required to meet the desired level of power supply. This section provides description only about the coal power plants without Carbon Capture and Storage (CCS) technologies. Power Plants with CCS technologies are explained in the next section. As discussed before, four technologies have been considered in the model for coal-based power plants:

- Sub-Critical (SubC)
- Super-Critical (SC)
- Ultra Super-Critical (USC)
- Advanced Ultra Super-Critical (AUSC)

LEVEL 1

In this trajectory, the SubC technology still continues to be part of the new capacity addition while the AUSC technology has not been considered. The share of SubC technology and SC technology in new capacity addition is around 18% and 82% respectively in 2022. These shares change with the penetration of SC and USC technologies rising gradually. By 2047, there is no new capacity addition in SubC with 90% share of SC, and 10% of USC.

LEVEL 2

Level 2 is a slight improvement over level 1. The share of SubC technology in capacity addition is 13% in 2027 while 82% of capacity added is SC and 5% is USC. By 2037, capacity addition through SubC is eliminated. By 2047, 70% of capacity addition is through SC technology, 20% USC and 10% is AUSC.

LEVEL 3

The share of SubC technology in capacity addition reaches 0% in 2027 while 8% of capacity added is USC and 6% AUSC, the rest is SC. The share of SC decreases gradually as USC and AUSC start penetrating more. By 2047, 30% of capacity addition is through SC technology, 40% USC and 30% is AUSC.

LEVEL 4

This level assumes a significant growth in USC and AUSC technologies. 50% of the total new capacity addition in 2047 comes from USC, while 40% comes from AUSC technology with rest 10% from SC. With this trajectory, the average efficiency of the coal fleet is expected to be above 40%.

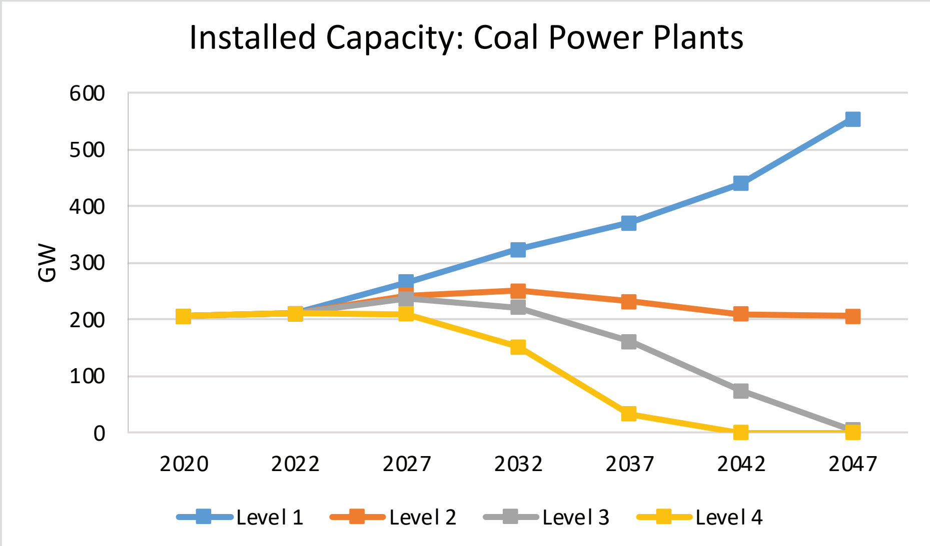


Figure XIB.1: Installed Capacity of Coal Power Plants

XIC: CARBON CAPTURE AND STORAGE (CCS)

The power sector is the largest consumer of coal in India. Out of the total generation capacity of 399 GW as of March 2022, coal and gas together constitute 59%. Electricity generation from fossil fuels accounted for 83% of the total in FY2021-22. Out of the total energy sector emissions, electricity production is the highest with 40% contribution. India being in an accelerated phase of economic growth, aiming to add more power generation capacity in the next two decades, it needs the new capacity at low or zero CO2 emissions to minimize the contribution to global warming.

Carbon Capture and Sequestration (CCS) (or carbon capture and storage), is the process of capturing waste carbon dioxide (CO2) from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere. A significant portion of India's carbon dioxide emissions originates from power plants. The construction of power plants at the gigawatt scale in recent times implies that these large, concentrated emission sources are ideally suited for the implementation of Carbon Capture and Storage (CCS). Such an approach could profoundly influence and substantially reduce CO2 emissions.

CCS technology is applicable to industries also. This module discusses the future trajectories of CCS in the power sector only.

LEVEL 1

No planned generation plants with CCS till 2025 - resultantly the rate of CCS technology deployment will be low. Generation with CCS usage till 2025 will be negligible and starts to increase, but at a very slow pace due to a lack of efficient and cheap technology. In this scenario, the generation with CCS usage is expected to increase up to 7 GW by 2047 from 0 GW in 2020. The high cost of CCS technology becomes a deterrent to its adoption. Electricity generation from CCS-based plants is around 34 TWh by 2047.

LEVEL 2

Generation with CCS usage will be deployed at a slow rate. In this level, it is expected that the CCS capacity installed is around 2.25 GW by 2030, and increases up to 15 GW by 2047. Electricity generation from CCS-based plants is around 74 TWh by 2047.

LEVEL 3

The amount of CCS-equipped capacity grows rapidly after 2027. The total installed capacity of CCS-based plants reaches 13.5 GW by 2037. This increases to 19.25 GW by 2042 which further to 25 GW by 2047. Electricity generation from CCS-based plants is 10 TWh in 2027 and reaches around 125 TWh by 2047.

LEVEL 4

More generation plants with CCS technology will be deployed as an outcome of technology up-gradation and reduction in capital requirement. India will begin constructing its own demonstration-scale facilities, and more ambitious CCS projects. Generation capacity with CCS is expected to be 7.75 GW by 2032 which will increase up to 35 GW by 2047. Electricity generation from CCS-based plants is around 175 TWh by 2047.

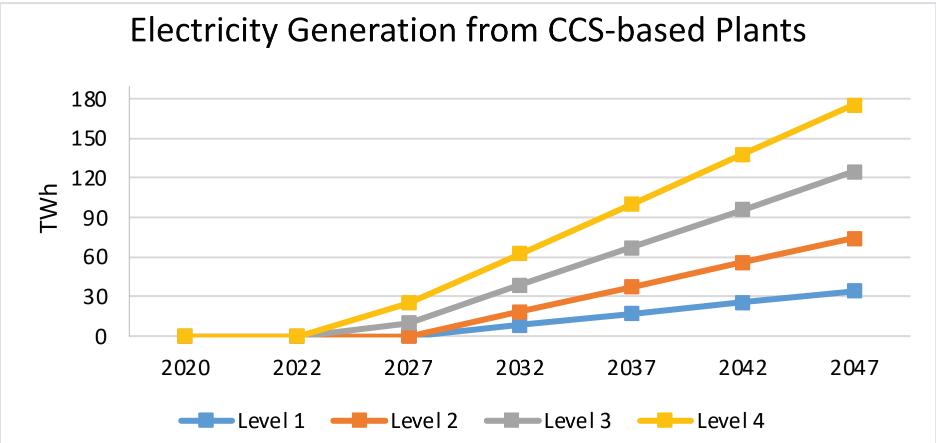


Figure XIC.1: Electricity Generation from CCS-based plants

XID: NUCLEAR POWER STATION

The installed capacity as of March 31st 2022 was 6.78 GW. There are 22 operating reactors in seven sites. Pressurized Heavy Water Reactors (PHWR), which use natural uranium, account for about 65% of the present installed capacity. These reactors are being operated at a PLF of around 75%-80%.

Presently, to run 14 out of the 22 operating reactors, India relies on uranium imports. Uranium is assumed to be available for imports until 2047. Significant new nuclear build rates would require additional power plant locations, which is a critical factor. This forms a vital lever in the differing numbers for the growth of this source of power under the four levels. In the total nuclear power capacity of 6.78 GW in 2022 the contribution of Boiling Water Reactor (BWR), Pressurised Heavy Water Reactor (PHWR) and Pressurised Water Reactor (PWR) are 0.32 GW, 4.46 GW and 2 GW respectively.

LEVEL 1

Level 1 assumes that the present reactors under construction will not be commissioned due to delay in administrative clearances. Also, the present public sentiment regarding nuclear power results in a limited capacity addition in nuclear power, while a few of the older reactors get decommissioned. The cumulative nuclear capacity is expected to grow at 8% p.a. and reach up to 54 GW by 2047 from 6.78 GW in 2020 at a PLF of 78%. The corresponding electricity generation will increase up to 380 TWh by 2047 from 47 TWh in 2020.

LEVEL 2

Level 2 assumes that new reactors will be developed apart from the already identified sites and under-construction projects. New LWR reactors are also expected to be introduced. In this scenario, the cumulative nuclear power installed capacity is expected to increase up to 64.5 GW by 2047. The corresponding electricity generation will increase up to 498 TWh by 2047 from 47 TWh in 2020.

LEVEL 3

Level 3 is an optimistic trajectory and assumes that all the new PHWR sites are fully utilized with new reactors. In addition, the spent fuel from thermal reactors is used to build more FBR capacity. Thus, new reactors are developed taking the installed capacity up to 100.5 GW by 2047. The electricity generation will increase steeply up to 775 TWh by 2047.

LEVEL 4

Level 4 is aligned with the ambitious vision of Department of Atomic Energy. It assumes that over and above level-1, 2&3 projects, 10×1000 MW IPWRs and 6×1000 MW Metallic Fuel Fast Breeder Reactors (MFBRs) would be launched and progressively completed by 2047. Required sites will have to be selected and acquired. The cumulative nuclear power installed capacity is expected to increase up to 160 GW by 2047 from 6.8 GW in 2020. Electricity generation increases to 1100 TWh by 2047.

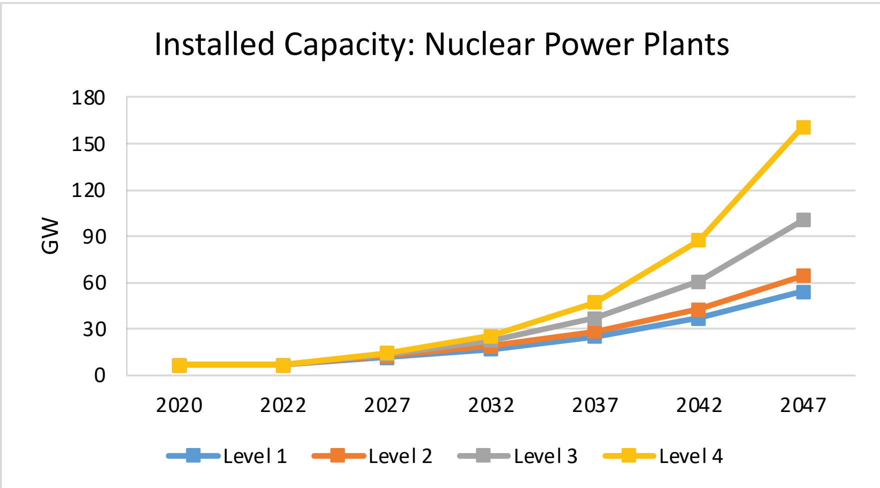


Figure XID.1: Installed Capacity of Nuclear Power Plants

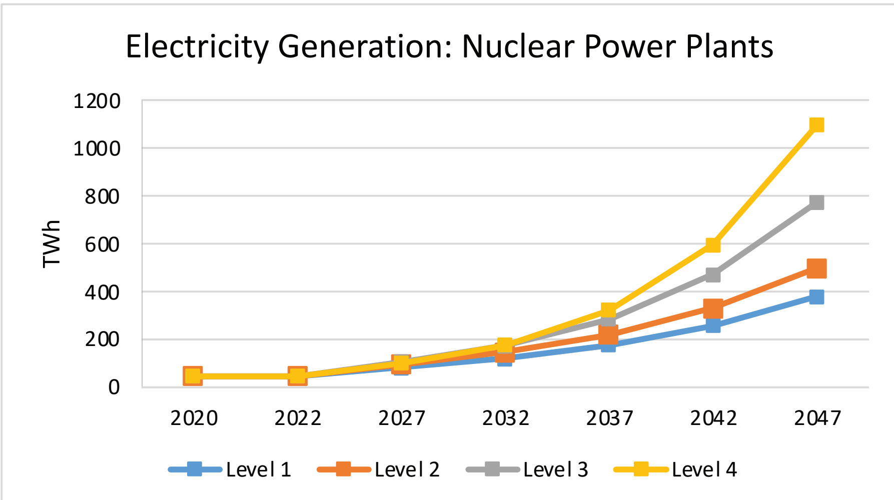


Figure XID.1: Electricity Generation from Nuclear Power Plants

XIE: LARGE HYDROELECTRIC POWER STATIONS

Large Hydropower plants (Capacity > 25 MW) constitute around 12% of the total installed capacity in India as of March 2020. With a plant load factor of less than 40%, the share of hydropower in total electricity generation is 11.3% in 2020. The PLF has almost been constant within a narrow range of 32% - 38% between 2010 and 2020. In 2020, the total installed capacity was 45699 MW with Brahmaputra, Indus and Ganga as major sources. Analysis of small hydro plants (Capacity <25 MW) has been considered separately. The hydropower sector faces challenges of land acquisition, resettlement and rehabilitation on a large scale. Pumped Hydro Plants (PHPs) are not accounted for in the installed capacity.

LEVEL 1

In this trajectory, a low growth scenario has been considered. Only the power plants which are currently under construction and have been approved are assumed to materialize. The installed capacity grows at a CAGR of 2.1% and reaches 63.3 GW in 2047. No new plants are constructed after reaching that capacity. Electricity generation from large hydro plants increases to 221 TWh by 2047.

LEVEL 2

In the BAU trajectory, the installed capacity grows at a rate of 2.17% which was the decadal growth rate observed between 2010-20. It continues to grow at the same pace till 2047. The total installed capacity of large hydro plants in 2047 is 81.6 GW. The electricity generation from large hydro plants increases from 155 TWh in 2020 to 285 TWh by 2047.

LEVEL 3

In addition to the achievement of Government plans and targets, Level 3 includes the benefits from the completion of Renovation and Modernisation (R&M) and Life Extension (LE) efforts, and the effect of National R&R Policy 2007 (rehabilitation and resettlement processes), which will help to increase the hydropower plant capacity in the country. Total installed capacity grows at a CAGR of 3.10% till 2047 and cumulative capacity reaches 104.2 GW in 2047. Electricity generation increases to 363 TWh by 2047

LEVEL 4

In this scenario, technology advancements are assumed to result in the exploitation of the maximum potential of large hydro. It is assumed that advanced technology development, integration of regional grids, rehabilitation, and issues related to hydropower will be resolved. In this trajectory, the final capacity of large hydro plants reaches 140.9 GW by 2047, close to the estimated potential of hydropower in the country. Electricity generation in this trajectory increases to 491 TWh by 2047 from 155 TWh in 2020.

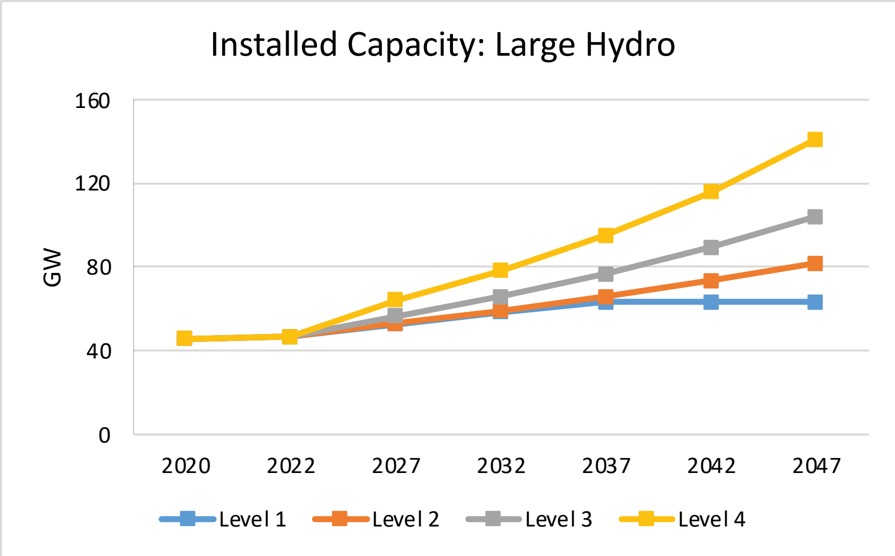


Figure XIE.1: Installed Capacity of Large Hydro Power Plants

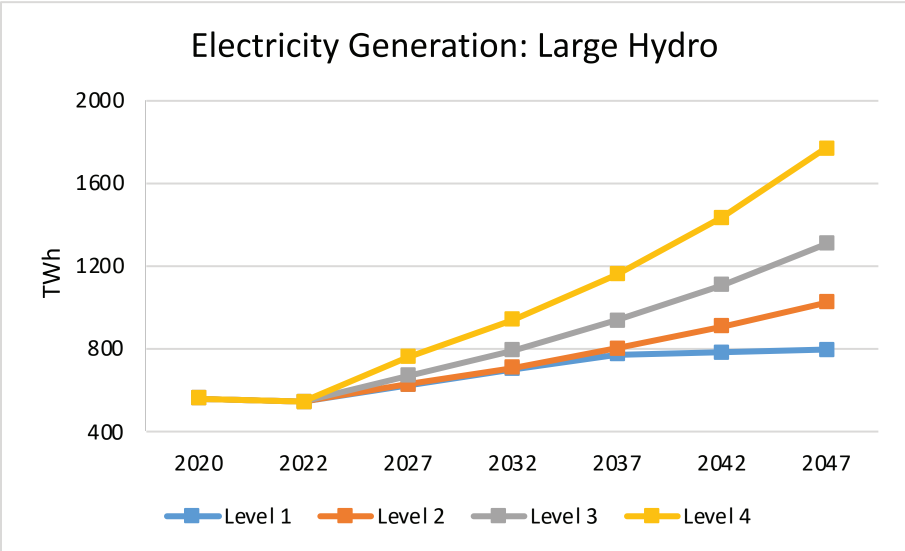


Figure XIE.2: Electricity Generation from Large Hydro Power Plants

XIF: UTILITY-SCALE SOLAR PV PLANTS

Solar energy has seen an incredible transformation in the last decade in the Indian power sector. As the power from fossil fuels started getting more expensive and its detrimental effects on the climate came to the fore on different global platforms, such as 21st Conference of the Parties (COP 21), countries worldwide began to move to renewables for energy production. India launched a National Solar Mission in January 2010 as a part of the NAPCC, aiming to install 20 GW grid-connected solar PV capacity in India by 2022. The targets for solar PV were revised in 2015 to a total of 100 GW grid-connected capacity by 2022 (60 GW utility-scale projects and 40 GW rooftop PV projects). As of March 2020, 32 GW capacity of utility-scale PV plants has been built. A sharp decline in the price of technology and supporting policy mechanisms such as Renewable Purchase Obligations (RPOs), tax credits, and favorable financing are the primary reasons behind the sector's growth.

LEVEL 1

Level 1 assumes a slow and sluggish growth of the solar PV sector. The capacity will reach only 120 GW by 2030 at an average annual CAGR of 14%. After 2030, PV growth rate increases, and capacity will eventually reach 457 GW in 2047.

LEVEL 2

This level has a slightly better outlook for the solar energy sector. It assumes that some additional investments will be made to improve the power evacuation infrastructure in the country. Current policies are expected to continue in the future. The capacity is assumed to grow to 150 GW in 2030 and 725 GW in 2047.

LEVEL 3

The Government of India has has notified a year-wise trajectory of Renewable Purchase Obligations (RPOs) till 2030. According to this, in year 2030, each state has to purchase 43.3% of their total electricity consumption from renewable energy. With this, the optimistic trajectory exceeds the target of 200 GW utility PV capacity by 2030 and the total capacity is assumed to reach 885 GW in 2047.

LEVEL 4

This level assumes that the sector can maintain low tariffs, making it the most sought-after power source rather than gas and coal power. The cumulative capacity will reach 250 GW in 2030. Heroic effort trajectory considers a very high penetration of utility-scale PV. The total capacity of utility-scale PV reaches 1176 GW by 2047.

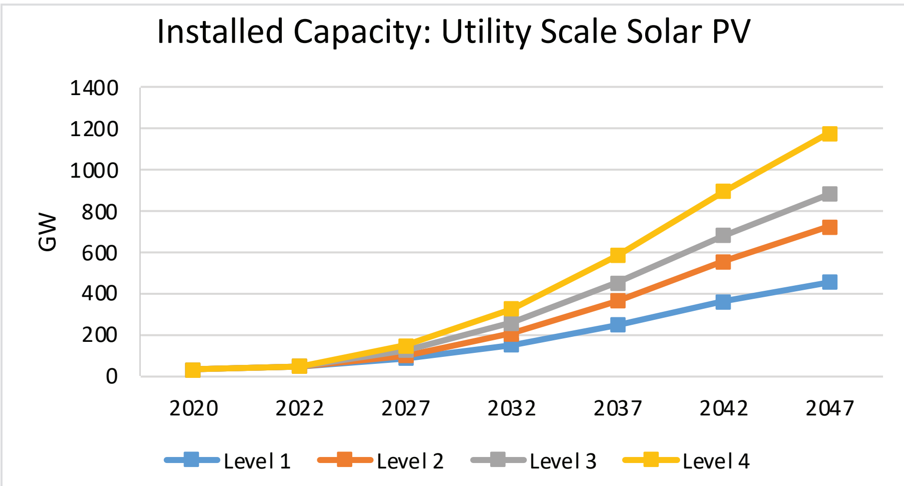


Figure XIF.1: Installed Capacity of Solar PV Plants

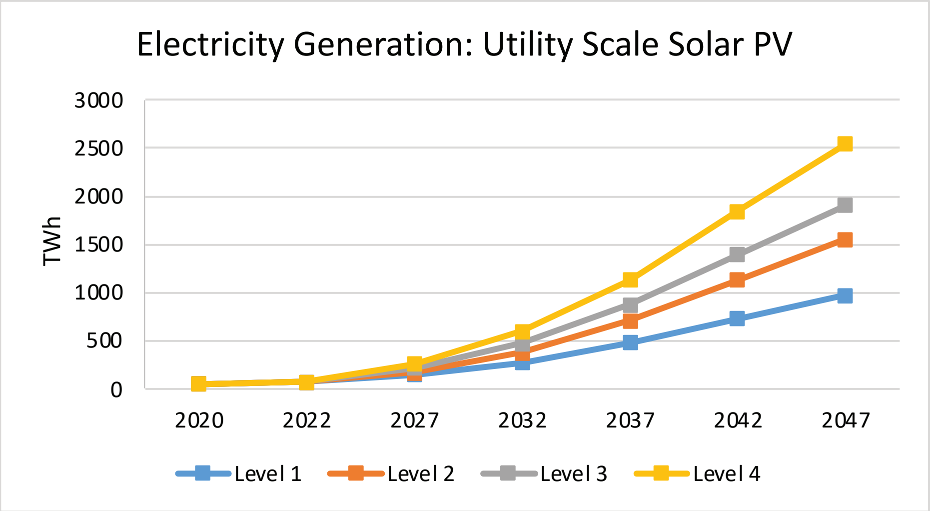


Figure XIF.2: Electricity Generation from Solar PV Plants

XIG: CONCENTRATED SOLAR POWER

Concentrated Solar Power (CSP) is a source of utility large-scale electricity generation. CSP uses only the Direct Normal Radiation fraction of the solar radiation and uses solar heat for steam generation and finally electricity production. This technology has been tried and tested in many parts of the world and is most widely used in Spain and USA now. The total estimated technical potential of CSP in India is over 1500 GW, whereas the economic potential is around 571 GW. Like PV, the resource potential is unlikely to be the limiting factor for CSP; it would more likely driven by technology and price development and development.

National Solar Mission (NSM) helped kick-starting the CSP program in India. Under phase 1 (2010-13) of the mission, 50% of the allotted capacity was earmarked for CSP. A total of 470 MW were bid out which are under progress. Owing to revised JNNSM targets from the Government of India, systematic support and development have culminated in the installation of 51330 sq.mt of aperture area of CSP systems as of 2020 mostly in the state of Rajasthan.

As a country with an abundance of sunlight, India has the potential to harness CSP to significantly expand its renewable energy capacity, supporting its goals for energy security and reducing dependence on fossil fuels. With CSP, India can produce power even after sunset, addressing the intermittent nature of solar power and contributing to a more stable and reliable power grid, essential for the country's rapidly growing economy and increasing electricity demand.

LEVEL 1

Level 1 assumes that only 2 GW would be operational in the next 10 years mainly due to higher costs and slower growth of the solar CSP in the country. There will be a slight increase in generation capacity from the current. Deployment of solar CSP is expected to increase slowly and capacity will reach 9.8 GW by 2047. Electricity generation from CSP will increase to 38 TWh by 2047.

LEVEL 2

Level 2 assumes that there is slow but consistent growth in capacity addition of solar CSP. In this scenario, the total solar CSP installation capacity is expected to go up to 5.4 GW by 2037 and 17.2 GW by 2047. Electricity generation from CSP increases to 68 TWh by 2047.

LEVEL 3

Level 3 assumes relatively rapid capacity addition. In this scenario, solar CSP capacity is expected to go up to 5.8 GW by 2037 and culminate at 19.6 GW by 2047. As a result, electricity generation from CSP increases to 77 TWh by 2047.

LEVEL 4

Technological development and policy impetus help solar CSP to reach high capacity in Level 4. In this level, it is expected that the cumulative capacity of solar CSP will go up to 22.8 GW by 2047, at an average CAGR of 18.5% over 27 years. Electricity generation from CSP increases to 91 TWh by 2047.

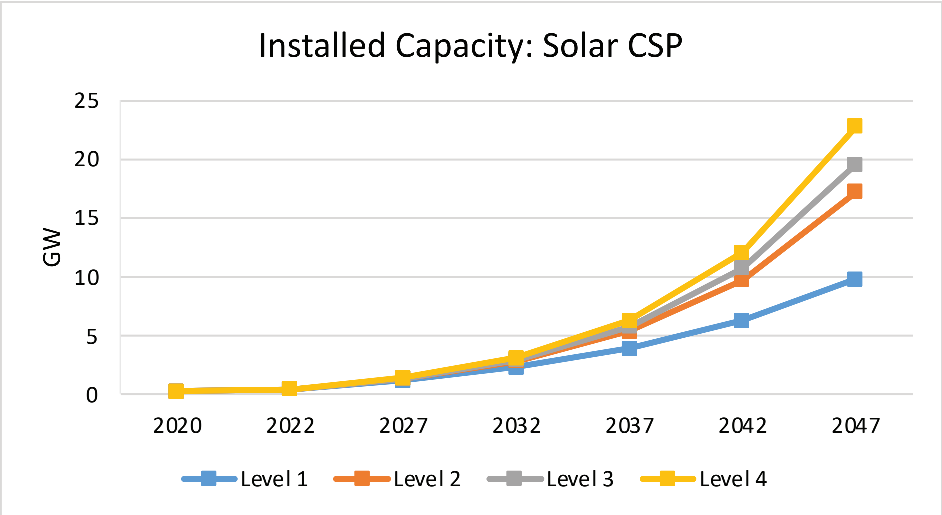


Figure XIG.1: Installed Capacity of Solar CSP

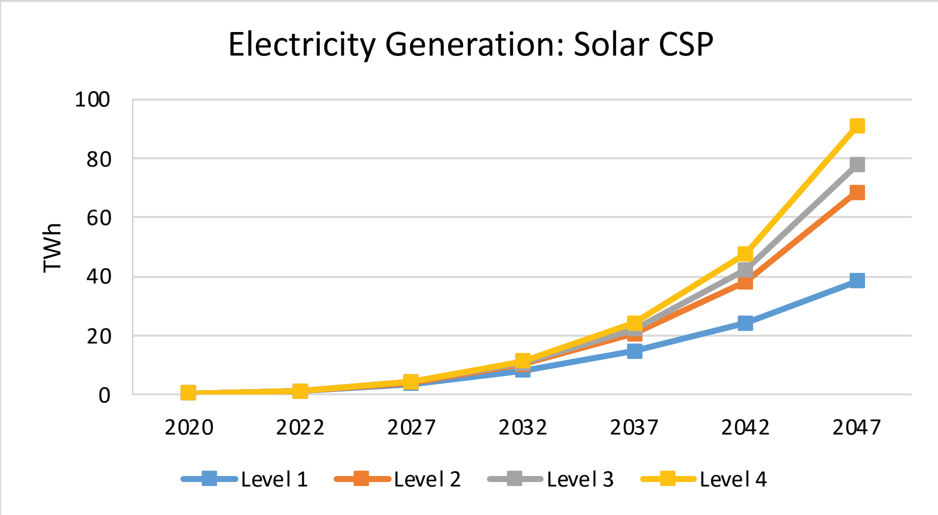


Figure XIG.2: Electricity Generation from Solar CSP

XIH: DISTRIBUTED SOLAR PHOTOVOLTAIC POWER

Rooftop solar PV systems are distributed electricity generation options, which help to meet a building's energy needs or provide electricity within an existing distribution network. Rooftop PV is distributed in two parts - Residential rooftop PV and Non-residential rooftop PV. Rooftop PV is getting more popularised in the non-residential sector as compared to the residential sector as the payback period in the non-residential sector is lower. The overall capacity has only reached 2.5 GW, whereas the target for 2022 according to the Jawaharlal Nehru National Solar Mission (JNNSM) was to achieve 40 GW. Distributed Solar PV is expected to grow significantly in the coming years due to an increase in economic viability for certain consumer segments (commercial, industrial and high-use residential) in particular geographical areas in India. While many states have already put favourable net metering policies in place, some state electricity regulatory commissions support rooftop projects through the feed-in tariff route.

LEVEL 1

This level assumes that the growth of the distributed PV will be slow, and the capacity of the residential sector will reach only 2.8 GW by 2030 and 20 GW by 2047. While for the non-residential sector, capacity will reach only 30 GW by 2030 and reaching 60 GW by 2047. Hence, the total rooftop capacity will be 32.8 GW in 2030 and 79.8 GW in 2047. Electricity generation from distributed PV reaches 133 TWh by 2047.

LEVEL 2

Current policies are expected to continue in the future. The residential sector capacity will grow to 3.8 GW by 2030 and 40 GW by 2047. In the case of the non-residential sector, the installed capacity grows to 35 GW by 2030 and reaches 80 GW by 2050. Thus, the total rooftop PV capacity will reach 38.8 GW in 2030 and 119.7 GW in 2047. Electricity generation from distributed PV increases to 199 TWh by 2047 from 4 TWh in 2020.

LEVEL 3

Level 3 assumes that the prices of rooftop PV will come down, which will provide an incentive for the residential consumer to install rooftop PV. The residential rooftop PV capacity will grow to 60 GW in 2047. The uptake of rooftop PV technology is sustained in the non-residential sector and reaches 100 GW by 2047. Thus, the total rooftop PV capacity is expected to reach 44.5 GW by 2030 and 159.6 GW by 2047. Electricity generation in 2047 reaches up to 266 TWh.

LEVEL 4

This level assumes a steady decline in the technology prices coupled with favourable policies for Discoms. The installed capacity will reach 80 GW in 2047 for the residential sector. In the case of the non-residential sector, capacity reaches up to 50 GW in 2030 and 120 GW in 2047. Thus, the total rooftop PV capacity will reach 55 GW by 2030 and 199.7 GW by 2047. In this trajectory, electricity generation from distributed PV reaches up to 332 TWh by 2047.

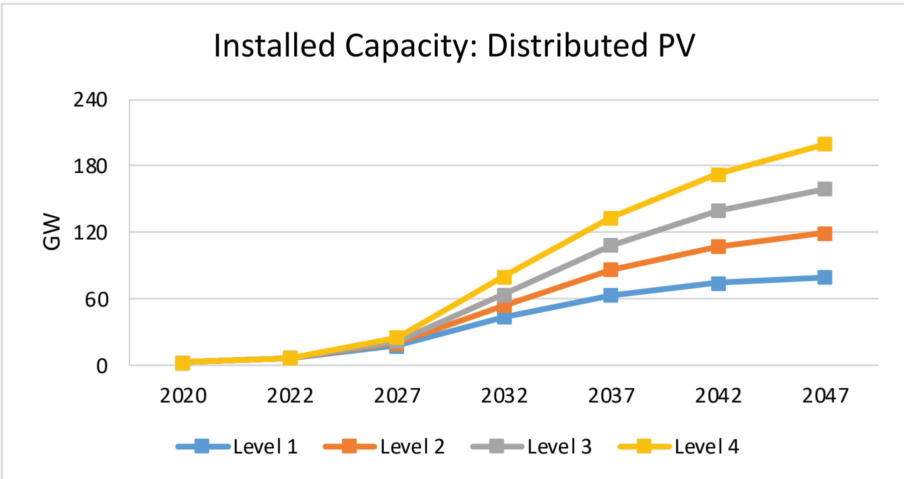


Figure XIH.1: Installed Capacity of Distributed Solar PV Power

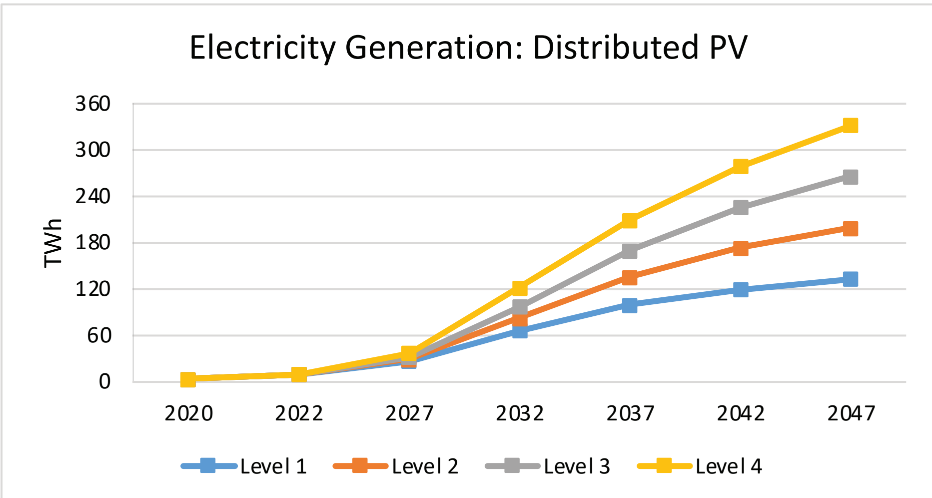


Figure XIH.2: Electricity Generation from Distributed Solar PV Power

XII: ON-SHORE WIND POWER STATION

India is ranked fourth globally with an on-shore wind capacity of 37.6 GW as of March 2020. At the same time, wind power alone contributes 46% of the total renewable energy generation and 43% of the country's total installed capacity of renewables. Studies by the National Institute of Wind Energy suggest a countrywide potential of 302 GW at 100 m hub height and 695 GW at 120 m hub height. Most of the potential is situated in the coastal regions of Tamil Nadu, Gujarat and hilly regions of western ghats in Maharashtra and Karnataka. An average Capacity Utilization Factor (CUF) of wind turbines is around 20% in 2020 which is expected to rise sharply due to better site selection as well as the installation of newer wind turbines.

Availability of land, transmission infrastructure and reliable integration of variable generation would be key factors that may limit the uptake of wind power in the future. Improvement in the techniques used to forecast wind speed and availability is also crucial for the integration of wind energy in the grid.

LEVEL 1

Level 1 assumes a pessimistic growth of the wind power sector. This trajectory misses the goal of 60 GW installed capacity of wind in 2022 by a long margin and achieves that goal in the year 2030. The total installed capacity reaches 255 GW in 2047. The net electricity generation from wind turbines increases to 977 TWh by 2047 from 65 TWh in 2020

LEVEL 2

Level 2 assumes that some additional investments will be made to improve the power evacuation infrastructure in the country. The installed capacity reaches 80 GW in 2030. The wind power sector experiences steady growth and the total installed capacity reaches 275 GW in 2047.

LEVEL 3

Level 3 assumes the introduction of novel policy regulations along with technological improvements. Issues related to land acquisition & environmental constraints will be resolved. As a result, the sector is able to reach 90 GW in 2030. 356 GW onshore wind capacity is achieved in 2047. The net electricity generation from onshore wind power plants increases to 1365 TWh by 2047 in this trajectory.

LEVEL 4

Onshore wind power technology saw a 13% growth rate in the last decade (2010-20). It is assumed that the sector is able to witness a similar growth between 2020-30, and cumulative installed capacity will reach 110 GW by 2030 in Level 4. Cumulative installed capacity will reach 397 GW in 2047.

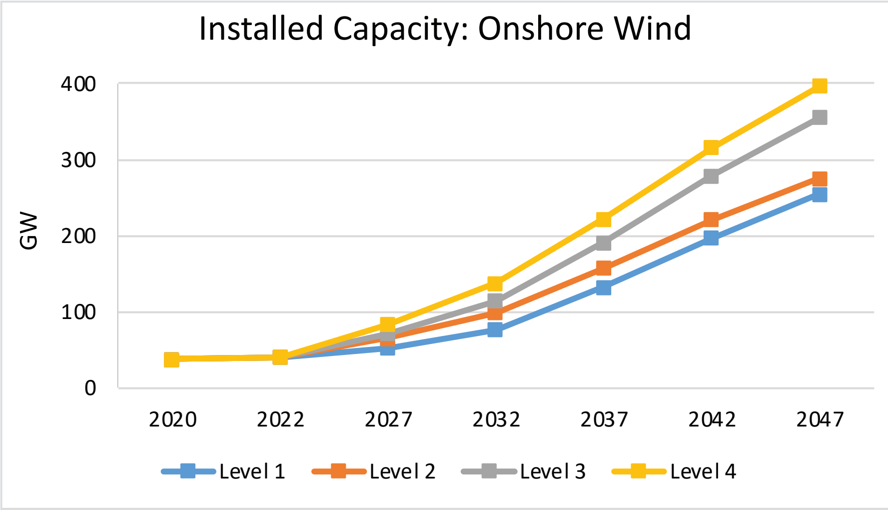


Figure XII.1: Installed Capacity of Onshore Wind Power Plants

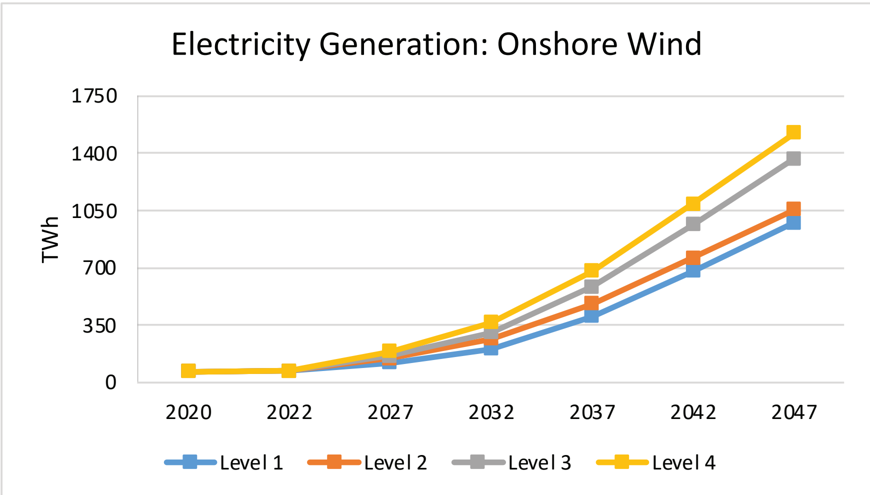


Figure XII.2: Electricity Generation from Onshore Wind Power Plants

XIJ: OFF-SHORE WIND PLANTS

Offshore wind power is a potential source of electricity generation primarily due to higher wind speeds, higher Capacity Utilization Factors (CUFs) and the absence of land constraints. However, the downside of this technology is that the cost of installation and operation is much higher compared to onshore wind power. Factors such as the need for specialized installation vessels, the challenges of building and maintaining structures in often harsh ocean conditions, and the higher costs associated with connecting the offshore wind farms to the power grid significantly contribute to the high cost.

India has a coastline of more than 7500 km which provides ample space for installing offshore wind turbines. A preliminary assessment by the National Institute of Wind Energy (NIWE) using satellite data projects a potential of 70 GW across eight zones each in Gujarat and Tamil Nadu near the Gulf of Khambhat and Dhanushkodi respectively. This indicates that resource availability is not a constraint for wind power development. Higher costs, transmission infrastructure and reliable integration of variable generation would be key factors that may limit the uptake of offshore wind power in the future.

Hybrid projects and removing reverse-auction policy regime are likely to help the development of offshore wind sector in India.

LEVEL 1

Level 1 assumes a slow growth for offshore wind technology, mainly due to the high costs and other technological barriers. It assumes that 2 GW capacity will be installed in 2027 and final capacity reaches 30 GW in 2047. The corresponding electricity generation would be 7 TWh in 2027 and it will increase to 116 TWh in 2047.

LEVEL 2

Level 2 assumes a slightly higher growth rate with installed off-shore wind power capacity reaching 3 GW by 2027. Total capacity reaches 65 GW in 2047. The corresponding annual electricity generation from offshore wind plants will increase up to 251 TWh by 2047 from 10 TWh in 2027.

LEVEL 3

Level 3 assumes that with the improvement in potential offshore site identification and cost reductions along with significant investments in the transmission and evacuation systems, India would gradually build up its offshore wind capacity to 4 GW by 2027 which is expected to further reach 100 GW by 2047. The corresponding annual electricity generation will increase up to 386 TWh by 2047 from 14 TWh in 2027.

LEVEL 4

Level 4 assumes that offshore wind power does not face many economic or physical constraints. It is assumed that 4 GW capacity in installed in 2027, and it increases upto 22 GW by 2030. Final capacity reaches 120 GW in 2047. A significant amount of investment is required to achieve this level of growth in offshore wind sector. The corresponding annual electricity generation will increase up to 463 TWh by 2047 from 14 TWh in 2027.

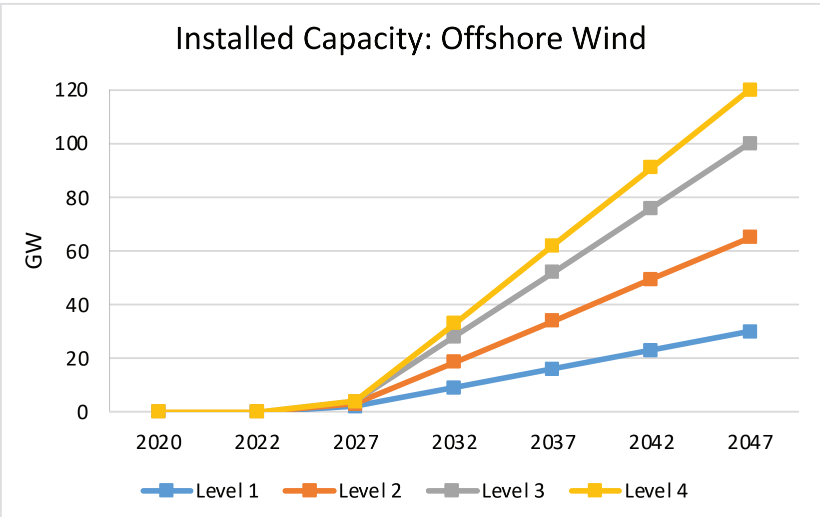


Figure XIJ.1: Installed Capacity of Offshore Wind Power Plants

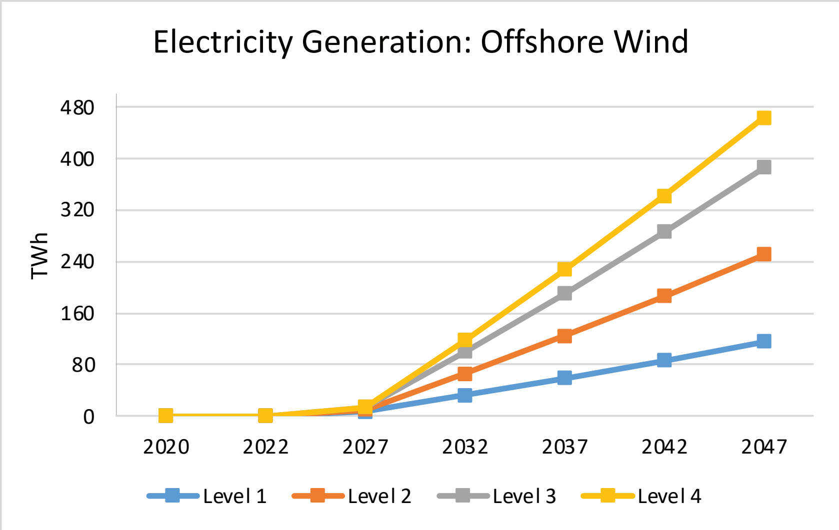


Figure XIJ.2: Electricity Generation from Offshore Wind Power Plants

XIK: SMALL HYDRO POWER STATIONS

According to MNRE, the total potential for small hydro power in India is 21,134 MW from more than 7000 sites across India. As of March 2020, 4683 MW capacity has been installed. In the last ten years, on average, 230 MW capacity has been added every year. 1512 number of small hydroelectric plants with an aggregate capacity of 6.8 GW has also been identified.

The climate impacts are calculated in terms of GHG emissions and local emissions. Ecological impacts due to the construction of small hydro plants have not been considered in this analysis. Small hydro plants largely depend upon the seasonal flows of rivers, and hence no improvement in Capacity Utilization Factor (CUF) has been considered. Average CUF has been considered constant throughout the timeline. CEA's electricity plan does not mention any capacity retirement plan.

LEVEL 1

The rate of yearly capacity addition has declined in recent times. On average, 126 MW capacity has been added every year since 2016. In level 1, it is assumed that the future capacity will be added at the same rate. In this trajectory, installed capacity reaches 4.84 GW by 2022 and 6.7 GW by 2047. Thus, in this trajectory, the government target is not met.

LEVEL 2

This trajectory reflects the overall capacity addition trend from the year 2009-10. The average yearly capacity addition in the last ten years is around 229 MW. In this trajectory, it is assumed that future capacity addition will take place at a rate of 229 MW per year, constant up to 2047. Installed capacity reaches 4.84 GW in 2022, thereby achieving the government target, and reaches 8 GW in 2047.

LEVEL 3

The government puts effort into facilitating the infrastructure development for the small hydro sector. With those efforts, the rate of capacity addition increases over time. In this trajectory, capacity reaches 14 GW in 2047.

LEVEL 4

In this trajectory, it is assumed that aggressive efforts are put in each of the renewable energy sectors to achieve the ambitious goal of 500 GW non-fossil power capacity by 2030. Capacity addition increases at a rapid rate in future. Total installed capacity reaches 20 GW in 2047, which signifies more than 90% exploitation of the estimated 21 GW potential of the small hydro sector in India.

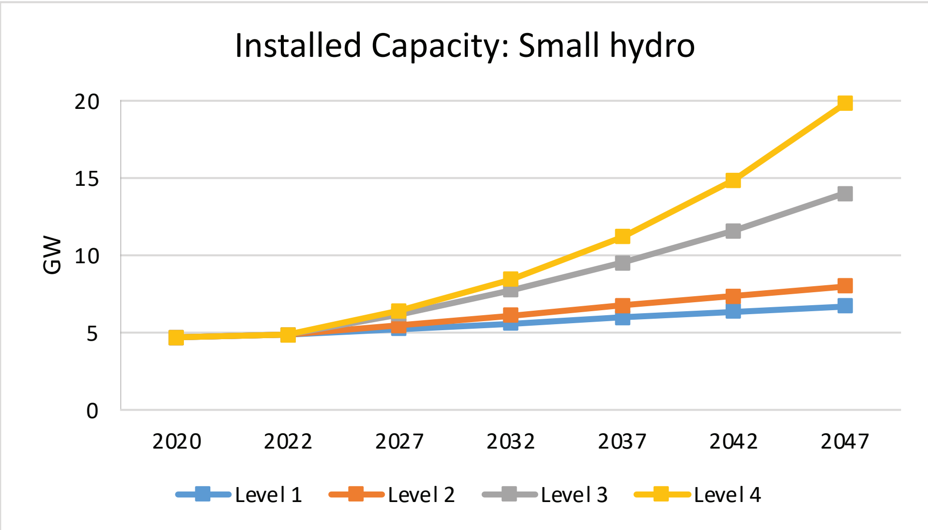


Figure XIK.1: Installed Capacity of Small Hydro Power Plants

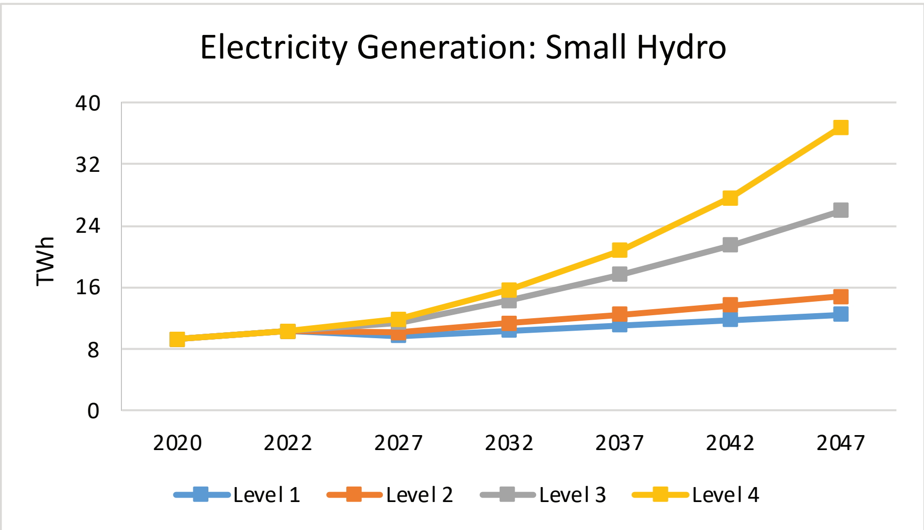


Figure XIK.2: Electricity Generation from Small Hydro Power Plants

XIL: BIOENERGY: BIOMASS TO ELECTRICITY GENERATION

Biomass can be used to produce electricity in dedicated Rankine cycle-based power plants as well as bagasse-based cogeneration plants. So, for the promotion of technologies to make optimal use of the country's biomass resources for grid power generation, the biomass power and cogeneration programme is implemented by MNRE. Bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, groundnut shells and saw dust are the biomass materials used for power generation. According to the MNRE, the total potential of producing electricity from biomass in India is 42 GW. The total installed capacity of biomass-based power plants is 9.9 GW as of 2020. Future capacity projections are based on past trends and the maximum potential of technology.

LEVEL 1

Level 1 assumes limited capacity addition, from the capacity of 9.9 GW in 2020. With no investment in technology, the efficiency of technology also remains constant at 25%. The capacity addition happens at a CAGR of 1%. Electricity generated increases slightly from 12 TWh in 2020 to 13.3 TWh due to higher PLF of biomass plants in 2022 compared to 2020, and further increases at 19.6 TWh till 2047

LEVEL 2

In this level, the total installed capacity reaches 15 GW by 2047 increasing at a rate of 1.6%. The efficiency of conversion starts improving and reaches 28% by 2047. Total electricity generation from biomass increase up to 24 TWh by 2047 from 12 TWh in 2020.

LEVEL 3

Level 3 is an optimistic trajectory which assumes a growth in capacity up to 20 GW by 2047 along with an improvement in conversion efficiency up to 30%. In this trajectory, the electricity generation from biomass rises to 32 TWh by 2047.

LEVEL 4

Level 4 is the heroic trajectory which assumes that the total capacity reaches 28 GW in 2047 along with an improvement in conversion efficiency up to 33%. In this trajectory, the electricity generation from biomass rises to 44 TWh by 2047.

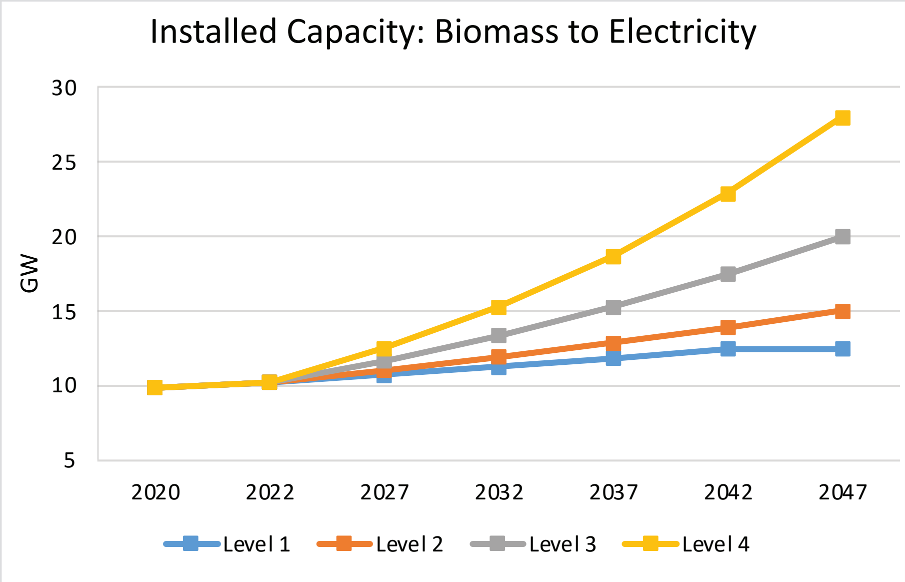


Figure XIL.1: Installed Capacity of Biomass-based Power Plants

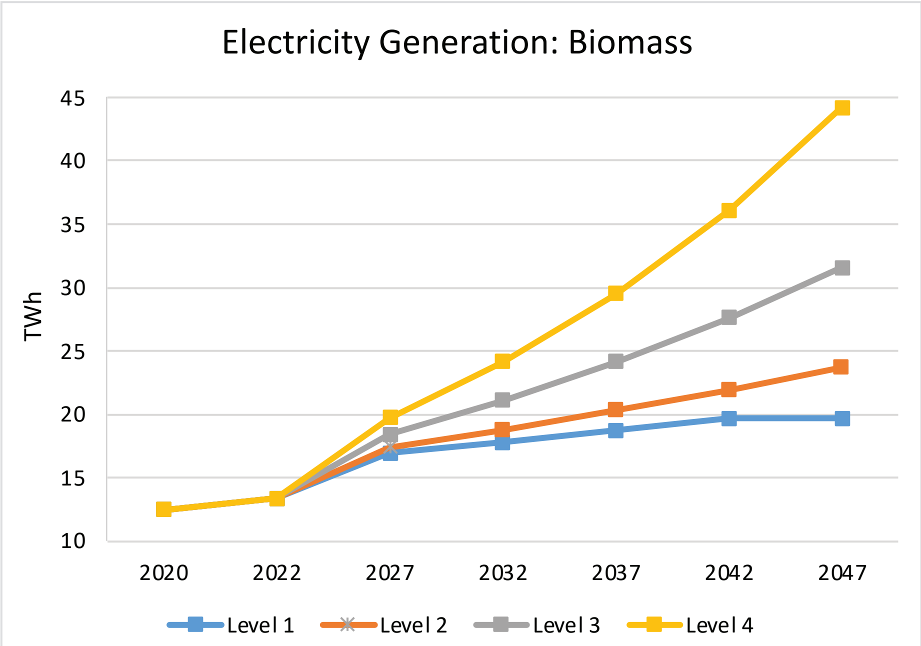


Figure XIL.2: Electricity Generation from Biomass-based Power Plants

MISCELLANEOUS

CHAPTER-XII
GRID

XIIA: CROSS BORDER ELECTRICITY TRADE

As of 2020, India is importing 1.8 GW hydropower from Bhutan, and also exporting 1.9 GW to Nepal, Bangladesh and Myanmar. India exported 9355 million Units to Nepal, Bangladesh and Myanmar and imported around 6313 million units from Bhutan in FY2019-20. Export to Nepal and Bangladesh increased significantly in last few years. The export and import capacities considered in Level 2 have been estimated using the data provided by CEA. Level 1 is expected to see 5% increment in imports and a reduction of 5% in exports compared to Level 2. The imports in Level 3 and Level 4 are assumed to be 5% and 10% lower compared to Level 2. It is assumed that exports will increase in Level 3 and Level 4 by 5% and 10% respectively compared to Level 2.

Options of power export/imports from Myanmar, Bangladesh, Pakistan and Sri Lanka are also being explored. The inter-connection with India's neighbours is important from future import/export/balancing viewpoints. This analysis captures only the contracted electricity imports and exports. The recent SAARC agreement on a south Asian grid will enable this trade.

LEVEL 1

Level 1 assumes that India's electricity imports from Himalayan riparian counties will increase at higher pace compared to its exports to neighbouring countries. In this scenario Imports capacity is expected to grow up to 28.3 GW by 2047 from 1.8 GW in 2017. Exports capacity is expected to increase to 18.6 GW by 2047 from 1.9 GW in 2017.

LEVEL 2

Level 2 assumes imports continue to grow at a moderate pace. The country is planning to have imports of 5.5 GW by 2026-27 from neighbouring countries. If the growth rate continues at similar pace between 2027 and 2040, then the cumulative imports capacity is expected to increase up to 26.9 GW by 2047. The cumulative exports capacity is expected to increase up to 19.6 GW by 2047.

LEVEL 3

Level 3 assumes an optimistic scenario where exports capacity increases at a higher rate compared to Level 2. However, imports increases at a slower pace compared to Level 2 It is also assumed that Nepal will commission its 23 GW HEP projects and will export to India. In this scenario, cumulative imports capacity is expected to increase up to 25.6 GW by 2047. The cumulative exports capacity is expected to increase up to 20.6 GW by 2047.

LEVEL 4

Level 4 is the heroic trajectory, which assumes a very fast growth in export capacities and a very slow growth in import capacities compared to Level 2. In this scenario, electricity imports cumulative capacity is expected to increase up to 14.9 GW by 2037 and 24.2 GW by 2047. The cumulative exports capacity is expected to increase up to 21.5 GW by 2047.

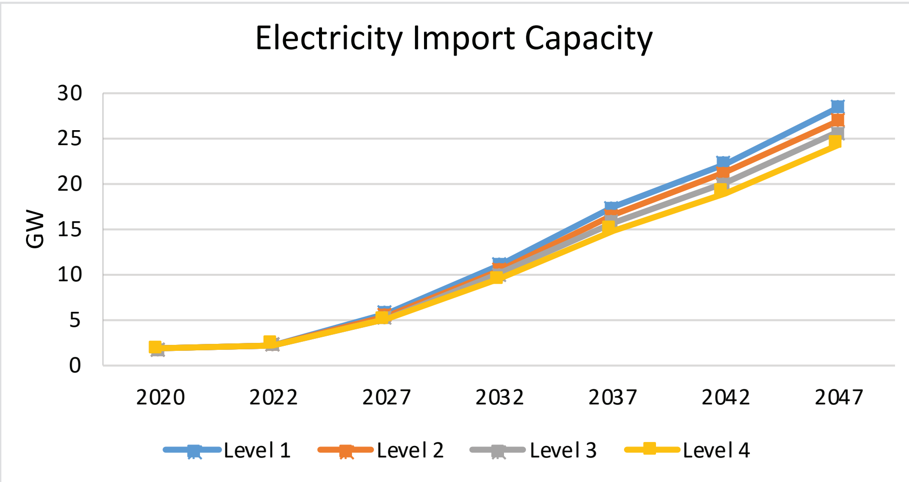


Figure XIIA.1: Electricity Import Capacity

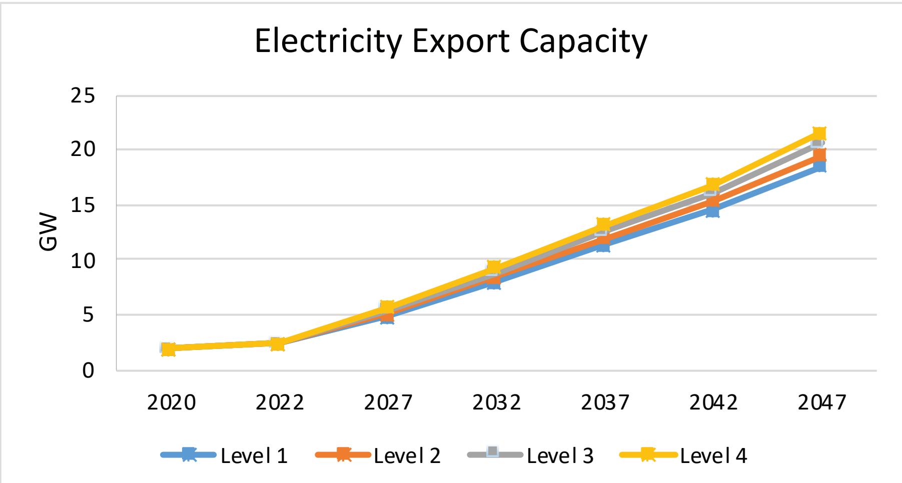


Figure XIIA.2: Electricity Export Capacity

XIIB: TRANSMISSION AND DISTRIBUTION LOSSES (T&D)

The present analysis captures electricity savings under different scenarios of T&D losses from the present losses of 20.33% in 2019-20. The aggregate technical and commercial losses are not captured herein, as they do not impact electricity availability/consumption. The Government of India approved the Integrated Power Development Scheme (IPDS) on 20.11.2014 with the aim to ensure quality and reliable power supply in the urban areas and reduction of Aggregate and Technical & Commercial Losses (AT&C).

T&D losses in India are one of the highest in the world. With an objective to reduce distribution losses and strengthen the distribution sector, the Ministry of Power has launched several programmes such as Accelerated Power Development & Reforms Programme (APDRP), National Smart Grid Mission, etc. A change in the Electricity Act, 2003 is also envisaged to improve the business structure towards this end – separation of carriage and content.

LEVEL 1

Level 1 assumes only a marginal improvement in T&D losses, which is currently at 20.33% in 2019-20 on all India basis. Owing to financial losses of distribution utilities, investments towards strengthening the grid are minimal and hence the reduction in T&D technical losses is expected up to 9% by 2047.

LEVEL 2

Although the 14 Smart Grid pilot projects demonstrate the benefits of Smart Grid technologies at the pilot scale, a pan India large-scale deployment of Smart Grid technologies is assumed to happen at a relatively low rate. Projections are based on conservative estimates of leveraging the Smart Grid technologies. T&D technical losses is expected to reduce up to 8% by 2047.

LEVEL 3

It is assumed that the investments are made as envisaged in the India Smart Grid Roadmap towards achieving the stated goals of reduction in losses, demand response and integration of renewable energy. Building on the success of the pilot projects, various technologies are leveraged under a clean energy policy drive to achieve financially viable and sustainable Smart Grids. T&D technical losses is expected to reduce up to 7% by 2047.

LEVEL 4

An aggressive drive is adopted toward achieving sustainable economic growth, energy independence and energy security. Reforms in the transmission and distribution sectors are carried out via the elimination of cross-subsidies, competitive tariff structures, increased private participation, real-time energy markets, and bi-directional flow of electricity. Therefore, T&D technical losses is expected to reduce up to 6% by 2047.

GLOBAL ASSUMPTIONS AND SCENARIOS

A. GLOBAL ASSUMPTIONS

India is now the fifth largest economy in the world and aspires to be the third largest by 2027. The country's growth will be facilitated by an expansion of urban, industrial and infrastructural services. Hon'ble Prime Minister of India challenged India to be a developed nation by 2047. To meet such developmental aspirations, IESS assumes various four different trajectories for GDP growth rate which include: 6%, 7%, 7.5% and 8% till 2047. User can choose among the four defined trajectories to understand the implications on energy demand and energy supply. Further, user also has a choice to define a customized GDP trajectory different from the trajectory specification defined in IESS.

Table A.1: Sectoral Share of GDP

Sectors	2020	2022	2027	2032	2037	2042	2047
Agriculture	17.3%	18.4%	16.6%	14.8%	13.0%	11.2%	6.8%
Industry	27.2%	27.2%	28.6%	29.9%	31.3%	32.6%	34.5%
Services	55.6%	54.4%	54.8%	55.3%	55.7%	56.2%	58.7%

Table A.2: Assumptions of Various Parameters over the Study Period

Parameter	Units	2020	2022	2027	2032	2037	2042	2047
Population	Millions	1349	1375	1436	1490	1535	1569	1592
Urban Population	Millions	472	497.4	562.1	627.5	691.9	753.5	811.9
Rural Population	Millions	876.6	877.2	873.8	862.6	843.1	815.1	780.1
Household Size - Urban	People/ household	4.20	4.14	4.00	3.85	3.70	3.56	3.41
Household Size - Rural	People/ household	4.50	4.45	4.32	4.19	4.07	3.94	3.81
Total Households	Millions	307.2	317.3	342.9	368.8	394.2	418.9	442.9
Urban Households	Millions	112.4	120.1	140.7	163.0	186.9	211.9	238.1
Rural Households	Millions	194.8	197.2	202.2	205.7	207.4	207.0	204.8
Urbanization	%	35%	36.2%	39.1%	42.1%	45.1%	48.0%	51%
Share of Manufacturing	%	14.4%	15.7%	19.0%	22.2%	25.5%	28.7%	32.0%

B. SCENARIO

B1. Net Zero Scenario

The Net Zero scenario in IESS 2047 is designed based on careful selection of policy levers wherein India will not only achieve its goal of being a developed economy by 2047 but also be on a path of reaching net zero by 2070. Real GDP growth is assumed to be growing at CAGR of 7% till 2047. Fuelled by initiatives taken to promote growth of industrial and services sector, the share of industrial sector in overall GDP is expected to improve from 27.2% (2022) to 34.5% (2047) and service sector from 54.4% (2022) to 58.7% (2047) while the share of agriculture sector sees a decline from 18.4% (2022) to 6.8% (2047).

Against the context that India's current per-capita GDP is 1/5th and per-capita energy consumption 1/3rd of the global average, there is a need for significant investments needed in health, education, skilling and infrastructure. Reaching the standard of living as observed in developed economies entails huge increase in energy demand. The choices therefore allow for energy demand to increase while there will be substantial investments in adoption of energy efficiency measures and changes in fuel mix towards cleaner fuels. The chosen net zero scenario choices consider various policy announcements of government such as increasing the share of EVs in new car sales to reach 30% and production of 5 MMT of Green Hydrogen by 2030, ethanol blending target of 20% by 2025 etc. On the supply side, choices reflect the achievement of various commitments such as updated NDCs while ensuring that our emissions reach net zero by 2070.

Due to poor economic viability of gas based power plants which largely depend on imported gas, there is no improvement considered in gas based capacity in future. Further, due to several factors such as lack of prior experience in set-up of offshore wind plants and lack of conducive ecosystem for growth of distributed solar, the choices reflect conservative growth rather than assuming aggressive growth in capacity addition. Same is the case also with Bio-energy.

Based on selected choices, the results indicate that energy demand will grow at a moderate CAGR of 3% till 2047 as compared to 3.4% in BAU scenario largely driven by growth in Industry and Buildings. Total primary energy supply will grow at CAGR of 4% till 2030 and growth rate is expected to decline to 2.5% thereafter primarily driven by increasing shift to clean energy options, increased demand electrification and adoption of energy efficiency measures.

Implications

- Energy demand will grow by a factor of 2.1 times by 2047 and per-capita energy demand grows from 18.1 GJ (2022) to 33.8 GJ (2047). With expected increase in industrialization and living standards, the share of industry in overall energy demand will increase from 43.5% (2022) to 50% (2047) and share of buildings increase from 6% (2022) to 12% (2047).
- Primary energy supply is expected to increase from 824 Mtoe (2022) to 1717 Mtoe (2047), with CAGR of almost 2.8%. In-terms of per-capita, it is expected to grow by a factor of 1.8 times with increase from 6,967 kWh (2022) per person to 12,544 kWh (2047). As economic growth decouples from energy requirements, the expected

per-capita primary energy supply is still lower compared to world average of 20,758 kWh in 2021.

- With strong impetus to clean energy transition in a net zero scenario, the share of non-fossil is expected to increase from 16% (2022) to 40% (2047). Coal which accounts for almost 50% of primary energy supply in 2022 will see its contribution decline to 29% by 2047.
- Electrification continues to be one of the major strategies adopted world-over to transition to net zero. In Indian context, we expect that share of electricity in overall energy demand will increase from 18.5% (2022) to 40.5% (2047), almost more than double.
- Decarbonization of power sector with increasing share of RE is another dominant strategy employed to transition to net zero. With enabling ecosystem for RE, India already has world's fourth installed RE capacity. We will see that share of non-fossil in total installed electricity capacity will increase from 42.3% (2023) to 90% (2047) while the total installed capacity is expected to increase by a factor of 5.
- Energy sector emissions which account for almost 75% of the overall emissions will see increase from 2.5 Gt (2022) to 3.6 (2040s) wherein it is expected to plateau. Due to aggressive push towards demand electrification, decarbonization of power sector and adoption of green hydrogen, the energy sector emissions are expected to decline thereafter and are expected to reach 3.5 Gt (2047). In terms of per-capita energy related emissions, with improvement in economy, population and energy requirements, they are expected to increase from 1.9 tons (2022) to 2.2 tons (2047).
- Energy emission intensity to GDP is expected to decline from 17.33 (2022) to 4.43 (2047) due to strong impetus given to clean energy transition and decoupling of economic growth from emissions.

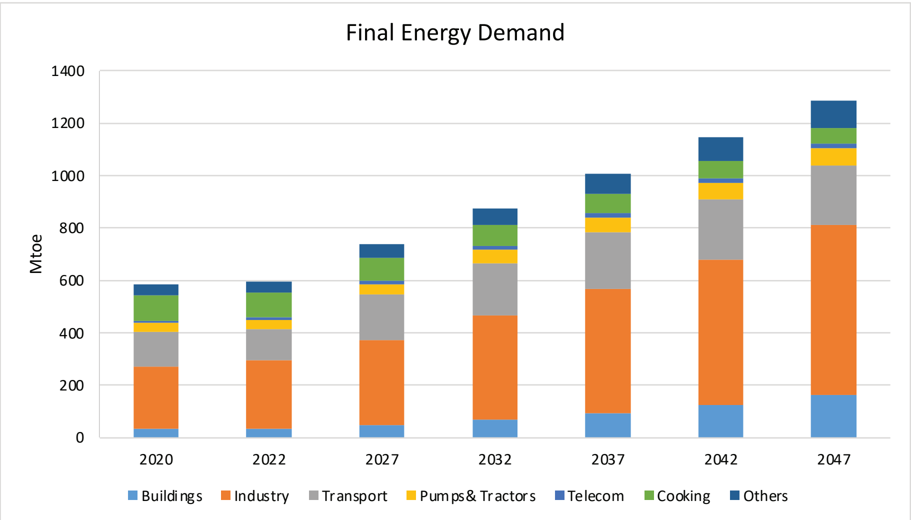


Figure B1.1: Final Energy Demand in Net Zero Scenario

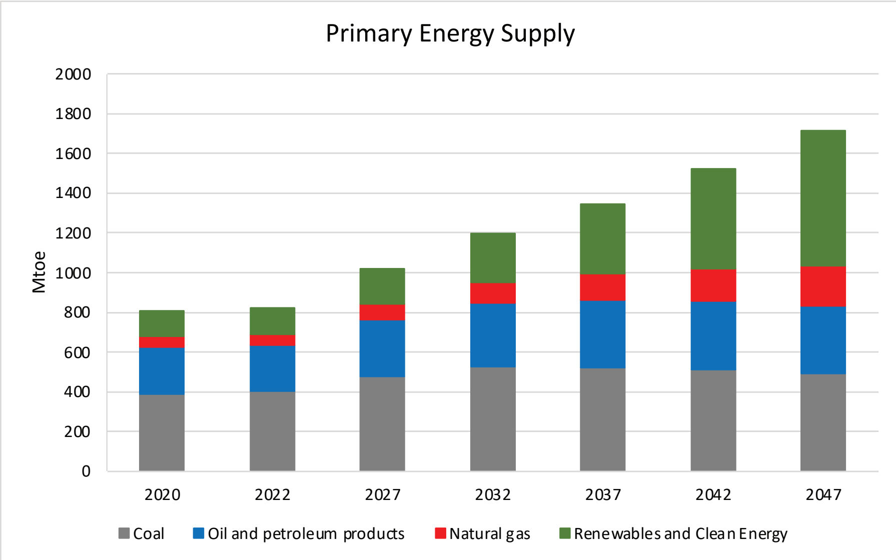


Figure B1.2: Primary Energy Supply in Net Zero Scenario

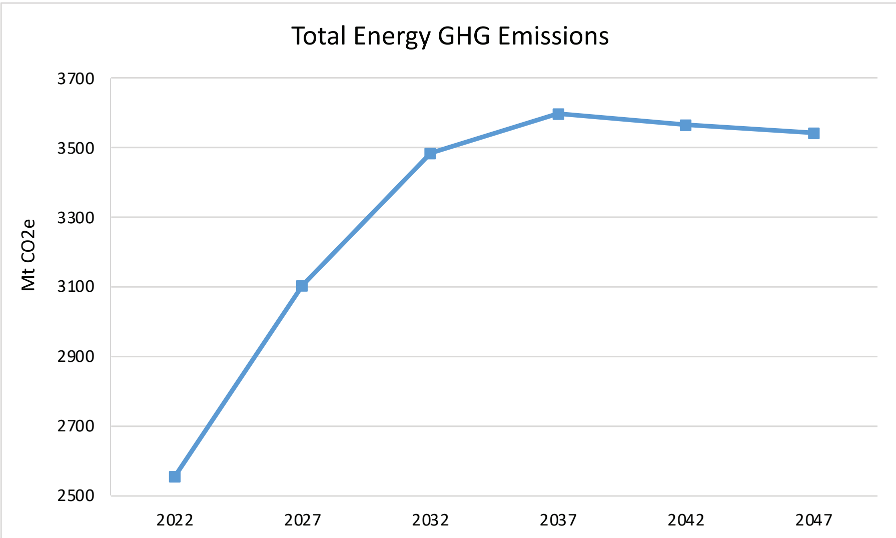


Figure B1.3: Total Energy GHG Emissions in Net Zero Scenario

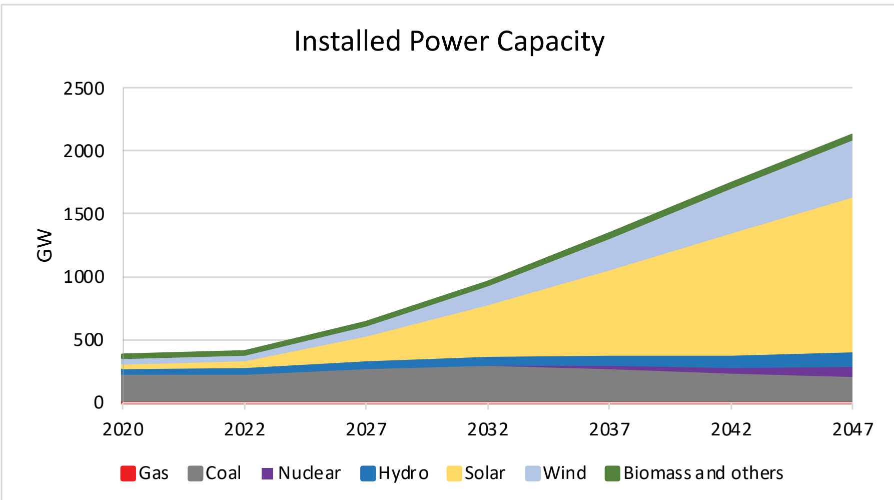


Figure B1.4: Installed Power Capacity in Net Zero Scenario

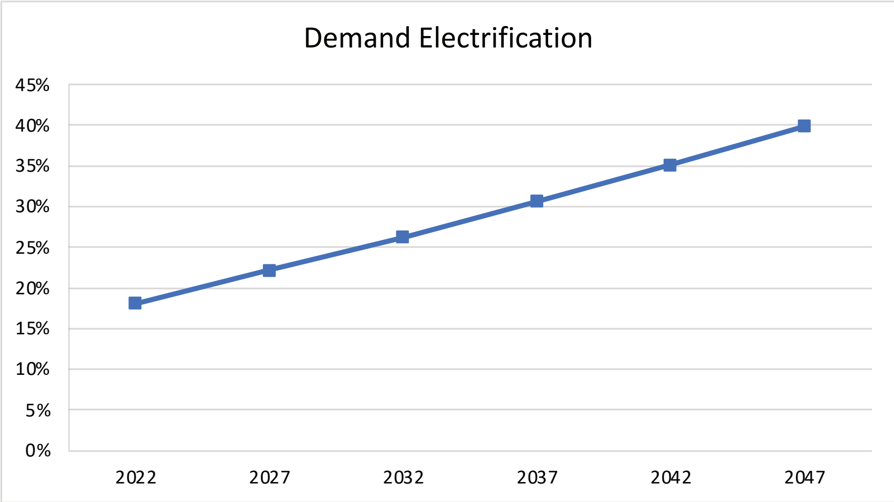


Figure B1.5: Demand Electrification in Net Zero Scenario

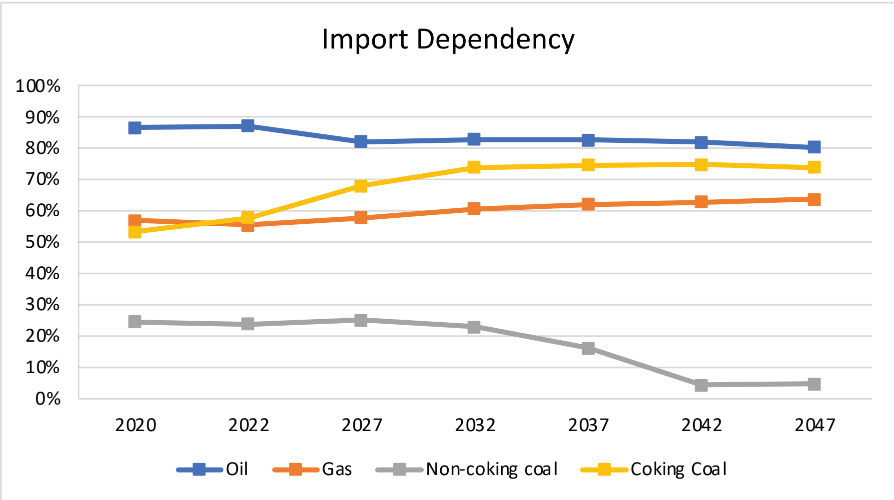


Figure B1.6: Import Dependency in Net Zero Scenario

B2: Aatmanirbhar Scenario

Hon'ble Prime Minister of Inda has given a call to be Aatmanirbhar in the energy sector by 2047 during his Independence Day speech in 2022. Therefore, India's effort towards becoming net zero by 2070 should go hand-in-hand with the goal being energy independent by 2047 and being a developed economy by 2047. This dictates careful selection of policy choices through which we can achieve all the three goals of being developed economy, achieving energy security and reaching net zero by 2070.

Import dependency is one of the major determinants of energy independence. In the current context, 85% of Crude oil and 49% of gas requirement is met through imports. The strategy for reducing import dependency is to reduce the demand for such products and second is to increase the domestic production capacity. The policy choices reflect the same.

Also, as we transition towards net zero, the demand for renewable energy is only going to increase. Concomitant with this is also the increase in energy storage requirements. Given the highly concentrated supply chains of critical minerals and metals required for energy storage, this scenario incorporates aggressive growth in both Hydro and Nuclear which play a critical role in reducing storage demand by providing base-load power and flexible power. The other important choices from the perspective of Aatmanirbhar energy sector such as stable and affordable energy prices, diversification of imports and adequate buffer capacities have not been considered in the modeling.

The policy choices also assume GDP CAGR of 7% till 2047 while share of agriculture, industry and services in overall GDP follow the same trajectory as in the net zero scenario. Also, as in net zero scenario, the choices allow for energy demand to increase along with adoption of energy efficiency measures and changes in fuel mix towards cleaner fuels.

Based on selected choices, the results indicate that energy demand will grow at a moderate CAGR of ~3% till 2047. Total primary energy supply will grow at CAGR of 3.8% till 2030 and growth rate is expected to decline to 2.8% thereafter primarily driven by increasing shift to clean energy options, increased demand electrification and adoption of energy efficiency measures.

Implications

- Due to adoption of increased demand electrification and boost to domestic production, import dependency in oil will decline from 87% (2022) to 57% (2047) and non-coking coal from 20% (2022) to 4% (2047). Non-availability of domestic coking coal especially for consumption in steel sector leads to marginal change in import dependency in coking coal with decline from 56% (2022) to 54% (2047). By 2047, reducing the import dependency remains a challenge in case of coking coal due to quality considerations. With increased measures towards gasification of economy, gas dependency is expected to increase from 55% (2022) to 63% (2047).
- With expected increase in industrialization and living standards, per-capita energy demand grows from 17.9 GJ (2022) to 33.0 GJ (2047). Demand electrification grows from 18.5% (2022) to 47% (2047).
- With measures to meet the demand from alternatives to oil and gas, the share of oil and gas in the overall primary energy supply will decline from 34.9% (2022) to 22.2% (2047).
- The total installed electric capacity will increase by 6 times by 2047 with 78% share from non-fossil in 2047 compared to 43.2% in 2023.
- Energy sector emissions will see increase from 2.5 Gt (2022) to 3.6 (2040s) declining thereafter to 3.36 Gt (2047) with adoption of measures such as demand electrification, decarbonization of power sector and green hydrogen.

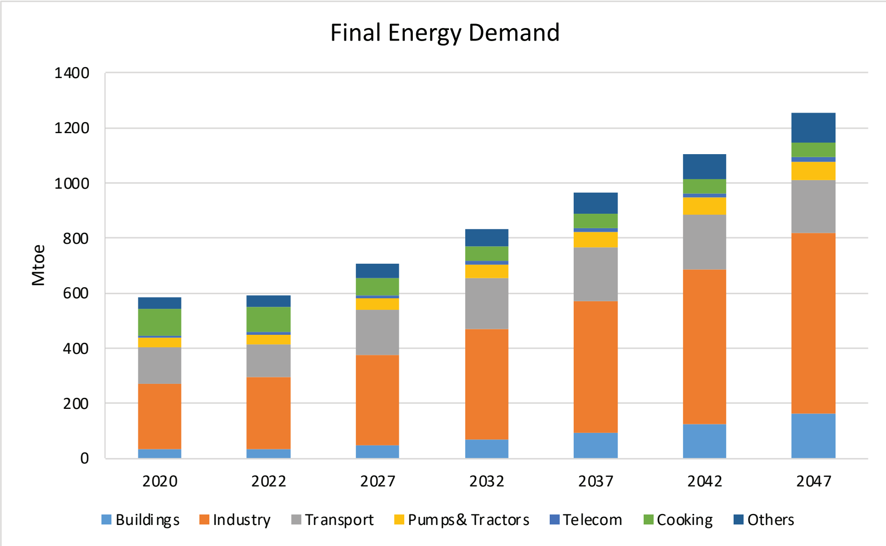


Figure B2.1: Final Energy Demand in Aatmanirbhar Scenario

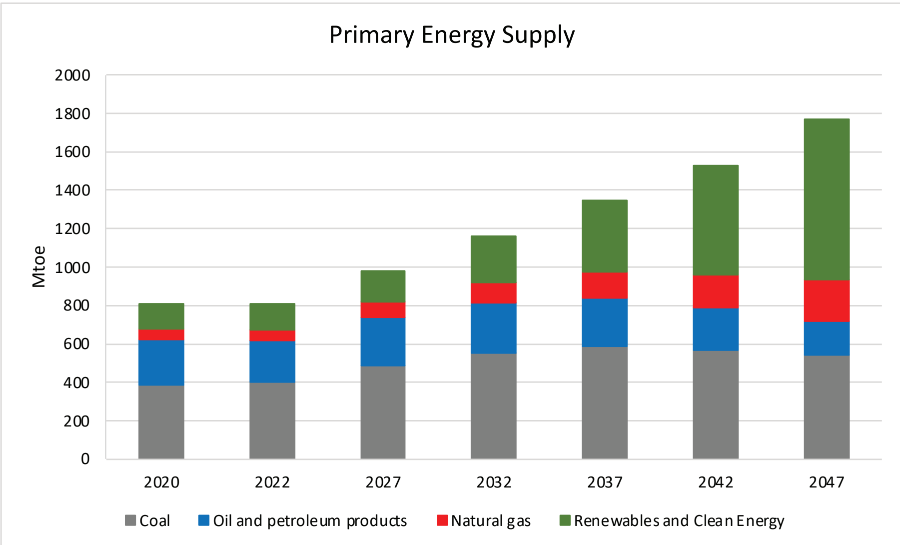


Figure B2.2: Primary Energy Supply in Aatmanirbhar Scenario

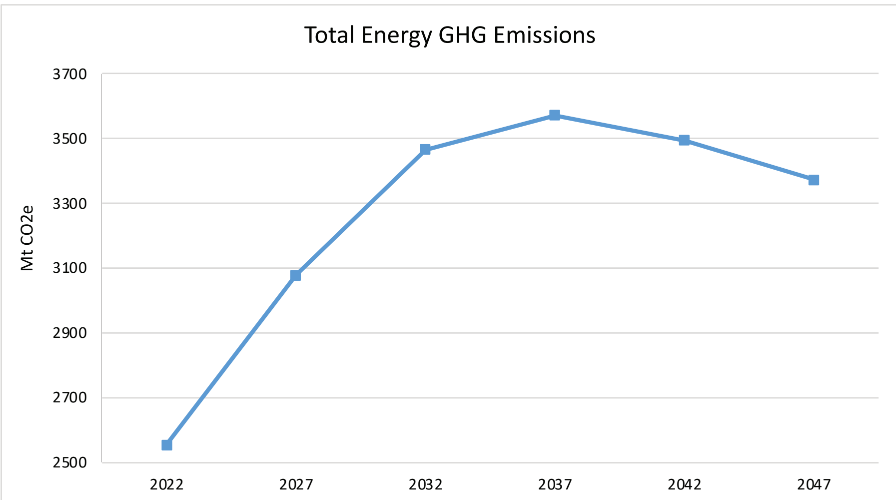


Figure B2.3: Total Energy GHG Emissions in Aatmanirbhar Scenario

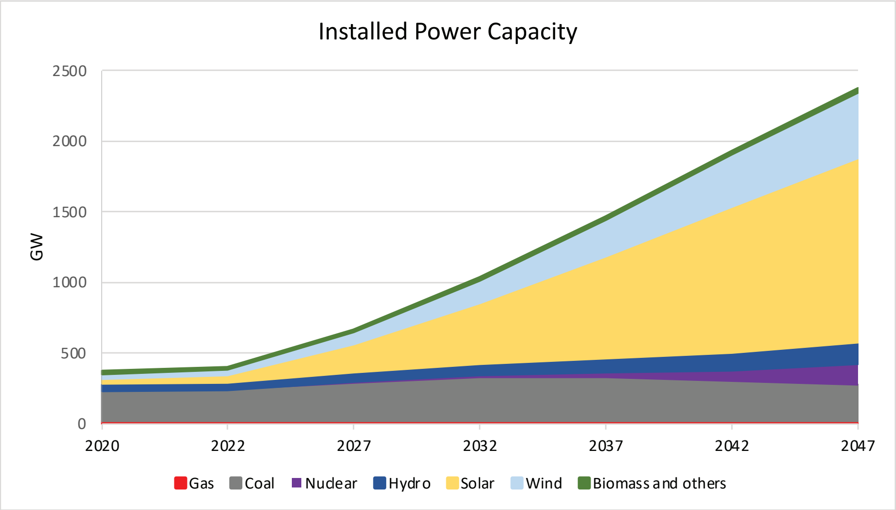


Figure B2.4: Installed Power Capacity in Aatmanirbhar Scenario

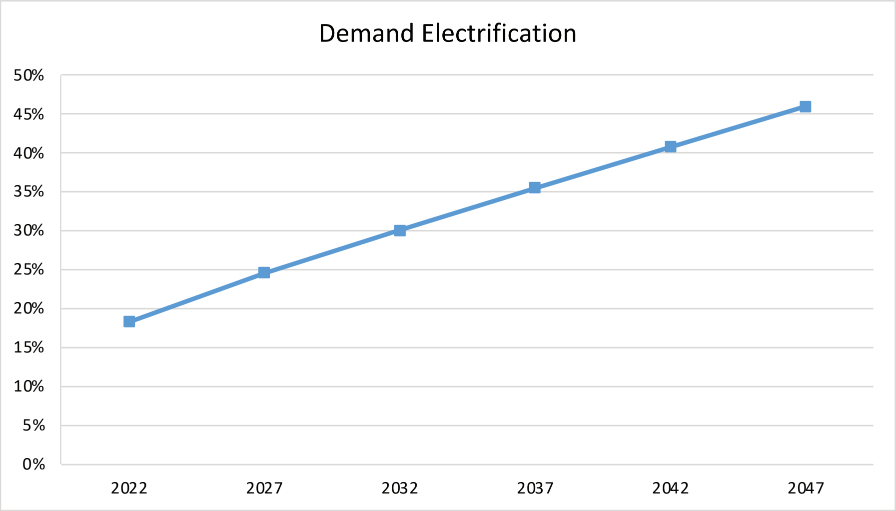


Figure B2.5: Demand Electrification in Aatmanirbhar Scenario

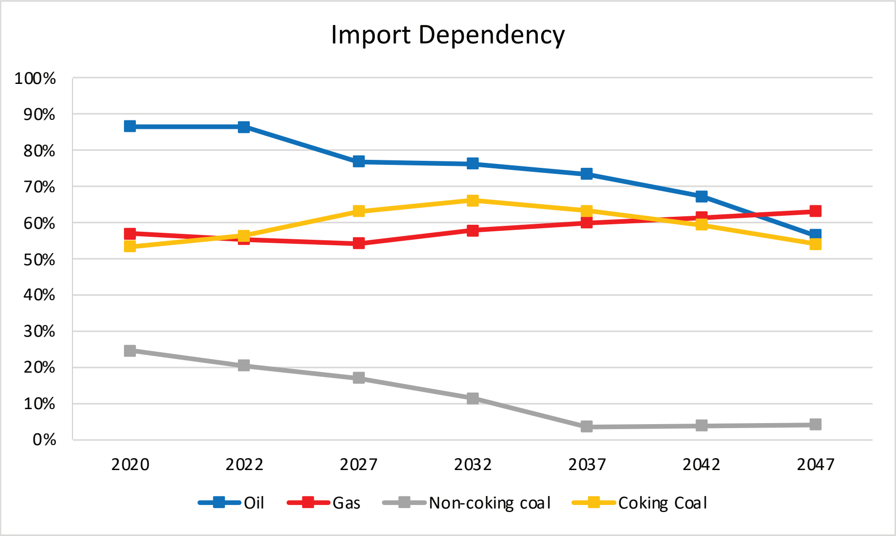


Figure B2.6: Import Dependency in Aatmanirbhar Scenario

C. SUMMARY STATISTICS

CI. Analysis of Sector(s) in BAU Scenario (Level 2) vs Net Zero Scenario

Demand in 2047 (Mtoe)			
Sector	Business-as-usual (BAU) Scenario	Net Zero Scenario	% Saving
Buildings	172.24	162.18	5.8%
Industry	774.31	648.60	16.2%
Transport	252.26	227.85	9.7%
Pumps & Tractors	67.98	67.12	1.3%
Telecom	16.99	16.99	0.0%
Cooking	58.54	58.54	0.0%
Others	108.39	105.95	2.3%
Total	1450.71	1287.24	11.3%

Primary Energy in 2047 (Mtoe)			
Resources	Business-as-usual (BAU) Scenario	Net Zero Scenario	% Saving
Coal	685.21	490.44	28.4%
Oil and Petroleum Products	430.60	340.52	20.9%
Natural Gas	178.94	203.27	-13.6%
Renewables and Clean Energy	548.92	682.22	-24.3%
Total	1843.67	1716.43	6.9%

Installed Power Capacity in 2047 (GW)		
Resources	Business-as-usual (BAU) Scenario	Net Zero Scenario
Gas	28.55	24.96
Coal	229.60	176.49
Nuclear	64.54	100.46
Hydro	89.62	112.20
Solar	1042.13	1233.59
Wind	367.32	452.39
Biomass and Others	18.54	20.85
Total	1840.30	2120.94

Energy Emissions in 2047 (Mt CO2e)		
Sector	Business-as-usual (BAU) Scenario	Net Zero Scenario
Industry	2618	1865
Transport	656	538
Agriculture	76	49
Power	1143	816
Other	291	274
Total	4785	3542

Scenario Implications		
	Business-as-usual (BAU) Scenario	Net Zero Scenario
Total Land (MH)	1.76	2.11
Total Water (MCM)	11672.55	11537.03
Cost (USD Billion/Year)	256.32	255.36

CII. Analysis of Sector(s) in BAU Scenario (Level 2) Vs Optimistic Scenario (Level 3)

Demand in 2047 (Mtoe)			
Sector	Business-as-usual (BAU) Scenario	Optimistic Scenario	% Saving
Buildings	172.24	146.36	15.0%
Industry	774.31	648.60	16.2%
Transport	252.26	206.28	18.2%
Pumps & Tractors	67.98	52.86	22.2%
Telecom	16.99	15.07	11.3%
Cooking	58.54	54.06	7.7%
Others	108.39	102.63	5.3%
Total	1450.71	1225.86	15.5%

Primary Energy in 2047 (Mtoe)			
Resources	Business-as-usual (BAU) Scenario	Optimistic Scenario	% Saving
Coal	685.21	355.18	48.2%
Oil and Petroleum Products	430.60	280.37	34.9%
Natural Gas	178.94	206.17	-15.2%
Renewables and Clean Energy	548.92	713.02	-29.9%
Total	1843.67	1554.73	15.7%

Installed Power Capacity in 2047 (GW)		
Resources	Business-as-usual (BAU) Scenario	Optimistic Scenario
Gas	28.55	32.65
Coal	229.60	50.50
Nuclear	64.54	100.46
Hydro	89.62	118.19
Solar	1042.13	1271.52
Wind	367.32	486.75
Biomass and Others	18.54	25.85
Total	1840.30	2085.91

Energy Emissions in 2047 (Mt CO2e)		
Sector	Business-as-usual (BAU) Scenario	Optimistic Scenario
Industry	2618	1865
Transport	656	436
Agriculture	76	43
Power	1143	179
Other	291	251
Total	4785	2773

Scenario Implications		
	Business-as-usual (BAU) Scenario	**Optimistic Scenario**
Total Land (MH)	1.76	2.11
Total Water (MCM)	11672.55	9868.91
Cost (USD Billion/Year)	256.32	244.67

D. LIMITATIONS

Efforts have been made to incorporate various policy commitments announced by the Government of India such as Green Hydrogen, NDC targets, Ethanol Blending, Share of EVs etc. However, there are certain limitations which are listed below:

- Battery Energy storage in India Energy Security Scenarios (IESS) is estimated based on simple regression analysis between storage and penetration of solar energy. However, there are a multitude of factors such as penetration of wind energy, penetration of hydro-power and total available capacity for base load power which determine storage requirement.
- Flex vehicles which can support ethanol blending more than 20%, are not considered in the current version. In the next update of IESS, we intend to explore on the possible trajectories for ethanol blending which in the current version-3 is limited to 20%.
- Total GHGs include emissions from sectors such as Energy, Agriculture, Forestry and Land-use (AFOLU) and Industrial Processes and Product Use (IPPU). IESS however estimates only emissions from energy sector.
- Advanced Generation-IV Nuclear reactors and Small Modular Nuclear Reactors have not been considered in the modeling.
- The current version of IESS only considers carbon capture and does not consider carbon utilization and carbon storage.
- The current version of IESS considers Integrated Gasification Combined Cycle for power sector but it does not consider coal gasification for other derivatives.
- The current version of IESS only considers energy consumed by tractors and pumps in agriculture sector and does not include energy required for other mechanized instruments such as tillers, levelers etc.
- Transmission and Distribution requirements to support the growing capacity needs has not been modeled.
- The use of Sustainable Aviation Fuel (SAF) to promote greening of aviation sector has not been considered in the current version.
- The infrastructure required for supporting greening of transport sector such as EV charging stations and Hydrogen refilling stations has not been considered in the current version.

- **Costs**
  - Infrastructure costs have not been considered in the model. For example, cost of setting up EV charging stations in the country, cost of developing new refineries, etc.
  - Alternate technologies have been considered in the model such as green hydrogen and biofuels. Costs regarding these technologies have not been considered. E.g. cost of biofuel production and setting up infrastructure of biofuel production, cost of electrolyzers and hydrogen storage equipment, etc.
  - The prices of fossil fuels are governed by multiple non-energy sector related variables, and hence the prices are highly uncertain and volatile. These uncertainties as well as oscillatory nature of prices have not been covered in the trajectories.
  - Fossil fuel prices also witness a high amount of variation over a short period of time, a month or a year. IESS2047 being an annual scale model can only capture the prices at annual level granularity and not beyond it.

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