Energy Outlook 2047

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CERTIFICATE OF RECOMMENDATION

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ABBREVIATION

AEEE	Alliance for an Energy Efficient Economy
BAU	Business As Usual
BEE	Bureau of Energy Efficiency
BPKM	Billion Passenger Kilo Meter
BTKM	Billion Tonne Kilo Meter
CAGR	Compound Annual Growth Rate
CNG	Compressed Natural Gas
EWS	Economically Weaker Section
DFC	Dedicated Freight Corridor
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
GDP	Gross Domestic Product
HELP	Hydrocarbon Exploration and Licensing Policy
kWh	kilo Watt hour
LIG	Low-Income Group
LPG	Liquefied Natural Gas
Lph	liters per hour
MIG+	Middle-Income Group and Above
MNRE	Middle-Income Group and Above
MoP	Ministry of Power
MoSPI	Ministry of Statistics and Programme Implementation
MoUD	Ministry of Urban Development
Mtoe	Million Tonnes of Oil Equivalent
	National Action Plan on Climate Change

NAPCC	
PAHAL	Pratyaksh Hanstantrit Labh
PAT	Perform, Achieve, Trade
NIUA	National Institute of Urban Affairs

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Chapter-1

Introduction

1.1 Introduction

India is the world's third largest energy consuming country, thanks to rising incomes and improving standards of living. Energy use has doubled since 2000, with 80% of demand still being met by coal, oil and solid biomass [10]. On a per capita basis, India's energy use and emissions are less than half the world average, as are other key indicators such as vehicle ownership, steel and cement output. As India recovers from a Covid induced slump in 2020, it is re entering a very dynamic period in its energy development. Over the coming years, millions of Indian households are set to buy new appliances, air conditioning units and vehicles. India became world's most populous country, adding the equivalent of a city the size of Los Angeles to its urban population each year. To meet growth in electricity demand over the next twenty years, India will need to add a power system the size of the European Union to what it has now[9]. An expanding economy, population, urbanisation and industrialisation mean that India sees the largest increase in energy demand of any country, across all of our scenarios to 2040 [9]. India's economic growth has historically been driven mainly by the services sector rather than the more energy intensive industrial sector, and the rate at which India has urbanised has also been slower than in other comparable countries. But even at a relatively modest assumed urbanisation rate, India's sheer size means that 270 million people are still set to be added to India's urban population over the next two decades [9]. This leads to rapid growth in the building stock and other infrastructure. The resulting surge in demand for a range of construction materials, notably steel and cement, highlights the pivot in global manufacturing towards India. Thus Energy security is a must be prioritize.

1.2 Concept of Energy security

The concept of energy security is the ability of the country to meet its energy needs in a reliable, affordable, and sustainable manner. This means having access to adequate supplies of energy, at a price that does not unduly burden the economy, and without causing unacceptable environmental damage. With the growing demand of Energy across different sector and rise of middle class along with rapid urbanization, energy security is a major challenge. Other factors such as Russia-Ukraine war, Covid19,flood ,geopolitics, the dynamics of suppy demand changes every moment. So to cater 1.4 billion populations`energy security is required for India as well as world.Also India's commitment towards green energy which is another challenge for India specially with current level of technology. ` ` ` ` ` ` ` ` ` `

1.3 Classifications of Energy

Energy can be classified into several types based on the following criteria:

- ✓ Primary and Secondary Energy
- ✓ Commercial and Non-Commercial Energy
- ✓ Renewable and Non-Renewable Energy
- ✓ Conventional and Non-conventional Energy

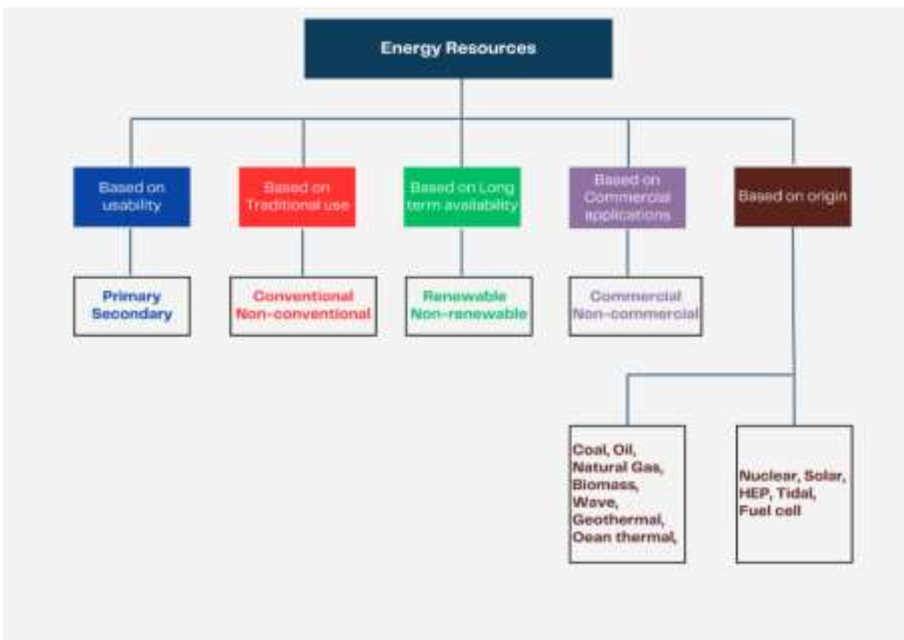


Fig 1. 1 :Classification of Energy Resources

- ❖ **Primary Energy**

Primary sources of energy can be defined as the energy source which is either found or stored in nature & can be used directly without any type of modification. The most common example of primary energy sources is coal, oil, natural gas, biomass, nuclear energy from radioactive substances, thermal energy stored in the core of the earth, gravitational potential energy, etc. Primary energy can be further divided into two distinct groups

- ✓ Renewable Energy (Wind, Solar, Geothermal, Hydro, etc.)
- ✓ Non-renewable Energy (Coal, Natural Gas, Oil Fossil Fuels, Nuclear, etc.)

The primary energy content of all fuels is generally expressed in terms of the tonne of oil equivalent.

- ❖ **Secondary Energy**

The more convenient form of converted energy from primary energy sources is known as secondary energy. Primary energy is mostly converted into secondary energy sources due to industrial utilities & use cases, for example, petrol is obtained from Crude oil, electric energy is obtained from thermal power plants by using coal as fuel, etc.

- ❖ **Commercial Energy**

The Energy which is available in the global market for a certain price rate is known as commercial energy. Irrespective of the method of the production of energy, whether it is from fossil fuels, nuclear or renewable sources, any form of energy used for commercial purposes is termed as commercial energy. The most important forms of commercial energy are coal, refined petroleum products, natural gas, and electricity. Commercial energy is the building block of agricultural, industrial, commercial, and transport development in modern days. For every country, whether it is developing or developed, commercialized fuels are the main building blocks not only for economic development but also for many household tasks.

- ❖ **Non-Commercial Energy**

The energy sources that are generally free to use and is not available in the commercial market for a price are known as non-commercial energy. This form of energy is used for domestic consumption purposes. It includes fuels such as firewood, cattle dung, and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural areas. These are also known as traditional fuels. Examples of non-commercial fuels are solar and wind energy for electricity generation, agro waste, animal-powered transport, etc.

- ❖ **Renewable Energy**

The energy those are comes from natural sources & constantly refilled by nature is known as renewable energy. Such as solar energy, wind energy, hydroelectric, and geothermal energy.

The two most important features of renewable energy are that it can be harnessed without the release of harmful pollutants and unlimited availability in nature. These can be renewed over a relatively short period compared to fossil fuels. These include firewood from the forest, petro plants (Petro-crops are those plants that produced petroleum substances as supplementary to petrol. These plants or algae produces hydrocarbon compound or ethanol) , plant biomass, agricultural waste like animal dung, solar energy, wind energy, water energy in the form of hydroelectricity and tidal energy, geothermal energy, etc.

- **Non-renewable Energy**

Non-renewable Energy is considered as a natural source of energy that cannot be reproduced, grown, or used in such a way that can sustain its consumption rate. The consumption rate of these resources is faster than the production rate, Natural resources like oil, natural gas, and coal take millions of years to form and they cannot be replaced as fast as they are being consumed nowadays. As a result, these resources will be drained with time.

- **Conventional Energy Sources**

The sources of energy which are used since the beginning of mankind such as petroleum, natural gas, coal, and water power are known as conventional energy. They are exhaust able except for water and cause pollution when used, as they emit smoke and ash.

- **Non-conventional energy sources**

The source of energy which are still in the process of development over the past few decades such as wind, solar, geothermal, and biomass are known as non-conventional energy. They are inexhaustible, pollution free, easy to maintain, and less expensive compared to conventional energy sources.

1.4 Global Energy Scenario

- **Coal**

World coal reserves in 2020 were at 1074 billion tonnes and are heavily concentrated in the following counties US (23%), Russia (15%), Australia (14%), and China (13%). Most of the reserves coals are anthracite and bituminous (70%) types. Based on the current global (Reserve to Production) R/P ratio the coal reserves in 2020 accounted for 139 years of the current production rate [3]. Figure 1.2 shows the reserves scenario of coal in 2000, 2010, and 2020 respectively.

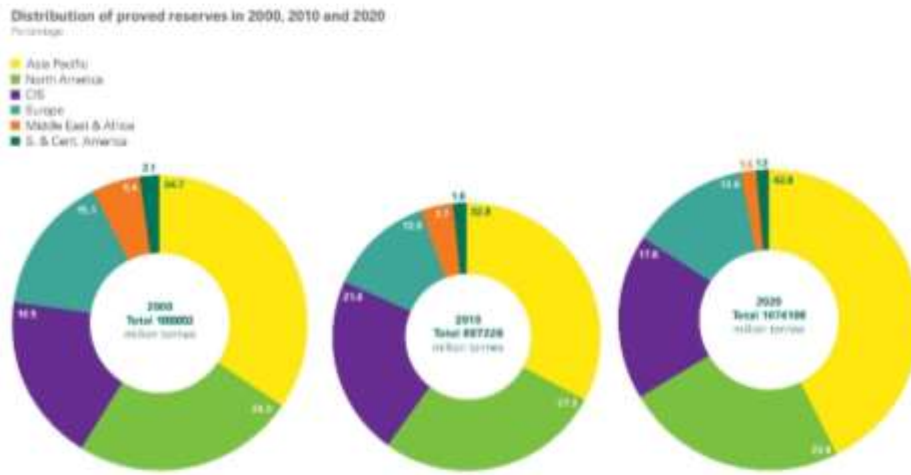


Fig 1. 2 Coal Reserves Scenario

- **Oil**

Globally proved oil reserves were near about 1732 billion barrels at the end of the year 2020. Based on the current global R/P ratio the oil reserves in 2020 accounted for nearly about 50 years of current production. OPEC holds 70.2% of global reserves [3]. The World's top countries in terms of oil reserves are Venezuela (17.5%), Saudi Arabia (17.2%), and Canada (9.7%). Figure 1.3 shows the reserves scenario of oil in 2000, 2010, and 2020 respectively.

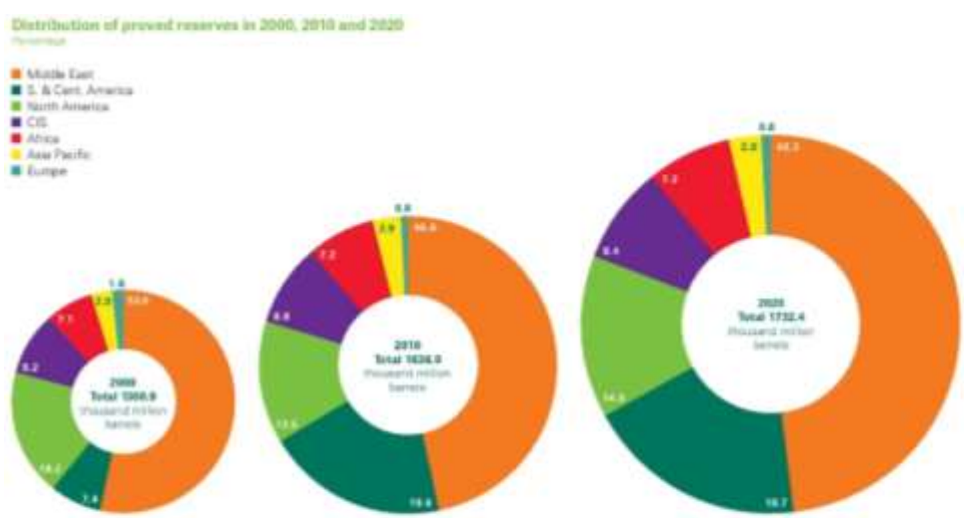


Fig 1. 3 Oil Reserves Scenario

❖ Natural Gases

Globally proved natural gas reserves were near about 188.1 (Trillion Cubic Cm) Tcm in 2020. The largest natural gas reserves in terms of countries are Russia (37 Tcm), Iran (32 Tcm), and Qatar (25 Tcm). Based on the current global R/P ratio the gas reserves in 2020 accounted for 48.8 years of current production. The Middle East (110.4 years) and CIS (70.5 years) are the regions with the highest R/P ratio[3] .Figure 1.4 shows the reserves scenario of oil in 2000, 2010, and 2020 respectively.

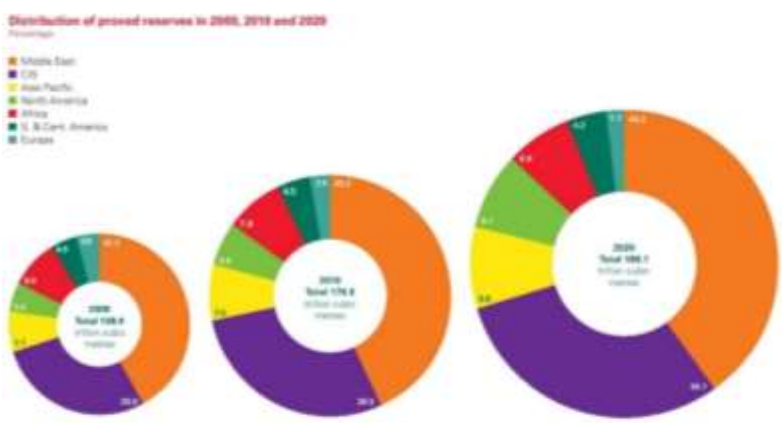


Fig 1. 4 Natural Gas Reserves Scenario

❖ Worldwide Fossil Fuels Consumption Statistics

Primary global energy consumption grew by 5.5% in 2021 compared to 2020 to a new all-time high. In 2020 there is a huge dip in energy consumption due to COVID-19 but since everything is back to normal the energy consumption is increasing day by day. Figure 1.5 shown represented the fastest energy consumption growth since the early 2000s and is a reflection of strong global demand bouncing back from 2020's Covid-19 energy consumption decline. Almost 82% of primary energy use for 2021 accounted for Fossil fuels, in terms of which Coal (26.9 %), Oil (31.0 %) & Natural gas (24.4%). The remaining share of primary energy use consisted of hydroelectric power (6.8%), renewables (6.7%), and nuclear power (4.3%) . Figure represents the worldwide primary energy consumption based on per capita [12]

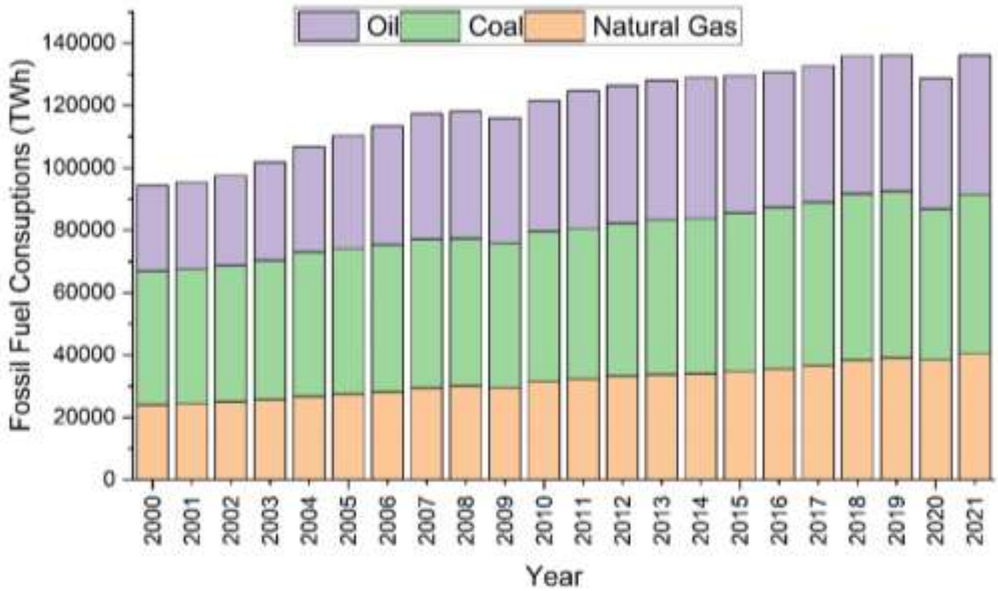


Fig 1. 6 Worldwide Fossil Fuels Consumption Scenario

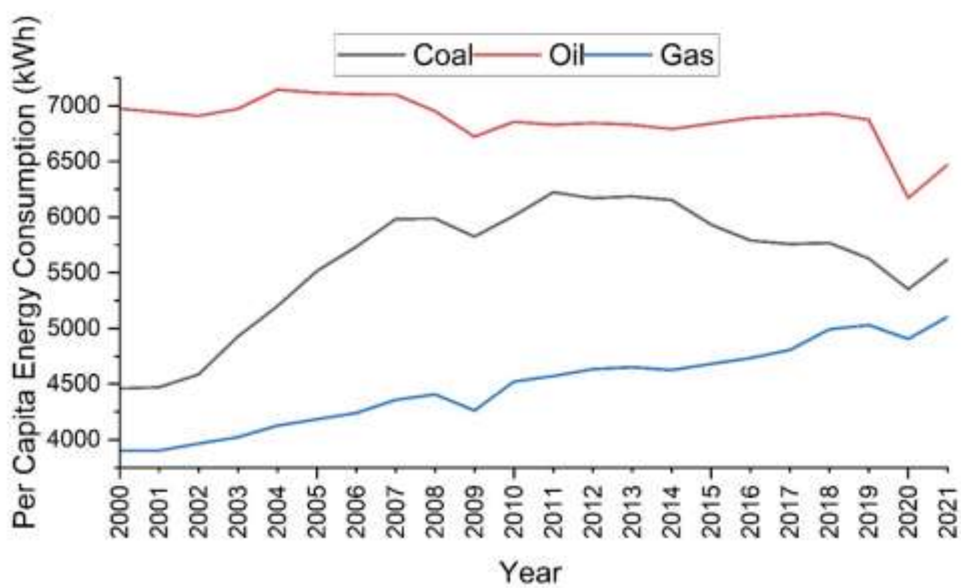


Fig 1. 7 Worldwide Per Capita Energy Consumption Scenario

1.5 India's Energy Scenario

Reserves Statistics

- **Coal**

Total estimated reserves of coal as of 01-04-2022 were 361.41 billion tonnes, an addition of 9.28 billion tonnes compared to the previous year. In terms of the percentage the available coal for extraction considering the economic viability, feasibility study, and geologically exploration level, is almost 52%. Figure 1.7 shows the total estimated reserves of coal in India as of 01-04-2022[1].

- **Oil**

The estimated reserves of crude oil in India as of 01-04-2022 were 651.77 million tonnes. The geographical distribution of Crude Oil in the Indian subcontinent shows that the maximum reserves are in the Western side of the country almost 33% followed by Assam (23%). Figure-1.8 Shows the state-wise total estimated reserves of oil in India as of 01-04-2022[1].

- **Natural Gas**

The estimated reserves of Natural Gas as of 01-04-2022 were at 1138.67 Billion Cubic Meters. The maximum reserves of Natural Gas are in the Western Offshore at 29.6% followed by the Eastern offshore at 23.6%. Figure 1.9 Shows the total estimated reserves of natural gases in India as of 01-04-2022[1].

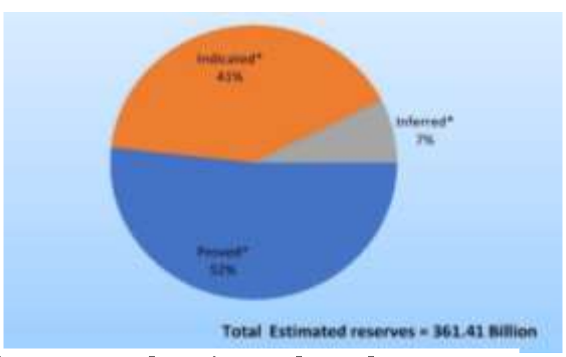


Fig 1. 8 Total Estimated Coal Reserves in India as of 01-04-2022

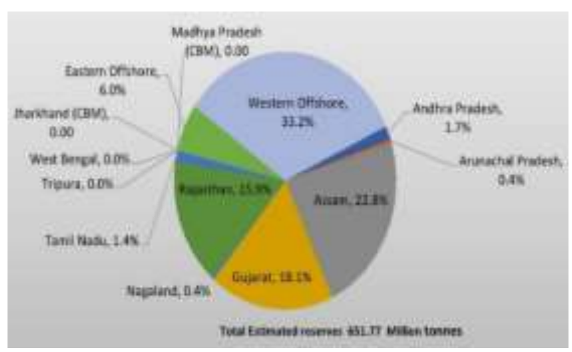


Fig 1. 9 : Total Estimated Oil Reserves in India

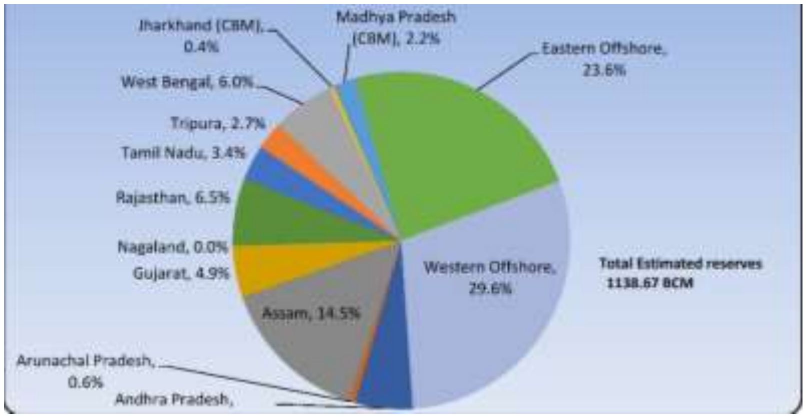


Fig 1. 10 Total Estimated Natural Gas Reserves in India as of 01-04-2022

❖ **Consumption Statistics**

Figure1.9 represents Energy consumption statistics from 2000 to 2021. From the figure, it can be observed that throughout the year the energy consumption rate kept increasing where the maximum percentage of primary energy consumed in the form of oil. Figure1.10 shows a comparison of the per capita energy consumption of India along with some other developed countries. Looking at the graph one can conclude that the per capita energy consumption in India is less compared to other developed countries so energy consumption rate is not a concern but in the real scenario, Country need to be careful about two things first India is still a developing country means the per capita energy consumption will grow day by day and the other point is the population of India(1.4 billion).

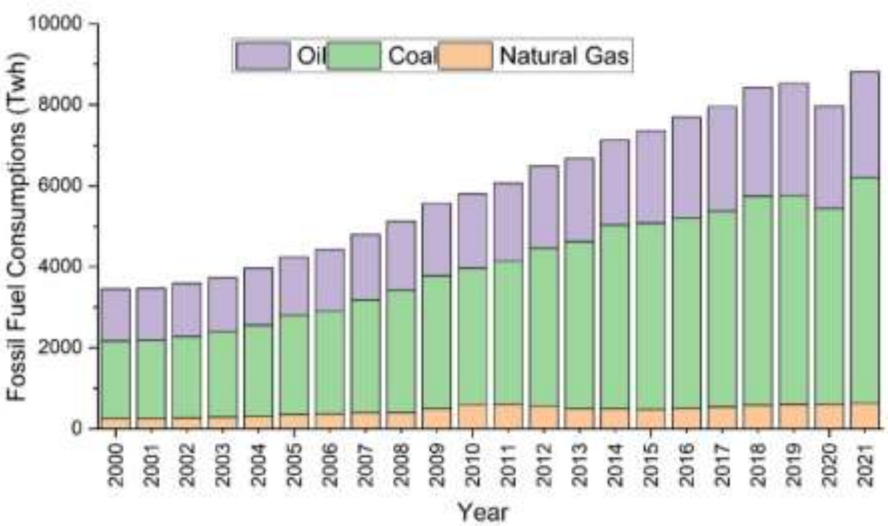


Fig 1. 11 Total Energy Consumptions by Sources in India

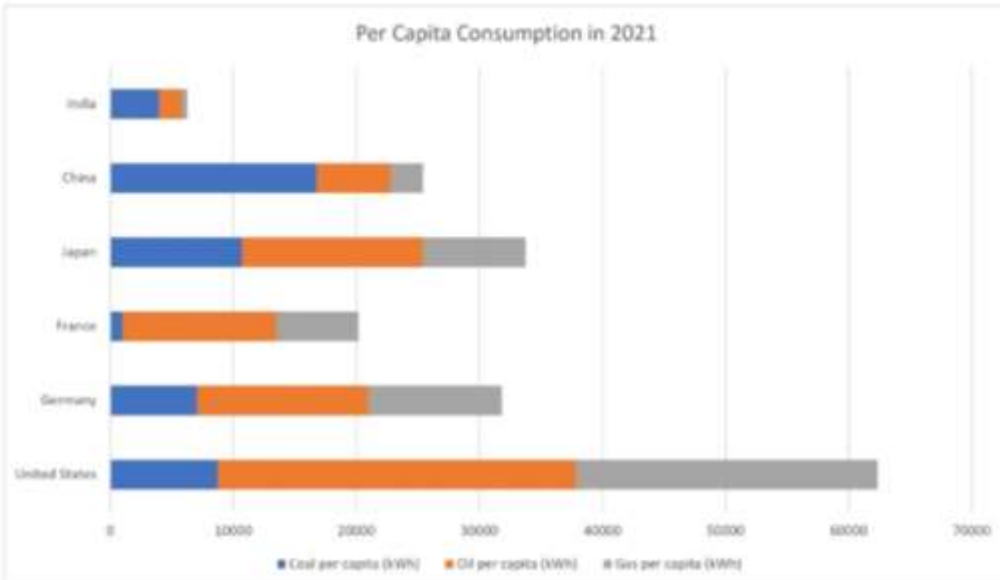


Fig 1. 12 per Capita Energy Consumption Comparison

❖ Renewable Energy Generation Potential in India

There is a high potential in terms of energy generation from renewable energy from various sources like wind, solar, biomass, small hydro, and biogases in India. According to MNRE Survey, the total potential for renewable power generation in India as of 31.03.2022 is nearly about 14, 90,727 MW [13]. Figure1.13 shows that The solar power potential of 7, 48,990 MW is almost 50.24%, the wind power potential of 6, 95,509 MW is almost 46.66%, the Small-Hydro Power potential of 21,134 MW is almost 1.42%, Biomass power of 17,538 MW nearly about 1.18% of total renewable potential..Figure-1.15 shows the geographic distribution of the estimated potential of renewable power as of 31.03.2022 which indicates that Rajasthan has the highest potential of about 18.2% followed by Gujarat with 12.1% & Maharashtra, Karnataka with 11.2% and 10.3% shares respectively. These four states are having more than 50% of the total potential of renewable Power in India[13].

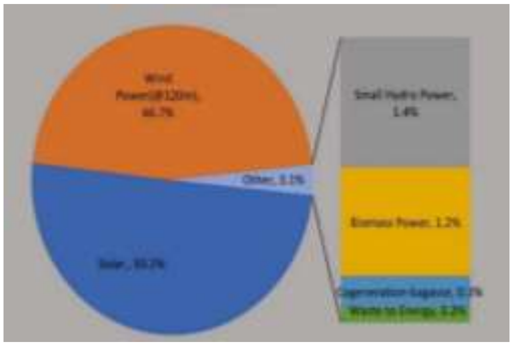


Fig 1. 14 Source-wise Potential of Renewable Energy in India

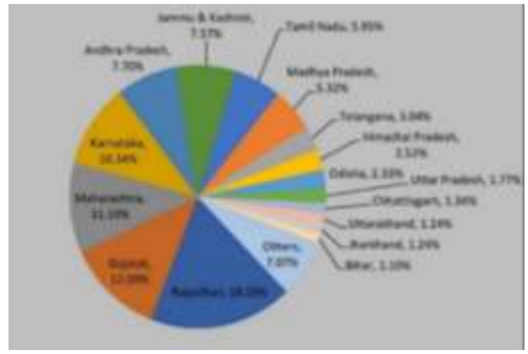


Fig 1. 13 State-wise Potential of Renewable Energy in India

1.6 The Objective of the Study

India is now the fifth largest economy in the world and aspires to be the third largest by 2027. Looking at rise in energy demand and Commitment of Prime Minister to be a developed Nation by 2047 along with target of achieving Net Zero by 2070s ,Energy security of Country is a must. The Government of India has articulated and put across the concerns of developing countries at the 26th session of the Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Glasgow, United Kingdom. Further, India presented the following five nectar elements of India's climate action which is ,Popularly known as Panchamrit, : these are a) reach 500GW Non-fossil energy capacity by 2030, b)50 per cent of its energy requirements from renewable energy by 2030 ,c) reduction of total projected carbon emissions by one billion tonnes from now to 2030,d) reduction of the carbon intensity of the economy by 45 per cent by 2030, over 2005 levels, e) achieving the target of net zero emissions by 2070.

Hence the focus of present work is to present a case study of how energy demand is varying across major sectors such as Industry, Transport, Telecom etc in future particulary till 2047. The sole purpose of considering a time line of 2047 is that it is 100 years of India's Independence. Also it commitment of Prime Minister to be a developed Nation by 2047. The Energy demand are considered across different sectors in different scenario (Level 1 to Level 4 along with the special case of Net Zero scenario as explained in article 1.7). This also includes supply side analysis in similar way. Later a comparison of Energy deviation for energy demand side are done between Business-As-Usual (BAU) Scenario and different levels (L1,L3,L4,Net Zero scenario) which is a representation of %saving in energy. Main focus is done on Net Zero Scenario because that is the ultimate obligation of Government of India to achieve it by 2070s . A brief mention of Government policy and steps to ensure future energy security is also done .To execute this, an extensive data collection from various government websites (MNRE, Coal Ministry , Power Ministry etc) , Popular organization such as International Energy Agency(IEA), Press India Bureau(PIB) are done. Tools Such as IESS 2047 are also used for data.

1.7 About IESS tool

India Energy Security Scenarios (IESS) 2047 Version-3.0 is a scenario based accountingtool developed by NITI Aayog in collaboration with IIT Bombay to model supplyand 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 renewable 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 provide simplications on water, land, cost besides emissions and energy transition. The views of various stakeholders (eg. National Institute of Urban Affairs, Coal ministry, Ministry of Renewable Energy etc.) have been suitably incorporated after due consultations.Each sector in IESS is modelled into different levels as shown in Fig:

Levels are defined as explained below:

1. **Level 1-** Pessimistic Scenario (Least effort 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.

Fig 1. 15 Levels of IESS tools [6]

It also provides hypothetically generated pathways representing scenarios of Net Zero.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.

Chapter-2

Literature Review

2.1 Review of Earlier work

Mustafa E.Başoğlu et al. (2021)**[14]** analyzed Energy demand in India in 2047: A multi-scenario analysis. The paper considers four scenarios. Baseline scenario which assumes that India's energy demand will grow at a rate of 5% per year between 2020 and 2047.Renewable energy scenario which assumes that India will increase the share of renewable energy in its energy mix to 50% by 2047. Energy efficiency scenario which assumes that India will improve energy efficiency by 30% by 2047. Combined scenario which combines the renewable energy scenario and the energy efficiency scenario.The paper found that India's energy demand is expected to reach 2.3 trillion kWh in 2047 under the baseline scenario. Under the renewable energy scenario, India's energy demand is expected to reach 1.8 trillion kWh in 2047. Under the energy efficiency scenario, India's energy demand is expected to reach 2.0 trillion kWh in 2047. Under the combined scenario, India's energy demand is expected to reach 1.6 trillion kWh in 2047.The paper concludes that India has a number of options to meet its energy demand in 2047. However, the paper argues that the most sustainable option is to increase the share of renewable energy in India's energy mix and to improve energy efficiency.

Akhilesh Kumar et al. (2021)**[15]** has done study on Energy demand in India in 2047: A review of literature and projections. Renewable and Sustainable Energy.The paper finds that there is a wide range of projections for India's energy demand in 2047, with some projections as high as 2.5 trillion kWh and others as low as 1.5 trillion kWh. The paper attributes this range of projections to a number of factors, including, the uncertainty of future economic growth in India, the uncertainty of future population growth in India, the pace of technological change in the energy sector, the policies that India implements to meet its energy demand.The paper concludes that India's energy demand in 2047 will depend on a number of factors, and that it is difficult to make accurate projections at this time. However, the paper argues that India needs to take steps to reduce its energy demand and to increase its reliance on renewable energy in order to meet its energy needs in 2047 and beyond.

Satyawati Sharmaet al.**[16]** has done study on Renewable energy in India: Current status and future potentials.In this paper, efforts have been made to summarize the availability, current status, major achievements and future potentials ofrenewable energy options in India. This paper also assesses specific policy interventions for overcomingthe barriers and enhancing deployment of renewables for the future.Energy security, economic growth and environment protectionare the national energy policy drivers of any country of the world.The need to boost the efforts for further development andpromotion of renewable energy sources has been felt world overin light of high prices of crude oil. According to NAPCC other sources ofrenewable energy would be promoted. Specific action points thathave been mentioned include promoting deployment, innovationand basic research in renewable energy technologies, resolving thebarriers to development and commercial deployment of biomass,hydropower, solar and wind technologies, promoting straight(direct) biomass combustion and biomass gasification technologies,promoting the development and manufacture of small windelectric generators, and enhancing the regulatory/tariff regime inorder to main stream renewable energy sources in the nationalpower system. Accordingly, increased focus is being laid on thedeployment of renewable power that is likely to account foraround 5% in the electricity-mix by 2032. Alternate fuels,essentially bio-fuels, are proposed to be progressively used forblending with diesel and petrol, mainly for transport applications.

Sharma S et al.[17] has done study on Energy demand and use in Indian agriculture: Trends, drivers, and policy options. Paper concluded e agriculture sector is a major consumer of energy in India, accounting for about 15% of total energy demand in 2021. The main drivers of energy demand in the agriculture sector are Pumping water: Irrigation is the largest energy-consuming activity in the agriculture sector, accounting for about 70% of total energy demand,Machinery: The use of agricultural machinery, such as tractors and harvesters, is also a major source of energy demand in the agriculture sector,Fertilizer production: The production of fertilizer is a energy-intensive process, and it accounts for about 10% of total energy demand in the agriculture sector,Processing and storage: The processing and storage of agricultural products also consumes a significant amount of energy a)2030: Energy demand in the agriculture sector is projected to reach 2.0 trillion kWh. b)2040: Energy demand in the agriculture sector is projected to reach 2.5 trillion kWh. c)2047: Energy demand in the agriculture sector is projected to reach 3.0 trillion kWh.

International Energy Agency (IEA) (2021) et al.[18] has projected India energy outlook 2047. This report provides an overview of the energy outlook for India in 2047. The report projects that India's energy demand will grow by 6% per year in the coming decades. This growth in energy demand will put a strain on India's energy resources and its ability to meet its energy security needs. The report recommends that India accelerate the transition to renewable energy and improve energy efficiency.The report found that India's energy demand is expected to reach 1.8 trillion kWh in 2047. This growth in energy demand will be driven by the country's growing population and economy. The report recommends that India increase the share of renewable energy in its energy mix to 50% by 2047. The report also recommends that India improve energy efficiency by 30% by 2047.

Lazar Gitelmanet al.[19] has done study on Energy Security: New Threats and Solutions.The article presents the conceptual features of energy security management under aradically changed context, increasing crisis phenomena, and threats of various natures. Based on an analysis of scientific publications and practical energy security models, the authors developed theoretical provisions, methodological principles, and management tools for energy security that meet modern requirements. In particular, the authors developed the terminological apparatus and identified the types and forms of modern energy threats and risks. The authors analyzed the impact of structural shifts in the electric power industry on the cost of electricity. In addition, the authors considered the impact of the transition to low-carbon energy production on energy security.

Sandeep Kumar et al. [20] has done study India's Energy Security: Critical Considerations" and found out that India's energy demand is growing at a rate of 5-6% per year, the country is heavily reliant on imported oil, accounting for 80% of its crude oil needs. India's coal reserves are the fifth largest in the world, but the country is still importing coal to meet its energy needs.The Indian government has taken some steps to address the challenges to energy security, such as increasing investment in renewable energy and energy efficiency.However, more needs to be done to ensure India's long-term energy security.

Deepak Mohantyet al. [21] has done study Indian electricity sector, energy security and sustainability: An empirical assessment". He concluded the Indian electricity sector is responsible for about 25% of the country's total energy consumption.The sector has made significant progress in terms of energy security in recent years. The country's reliance on imported oil has declined, and the share of renewable energy in the electricity mix has increased. However, the sector has made less progress in terms of sustainability. The emissions of greenhouse gases from the electricity sector have increased, and the sector's reliance on coal has remained high.The Indian government needs to take steps to improve the sustainability of the electricity sector in order to ensure long-term energy security.

Smith et al. [22] conducted an extensive analysis of energy consumption patterns in residential cooking. Their study utilized data from households to quantify energy usage across different cooking methods, appliance types, and culinary habits. The research highlighted significant variations in energy demand based on cooking practices, appliance efficiency, and fuel sources. This variation underscored the need for tailored strategies to reduce energy consumption in cooking activities .

Energy demand in the cooking sector of India was conducted by Sharma et al. (2017)[23]. They found that energy demand in the cooking sector is expected to grow by 60% between 2017 and 2040. This growth will be driven by the following factors: a) Increased population: The population of India is expected to grow by 20% between 2017 and 2040. This will lead to an increase in the demand for food, which will in turn lead to an increase in the demand for cooking energy b) Rise in incomes: The incomes of Indians are expected to rise by 50% between 2017 and 2040. This will lead to an increase in the demand for convenience foods, which are often cooked using electricity or LPG .c) Urbanization: The urbanization of India is expected to accelerate between 2017 and 2040. This will lead to a shift away from traditional cooking methods, such as wood and kerosene stoves, to more efficient and cleaner methods, such as LPG.

Sharma et al. (2017) **[24]** also found that the use of LPG is expected to grow rapidly in the cooking sector in India. They project that the share of LPG in total cooking energy demand will increase from 25% in 2017 to 50% in 2040. This growth will be driven by the following factors: Government policies: The government of India is promoting the use of LPG through subsidies

Energy demand in the telecom sector of India was conducted by Jain et al. (2019) **[25]**. They found that energy demand in the telecom sector is expected to grow by 30% between 2019 and 2040. This growth will be driven by the following factors: a) Increased data traffic: Jain et al. (2019) found that the amount of data traffic in India is expected to grow by 1000% between 2019 and 2040. This will lead to an increase in the demand for energy to power base stations and data centers. b) The rise of 5G: Jain et al. (2019) found that the rise of 5G is expected to lead to a significant increase in energy demand in the telecom sector. 5G networks are more energy-intensive than 4G networks. c) Government policies: Jain et al. (2019) found that the government of India is promoting the use of renewable energy in the telecom sector. This will lead to an increase in the demand for renewable energy to power telecom networks.

Jain et al. (2019) **[26]** found that the telecom sector in India has the potential to be a major user of renewable energy. They project that the share of renewable energy in total telecom energy demand will increase from 10% in 2019 to 50% in 2040. This growth will be driven by the following factors :a) The falling cost of renewable energy: The cost of renewable energy has fallen significantly in recent years. This makes it more affordable for telecom operators to use renewable energy b) The government of India's policies: The government of India is promoting the use of renewable energy in the telecom sector. This is providing incentives for telecom operators to use renewable energy. It concluded that the telecom sector is a major consumer of energy in India, and its energy demand is expected to grow significantly in the coming years. This growth will be driven by factors such as increased data traffic, the rise of 5G, and government policies promoting the use of renewable energy. The telecom sector has the potential to be a major user of renewable energy, and its energy demand could be met with renewable energy sources such as solar and wind power.

Smith et al.(2020)[27] in his study found that India's energy demand has been on an exponential rise due to rapid industrialization, urbanization, and population growth This surge has placed immense pressure on the existing energy supply infrastructure, leading to concerns about future energy security .According to recent data from the Central Electricity Authority (CEA), India's total installed power capacity reached 375 GW by 2022, with a substantial share coming from coal-based sources (CEA, 2022). However, there is an increasing recognition that overreliance on fossil fuels poses significant environmental and climate risks, necessitating a transition to cleaner energy sources . Therefore, it is crucial to assess strategies for protecting India's future energy supply while balancing environmental and sustainability goals.

Prasad et al. (2021)[28] in his study found that the need for sustainable energy supply has led India to adopt ambitious renewable energy targets. According to Prasad et al. (2021), the National Solar Mission aims to achieve 100 GW of solar capacity by 2022, and the National Wind Mission targets 60 GW of wind capacity. Despite these efforts, challenges remain in integrating intermittent renewable sources into the grid . The Energy Security Index developed by Mohanty (2018) highlights that diversifying the energy mix, investing in energy storage technologies, and improving grid infrastructure are essential for ensuring a reliable energy supply. Furthermore, innovative policy frameworks like feed-in tariffs and competitive bidding have facilitated private sector participation in renewable energy projects .Achieving energy security requires a multi-pronged approach that combines technological advancements, regulatory support, and international collaborations (Mishra et al., 2017)[29]

According to the Gupta et al.(2019)[30] the industrial sector is a major contributor to India's energy consumption (Industries account for a significant portion of electricity and fuel demand, primarily for manufacturing processes and heating .The cement, steel, and chemical industries are particularly energy-intensive and often rely on fossil fuels .According to the Energy Consumption in the Industrial Sector report by the Bureau of Energy Efficiency (BEE, 2021), energy-intensive industries account for over 60% of the sector's energy consumption. Implementing energy-efficient technologies, promoting cogeneration, and encouraging adoption of cleaner fuels are crucial for reducing energy demand in this sector .

Reddy et al., 2019)[31] is his studies found that in the cooking sector, traditional biomass remains a significant energy source for a large segment of the population. A substantial number of households in rural and urban areas still rely on solid biomass, such as wood and crop residues, for cooking (Smith et al., 2022)[32]. Transitioning to cleaner cooking solutions is vital for reducing indoor air pollution and curbing the demand for biomass-based fuels. The Pradhan Mantri Ujjwala Yojana, a government initiative providing LPG connections to rural households, has made strides in this direction (Ministry of Petroleum & Natural Gas, 2020). However, challenges persist in ensuring sustained adoption of clean cooking technologies and promoting behavior change (Bhojvaid & Dwivedi, 2018)[33].

Agriculture remains a significant consumer of energy, primarily for irrigation, mechanization, and agro-processing (Sharma & Srinivasan, 2019)[34]. Groundwater irrigation, powered by electricity and diesel pumps, accounts for a substantial portion of energy use in this sector.According to the Ministry of Agriculture & Farmers' Welfare (2022), more energy-efficient irrigation techniques, such as drip and sprinkler systems, have been promoted to reduce energy demand. Additionally, integrating renewable energy sources for powering agricultural operations can contribute to energy security .

Mukherjee & Gulati, 2020)[35] found that the passenger transport sector is a significant contributor to energy demand, primarily driven by road transportation Private vehicles, especially two-wheelers and cars, dominate the energy consumption in this sector . With rising urbanization and income levels, there's a growing need for efficient and sustainable urban transportation systems.Initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme have incentivized the adoption of electric vehicles (EVs) (Ministry of Heavy Industries & Public Enterprises, 2021). However, challenges related to charging infrastructure and affordability hinder widespread EV adoption.

Sarkar et al., 2022 [36] in his study found that the freight transport sector plays a crucial role in moving goods across the country, contributing significantly to energy demand Road and rail transport are the primary modes for freight movement .The adoption of efficient logistics practices and technologies, such as intermodal transportation and higher load capacity trucks, can lead to energy savings. Furthermore, exploring alternative fuels like liquefied natural gas (LNG) for heavy-duty trucks could mitigate the sector's carbon footprint (Rathi et al., 2021).

Apart from the major sectors mentioned above, other energy demand segments include commercial establishments, public services, and households. Commercial buildings, including offices and retail spaces, consume energy for lighting, cooling, and electronic devices (Ramachandran et al., 2017)[37] . Energy-efficient building designs and technologies, such as LED lighting and smart HVAC systems, are key to reducing energy demand in this sector.

Goyal et al., 2018 [38]. in his study found that the Public services like healthcare facilities and educational institutions also require energy for operations Ensuring reliable and sustainable energy supply for critical services is essential for overall societal well-being (Singh & Pandey, 2019).

Saha et al., 2020[39] observed that Households collectively contribute to a significant share of energy consumption, mainly for lighting, heating, and appliances Promoting energy conservation behavior, encouraging appliance efficiency labels, and disseminating energy-saving tips can help curb residential energy demand.

According to Agarwal et al., 2020 [40] energy demand in the agriculture sector is significantly influenced by water pumping and irrigation Electric and diesel pumps are widely used for groundwater extraction .Implementing solar-powered pumps and efficient irrigation practices, such as water scheduling, can optimize energy use in agriculture. The Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) scheme has been introduced to promote solar pumps and reduce the carbon footprint of agricultural operations (Ministry of New & Renewable Energy, 2021).

Gangwar & Singh, 2018 [41] found that the mechanization in agriculture, including tractors and machinery, contributes to energy consumption .Diesel-powered tractors remain a common choice for field operations .Transitioning to electric or hybrid tractors can reduce the reliance on fossil fuels and minimize greenhouse gas emissions .Developing a robust charging infrastructure for electric agricultural machinery is crucial for facilitating this shift .

Bhattacharya et al., 2022 [42] found that the building sector, comprising residential, commercial, and public structures, is a significant energy consumer. Energy demand is attributed to space heating, cooling, lighting, and appliances. Building energy codes and standards, such as the Energy Conservation Building Code (ECBC), mandate energy-efficient designs and technologies (Ministry of Power, 2017). The adoption of energy-efficient materials, insulation, and smart building systems can significantly reduce energy consumption and promote sustainability (Sharma & Sharma, 2022).

Raj et al., 2018 [43] showed that the rapid growth of the telecom sector has led to increased energy demand for network operations and data centers Mobile towers, powered mainly by diesel generators, contribute to energy consumption .Exploring renewable energy sources, such as solar and wind, for powering telecom infrastructure can help reduce the carbon footprint Furthermore, improving energy efficiency in data centers through advanced cooling technologies and server virtualization can contribute to energy savings .

Bera et al., 2021[44] mentioned in his study that the air freight sector plays a vital role in international trade, but it is energy-intensive. Air transport requires jet fuel for propulsion, contributing significantly to greenhouse gas emissions .Implementing fuel-efficient aircraft and adopting sustainable aviation fuels are crucial strategies to curb energy demand and environmental impacts. Collaborative efforts between airlines, governments, and industry stakeholders are essential for achieving sustainable aviation.

Gupta et al., 2022[45] showed that the transition to electric vehicles (EVs) is a critical step in reducing energy demand and emissions in the transport sector EVs are gaining traction in the passenger car segment due to advancements in battery technology and supportive policies .The Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme provides incentives for EV adoption (Ministry of Heavy Industries & Public Enterprises, 2023). Developing a comprehensive EV charging infrastructure and addressing range anxiety are essential for widespread EV adoption.

The cooking sector in India is undergoing a transition from traditional biomass to cleaner cooking solutions (Rathi et al., 2022)[46]. The Ujjwala scheme has significantly increased LPG penetration in households (Ministry of Petroleum & Natural Gas, 2022). However, challenges remain in ensuring sustained LPG access, affordability, and promoting behavior change (Shukla & Singh, 2021). Encouraging the adoption of induction cooktops and electric stoves powered by renewable energy sources can further reduce the carbon footprint of cooking (Mishra et al., 2023).

Apart from the prominent sectors, other miscellaneous sectors also contribute to energy demand. Water supply and wastewater treatment facilities require energy for pumping, treatment, and distribution (Roy & Mondal, 2019)[47]. The adoption of energy-efficient pumps and renewable energy integration can reduce energy consumption (Rao & Garg, 2020).The entertainment sector, including cinemas and theme parks, consumes energy for lighting, HVAC systems, and equipment.

(Roy et al., 2021)[48] found that energy-efficient designs and technologies can mitigate energy demand in the health care sector demands energy for medical equipment, lighting, HVAC systems, and essential services .Hospitals and clinics require a stable energy supply to ensure patient care and medical procedures Energy-efficient lighting and cooling systems, along with renewable energy integration, can contribute to reducing energy demand.

Pandit et al., 2022)[49] study shows that Educational institutions and research centers contribute to energy demand through classroom activities, laboratories, lighting, and climate control Implementing energy-efficient building designs, optimizing classroom lighting, and encouraging conservation practices among students and faculty members are essential .Renewable energy installations on campus can further enhance sustainability.

Bhattacharya & Mandal, 2020[50] study shows that that recreational facilities such as sports stadiums, swimming pools, and gyms have varying energy demands for lighting, ventilation, and equipment Integrating energy-efficient lighting systems and using renewable energy sources for power generation can reduce energy consumption in these facilities .Smart energy management systems can help optimize energy use based on occupancy and activity schedules.

Roy et al., 2020[51] study shows that religious places such as temples, churches, and mosques consume energy for lighting, air conditioning, and audio systems]. The integration of energy-efficient lighting technologies, LED bulbs, and solar panels can contribute to reducing energy demand in these spaces .Encouraging energy conservation practices among visitors and religious communities can also make a positive impact (Srivastava & Saini, 2022).Bhattacharya & Chatterjee (2021) in his study found that Retail establishments and shopping malls have diverse energy demands for lighting, heating, cooling, and electronic displays (Bhattacharya & Chatterjee, 2021). Implementing energy-efficient building designs, such as natural lighting and efficient HVAC systems, can lead to energy savings

.Encouraging retailers to adopt energy-efficient appliances and lighting solutions can further contribute to reducing energy consumption

2.2 Research Gap

A lot of research and journals are published in analyzing the demand and supply of energy and how different factors influence it along with the future demand projection. But the sectors(Variables) which were used earlier in projection of most of the studies are very few. Also data used are mostly outdated. The recent changing dynamic of world due to covid, Ukrain- Russia are not considered. Most of it's projection are based on old data not current. So there are high chances of deviation from real. None of above studies has shown energy demand into levels. None of the studies have considered Non- Zero emission as a separate level for comparison .But here in this case study we will try to address to gap. Our studies will have projection of 2047 energy requirement based on data till 2022. We will also try to find out which level is best suited for our need and commitment to World.

Chapter-3

Demand Side Analysis

3.1 Demand Sectors

For finding total Energy demand in the 2047, it is convenient to divide it into broad categories and then find energy requirement in individual sector. Though there could be minute overlapping between these sector in practice.The demand sector in the energy scenario of India refers to the different sectors of the economy that consume energy. Demand sectors are broadly classified into 6 major sectors (As per NITI Aagog) which are as follows [10]:

1. Transport
2. Building
3. Industry
4. Agriculture
5. Telecom sector
6. Cooking
7. Miscellaneous

Sector specific study

3.1.1 Transport

Overview and key trends of the transport sector

The transport sector in India plays an integral part in the country's economic growth and development while consuming a large volume of the total commercial energy of the country. It is the second highest energy consuming sector after industry in India[9]. Not only that, it is also responsible for consuming the largest share of the nation's petroleum products. Most of the motorized passenger transport in the country moves on roads, rail and air. In addition, some passenger traffic also moves on inland-waterways. Freight traffic on the other hand moves largely on road and rail. A small but increasing share of freight movement also happens via pipelines, coastal shipping and on inland-water ways. However, it is road transport that is responsible for meeting the major share of both passenger and freight transport in India. by a rapidly growing economy and the economic liberalization of the early 90's there has been a particularly high growth in transport movement on roads and a large increase in the number of passenger vehicles in the country. For instance, both passenger cars and two-wheelers have seen about 10 per cent CAGR between 1991 and 2011. From a mere 2.95 million registered cars and jeeps in 1991, the number of cars and jeeps has soared to over 19.23 million by 2011 (9.82% CAGR) and registered two-wheelers have grown from about 14.2 million in 1991, to about 101.86Million by 2011[7].

Categories of transport demand:

1. Passenger
2. Freight

3.1.1.1 Passenger Transport

- **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. National Institute of Urban Affair (NIUA) developed a correlation between per capita mobility (i.e. passenger-km per capita) and GDP per capita. 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 average distance travelled annually per person in India in 2020 was 6,900 km [10]. The correlation between GDP and passenger transport demand is used to create projections of future transport demand.

The projection (Levels) of Passenger Transport Demand depends upon different stage of Infrastructural development. Thus based on stage of development of infrastructure,it is categorized into 4 levels(As per IESS tools) which are as follows:

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 as shown in fig 3.1. 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 as shown in fig.3.1

Level 3

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 as shown in fig.3.1

Level 4

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 worker 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 as shown in fig.3.1

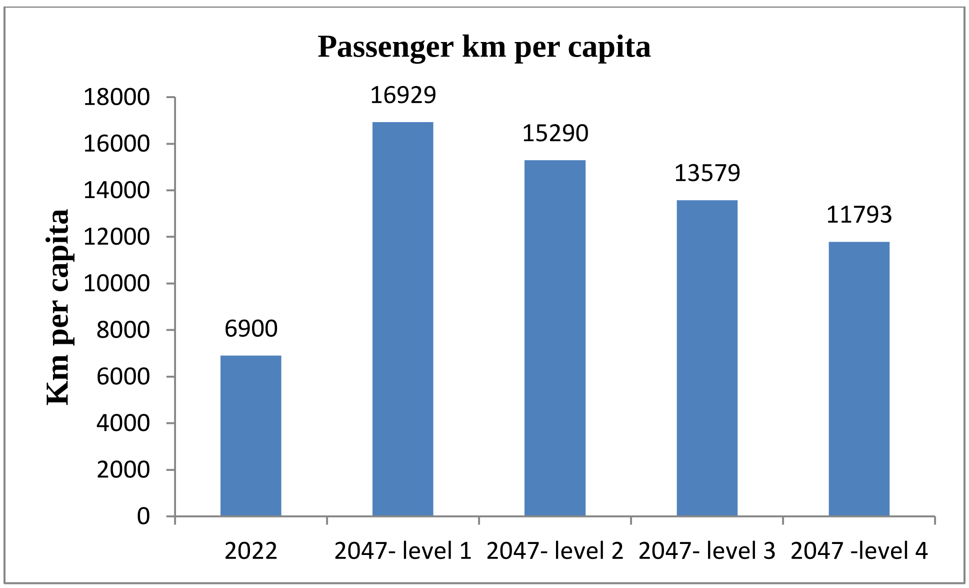


Fig 3. 1: Passenger Transport Demand Per Capita, [9]

- **Passenger transport modal shares**

Passenger transport is divided into three modes of travel - road, rail, and air travel. In2020, estimated travel by road accounted for 87.24% and rail accounted for 11.29% of total passenger traffic as shown in fig . 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 on which energy demand will depend.

Level 1

In the level 1 trajectory, it is assumed that the share of rail keeps declining asper 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 as shown in fig:3.2

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 as shown in fig:3.2

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 as shown in fig:3.2

Level 4

Level 4 trajectories 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 as shown in fig:3.2

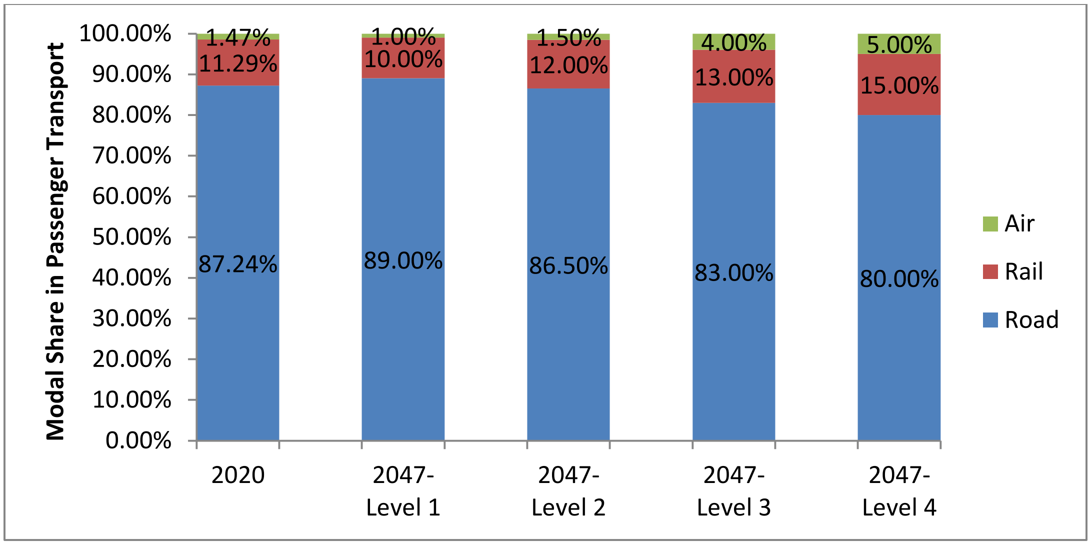


Fig 3. 2:Passenger Transport: Modal Share, [9]

3.1.1.2 Freight Transport

❖ **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[10].

4 different trajectories are shown for freight transport demand:

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 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 BTKMsby 2047 as shown in Fig: .3.3

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 as shown in Fig:3.3

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 as shown in Fig:.3.3

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, toreach 11,239 BTKMs by 2047 from 2,639BTKMs in 2020 as shown in Fig:.3.3

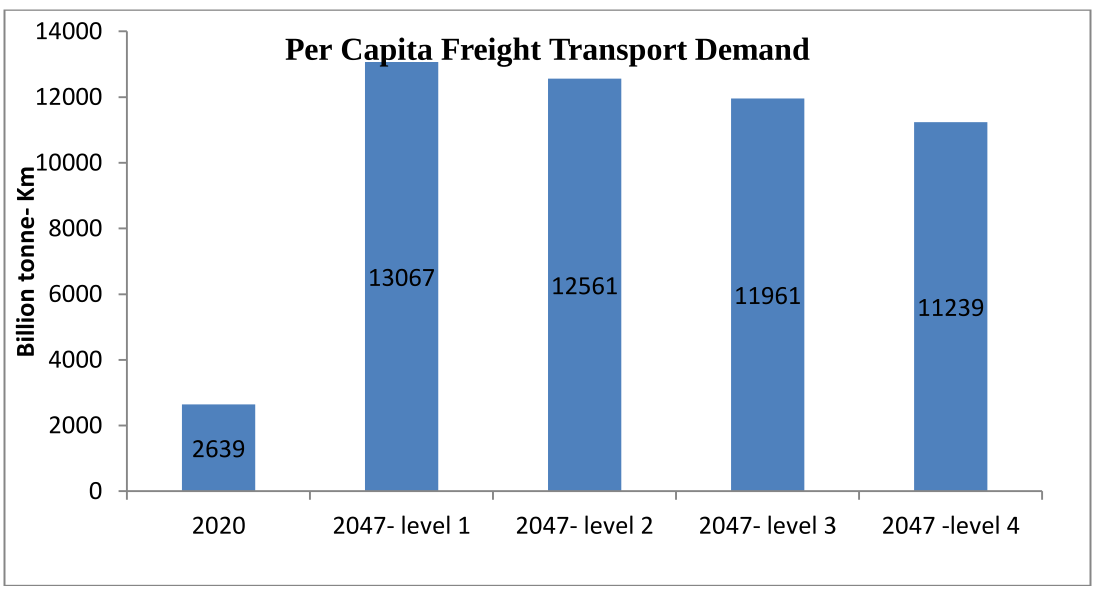


Fig 3. 3 Per Capita Freight Transport Demand, [10]

- **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[10]. 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 discussed 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% as shown in Fig:3.4

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 as shown in Fig:.3.4

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 as shown in Fig:3.4

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%.as shown in Fig:3.4

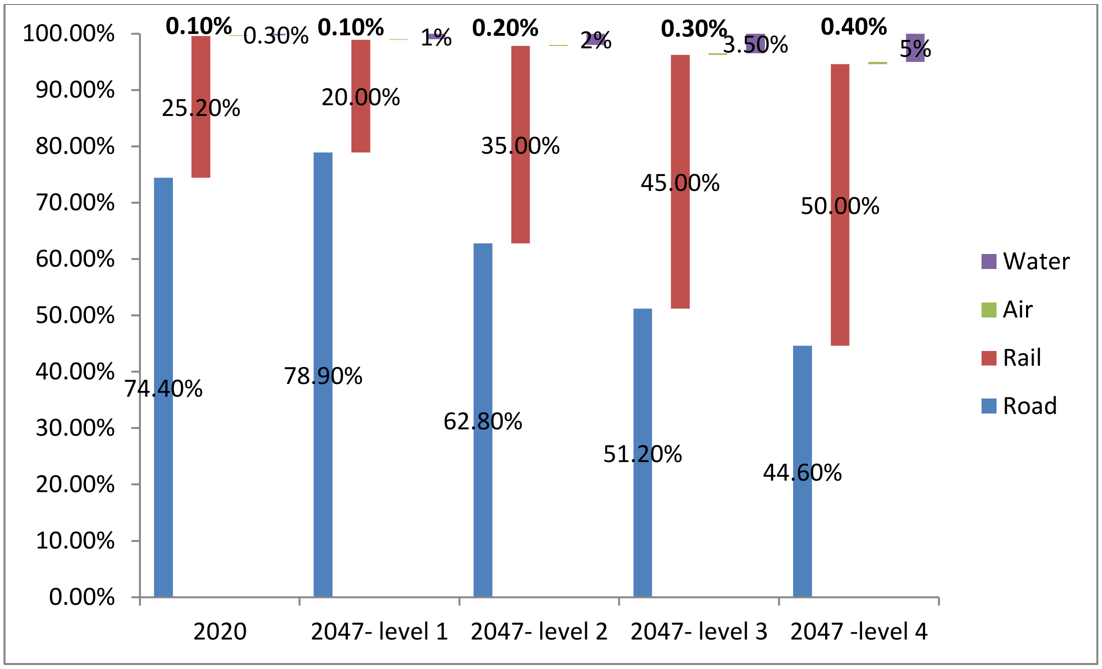


Fig 3. 4:freight Transport Modal Mix,[9]

3.1.1.3 Total energy demand in Transport sector

Thus based on above mentioned variable, energy demand in transport is projected. Other variables are also considered for trajectory projection.As shown in table 3.1 at Current level, the demand of energy in transport sector is 120.18 Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 331.36,252,206,164,227.85 respectively. Due to commitment of India for Net Zero , almost twice more energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy.

Table 3. 1: Energy demand in Transport sector,[6]

	Levels	2022	2027	2032	2037	2042	2047
Transport	**Level 1**	120.18	186.05	233.34	275.65	309.43	331.36
	Level 2	120.01	174.74	207.41	232	248	252
	Level 3	119	155	189	204	210	206
	Level 4	119	155.62	169	175	174	164
	Net zero scenario	119	171.12	199	219.29	229.73	227.85

3.1.2 Buildings

Size of building , Number of households, purchasing power of people, GDP per capita of people etc.majorly decides energy demand in building sector. Also type of family eg Nuclear family,extended family, or joint family plays a vital role in demand projection.

3.1.2.1 Residential buildings

❖ **Number of households**

Using the Household Data from Ministry of Statistics and Programme Implementation (MoSPI), the estimated number of households in India is 268 million in 2022. It is projected to grow in all 4 levels. But it is more than 450 million in Level 1 because of increase in nuclear family. While in level 4 it is approx. 350 million because of increase cost of building.Numbers as per projection are shown in fig 3.5 .Demand of energy requirement in household is proportional to it's number. Thus as no. grows , demand also grows.

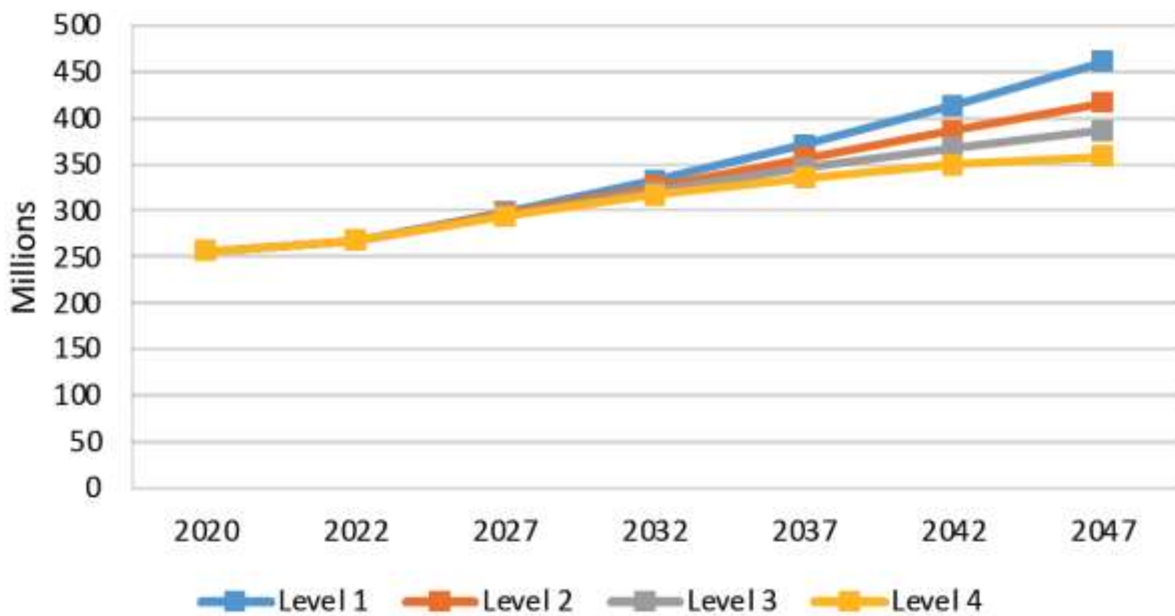


Fig 3. 5 Total Households,[MoSPI]

❖ **Economic Categories**

The purchasing power of population determines energy required. 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 by NIUA.

1) EconomicallyWeaker 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. 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.

In 2020, EWS in rural household is 59.8% while in 2047 , level 4 it is only 30%, Which is an indication of growing income. Thus rise in energy required. Similarly, it is shown for other category also in fig 3.6

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

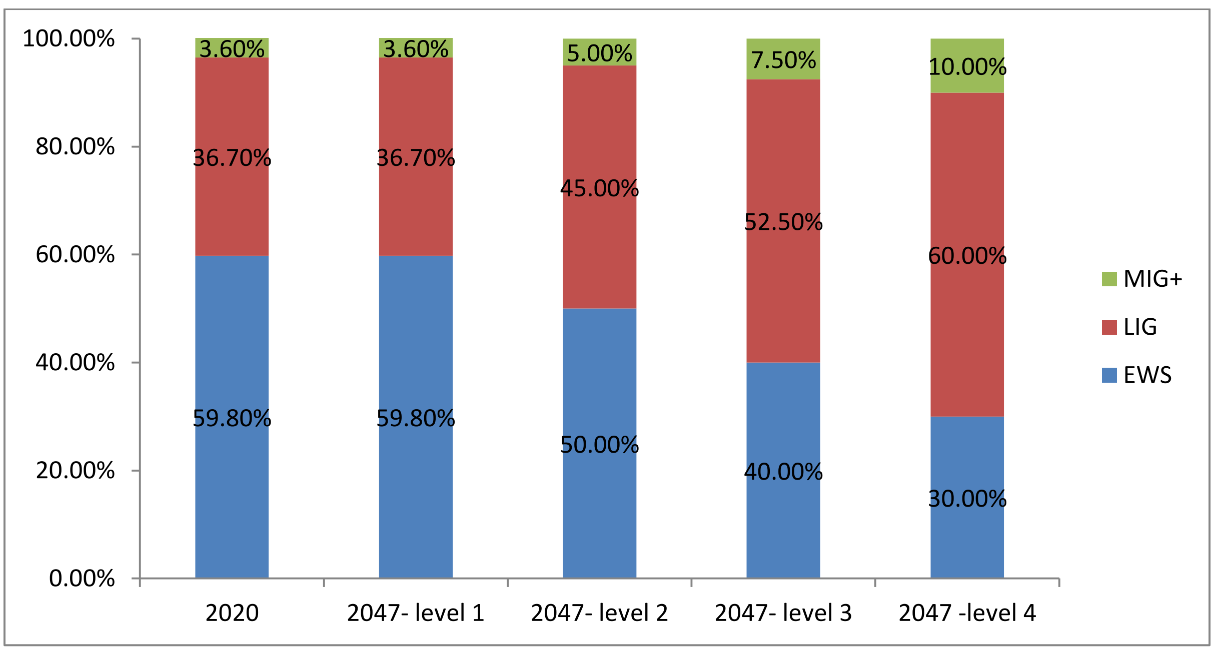


Fig 3. 6: Share of Economic Categories in Rural Households

In 2020, MIG+ in Urban household is 21.30% while in 2047, Level 4 it is 34%, Which is an indication of growing income. Thus rise in energy required. Similarly, it is shown for other category and levels also as represented in fig 3.7

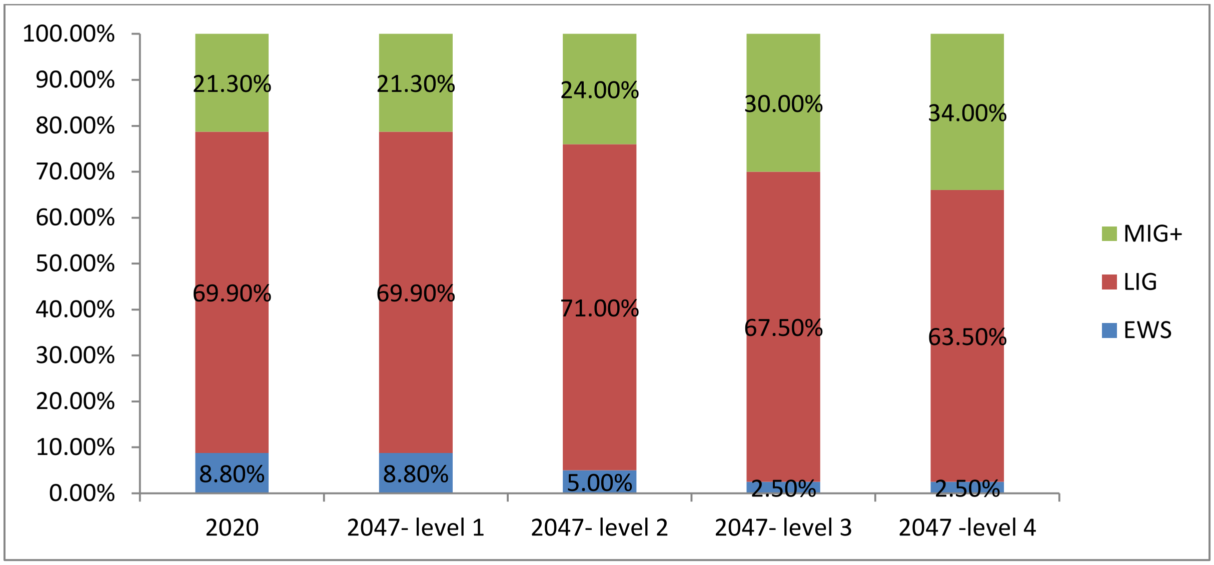


Fig 3. 7 Share of Economic Categories in Urban Households

3.1.2.2 Total energy demand in Building

Thus based on above mentioned variable, energy demand in building is projected. Other variables are also considered for trajectory projection.

As shown in table 3.2: at Current level, the demand of energy in building sector is 36.22Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 208.17,172,,147,119,162.18 respectively. Due to commitment of India for Net Zero , almost 4-5 times more energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy.

Table 3. 2 :Total energy demand in Building,[6]

Sector/year	**Levels**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Building	**Level 1**	36.22	51.33	72.84	103.42	146.8	208.17
	Level 2	36.17	50.24	69.43	95	129	172
	Level 3	36.12	49	66	89	116	147
	Level 4	36.05	47	62	80	100	119
	Net zero scenario	36	49.87	68.38	93	124.7	162.18

3.1.3 Industry

- **Energy consumption of industries**

The energy consumption of industry is the net summation of product of sectoral production and sectoral specific energy consumption. The industry sector is not homogeneous in nature. It comprises several manufacturing industries which engage in different energy-consuming activities.Compared to manufacturing industry, other industries also contributes in energy but since it is relatively less in quantity so it is clubbed together. 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(is a regulatory instrument to reduce Specific Energy Consumption in energy intensive industries, with an associated market based mechanism to enhance the cost effectiveness through certification of excess energy saving which can be traded). 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 whose data is taken . The rest of the industries have been clubbed together and denoted as 'others'. Energy consumption of the industry sector is estimated as: Further, the energy consumption of each industry is disaggregated into fuel-wise energy consumption with fuel mix assumptions. Table below 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. . To achieve a low carbon future, change in the fuel mix of the industry sector is crucial. Figure below show the impact of change in fuel mix on energy-related emissions from industries. In the table shown below , most of the industry except fertilizer industry , uses coal as primary source which pollutes more than anything else i.e Cement , iron and aluminium industry uses coal in percentage of 97%, 83.5% and 94% respectively. **Table 3. 3 : Fuel mix in various industries as of 2020,[BEE]**

	Coal	**Oil**	**Gas**	**Bioenergy**
Aluminium	94.00%	4.50%	0.50%	0%
Cement	97.00%	1.00%	0.00%	0%
Chlor-alkali	75.00%	2.00%	13.00%	0%
Fertilizer	8.00%	0.00%	90.00%	0%
Iron & Steel	83.50%	1.50%	2.00%	0%
Pulp & Paper	80.00%	5.00%	0.00%	0%
Textile	71%	1%	2%	0%
Others	33.50%	40.00%	6.00%	11.30%

In the fig 3.8 shown below , electricity consumption in all 4 levels will increase by manifold of 4.7 times in level 4 which require a consideration towards energy security. Other levels also require 3-4 times more electricity than current. Else GDP growth will be stunted.

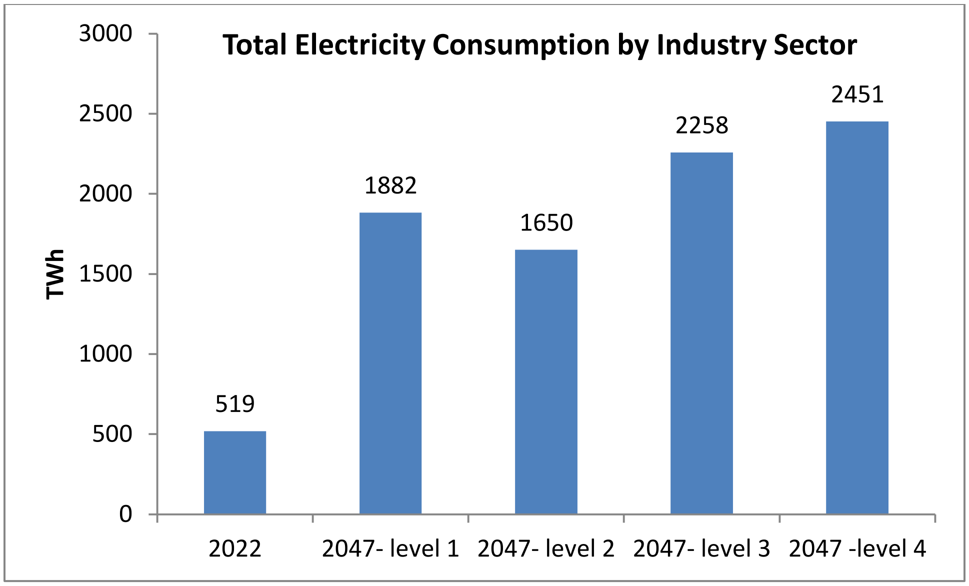


Fig 3. 8: Total Electricity Consumption by Industry Sector

3.1.3.1Total energy demand in Industry

Thus based on above mentioned variable, energy demand in industry is projected. Other variables are also considered for trajectory projection .As shown in table 3.4: at Current level, the demand of energy in Industry sector is 271.87Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 1043,774,,648,587,648.6 respectively. Due to commitment of India for Net Zero , almost 2.5 times more energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy while least efficient path is L1 which require more than 3.8 times than current.

Table 3. 4 : Total energy demand in Industry,[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Industry	**Level 1**	271.87	369.77	498.08	643.66	824.2	1043.3
	Level 2	262.41	338.38	431.26	528	642	774
	Level 3	260	324	399	472	555	648
	Level 4	257	315	381	443	512	587
	Net zero scenario	260	324.06	399	472.5	555.61	648.6

3.1.4 Agricultural Sector

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[10] . 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[Ministry of agriculture &farmer welfare) and. 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 as shown in fig . 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. No of tractor, type of tractor (Electric, diesel) , hour of operation are used to project energy demand for tractor using fig:3.9 , fig:3.10 , fig: 3.11 4 trajectories are explained below:

Energy demand for tractors

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 (Litre per hour) 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%. Thus projecting energy demand by tractors.

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%.

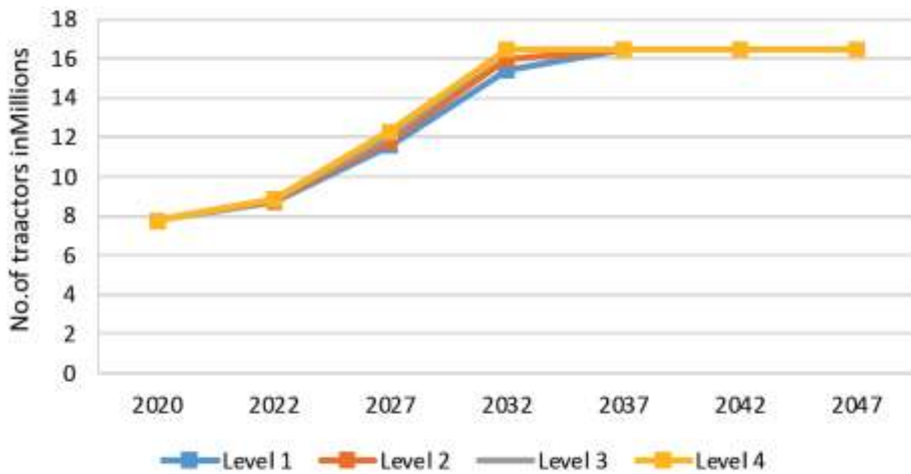


Fig 3. 9 No. of tractor in India,[10]

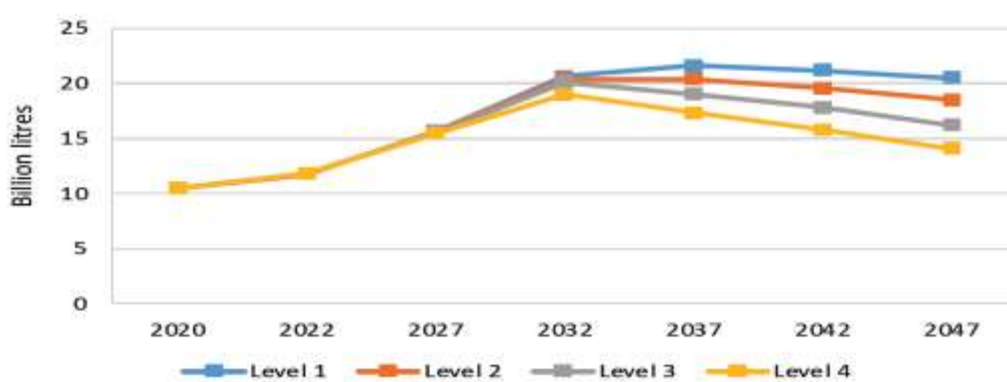


Fig 3. 10 Diesel Consumption by Tractors;[10]

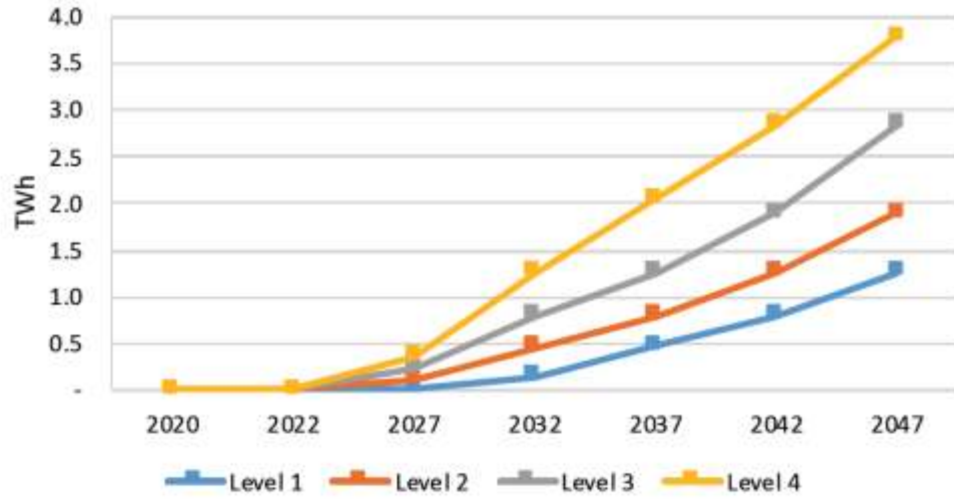


Fig 3. 11: Electricity Consumption by Tractors,[10]

❖ 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[14] . 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[10] .Using fig 3.12: 3.13, fig: 3.14, we can reach at demand of energy in pump for different trajectory .

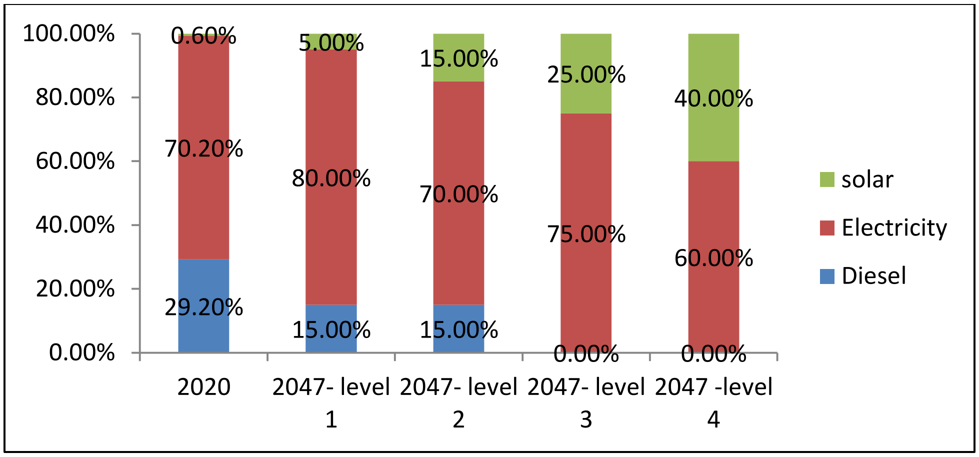


Fig 3. 12: Fuel mix of Pump,[10]

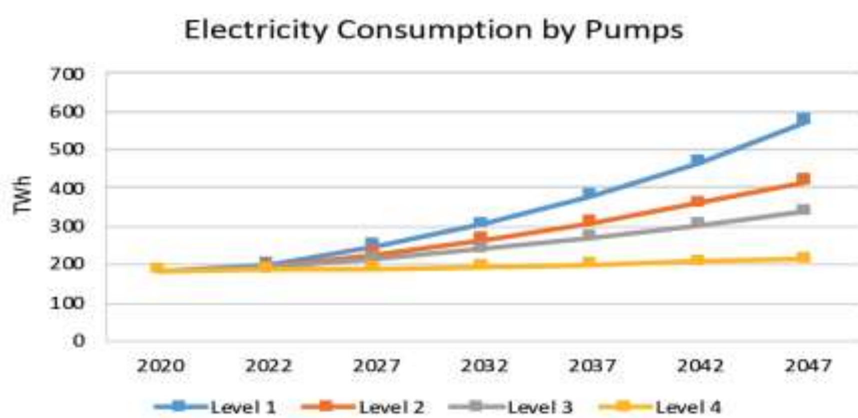


Fig 3. 13 Electricity consumption by Pumps,[10]

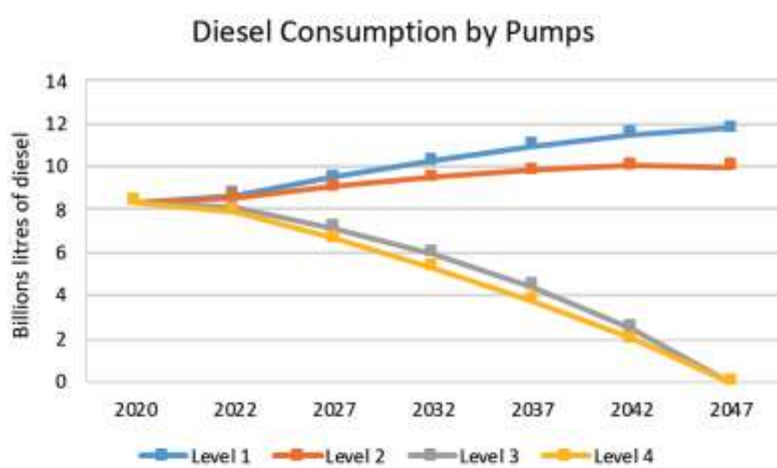


Fig 3. 14: projected Diesel consumption by Pumps,[10]

3.1.4.1 Total energy demand in Agriculture

Thus based on above mentioned variable, energy demand in agriculture sector is projected. Other variables are also considered for trajectory projection. As shown in table 3.5: at Current level, the demand of energy in Agriculture sector is 34.81 Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 34.81,34.49,33,33.5,34.46 respectively. Due to commitment of India for Net Zero , almost 2 times more energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy while least efficient path is L1 which require more than 2.4 times than current.

Table 3. 5: Energy demand by Agriculture sector,[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Agriculture	Level 1	34.81	43.14	53.47	61.61	70	79.99
	Level 2	34.49	41.73	50.51	55	61	67
	Level 3	33	39	46	48	50.5	52
	Level 4	33.5	37	42	42	42	42
	Net zero scenario	34.46	41.63	50.3	55	60.94	67.12

3.1.5 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[15]. Overall teledensity in the country is 86.55% whereas urban teledensity(Telephone density or teledensity is the number of telephone connections for every hundred individuals living within an area). is 139% and rural teledensity is 59.08%[15].The number of Broadband connections is 734.82 million as recorded 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[15] [. 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. As can be seen from fig: number of base transceiver station (BTS) increase from approx 20 lakh unit in 2020 to more than 100 lakh units in 2047 while from fig 3.15 and fig 3.16telecom energy mix is known which are some of the variable in energy demand projection in telecom sector .

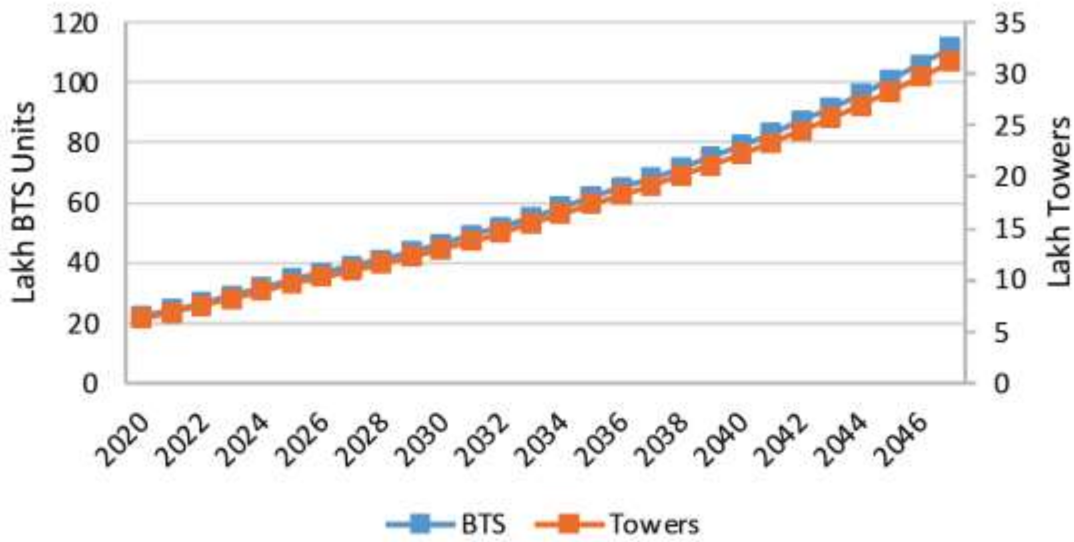


Fig 3. 15 Projected Growth of Telecom Sector,[10]

Projected path are explained below for telecom energy mix in rural and urban which are shown in fig : and fig

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 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. Fig3.16 : & fig :3.17

Level 2

A higher proportion of solar PV (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. Fig : 3.16& fig :3.17

Level 3-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. Fig3.16 : & fig :3.17

Level 4

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. Where as wind power solutions is expected to increase up to 10% in rural areas and 7% in urban areas by 2047. Bioenergy 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. Fig3.16 : & fig :3.17

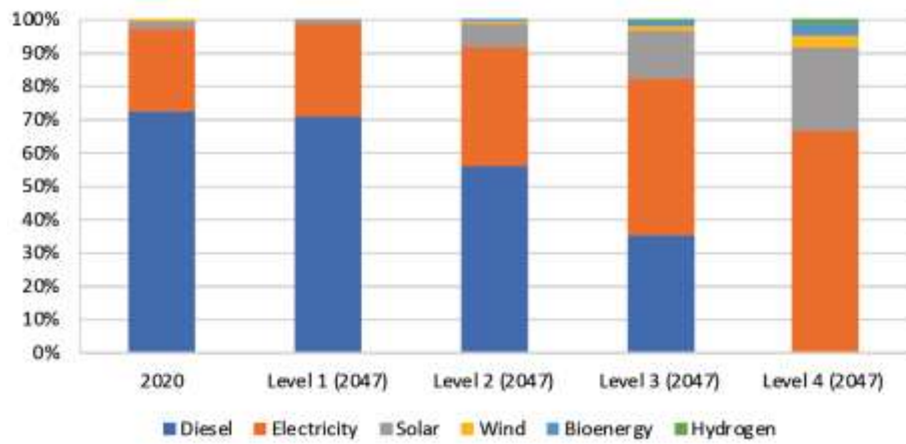


Fig 3. 16 Telecom Energy Mix – Rural,[10]

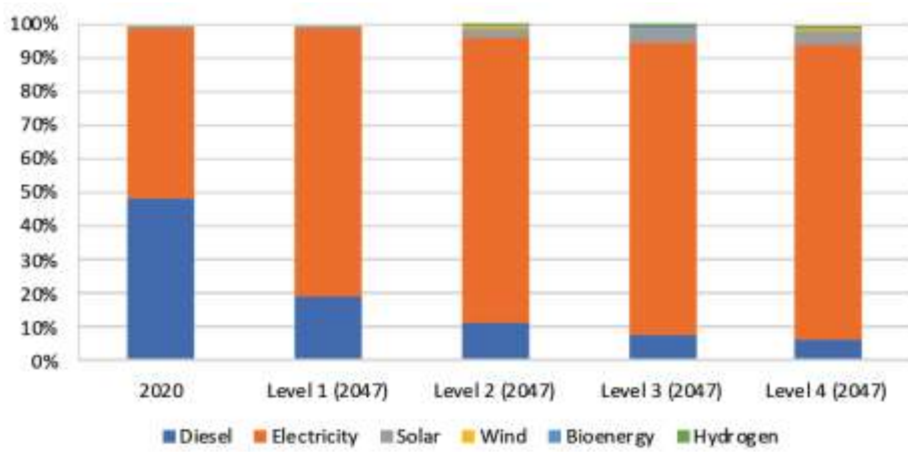


Fig 3. 17 Telecom Energy Mix – Urban,[10]

3.1.5.1 Total energy demand in telecom

Thus based on above mentioned variable, energy demand in telecom sector is projected. Other variables are also considered for trajectory projection.. As shown in table 3.6: at Current level, the demand of energy in telecom sector is 8.95 Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 19.66 ,16.99,15,13,16.99 respectively. Due to commitment of India for Net Zero , almost twice more energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy while least efficient path is L1 which require more than 2.2 times than current.

Table 3. 6 :Total energy demand in telecom ,[6]

Sector/year	**Levels**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Telecom	**Level 1**	8.95	11.89	14.32	16.64	18.38	19.66
	Level 2	8.93	11.75	13.95	15.84	16.88	16.99
	Level 3	8.93	11	13	15	15.63	15
	Level 4	8.89	11	13	14	14	13
	Net zero scenario	8.93	11.75	13.95	15.84	16.88	16.99

3.1.6 Cooking

A comprehensive literature survey of studies published on cooking energy requirement 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[10]. The overall energy requirement depends on the cook stove 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 tha on average a household in India consumes around 8 to 10 Liquefied Petroleum Gas(LPG) cylinders annually[10]. 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[10]. 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 as shown in fig:

It it can seen from fig : and fig : electricity consumption used for cooking will rise drastically from less than 1% to 25% in level 4 in urban , while from less than 1% to 20% in rural household respectively . 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(Piped Natural Gas) cookstoves as well as electric cookstoves is also higher. Thus,it takes less amount of energy to cook the food.

Using cooking fuel mix up for urban and rural 2047 trajectories are projected as shown below in fig : 3.18and fig:3.19

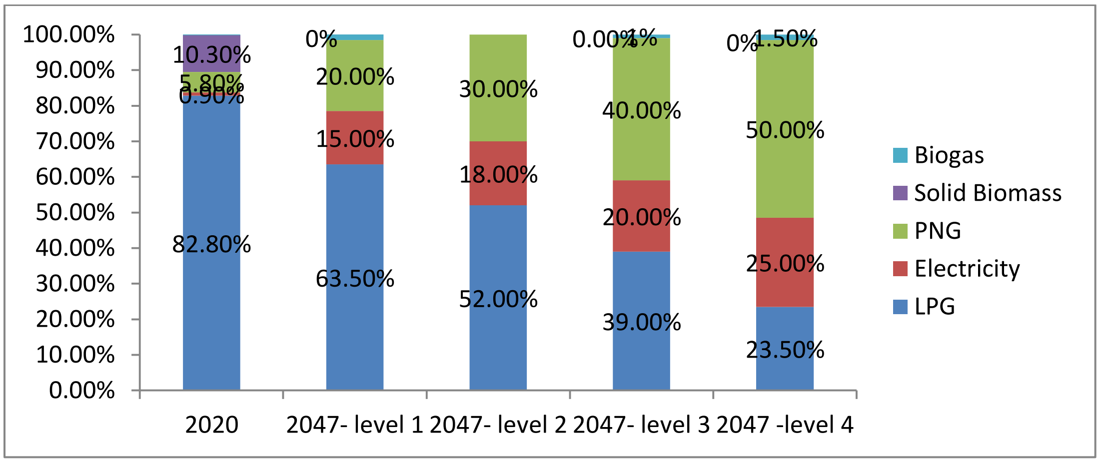


Fig 3. 18:Cooking fuel mix for Urban Household

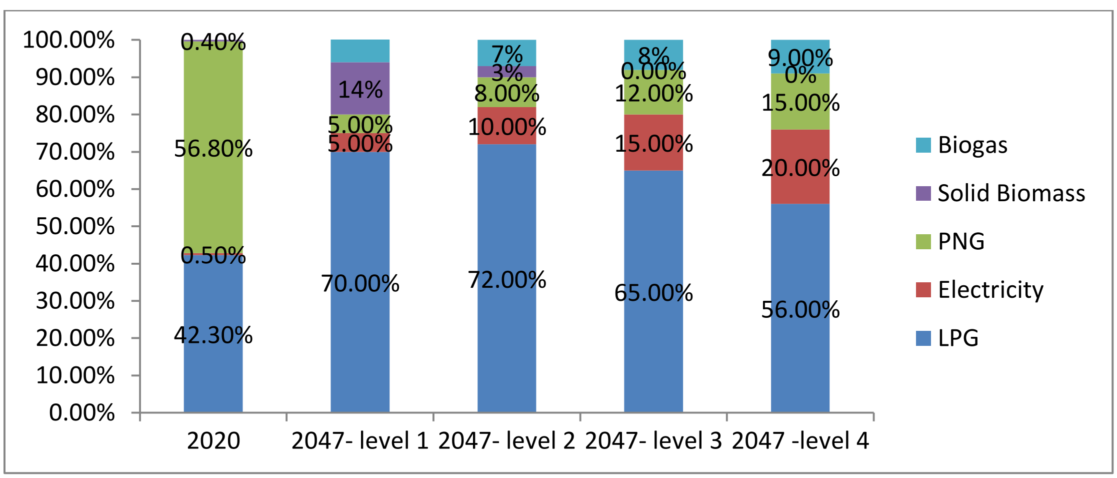


Fig 3. 19 Cooking fuel mix for Rural Household

3.1.6.1 Total energy demand in Cooking

Thus based on above mentioned variable, energy demand in cooking is projected. Other variables are also considered for trajectory projection.As shown in table:3.7 , at Current level, the demand of energy in cooking sector is 96.58 Mtoe. While projection of same in 2047 as per level 1, level 2, level 3, level 4 and Net Zero are 70.43,58.54,54,51,58.58 respectively. Due to commitment of India for Net Zero , almost more than half energy is needed in this sector else increase efficiency to follow path 4 which require minimum energy. Good thing about cooking sector is that all level shows a decrease in requirement because of increased efficiency of appliance.

Table 3. 7:Total energy demand in Cooking,[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Cooking	**Level 1**	96.58	92.21	87.21	83.1	77.83	70.43
	Level 2	95.3	88.5	81.33	75.08	67.98	58.54
	Level 3	92	73	58	53	53.63	54
	Level 4	90.41	61.91	52	42	50.75	51
	Net zero scenario	95.3	88.5	81.33	75.08	67.98	58.54

3.1.7 Total energy demand

Thus summing all above sector, total energy demand in all sectors are calculated as shown in table :3.8 It can be seen the energy demand in 2022 is 618 mtoe. While projected energy demand in 2047 are 1883,1450,1227,1076,1287 Mtoe for L1, L2, L3 ,L4 and Net zero scenario. Due to commitment of India for Net Zero , following on the it's trajectory is a must and it require more than twice as much of energy as it needed now. While when less efficient trajectory is followed , energy demand is almost thrice as of now.

Table 3. 8 :Total energy demand (mtoe),[6]

Total demand side	**Level 1**	611.65	809.56	1028.09	1269.28	1552.14	1883.56
	Level 2	600	757.93	917	1078	1257	1450
	Level 3	591	715.77	835	956	1089	1227
	Level 4	588	680.2	780	877	976	1076
	Net zero scenario	597	739.22	874.99	1006.36	1144.63	1287.24

3.1.8 Miscellaneous reason for rise in energy demand

GDP- It can be seen from table 3.9 that thought % GDP contribution in agriculture is decreasing (17.30% in 2020 to 6.80% in 2047 but in cumulative term , it is rising. Coming to industry sector , it's contribution is increasing both in term of % contribution and cumulative total i.e from 27.30% in 2020 t0 34.50% in 2047. Service sector is always more than 50%. It's contribution is somewhat stagnant.

Table 3. 9 : Sectoral Share of GDP,[10]

Sectors	**2020**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Agriculture	17.30%	18.40%	16.60%	14.80%	13.00%	11.20%	6.80%
Industry	27.20%	27.20%	28.60%	29.90%	31.30%	32.60%	34.50%
Services	55.60%	54.40%	54.80%	55.30%	55.70%	56.20%	58.70%

Urbanization -Other study parameters are shown in table : 3.10 which says rise in total population from 1349 million in 2020 to 1592 million in 2947. Zooming in , it can be seen that urban population is rising from 472 million in 2020 to 811 million in 2047 while rural population is shrinking and since urban population is more consumerist in nature , leading to demand rise in terms of energy . Parallelly urbanization % is also rising from 35% int 2020 to 51% in 2047. Which is also one of the indication of rise in energy demand.

Table 3. 10:Various Parameters over the Study Period related to urbanization[9]

Parameter	Units	2020	2022	2032	2037	2042	2047
Population	**Millions**	1349	1375	1490	1535	1569	1592
Urban Population	**Millions**	472	497.4	627.5	691.9	753.5	811.9
Rural Population	**Millions**	876.6	877.2	862.6	843.1	815.1	780.1
Household Size - Urban	**People/ household**	4.2	4.14	3.85	3.7	3.56	3.41
Household Size - Rural	**People/ household**	4.5	4.45	4.19	4.07	3.94	3.81
Total Households	**Millions**	307.2	317.3	368.8	394.2	418.9	442.9
Urban Households	**Millions**	112.4	120.1	163	186.9	211.9	238.1
Rural Households	**Millions**	194.8	197.2	205.7	207.4	207	204.8
Urbanization	**%**	35%	36.20%	42.10%	45.10%	48.00%	51%
Share of Manufacturing	**%**	14.40%	15.70%	22.20%	25.50%	28.70%	32.00%

Electrification - Electrification demand is also one of the parameter which is an indication of rise in power . It can seen from fig :3.20 that electrification demand in net zero is rising from 18% in 2022 to 40% in 2047. Similar pattern is observed in other scenario .

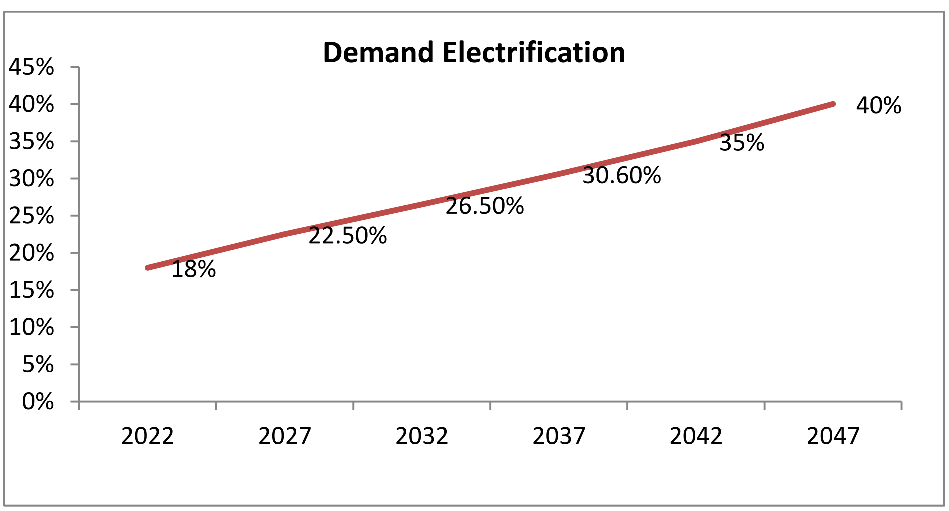


Fig 3. 20 : Demand Electrification in Net Zero Scenario

3.1.9 Government Policy

In order to achieve different levels of demand and supply, GOI in order to secure Self sufficient energy security 2047 & India's Panchamrit Goal: Few policy are adopted Which are as follows across different sectors:

Industry:

1. National Energy Efficiency Policy (NEEP)
2. National Solar Mission (NSM)
3. National Biomass Mission (NBM)
4. National Electric Mobility Mission Plan (NEMMP)
5. International Solar Alliance (ISA)
6. Green Energy Corridor (GEC)
7. Renewable Energy in Industry Policy
8. Emissions Reduction in Industry Policy
9. Industry Sustainability Policy
10. Green Industry Labeling Program

Cooking:

1. National Biofuels Policy and SATAT
2. Renewable Energy for Cooking Policy
3. Cooking Fuel Subsidy Policy
4. Cooking Education Policy
5. Cooking Sustainability Policy
6. Indoor Air Quality Policy
7. Fuelwood Plantation Policy

8. Cooking Stove Manufacturing Policy
9. Cooking Stove Distribution Policy
10. Cooking Stove Maintenance Policy

Transport:

1. Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME)
2. Electric Vehicles Promotion Policy
3. Non-Motorized Transport Promotion Policy
4. Transport Emissions Reduction Policy
5. Transport Sustainability Policy
6. Road Safety Policy
7. Public Transport Infrastructure Policy
8. Electric Vehicle Charging Infrastructure Policy
9. Non-Motorized Transport Infrastructure Policy
10. Transport Demand Management Policy

Building:

1. Energy Efficiency in Buildings Policy
2. Renewable Energy in Buildings Policy
3. Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA)
4. Indoor Air Quality Policy
5. Building Sustainability Policy
6. Building Codes Policy

7. Building Materials Policy
8. Building Energy Performance Standards Policy
9. Building Retrofit Policy
10. Green Building Certification Program

Telecom:

1. National Broadband Policy
2. Digital India Mission
3. Telecom Infrastructure Policy
4. Telecom Services Policy
5. Telecom Regulation Policy
6. Telecom Competition Policy
7. Telecom Cybersecurity Policy
8. Telecom Accessibility Policy
9. Telecom Education Policy
10. Telecom Research and Development Policy

Agriculture:

1. Water Efficiency in Agriculture Policy
2. Renewable Energy in Agriculture Policy
3. Soil Health Policy
4. Crop Diversification Policy
5. Agriculture Sustainability Policy

6. Agricultural Productivity Policy

7. Agricultural Marketing Policy

8. Agricultural Finance Policy

9. Agricultural Insurance Policy

10. Agricultural Research and Development Policy

These are just a few examples of government policies related to each of the sectors mentioned. There are many other policies that could be mentioned, but these are some of the most important ones.

Chapter-4

Supply Side Analysis

4.1 Supply Sectors

India's energy landscape is characterized by a constellation of supply-side challenges and potential disruptions that have significant implications for its economic development and environmental sustainability. The nation's diverse energy sources, including coal, oil, natural gas, renewables, and nuclear power, contribute to the complexity of ensuring a stable and reliable energy supply. However, the heavy reliance on coal, despite its environmental drawbacks, underscores the need to strike a balance between energy security and ecological concerns. Unprecedented issues like Russia –Ukraine war, Covid -19 have long term supply disruption challenges. Also CAATSA Policy of USA creates additional threat for India. Rising GDP/capita require more than double of energy demand in all 4 levels seen previously. The expansion of renewable energy, particularly solar and wind, presents a promising avenue for reducing carbon emissions; yet, integrating these intermittent sources into the grid while maintaining stability is a technical hurdle. Compounding these challenges are issues of energy access, with a substantial portion of India's population still lacking reliable electricity.Furthermore, inadequate infrastructure, particularly in transmission and distribution, leads to energy losses and inefficiencies, exacerbating the challenge of providing accessible and affordable energy. The burgeoning demand for natural gas surpassing domestic production has prompted increased reliance on imports, leaving India susceptible to global market fluctuations. As the country looks to expand its nuclear energy capacity, safety considerations, waste management, and international agreements introduce complexities in the path forward. Additionally, India's commitment to global climate goals necessitates a shift away from fossil fuels, prompting a reevaluation of energy strategies. Thus supply supply for future energy security is needed to resilient.

Supply sectors are roughly met by these sources which are as follows

- Sector specific insight
  1. Coal
  2. Oil pipe and petroleum
  3. Natural gas
  4. Solar
  5. Wind

6. Hydro
7. Nuclear
8. Electricity import
9. Others(eg biofuel etc)

4.1.1 Coal

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 fig :4.1 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. . 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.

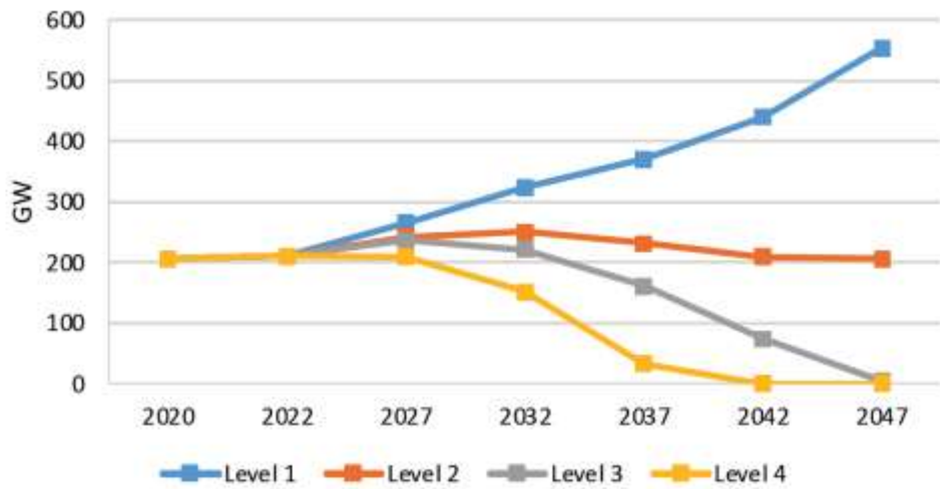


Fig 4. 1 Installed Capacity: Coal based Power Plants[10]

4.1.1.1 Energy Supply by Coal at different levels 2047(Mtoe)

The current energy supply by coal in 2022 is 427.77 mtoe while it is 1536,685,359,276,511 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in coal supply is not very significant i.e from 405 in 2022 to 511 in 2047(From table : 4.1) . It is because of focusing on reducing emission as committed in panchamrit (Net zero by 2070s) .

Table 4. 1 : Energy Supply by Coal at different levels 2047,[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Coal	**Level 1**	432.46	579.16	764	951.31	1201	1536
	Level 2	409	490.82	555.58	592.52	627	685
	Level 3	403.81	468	519	483	418	359
	Level 4	397	457	431.83	326	269	276
	Net zero scenario	405	477	527.52	522.95	511	511

4.1.2 Oil & Petroleum

India is the third-largest oil consumer and importer in the world. It imports around 84% of its crude oil needs. The top five countries where India imports most of its crude oil from are:Iraq, USA, Nigeria, Saudi, UAE, Russia. In May 2023, India's imports of Russian oil reached a record high of 950,000 barrels per day (bpd), making Russia the second-largest supplier of oil to India after Iraq[16]. This was a significant increase from the previous month, when India imported only 277,000 bpd of Russian oil.[16] The increase in India's imports of Russian oil is due to a number of factors, including the discounted prices offered by Russia, the sanctions imposed on Russia by the United States and its allies, and India's desire to diversify its oil imports. The increase in India's imports of Russian oil has been met with criticism from the United States and its allies, who have accused India of helping to fund Russia's war in Ukraine. However, India has defended its decision, saying that it is important to secure its energy supplies at a time when global oil prices are rising.India is also looking to increase its domestic oil production. In 2022, India produced 30.49 million tonnes of crude oil, but this is only about 16% of its total oil consumption. The government is planning to invest in new oil and gas exploration and production projects in order to increase domestic production.India is also looking to develop its renewable energy sector as a way to reduce its dependence on imported oil. In 2022, India's renewable energy capacity reached 100 gigawatts, and the government is targeting 500 gigawatts of renewable energy capacity by 2030[16].The increasing demand for oil and petroleum products in India is putting a strain on the country's economy. The government is taking steps to reduce India's dependence on imported oil, but this will take time and investment.

4.1.2.1 Energy Supply by Oil and petroleum at different levels 2047(Mtoe)

The current energy supply by oil & petroleum in 2022 is 235 mtoe while it is 727,431,463,141,344 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in slight increase in supply of oil and petroleum i.e from 235 in

2022 to 344 in 2047 .i.e 1.5 times only(table : 4.3). It is because of focusing on reducing emission for net zero commitment in 2070s as per GOI's panchamrit.

Table 4. 2 Energy Supply by Oil and petroleum at different levels 2047 (Mtoe),[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Oil and petroleum products	**Level 1**	236.57	333	425	519	619	727
	Level 2	232	299	348	385	414	431
	Level 3	230	277	305	316	316	463
	Level 4	216	240.85	241	221	183	141
	Net zero scenario	230.92	285.83	319.1	337	344	344

4.1.3 Natural Gas

India is the world's third-largest consumer of natural gas. It imports around 50% of its natural gas needs. The top five countries where India imports most of its natural gas from are: Qatar , Turkmenistan, UAE, Russia,Saudi . India is also looking to increase its domestic natural gas production. In 2022, India produced 32.56 billion cubic meters of natural gas, but this is only about 40% of its total natural gas consumption [17]. The government is planning to invest in new natural gas exploration and production projects in order to increase domestic production. India is also looking to develop its renewable energy sector as a way to reduce its dependence on imported natural gas. In 2022, India's renewable energy capacity reached 100 gigawatts, and the government is targeting 500 gigawatts of renewable energy capacity by 2030[17].The increasing demand for natural gas in India is putting a strain on the country's economy. 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[10]. 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

4.1.3.1 Energy Supply by Natural Gas at different levels 2047 (Mtoe)

The current energy supply by natural gas in 2022 is 54.6 mtoe while it is 176,179,206,215.34,166 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in coal supply is significant i.e from 54 in 2022 to 166 in 2047(From table :4.4) which is least among all levels. But still it is almost thrice than current.

Table 4. 3 :Energy Supply by Natural Gas at different levels 2047 (Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Natural Gas	**Level 1**	54.6	75	94	117	144	176
	Level 2	54.93	75	96	119	146	179
	Level 3	55.15	80	105	134	134	206
	Level 4	55.34	82.11	109.45	140	175	215.34
	Net zero scenario	54.83	79.31	104	133	166	166

4.1.4 Solar

Solar energy has seen an incredible transformation in the last decade in the Indianpower 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 National Action Plan for Climate Change (NAPCC), aiming to install 20 GW grid-connected solar PV capacityin 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[10]. 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.

4.1.4.1 Energy Supply by Solar at different levels 2047(Mtoe)

The current energy supply by solar in 2022 is 7.54 mtoe while it is 113,188,230,302,170 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in supply is huge i.e from7.54 in 2022 to 170 in 2047 .i.e almost 20 times (table : 4.5).It is because of focusing on reducing emission for net zero commitment in 2070s as per GOI's panchamrit. While in other levels also , jump is huge because of better technology evolvement as well as GOI policy of International solar Alliance.

Table 4. 4 : Energy Supply by Solar at different levels 2047(Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Solar	Level 1	7.54	19.28	37	61.3	87.98	113
	Level 2	7.72	23.65	52	91.86	140	188
	Level 3	7.89	29.2	65	114	173	230
	Level 4	8.13	34.82	82	147	225	302
	Net zero scenario	7.9	29	64	112	170	170

4.1.5 Wind

India has a vast wind resource potential, with an estimated onshore wind power potential of 300 gigawatts (GW) and an offshore wind power potential of 75 GW. The states with the highest wind power potential are Gujarat, Tamil Nadu, Maharashtra, Karnataka, and Andhra Pradesh.As of March 2023, India had an installed wind power capacity of 42.633 GW, making it the fourth-largest wind power market in the world. The government has set a target of 140 GW of installed wind power capacity by 2030[19].

4.1.5.1 Energy Supply by Wind at different levels 2047(Mtoe)

The current energy supply by wind in 2022 is 5.9 mtoe while it is 97,118,157,179,104 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in supply is huge i.e from 5.9 in 2022 to 104 in 2047 .i.e almost 17-18 times (table :4.6).It is because of focusing on reducing emission for net zero commitment in 2070s as per GOI's panchamrit. While in other levels also , jump is huge because of better technology evolvement.

Table 4. 5 : Energy Supply by Wind at different levels 2047(Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Wind	Level 1	5.9	11.89	22	42.21	68.77	97
	Level 2	5.9	15	31	55	86	118
	Level 3	5.9	16.71	37.97	71	113	157
	Level 4	5.9	19.23	45	83.87	130	179
	Net zero scenario	5.9	16.42	35	65.72	104	104

4.1.6 Hydro

India is the 5th largest producer of hydroelectricity in the world, with an installed capacity of 46,512 MW as of March 2023.[19] Hydropower is the largest source of renewable energy in India, accounting for about 12% of the country's total electricity generation.India has an estimated hydroelectric potential of 148,700 MW, of which only about 46,000 MW has been developed so far.[19]The states with the highest hydroelectric potential are Himachal Pradesh, Uttarakhand, Arunachal Pradesh, and Jammu and Kashmir.The largest hydroelectric power plant in India is the Tehri Dam in Uttarakhand, with an installed capacity of 2,400 MW.Other major hydroelectric power plants in India include the Bhakra Nangal Dam in Punjab, the Idukki Dam in Kerala, and the Nagarjuna Sagar Dam in Andhra Pradesh.Hydropower is a clean and renewable source of energy that has several advantages over other sources of energy..The government has set a target of installing 175 GW of hydroelectric power capacity by 2030[19]. In order to achieve this target, the government is promoting public-private partnerships for hydroelectric projects and is providing financial incentives for the development of hydropower projects. Major hydro plant are shown in the fig: 4.2

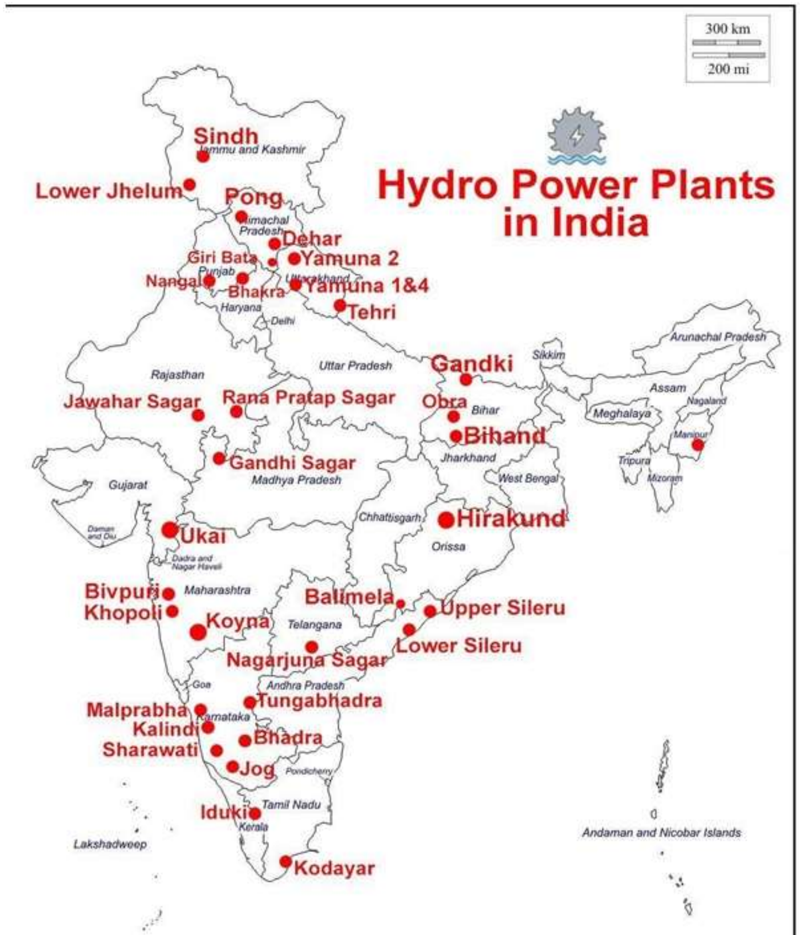


Fig 4. 2 Major hydro power plant,[20]

The states with the highest installed hydroelectricity capacity in India are:Maharashtra (11,295 MW),Uttarakhand (5,605 MW),Madhya Pradesh (5,433 MW),Karnataka (4,835 MW),Tamil Nadu (4,394 MW)

4.1.6.1 Energy Supply by Hydro at different levels 2047(Mtoe)

The current energy supply by hydro in 2022 is 13.94 mtoe while it is 20,25.9,33,45,27 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in supply is not significantly higher i.e from 13.94 in 2022 to 27 only in 2047 .i.e almost 2 times (table : 4.7).

Table 4. 6 : Energy Supply by hydro at different levels 2047(Mtoe)

	Levels	2022	2027	2032	2037	2042	2047
Hydro	Level 1	13.94	15.79	17	19.48	19.83	20
	Level 2	13.94	15.95	18	20.35	25	25.9
	Level 3	13.94	17	20.24	24	28	33
	Level 4	13.94	19.27	23.9	29.65	36.79	45
	Net zero scenario	13.94	16.93	19.98	23.55	27	27

4.1.7 Nuclear

Nuclear power is a clean and reliable source of energy that has been playing an important role in India's energy mix for over 50 years. Nuclear power currently accounts for about 6% of India's total electricity generation.India has 22 nuclear power plants in operation, with an installed capacity of 6,780 MW [21].The states with the most nuclear power plants are Maharashtra, Gujarat, Tamil Nadu, and Karnataka.Nuclear power is a controversial source of energy, and there are a number of concerns about its safety and environmental impact. However, the Indian government is committed to nuclear power, and it has plans to increase the share of nuclear power in the country's energy mix to 25% by 2050[21].. Pressurized Heavy Water Reactors (PHWR), which use natural uranium, account for about 65% of the present installed capacity. 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.

4.1.7.1Energy Supply by Nuclear at different levels

2047(Mtoe)

The current energy supply by nuclear in 2022 is 13 mtoe while it is 105,138,214,304,130 mtoe in level 1, level 2, level 3, level 4 and Net zero scenario. For net zero scenario , the increase in supply is huge i.e from 13 in 2022 to 130 in 2047 .i.e almost 10 times (table : 4.8).It is because of focusing on reducing emission for net zero commitment in 2070s as per GOI's panchamrit. While in other levels also , jump is huge because of better technology evolvement.

Table 4. 7: Energy Supply by Nuclear at different levels 2047(Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Nuclear	Level 1	13.04	22.6	33	48.8	71.7	105
	Level 2	13.04	26.52	40	61.07	91	138
	Level 3	13.04	29	48.08	79	130	214
	Level 4	13.04	27.55	48.76	89	165.53	304
	Net zero scenario	13.04	29.18	48	79.2	130	130

4.1.8 Cross border electricity trade(Net Electricity import)

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[10] as mentioned inTable: 4.9

4.1.8.1Electricity import at different levels 2047(Mtoe)

Table 4. 8 : Electricity import at different levels 2047(Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Electricity import	Level 1	-0.14	0.03	0.49	1.18	1.51	1.92
	Level 2	-0.14	-0.13	0.19	0.74	0.94	1.2
	Level 3	-0.14	-0.3	-0.1	0.29	0.29	0.47
	Level 4	-0.14	-0.47	-0.4	-0.15	-42.76	-119
	Net zero scenario	-0.14	-0.13	0.19	0.74	0.94	0.94

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 (Fig :4.3 , fig:4.4

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. Fig :4.3 , fig:4.4

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. Fig :4.3 , fig:4.4

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. Fig :4.3 , fig:4.4

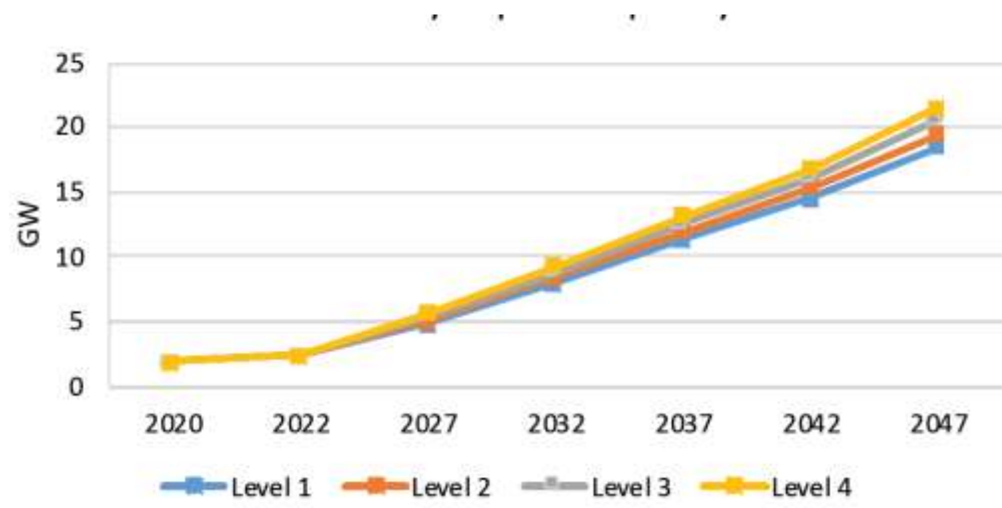


Fig 4. 3 :Electricity Export Capacity

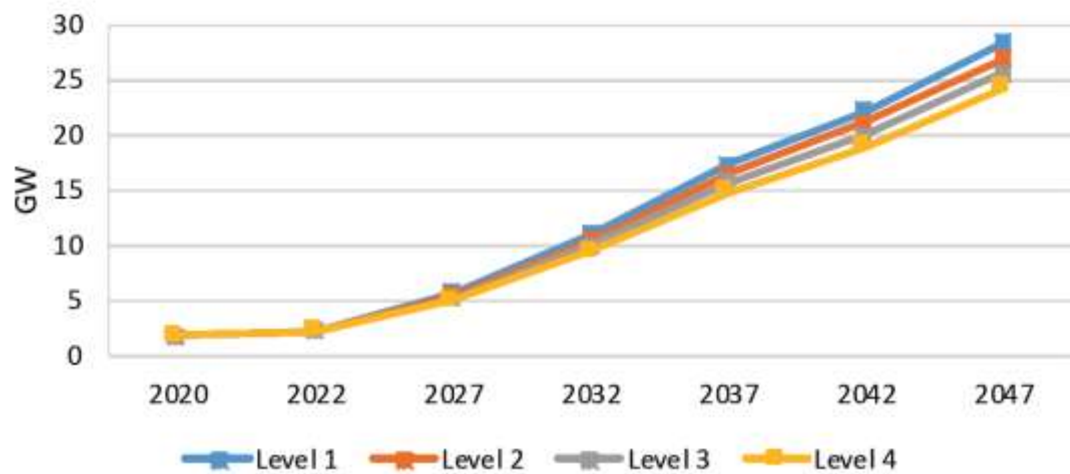


Fig 4. 4: Electricity Import Capacity

4.1.9 Biofuel

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.[10] Feed stocks 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.

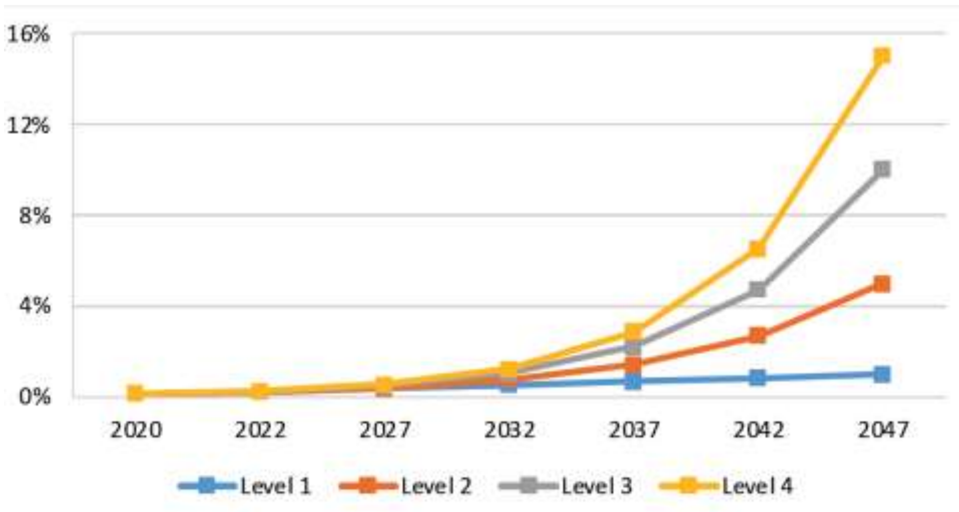


Fig 4. 5: Biodiesel Blending

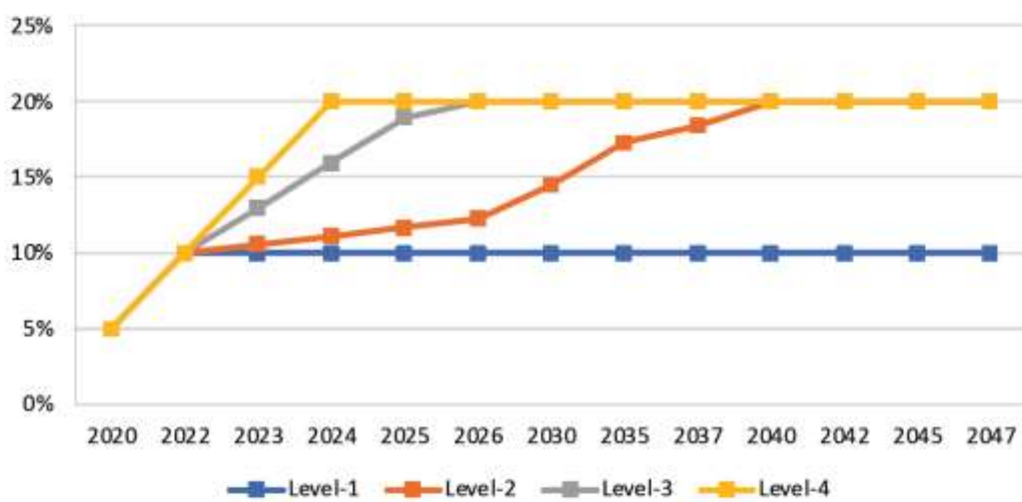


Fig 4. 6 Ethanol Blending in Petrol

4.2 Total supply

From table: 4.10 total supply in 2022 is 857 mtoe while it is 2895,1844,1559,1442,1523 in level 1, level 2, level 3, level 4 and Net zero in 2047 . All these supply are more than demand in respective levels of respective demand which is 1883,1450,1227,1076,1287 mtoe. So since supply surpass demand in all 4 levels thus making sure energy security is ensured.

Table 4. 9: Total supply projection (mtoe),[6]

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Total	**Level 1**	857.54	1152	1490	1861	2323	2895
	Level 2	829	1035	1229	1408	1609	1844
	Level 3	818	991	1160	1278	1403	1559
	Level 4	801	948	1044	1103	1220	1442
	Net zero scenario	823.5	1019	1196	1347	1523	1523

Chapter-5

Results and Discussion

5. 1 Net Zero?

Before discussion result , discussion & analysis side, it is to be noted that Net Zero scenario is the prime focus area of this thesis. It is mainly because of our commitment on international platform such as UNEP,IUCN, UNFCCC, UNCBD and IPCC ete Other scenario such as Level 1, level 2, level 3 and level 4 focused more on economic aspect while is more focused on environmental aspect.

Net zero emission is a target where the amount of greenhouse gases emitted into the atmosphere is balanced by the amount of greenhouse gases removed from the atmosphere. India has committed to achieving net zero emissions by 2070[PIB] This is a challenging but achievable target, and there are a number of pathways that India could take to reach it. One important pathway is to accelerate the transition to renewable energy. India has already made significant progress in this area, and it is now the world's fourth-largest producer of solar power. By 2070, India could be generating all of its electricity from renewable sources, such as solar, wind, and hydro power. Another important pathway is to improve energy efficiency. India's energy intensity (the amount of energy used per unit of GDP) is still high compared to developed countries. By improving energy efficiency, India could reduce its energy consumption and the associated emissions. 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 by2047 but also be on a path of reaching net zero by 2070.

Analysis of Energy savings

There are 5 trajectories(L1,L2,L3,L4 & Net Zero) and usually BAU(Level 2) is taken as reference for finding energy saving. It is calculated as percentage of ratio of change in BAU & Level to the BAU in 2047. □

Each sector as well as total demand, total supply are also compared.

5.2 Sector specific energy analysis :

1. **Building** -Total Saving of energy in building sector when compared between BAU and Net zero scenario is 5.71% energy as seen from fig: 5.1 While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -21%,14.53%, 30.81 % respectively as seen in table . It can be seen from table: , 5.1) L1 require highest energy while L4 require least energy. Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 1 % Saving of energy in building sector between BAU and other levels,[10]

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Building	**2047- Level 1**	208.17	-36.17	-21.03%
	2047- Level 2	172	0	0.00%
	2047- Level 3	147	25	14.53%
	2047- Level 4	119	53	30.81%
	Net zero scenario	162.18	9.82	5.71%

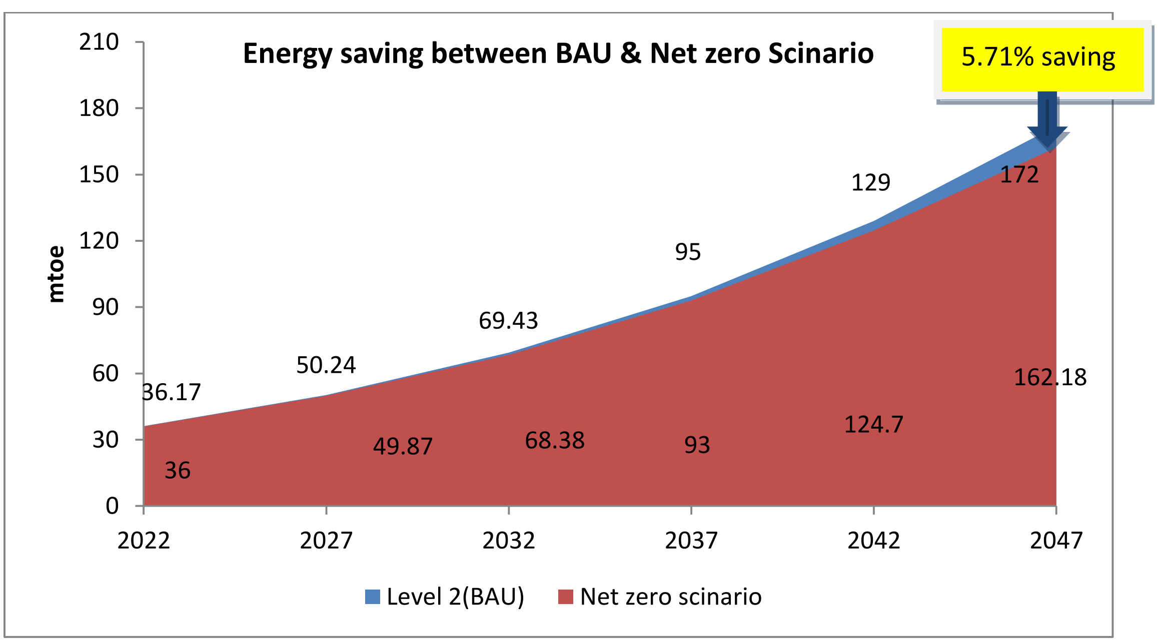


Fig 5. 1 Energy saving between BAU & Net zero Scenario in Building sector,[10]

2 .Industry -Total Saving of energy in industry sector when compared between BAU and Net zero scenario is 16.20% energy as seen from fig: 5.2. While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -34.79%,16.28%,24.16 % respectively as seen in table . It can be seen from table: 5.3. L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 2 % Saving of energy in industry sector between BAU and other levels

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Industry	2047- Level 1	1043.3	-269.3	-34.79%
	2047- Level 2	774	0	0.00%
	2047- Level 3	648	126	16.28%
	2047- Level 4	587	187	24.16%
	Net zero scenario	648.6	125.4	16.20%

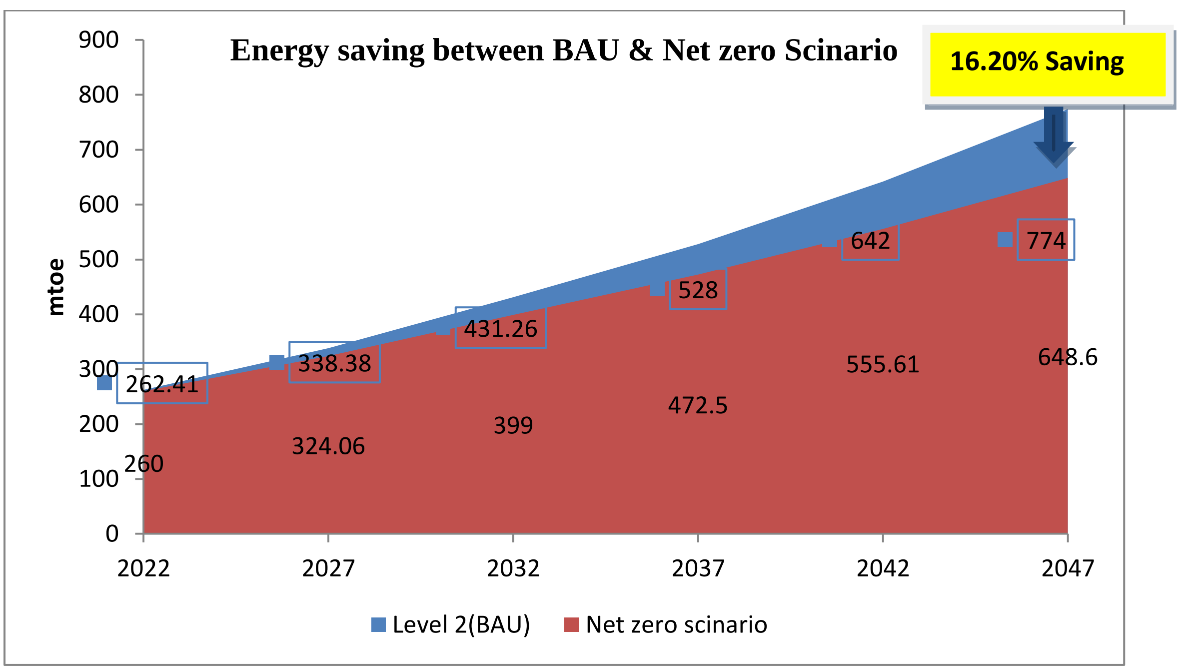


Fig 5. 2 Energy saving between BAU & Net Zero Scenario in industry sector

3. Transport

Total Saving of energy in transport sector when compared between BAU and Net zero scenario is 9.58% energy as seen from fig:5.3 . While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -31.49%,18.25%,34.92 % respectively as seen in table 5.4 . It can be seen from table: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 3 % Saving of energy in transport sector between BAU and other levels,[10]

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Transport	2047- Level 1	331.36	-79.36	-31.49%
	2047- Level 2	252	0	0.00%
	2047- Level 3	206	46	18.25%
	2047- Level 4	164	88	34.92%
	Net zero scenario	227.85	24.15	9.58%

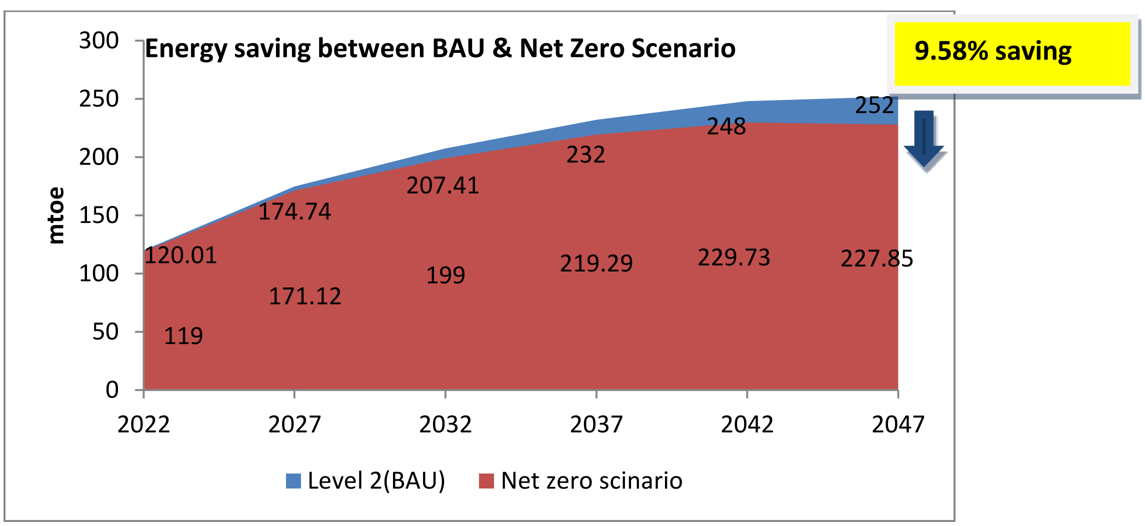


Fig 5. 3 Energy saving between BAU & Net Zero Scenario in Transport sector

4. Agriculture (Pumps and Tractor)

Total Saving of energy in agriculture sector when compared between BAU and Net zero scenario is 0 % energy as seen from fig: 5.4While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -19.39%,22.39%,37.31 % respectively as seen in table . It can be seen from table: ,5.5 L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 4 % Saving of energy agriculture sector between BAU and other levels

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Agriculture	2047- Level 1	79.99	-12.99	-19.39%
	2047- Level 2	67	0	0.00%
	2047- Level 3	52	15	22.39%
	2047- Level 4	42	25	37.31%
	Net zero scenario	67	0	0.00%

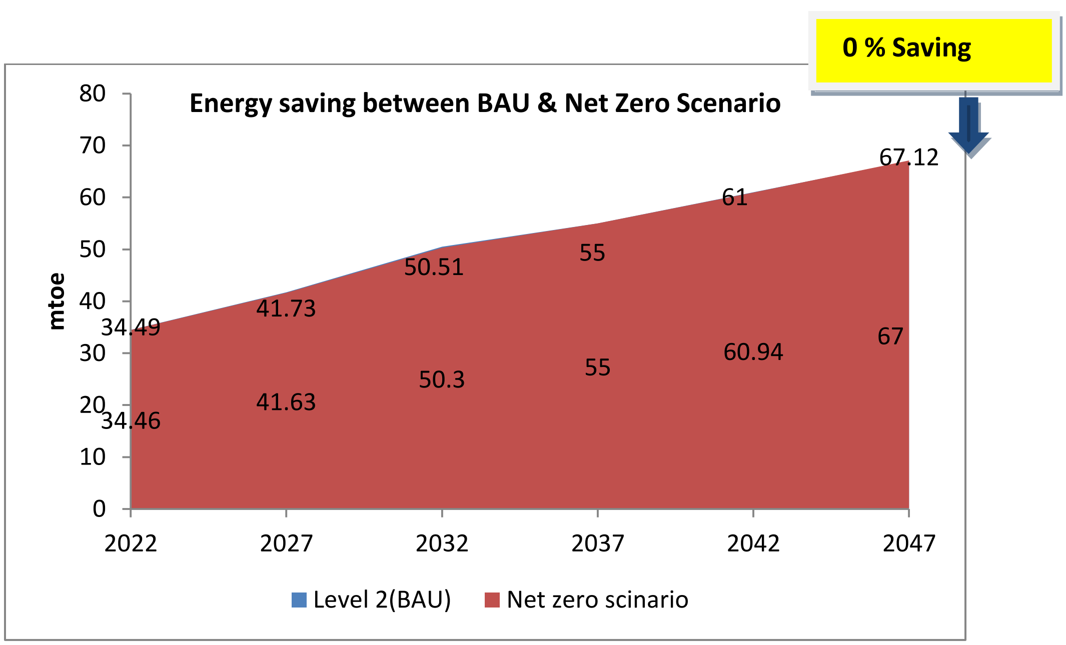


Fig 5. 4 Energy saving between BAU & Net Zero Scenario in Agriculture Sector

5. Telecom

Total Saving of energy in telecom sector when compared between BAU and Net zero scenario is 0 % energy as seen from fig: 5.5. While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -15.72%,11.71%,23.48 % respectively as seen in table .5.6 It can be seen from table: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 5 % Saving of energy telecom sector between BAU and other levels,[10]

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Telecom	2047- Level 1	19.66	-2.67	-15.72%
	2047- Level 2	16.99	0	0.00%
	2047- Level 3	15	1.99	11.71%
	2047- Level 4	13	3.99	23.48%
	Net zero scenario	16.99	0	0.00%

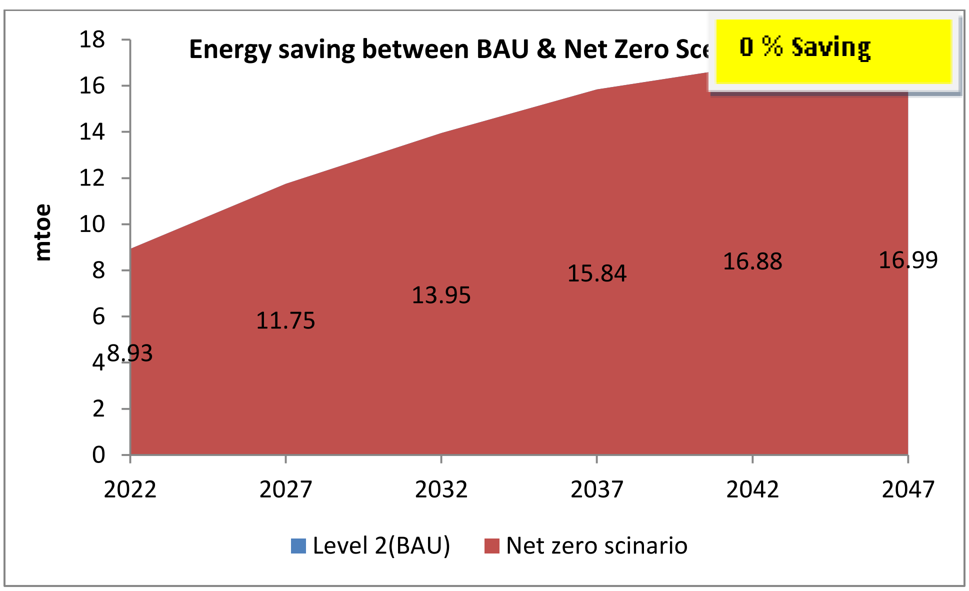


Fig 5. 5: Energy saving between BAU & Net Zero Scenario in Telecom Sector

6. Cooking

Total Saving of energy in cooking sector when compared between BAU and Net zero scenario is 0 % energy as seen from fig: 5.6 While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -20.31%,7.76%,12.88 % respectively as seen in table . It can be seen from table:5.7 , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 6: % Saving of energy cooking sector between BAU and other levels

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Cooking	2047- Level 1	70.43	-11.89	-20.31%
	2047- Level 2	58.54	0	0.00%
	2047- Level 3	54	4.54	7.76%
	2047- Level 4	51	7.54	12.88%
	Net zero scenario	58.54	0	0.00%

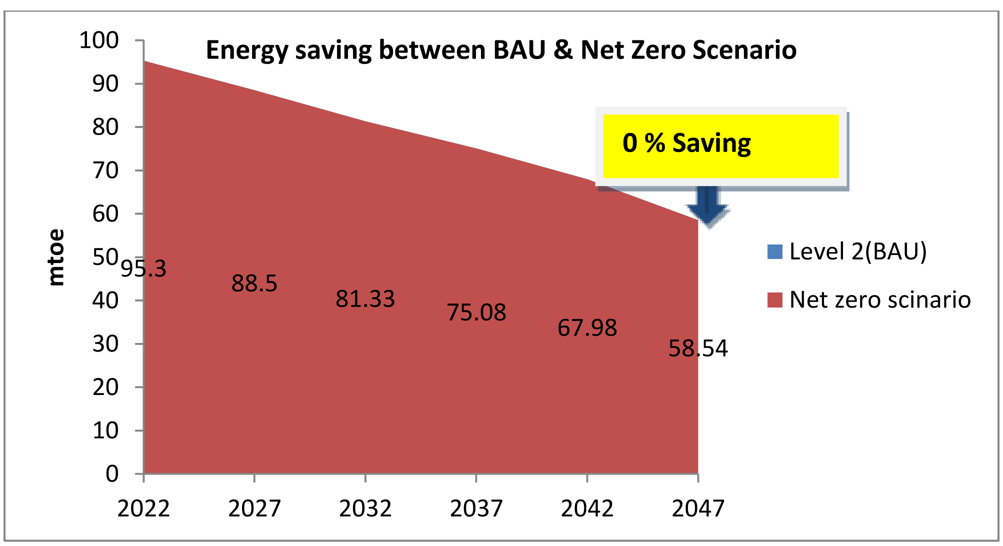


Fig 5. 6: Energy saving between BAU & Net Zero Scenario in Cooking Sector

5.3 Total demand

Total demand side saving when compared between BAU and Net zero scenario is 11.22 % energy as seen from fig: 5.7. While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -29.90%,15.38%,25.75 % respectively as seen in table . It can be seen from table:5.8, L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Table 5. 7 % Saving of total demand between BAU and other levels

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Total demand	**2047- Level 1**	1883.56	-433.56	-29.90%
	2047- Level 2	1450	0	0.00%
	2047- Level 3	1227	223	15.38%
	2047- Level 4	1076	374	25.79%
	Net zero scenario	1287.24	162.76	11.22%

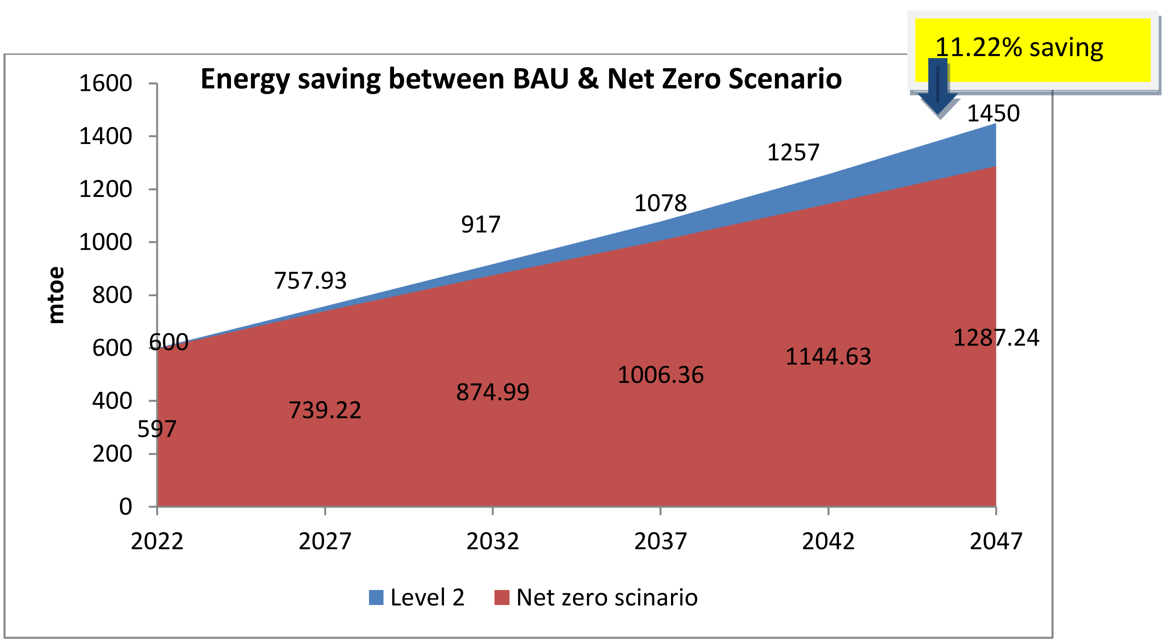


Fig 5. 7 Energy saving between BAU & Net Zero Scenario in total energy demand

5.4 Total Supply

Total Saving of energy in supply when compared between BAU and Net zero scenario is 17.41 % energy While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -57%, 15.46%, 21.8 % respectively as seen in table .5.9 It can be seen from table: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved (Can be seen from table 5.9).

Table 5. 8 % Saving of total supply between BAU and other levels

Sector/year	Levels(2047)	Mtoe	Change in energy wrt BAU	%Energy saving
Total Supply	**2047- Level 1**	2895	-1051	-57.00%
	2047- Level 2	1844	0	0.00%
	2047- Level 3	1559	285	15.46%
	2047- Level 4	1442	402	21.80%
	Net zero scenario	1523	321	17.41%

5.5 Resource wise Energy Supply saving

All resource of energy supply are clubbed in to 5 major(Coal, oil, petroleum, natural gas and Renewable resource), then %saving in energy is calculated between BAU and Net Zero. Energy saving in coal, oil& petroleum, Natural gas and Renewable energy are 28.40%,20.90%,-13.90%,-24.30% respectively(Fig 5.8) which clearly means that to achieve net Non Zero carbon by 2070s coal , oil petroleum has to be less than BAU while natural gas and Renewable resource has to be more than BAU Value.

Table 5. 9 : Energy supply in BAU Scenario (Level 2) vs Net Zero Scenario

Resource wise Energy Supply in 2047 (mtoe)			
Resources	**Business-as-usual (BAU) Scenario**	**Net Zero Scenario**	**% Saving**
Coal	685.21	490.44	28.40%
Oil and Petroleum Products	430.6	340.52	20.90%
Natural Gas	178.94	203.27	-13.60%
Renewables and Clean Energy	548.92	682.22	-24.30%
Total	1843.67	1716.43	6.90%

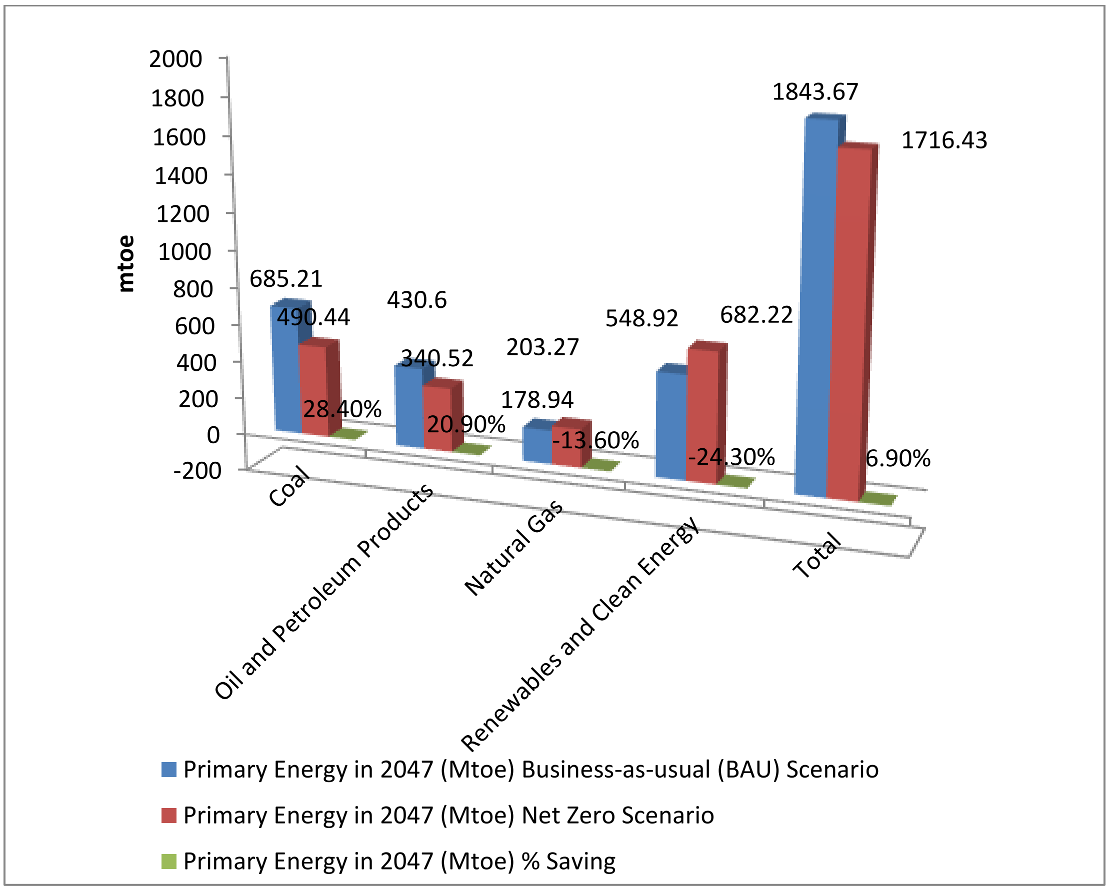


Fig 5. 8 Energy supply

5.6 .Demand vs supply comparison

From the table , it is very clear that supply of energy in 2047 in all 5 scenario(2895 mtoe,1844 mtoe,1559 mtoe, 1442 mtoe, 1523 mtoe) is more than it's respective demand (1883 mtoe, 1450 mtoe, 1227 mtoe, 1076 mtoe, 1287 mtoe) thus having surplus of supply, leading to ensuring energy security. It can be also observed from table 5.11 that net zero supply value 1523 mtoe is more than all levels of demand value i.e 1450,1227,1076 except for L1 which is 1883 . Thus following the trajectory of net zero scenario of supply side , we can ensure energy security irrespective of levels of demand side(except L1 of demand).

Note: % Surplus of supply over is calculated as ratio of difference between supply and demand to the demand.

Table 5. 10 : Total supply vs demand comaparison(Mtoe)

Parameter	2047-L1	2047-L2	2047-L3	2047-L4	2047-Net Zero scenario
Demand(mtoe)	1883	1450	1227	1076	1287
Supply (mtoe)	2895	1844	1559	1442	1523
(Surplus)Supply- Demand	1012	394	332	366	236
% Surplus of supply over demand	54%	27%	27%	34%	18%

Chapter-6

Conclusion

6.1 Conclusion

Findings

Demand Supply comparison- it is very clear that supply of energy in 2047 in all 5 scenario(2895 mtoe,1844 mtoe,1559 mtoe, 1442 mtoe, 1523 mtoe) is more than it's respective demand (1883 mtoe, 1450 mtoe, 1227 mtoe, 1076 mtoe, 1287 mtoe) thus having surplus of supply(as surplus in L1, L2, L3, L4 and Net Zero is 1012,394,332,366,236 respectively) , leading to ensuring energy security. It can be also observed that net zero supply value 1523 mtoe is more than all levels of demand value i.e 1450,1227,1076 except for L1 which is 1883 . Thus following the trajectory of net zero scenario of supply side , we can ensure energy security irrespective of levels of demand side(except L1 of demand).

Energy Demand: Total demand side saving when compared between BAU and Net zero scenario is 11.22 % energy a While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -29.90%,15.38%,25.75 % respectively .It can be observed: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved. 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.

Energy supply: Total Saving of energy in supply when compared between BAU and Net zero scenario is 21.8 % .While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -57%, 15.46%, 21.8 % respectively. It is found that L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.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.

Demand in building sector- Total Saving of energy in building sector when compared between BAU and Net zero scenario is 5.71% energy. While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -21%,14.53%, 30.81 % respectively .It can be seen from table: , L1 require highest energy while L4 require least energy. Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Demand in industry sector- Total Saving of energy in industry sector when compared between BAU and Net zero scenario is 16.20% energy While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -34.79%,16.28%,24.16 % respectively. It can be seen, that L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Demand in transport sector- Total Saving of energy in transport sector when compared between BAU and Net zero scenario is 9.58% energy While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -31.49%,18.25%,34.92 % respectively as seen in table . It can be seen : , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2nd best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved

Demand in agriculture sector-Total Saving of energy in agriculture sector when compared between BAU and Net zero scenario is 0 % energy: . While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -19.39%,22.39%,37.31 % respectively as seen in table . It can be seen, L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2^{nd} best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved

Demand in telecom sector- Total Saving of energy in telecom sector when compared between BAU and Net zero scenario is 0 % energy While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -15.72%,11.71%,23.48 % respectively .It can be seen from table: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2^{nd} best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Demand in cooking sector- Total Saving of energy in cooking sector when compared between BAU and Net zero scenario is 0 % energy. While energy saving in between L1 and BAU(L2) , L3 and BAU(L2) , L4 and BAU(L2) are -20.31%,7.76%,12.88 % respectively.. It can be seen from table: , L1 require highest energy while L4 require least energy. . Though path 4 is the best path because of highest savings but it is practically very difficult to achieve. 2^{nd} best path is Net Zero path. Following it , will make sure India's commitment to World for Net Zero carbon emission by 2070s will be achieved.

Resource wise Energy Supply saving- All resource of energy supply are clubbed in to 5 major(Coal, oil, petroleum, natural gas and Renewable resource), then %saving in energy is calculated between BAU and Net Zero. Energy saving in coal, oil& petroleum, Natural gas and Renewable energy are 28.40%,20.90%,-13.90%,-24.30% respectively which clearly means that to achieve net Non Zero carbon by 2070s coal , oil petroleum has to be less than BAU while natural gas and Renewable resource has to be more than BAU Value.

Import dependence : Import dependence in oil , coking coal, Gas and Non coking coal changed from 87.15%(2022) to 80.34%(2047), 57.76%(2022) to 70.86%(2047), 55.41%(2022) to 63.66%(2047), 23.79%(2022) to 4.64%(2047) which means that moving more towards renewable target because decrease in oil % and increase in gas which is less polluting.

Renewable and clean energy : 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 demand :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 means rise in ensuring electricity connectivity.

Decarbonization in installed power Capacity : 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 :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. And CO_2 emission from 2553 million(2022) to 3541 million tone in 2047, a move towards panchamrit scheme.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: 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.

Based on above findings, it can be said that supply availability in all level is more than demand of energy despite pushing towards renewable energy thus energy security with rise in population, GDP, and urbanization is a challenge but achievable if working as per prescribed scenario. And best case optimized scenario is Net zero scenario because it address both environment- ecology and economy. A push to solar, nuclear, hydro is need of hour having a clear cut future policy as per demand projection.

6.2 Scope of Future Work

Projected data used in the case study have some of the limitation and projection next projection can be made after filling those gap and increasing the number of variables used in projection. Also future supply is very dynamic , varies every moment depending on geopolitics. So projected data used should have a robust and resilient supply side.Flex vehicles which can support ethanol blending more than 20%, are also to be considered for wider scope projection because our study had data projection based on less than 20% blending. Energy consumed by tractors and pumps in agriculture sector are only considered hence, further parameters like energy required for other mechanized instruments such as tillers, levelers etc. can be taken into consideration .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. These factor can thought for better projection. Transmission and Distribution requirements to support the growing capacity needs has not been modeled thus has could be included. The use of Sustainable Aviation Fuel (SAF) to promote greening of aviation sector Can be desired parameter . Infrastructure cost of setting of green hydrogen and charging station must be taken in account. 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. 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. So considering the limitation of these in projection could be considered.

Chapter-7

Annexure

7.1 Annexure

7.1.1 Energy Demand 2047(In Mtoe)

Sector/year	Levels	2022	2027	2032	2037	2042	2047
Building	**Level 1**	36.22	51.33	72.84	103.42	146.8	208.17
	Level 2	36.17	50.24	69.43	95	129	172
	Level 3	36.12	49	66	89	116	147
	Level 4	36.05	47	62	80	100	119
	Net zero scenario	36	49.87	68.38	93	124.7	162.18
Industry	**Level 1**	271.87	369.77	498.08	643.66	824.2	1043.3
	Level 2	262.41	338.38	431.26	528	642	774
	Level 3	260	324	399	472	555	648
	Level 4	257	315	381	443	512	587
	Net zero scenario	260	324.06	399	472.5	555.61	648.6
Transport	**Level 1**	120.18	186.05	233.34	275.65	309.43	331.36
	Level 2	120.01	174.74	207.41	232	248	252
	Level 3	119	155	189	204	210	206
	Level 4	119	155.62	169	175	174	164
	Net zero scenario	119	171.12	199	219.29	229.73	227.85
Agriculture	**Level 1**	34.81	43.14	53.47	61.61	70	79.99
	Level 2	34.49	41.73	50.51	55	61	67
	Level 3	33	39	46	48	50.5	52
	Level 4	33.5	37	42	42	42	42
	Net zero scenario	34.46	41.63	50.3	55	60.94	67.12
Telecom	**Level 1**	8.95	11.89	14.32	16.64	18.38	19.66
	Level 2	8.93	11.75	13.95	15.84	16.88	16.99
	Level 3	8.93	11	13	15	15.63	15
	Level 4	8.89	11	13	14	14	13
	Net zero scenario	8.93	11.75	13.95	15.84	16.88	16.99
Cooking	**Level 1**	96.58	92.21	87.21	83.1	77.83	70.43
	Level 2	95.3	88.5	81.33	75.08	67.98	58.54
	Level 3	92	73	58	53	53.63	54
	Level 4	90.41	61.91	52	42	50.75	51
	Net zero scenario	95.3	88.5	81.33	75.08	67.98	58.54

Miscellaneous	**Level 1**	43.04	55.18	68.83	85.2	105.44	130.63
	Level 2	42.68	52.58	63.3	75.68	90.52	108.39
	Level 3	42	51.9	62	73	86.84	102.73
	Level 4	42	50.65	59	14.78	81.75	96
	Net zero scenario	42.54	52.29	62.64	74.58	88.84	105.95
Total	**Level 1**	611.65	809.56	1028.09	1269.28	1552.14	1883.56
	Level 2	600	757.93	917	1078	1257	1450
	Level 3	591	715.77	835	956	1089	1227
	Level 4	588	680.2	780	877	976	1076
	Net zero scenario	597	739.22	874.99	1006.36	1144.63	1287.24

7.1.2 Energy Supply 2047(In Mtoe)

Sector/year	**Levels**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Solar	**Level 1**	7.54	19.28	37	61.3	87.98	113
	Level 2	7.72	23.65	52	91.86	140	188
	Level 3	7.89	29.2	65	114	173	230
	Level 4	8.13	34.82	82	147	225	302
	Net zero scenario	7.9	29	64	112	170	170
Wind	**Level 1**	5.9	11.89	22	42.21	68.77	97
	Level 2	5.9	15	31	55	86	118
	Level 3	5.9	16.71	37.97	71	113	157
	Level 4	5.9	19.23	45	83.87	130	179
	Net zero scenario	5.9	16.42	35	65.72	104	104
Hydro	**Level 1**	13.94	15.79	17	19.48	19.83	20
	Level 2	13.94	15.95	18	20.35	25	25.9
	Level 3	13.94	17	20.24	24	28	33
	Level 4	13.94	19.27	23.9	29.65	36.79	45
	Net zero scenario	13.94	16.93	19.98	23.55	27	27
Nuclear	**Level 1**	13.04	22.6	33	48.8	71.7	105
	Level 2	13.04	26.52	40	61.07	91	138
	Level 3	13.04	29	48.08	79	130	214
	Level 4	13.04	27.55	48.76	89	165.53	304

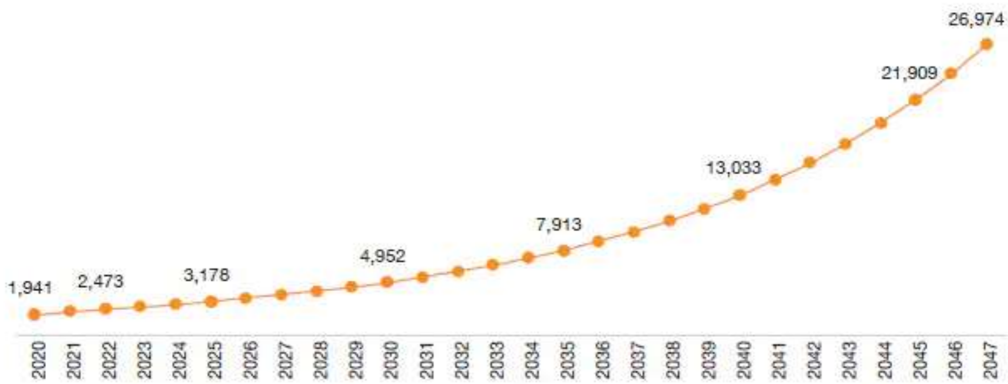
	Net zero scenario	13.04	29.18	48	79.2	130	130
Coal	**Level 1**	432.46	579.16	764	951.31	1201	1536
	Level 2	409	490.82	555.58	592.52	627	685
	Level 3	403.81	468	519	483	418	359
	Level 4	397	457	431.83	326	269	276
	Net zero scenario	405	477	527.52	522.95	511	511
Oil and petroleum products	**Level 1**	236.57	333	425	519	619	727
	Level 2	232	299	348	385	414	431
	Level 3	230	277	305	316	316	463
	Level 4	216	240.85	241	221	183	141
	Net zero scenario	230.92	285.83	319.1	337	344	344
Natural Gas	**Level 1**	54.6	75	94	117	144	176
	Level 2	54.93	75	96	119	146	179
	Level 3	55.15	80	105	134	134	206
	Level 4	55.34	82.11	109.45	140	175	215.34
	Net zero scenario	54.83	79.31	104	133	166	166
Electricity import	**Level 1**	-0.14	0.03	0.49	1.18	1.51	1.92
	Level 2	-0.14	-0.13	0.19	0.74	0.94	1.2
	Level 3	-0.14	-0.3	-0.1	0.29	0.29	0.47
	Level 4	-0.14	-0.47	-0.4	-0.15	-42.76	-119
	Net zero scenario	-0.14	-0.13	0.19	0.74	0.94	0.94
Others	**Level 1**	93.62	94.39	94	99.65	107.9	119
	Level 2	91.61	87.83	82.76	80.52	79.29	78.66
	Level 3	88	72	57.97	54	60	76
	Level 4	92.15	68	61.39	65	76.06	95.6
	Net zero scenario	91.39	85.59	77.91	72.1	66.63	66
Total	**Level 1**	857.54	1152	1490	1861	2323	2895
	Level 2	829	1035	1229	1408	1609	1844
	Level 3	818	991	1160	1278	1403	1559
	Level 4	801	948	1044	1103	1220	1442
	Net zero scenario	823.5	1019	1196	1347	1523	1523

7.1.3 Household (Rural & Urban)

Parameter	Units	2020	2022	2032	2037	2042	2047
Population	**Millions**	1349	1375	1490	1535	1569	1592
Urban Population	**Millions**	472	497.4	627.5	691.9	753.5	811.9
Rural Population	**Millions**	876.6	877.2	862.6	843.1	815.1	780.1
Household Size - Urban	**People/ household**	4.2	4.14	3.85	3.7	3.56	3.41
Household Size - Rural	**People/ household**	4.5	4.45	4.19	4.07	3.94	3.81
Total Households	**Millions**	307.2	317.3	368.8	394.2	418.9	442.9
Urban Households	**Millions**	112.4	120.1	163	186.9	211.9	238.1
Rural Households	**Millions**	194.8	197.2	205.7	207.4	207	204.8
Urbanization	**%**	35%	36.20%	42.10%	45.10%	48.00%	51%
Share of Manufacturing	**%**	14.40%	15.70%	22.20%	25.50%	28.70%	32.00%

7.1.4 India GDP 2047

Per capita GDP (USD)



Assumptions

Nominal GDP – growth rate of 12% p.a. applied on base-level GDP of 2021–22

Population growth – decelerating growth @0.01% after every 5 years used on base-level population growth of 0.99% for 2020

Exchange rate – depreciation vis-à-vis dollar assumed to be 2% p.a. during 2020–25 and improving @0.5% after every 5 years thereafter

Data Sources

(1) World Bank data (for base-level population and population growth)

(2) Second Advance Estimates of National Income released by the Ministry of Statistics and Programme Implementation, Government of India (for base-level GDP)

(3) Financial Benchmark India Pvt. Ltd (FBIL) (for base-level exchange rate)

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