Chapter 5
India Country Report[1]

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1. Background

India, now the most populous country globally, surpassing China in 2023, is the seventh-largest nation by area, covering over 3.2 million square kilometres. With a geographic expanse spanning 30° in longitudinal and latitudinal extent, India is a mosaic of diversity. This diversity is evident in its climate, topography, and cultural mosaic. From the majestic Himalayas in the north to the vast coastal plains, India's landscapes include mountains, plateaus, seas, deserts, and islands. These varied landscapes give rise to diverse climatic conditions, influencing regional patterns in diet, clothing, and culture. The Himalayas act as a climatic barrier, shielding the northern regions from extreme winters, whilst the coastal areas experience moderated temperatures due to the sea's influence. However, this diversity also brings challenges, as evident in the stark developmental contrasts between the western and eastern regions and the varying energy demands throughout the year.

Economically, India holds a significant position globally, boasting a gross domestic product (GDP) purchasing power parity of US$10.6 trillion (constant 2017) in 2022 (World Bank, 2023). Despite rapid economic growth, the nation faces challenges such as high inflation, unemployment, and external pressures like the conflict in Ukraine. Yet, India's resilience in economic expansion offers optimism for future growth. Concurrently, the country is tackling socioeconomic issues, including poverty and uneven access to modern energy services.

Since 2000, India's energy consumption has more than doubled, propelled by its burgeoning population and swift economic growth. Remarkably, over 900 million citizens

[1] Based on the Institute of Energy Economics, Japan (IEEJ) model and assumptions.

gained access to electricity in 2 decades, yet per capita energy consumption, at 0.7 toe in 2021, is half the Asian average (Enerdata, 2022). This discrepancy points to a broader issue of development, as reflected in India's Human Development Index (HDI), which stands at 0.633, ranking 132 globally in 2021 (UNDP, 2022). The increasing demand for commercial energy, volatile global fuel prices, and pressure to mitigate greenhouse gas emissions pose significant challenges. Balancing economic growth, enhancing energy infrastructure, and striving for environmental sustainability are critical issues confronting India's policymakers, emphasising the need for sustainable development and improved living standards.

2. Basic Concept of Low-carbon Energy Transition–Carbon Neutral Scenario for India

India is steadfast in its commitment to the international climate agreements, actively pursuing strategies to curtail carbon emissions, augment energy efficiency, and revolutionise energy use patterns. Central to this commitment is the ambitious Panchamrit plan, a quintet of objectives within India's Climate Action Plan. By 2030, the plan envisions achieving 500 gigawatts (GW) of power capacity from non-fossil sources, ensuring 50% of power generation capacity from renewables, reducing the greenhouse gas (GHG) emissions intensity of the economy by 45% by 2030 as compared to 2005 level, slashing carbon emissions by 1 billion tonnes and ultimately attaining net zero by 2070.

A notable endeavour was the introduction of the Lifestyle for the Environment (LiFE) at the United Nations Climate Change Conference in Glasgow (COP26) in November 2021. This initiative aims to foster a global movement towards conscious utilisation of resources, countering the prevailing trend of mindless consumption. It underscores the individual and collective responsibility to adopt lifestyles that minimally impact the Earth. Proponents of this sustainable lifestyle are recognised as 'Pro Planet People' under the LiFE framework.

The energy sector in India was responsible for approximately 75% of total GHG emissions in 2016. India's energy challenges have now got expanded with the need for sustainability and impetus to clean energy deployment becoming important goals to achieve. These include the imperatives of sustainability and a shift towards clean energy. Transitioning to a low-carbon energy system is pivotal for meeting India's net-zero emissions target. The low-carbon energy transition–carbon neutral (LCET–CN) scenario envisages India achieving net-zero emissions by 2070. .

As per the storyline of the LCET–CN scenario for this study, it is envisaged that India will aim for significant energy savings through renewable energy generation and energy efficiency enhancements across various sectors. In the industrial domain, this involves improving efficiency in both small plants and energy-intensive industries. The residential and commercial sectors can achieve substantial savings through efficient end-use

technologies and energy management systems. In transportation, enhancing vehicle fuel economy and effective traffic management are crucial for increased efficiency. Additionally, carbon sequestration initiatives, such as forestry, play a vital role in significantly lowering carbon emissions.

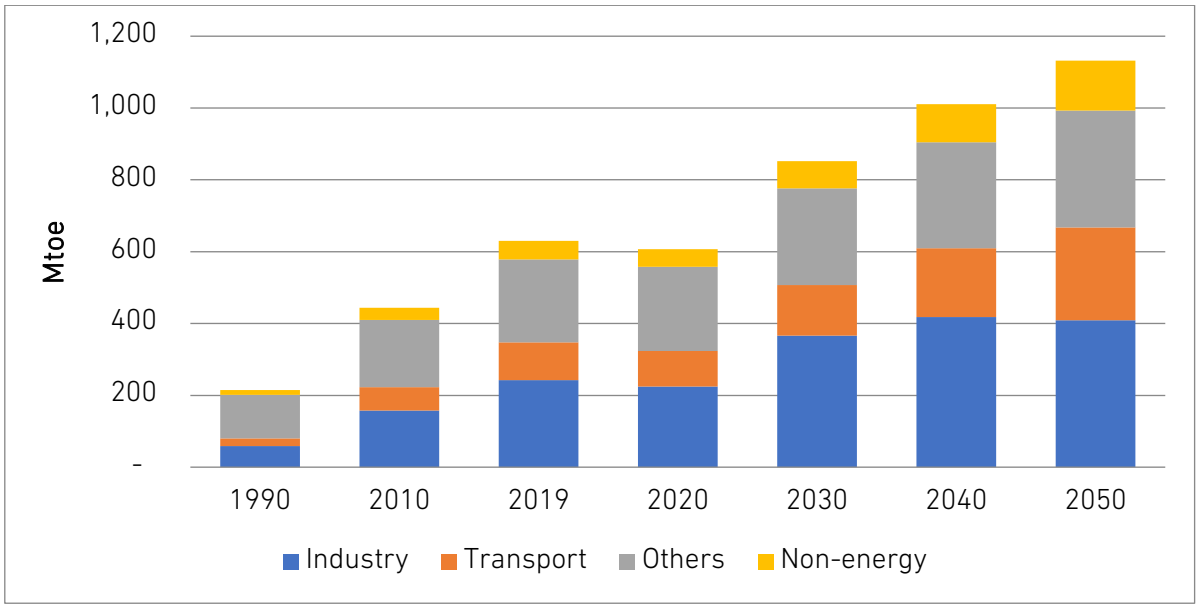
3. Outlook Results – LCET–CN Scenario

3.1. Final Energy Consumption

In the context of the LCET–CN scenario, which assumes robust economic growth and a growing population similar to the business as usual (BAU) scenario, India's total final energy consumption (TFEC) is projected to increase significantly. From around 630 million tonnes of oil equivalent (Mtoe) in 2019, the TFEC is expected to rise to 1132 Mtoe by 2050, growing at an average rate of 1.9% per year (Figure 5.1). This projected increase, whilst substantial, is anticipated to be lower than in the BAU scenario, reflecting the impact of vigorous energy-saving measures, improvements in end-use technology, and the adoption of more efficient energy management systems.

In terms of sector-specific results, the non-energy end-use sector is expected to exhibit the most marked growth, increasing at an average rate of 3.3% annually between 2019 and 2050. The transport and industry sectors also show significant growth, with projected average annual growth rates of 2.9% and 1.7%, respectively. The combined residential and commercial sector ('others') is expected to see modest growth, increasing at an estimated 1.1% per year. However, in terms of share, the energy consumption in the 'others' category is projected to decline from 37% (231 Mtoe) in 2019 to 29% (326 Mtoe) in 2050. By 2050, the industry is continued to be expected to continue holding the highest share of energy demand, although its share is predicted to decrease from 39% in 2019 to 36%. Conversely, driven by the high demand for mobility from the burgeoning population, the transport sector's share is anticipated to increase both in value and proportion, rising from around 17% (105 Mtoe) to 23% (258 Mtoe). Similarly, the non-energy sector's share is projected to grow from about 8% (51 Mtoe) to 12% (139 Mtoe) during the same period. These shifts reflect the evolving landscape of India's energy consumption under the LCET–CN scenario, underscoring the necessity of integrating sustainable and efficient energy practices to meet the country's future energy needs.

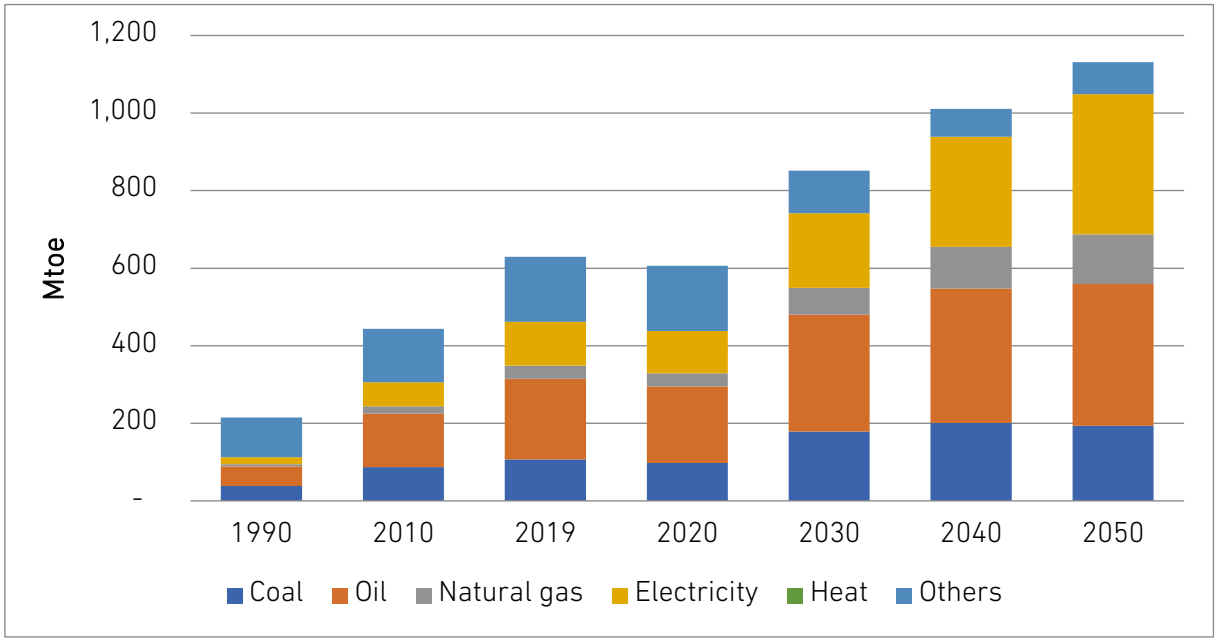
Figure 5.1. Total Final Energy Consumption by Sector, LCET–CN Scenario



Mtoe = million tonnes of oil equivalent.
Note: 'Others' includes residential and commercial sectors.
Source: IEEJ model results.

In the LCET–CN scenario, the analysis of India's final energy demand on a per-fuel basis reveals significant shifts in fuel contributions from 2019 to 2050 (Figure 5.2). Natural gas is projected to experience the most significant increase in its contribution to India's final energy demand, with an annual growth rate of 4.3%. Electricity follows closely, with its contribution expected to grow at an annual rate of 3.8%. This reflects the increasing reliance on electrical power in various sectors of the economy and the ongoing shift towards cleaner energy sources. In contrast, the role of coal in the total primary energy supply is anticipated to decrease by 2050. Whilst still a significant part of the energy mix, coal's contribution in 2050 is projected to be only 17%, equivalent to 193 Mtoe, growing at an annual average rate of 1.9% from 2019 to 2050. This gradual decline indicates a shift away from coal as India progresses towards more sustainable energy sources. The contribution of oil to the energy mix is expected to grow at a relatively modest rate of 1.8% per annum. This slower growth rate reflects the broader global and national trends of reducing dependence on oil for energy, in line with environmental and sustainability goals. Lastly, the end-use sector labelled 'others,' is projected to decrease significantly from 168 Mtoe (26%) in 2019 to 83 Mtoe (7.3%) in 2050. This decline, occurring at an average rate of 2.3% per annum, suggests a substantial reduction in the reliance on traditional biomass sources used for cooking very inefficiently, aligning with the country's transition towards cleaner, more sustainable energy options.

Figure 5.2. Total Final Energy Consumption by Fuel Type, LCET–CN Scenario



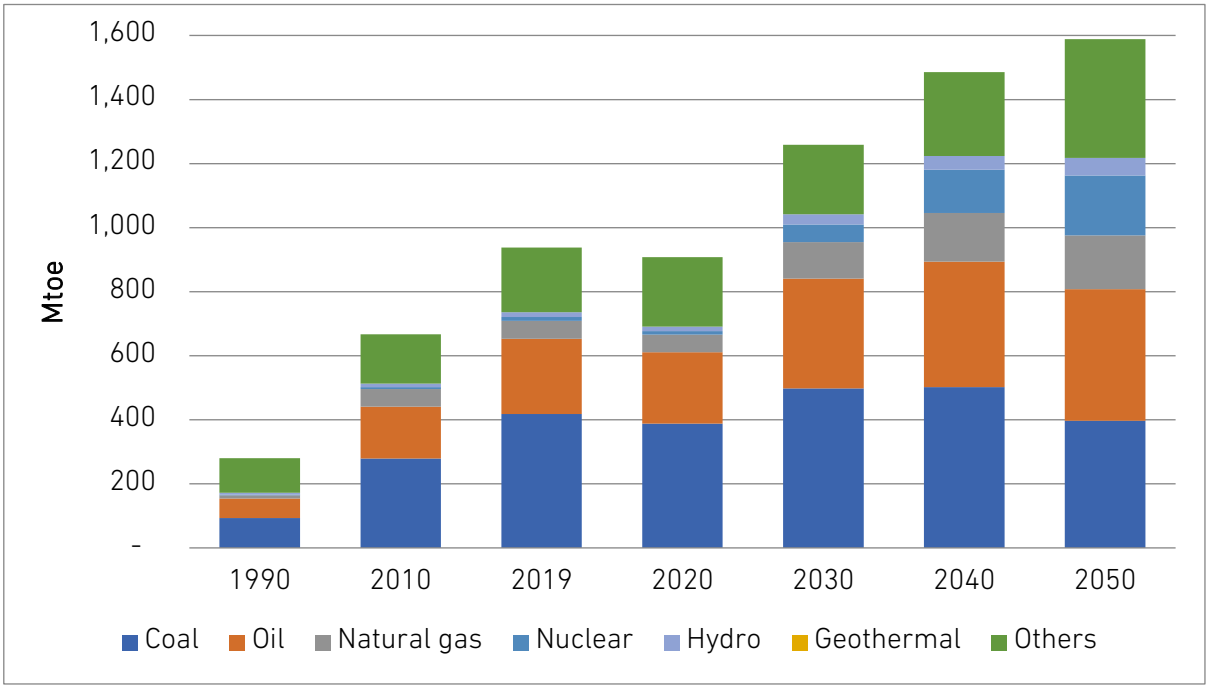
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: IEEJ model results.

Overall, these projections highlight the evolving landscape of India's energy consumption under the LCET–CN scenario, indicating a clear shift towards cleaner energy sources like natural gas and electricity, whilst simultaneously reducing dependence on coal, oil, and traditional biomass.

3.2. Primary Energy Supply

Figure 5.3 illustrates the projected changes in India's primary energy supply under the LCET-CN scenario, spanning from 2019 to 2050. In this scenario, the primary energy supply is projected to increase at a slower pace compared to the BAU scenario. Specifically, it is expected to grow at an average annual rate of 1.7%, reaching 1589 Mtoe by 2050 from 938 Mtoe in 2019. This represents a 30% (578 Mtoe) energy saving relative to the BAU scenario in 2050. The primary drivers behind this reduced consumption are the robust adoption and utilisation of more efficient low-carbon technologies and the implementation of strong energy-saving targets.

Figure 5.3. Total Primary Energy Supply, LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: IEEJ model results.

In the LCET–CN scenario, solar and wind energy are projected to see a significant increase, rising from a meagre share of 1.2% of the total primary energy supply (TPES) in 2019 to 14.7% by 2050. This growth translates to an impressive annual rate of 10.2%. Nuclear and hydro energy sources are also expected to grow at a higher rate than under the BAU scenario, with nuclear and hydro increasing by 9.2% and 4.3%, respectively under the LCET–CN scenario.

Oil supply is projected to rise both in value and share. It is expected to grow at an average annual rate of 1.8%, increasing from 235 Mtoe (25.1% share) in 2019 to 412 Mtoe (25.9% share) by 2050. This makes it the second-largest contributor to the primary energy supply mix. Natural gas, growing at a projected 3.6% per year, will see its share increase from 5.9% in 2019 to 10.5% by 2050.

Coal consumption, on the other hand, is expected to decrease both in value and share, declining at a rate of 0.2% per year. From about 418 Mtoe in 2019, coal consumption will drop to 397 Mtoe by 2050. Despite this decline, coal will still account for the second largest share of TPES at 25% in 2050, down from 44.6% in 2019.

Finally, the 'others' category, which includes traditional biomass, is expected to see a significant decrease. Its share of the total primary energy supply is projected to plummet from 20.1% in 2019 to just 0.5% by 2050, representing an annual average decay rate of 9.5%.

These projections under the LCET–CN scenario reflect a decisive shift in India's energy landscape, with a clear movement towards renewable energy, whilst reducing reliance on coal.

3.3. Power Generation

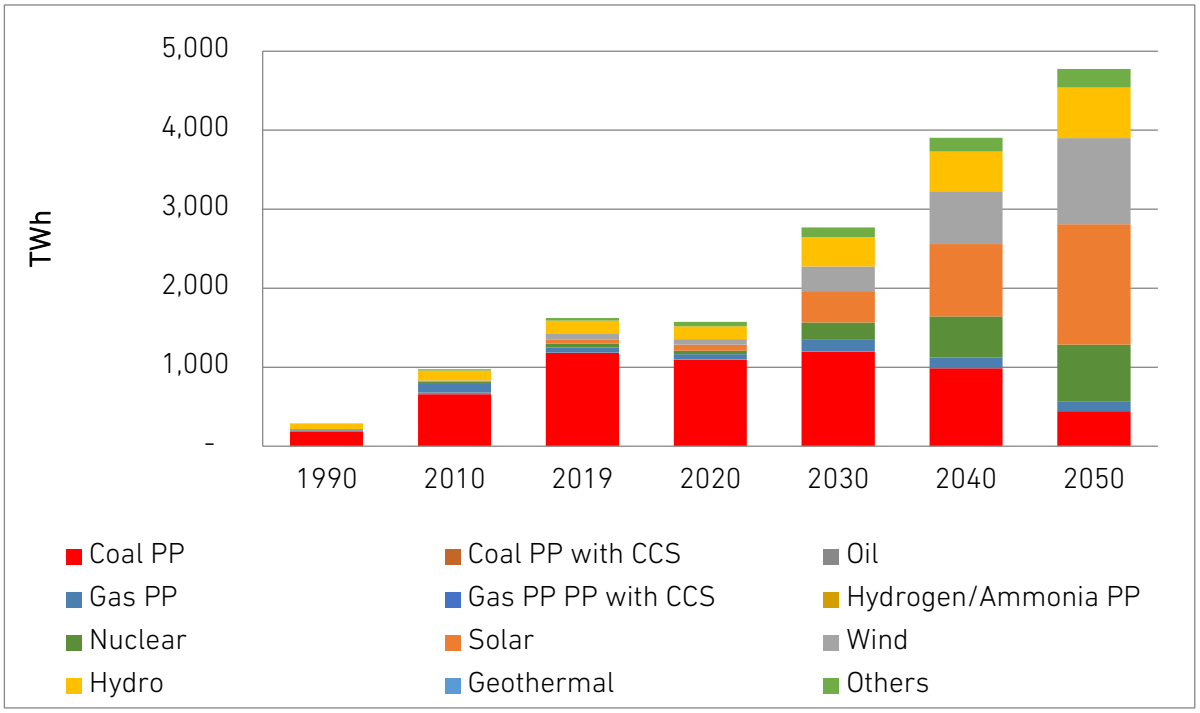
Under the LCET–CN scenario, India's electricity generation is set to undergo significant expansion. From a baseline of 1,624 watt-hours (TWh) in 2019, it is projected to surge to 4,776 TWh by 2050. This increase, at an average growth rate of 3.5% per year, will more than triple the country's power generation, indicating an effort to keep pace with escalating electricity demand.

Central to this expansion is the transition towards low-carbon fuels, leading to a substantial increase in the share of renewable and alternative energy sources. As a result, the proportion of non-fossil-based electricity (comprising renewable and nuclear sources) is anticipated to rise dramatically, from 22.9% in 2019 to 88.1% by 2050.

In this evolving energy mix, solar energy is expected to emerge as the dominant source of power generation, accounting for 31.9% of the total output in 2050. Wind power follows as the second major contributor, with a projected share of 22.8%. The growth rates for these renewable sources are notably high, with solar and wind power experiencing annual increases of 11.6% and 9.3%, respectively between 2019 to 2050. Nuclear power is also on a trajectory of significant growth, with a projected annual increase of 9.2%. Other energy sources, including biomass, imported electricity, natural gas, and hydro, are expected to grow at varying rates of 6.6%, 2.2%, and 4.3%, respectively.

This shift towards renewables, especially wind and solar, is largely attributed to their role in replacing coal in power generation. Consequently, the reliance on coal for electricity is projected to decrease markedly. From a dominant 72.7% share in 2019, coal's contribution to power generation is expected to reduce to just 9.2% by 2050. Figure 5.4 illustrates these projected changes in power generation for India under the LCET–CN scenario from 1990 to 2050.

Figure 5.4. Electricity Generation, LCET–CN Scenario



CCS carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: IEEJ model results.

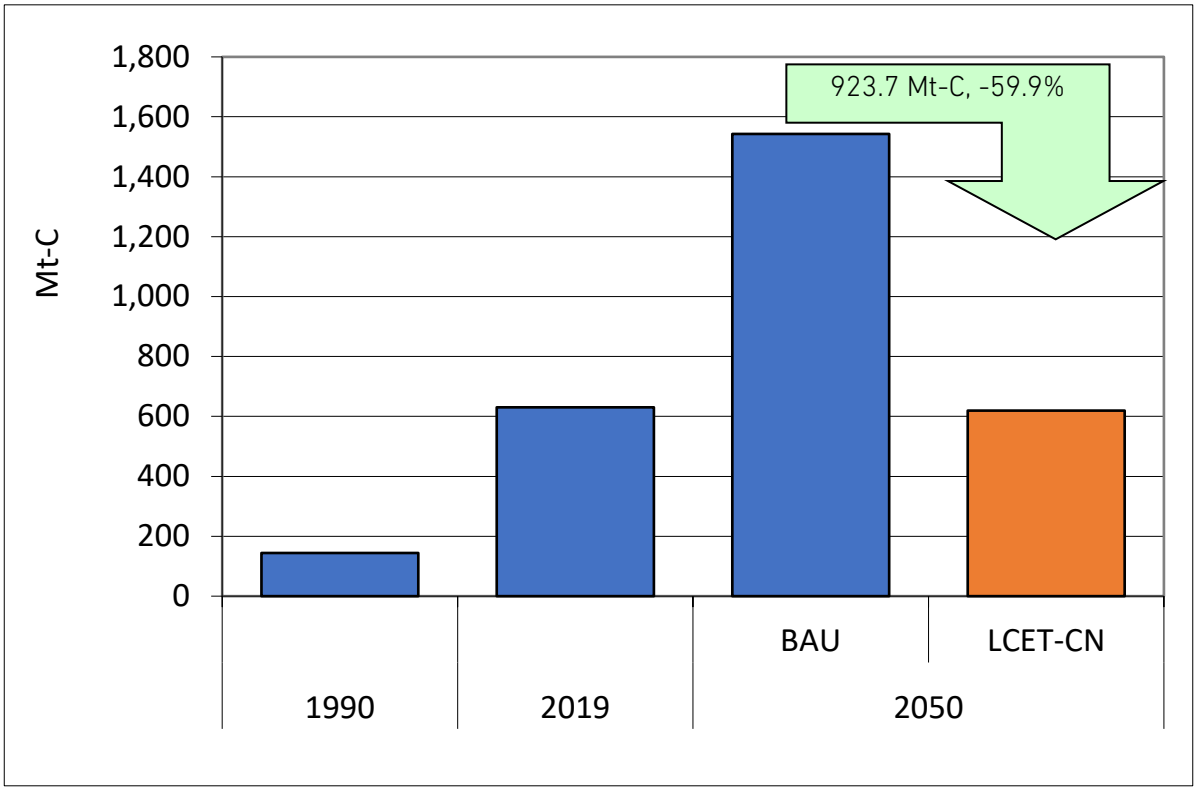
This projection underscores a significant transformation in India's power generation landscape, reflecting a decisive move towards renewable and nuclear energy, in line with global trends and commitments to reduce carbon emissions.

3.4. Carbon Dioxide Emissions

The LCET–CN scenario presents a promising outlook for carbon dioxide (CO_2) emissions in India. In 2019, the total CO_2 emissions stood at 630 million metric tonnes of carbon (Mt-C). Under this scenario, a gradual increase in emissions until 2040 and then a reduction in emissions is projected, leading to a decrease of 1.7% by 2050 as compared to the 2019 level, reaching 619 Mt-C. This decline represents an annual average reduction of 0.1% per year.

In contrast, the BAU scenario paints a different picture. Under BAU, carbon emissions from energy use are expected to rise significantly, with an annual growth rate of 2.9%, culminating in CO_2 emissions of 1543 Mt-C by 2050. Compared to the BAU scenario, the LCET–CN scenario envisages a substantial reduction of 60% (923.7 Mt-C) in CO_2 emissions by 2050, as illustrated in Figure 5.5.

Figure 5.5. CO_2 Emissions Trajectory, BAU vs LCET–CN Scenarios



BAU = business as usual, CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: IEEJ model results.

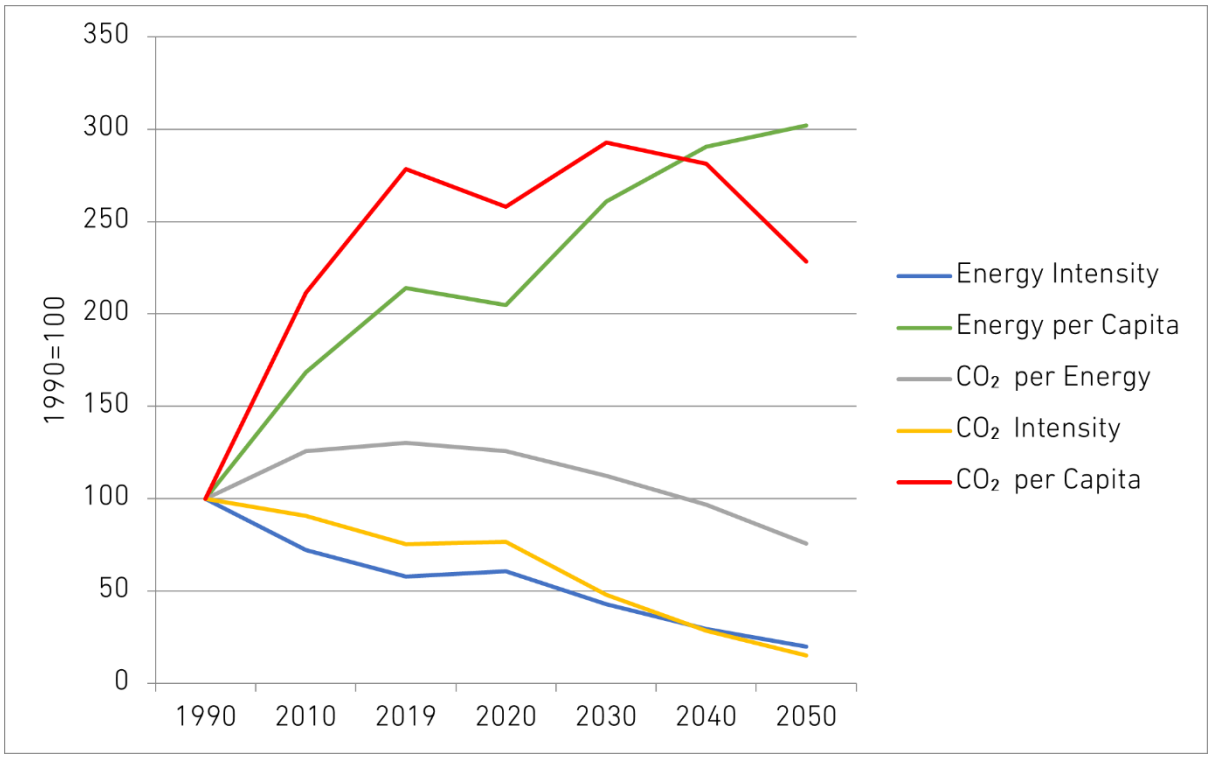
This marked decrease in emissions under the LCET–CN scenario can be attributed to several key factors. Primarily, it is the result of significant reductions in CO_2 emissions due to the vigorous implementation of energy-saving technologies and targets. A notable aspect of this scenario is the projected decrease in coal consumption in industries and power plants, which contributes to the overall reduction in emissions.

Additionally, the transition in the transport sector from oil products to more sustainable alternatives is expected to play a crucial role in lowering carbon emissions. This shift is crucial as it aims to reduce the environmental impact without compromising industrial output or the overall growth trajectory of the nation.

3.5. Energy Indicators

Figure 5.6, based on socioeconomic data projections and energy estimates, illustrates the indices of changes in various projected energy indicators for India under the LCET–CN scenario from 1990 to 2050. The LCET–CN scenario reveals a significant shift in energy efficiency and carbon intensity, driven by the adoption of more energy conservation measures and efficient energy technologies.

Figure 5.6. Energy Indicators, LCET–CN Scenario



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral.
Source: IEEJ model results.

A notable change is observed in energy intensity, a measure of the primary energy supply per unit of GDP. From US$341 tonnes of oil equivalent (toe)/million 2015 (2015 US dollars) in 2019, it is projected to decrease to US$118 toe/million (2015 US dollars) by 2050. This substantial decrease, representing a negative average annual growth of –3.4%, indicates improved energy efficiency across the economy. In contrast, energy consumption per capita is expected to rise, reflecting the growing energy needs of India's expanding population. The average growth rate of 1.1% per year will see this figure increase from 0.69 toe/person in 2019 to 0.97 toe/person by 2050.

Significant improvements are also projected in terms of CO_2 intensity, which measures CO_2 emissions per unit of GDP. A sharp decline from US$229 t-C/million (2015 US dollars) in 2019 to US$46 t-C/million (2015 US dollars) in 2050 is anticipated, equating to a negative annual average growth rate of –5.0%. This trend is indicative of a notable decrease in CO_2 emissions relative to economic output, largely due to the integration of renewable energy technology into India's energy mix.

Additionally, there is a projected decrease in CO_2 emissions per unit of primary energy consumption, falling from around 0.67 t-C/toe in 2019 to 0.39 t-C/toe in 2050. This change, equivalent to an average annual decline rate of 1.7%, demonstrates an overall reduction in the carbon intensity of the energy sector. Correspondingly, CO_2 emissions per capita

are expected to decrease from roughly 0.46 t-C/capita in 2019 to 0.38 t-C/capita in 2050, amounting to an 18% reduction.

These projections under the LCET–CN scenario point towards a future where India not only meets its growing energy demands but does so in a manner that significantly reduces its carbon footprint, aligning with global efforts to combat climate change.

3.5. Green Hydrogen Demand

Hydrogen, recognised as a clean alternative fuel, holds significant potential to replace fossil fuels in various sectors such as industry, transport, power generation, and energy storage systems.

In a strategic move to foster a hydrogen-based economy, India has outlined plans to mandate a compulsory purchase obligation for renewable hydrogen on fertiliser and petroleum companies. This initiative is a testament to the country's commitment to transitioning towards cleaner energy sources. In 2022, India's hydrogen use amounted to 6–7 million tonnes, with the refining sector accounting for 45% of this consumption, followed by the chemicals industry at 35%, and the iron and steel sector at 20%.

A significant policy development in 2023/2024 mandates that refineries must source 10% of their hydrogen demand from renewable sources, a requirement that is set to increase to 25% within the next 5 years. Similarly, fertiliser producers are required to meet 5% of their hydrogen demand with renewable hydrogen starting in 2023/2024, with this proportion rising to 25% in the subsequent 5 years. Plans are also in place to extend these requirements to the steel industry in the near future.

Model results under the LCET–CN scenario project that the consumption of green hydrogen in India will reach approximately 0.54 Mtoe by 2050. This projection underscores India's growing emphasis on green hydrogen as a cornerstone of its sustainable energy strategy, aiming to significantly reduce its carbon footprint and foster a more environmentally-friendly energy sector.

Cost Implications of LCET–CN Scenario

Table 5.1 offers a detailed cost comparison of the BAU and LCET–CN scenarios over the modelling period from 2019 to 2050. This 31-year span exceeds the typical lifetime of power plants, indicating that the entire power generation capacity existing in 2050 will need to be developed in the future. The Institute of Energy Economics, Japan model used for this study does not directly provide outputs for power generation capacity. Therefore, assumptions on normative capacity utilisation factors, along with the model output on annual electricity generation by different power generation technologies, are used to estimate the total installed capacity for these technologies over the respective years.

A key insight from Table 5.1 is the contrast in cost components between the BAU and LCET–CN scenarios. Whilst the BAU scenario is characterised by higher fuel costs, the

LCET–CN scenario incurs substantially higher capital costs. These costs are associated with power plants, energy storage, and energy-saving equipment. Notably, the cost of energy storage is estimated to be particularly significant, reaching approximately US$439 trillion cumulatively over the period from 2019 to 2050. This figure translates to around US$14.16 trillion annually for the next 31 years, an amount several times higher than the current GDP of India.

Such high investment requirements for the LCET–CN scenario, particularly for energy storage, have raised concerns regarding the financial feasibility of achieving ambitious targets for variable renewables. The capital-intensive nature of transitioning to a low-carbon energy system underscores the need for careful financial planning and possibly the exploration of innovative financing mechanisms to support this transition.

Table 5.1. Cost Comparison across the BAU and LCET–CN Scenarios

	BAU (US$ trillion)		LCET–CN (US$ trillion)	
	Cumulative (2019–2050)	Annual Average (2019–2050)	Cumulative (2019–2050)	Annual Average (2019–2050)
Fuel Cost	15.41	0.50	11.81	0.38
Power Plant – Capital Cost	1.39	0.04	1.82	0.06
Energy Storage – Capital Cost	-	-	438.93	14.16
Energy Saving Equipment – Capital Cost	-	-	1.47	0.05
Total	**16.81**	**0.54**	**454.04**	**14.65**

- = very small, BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors' estimation based on IEEJ model results.

4. Conclusion and Policy Recommendations

4.1. Conclusion

This chapter has examined India's ambitious journey towards a low-carbon future, as envisioned in the LCET–CN scenario. The focus has been on the transformative changes anticipated in the nation's energy landscape, encompassing shifts in energy consumption, the evolution of primary energy supply, and the dynamic changes in power generation patterns. The projections under the LCET–CN scenario illustrate a significant transition

from existing predominant energy supply source coal to an increased reliance on renewable and alternative energy sources, highlighting India's commitment to a sustainable and environmentally responsible future.

A critical aspect of this transition is the projected reduction in CO_2 emissions, a testament to India's efforts in aligning with global climate goals. The shift towards renewable energy, notably solar and wind, signifies a profound change in the energy sector. The move away from coal-fired powered generation and the increasing role of nuclear power further underscore the nation's dedication to reducing its carbon footprint.

Equally significant are the financial implications of this transition. The analysis delves into the capital-intensive nature of shifting to a low-carbon energy system, underlining the need for substantial investments in renewable energy infrastructure, energy storage, and energy-saving technologies. This economic aspect poses both a challenge and an opportunity for India, as it navigates the delicate balance between growth, sustainability, and environmental responsibility.

In essence, the LCET–CN scenario presents a future where India not only meets its burgeoning energy demands but does so through a lens of sustainability and reduced environmental impact. The journey is complex and laden with challenges, but it is also filled with immense potential for innovation, economic growth, and a leading role in the global transition towards cleaner energy.

4.2. Policy Implications

To achieve its ambitious net-zero emissions target, India needs to adopt a holistic approach, encompassing several key strategies:

- Expansion of Renewable Energy: Developing policies to support the growth of renewable energy, enhancing grid flexibility, and focusing on storage technology advancement.
- Energy Efficiency Enhancement: Making significant investments in energy infrastructure across urban and industrial areas, and in appliances and vehicles, to reduce the energy intensity of the economy.
- Transitioning to Renewable and Alternative Energy Sources: Shifting from traditional fossil fuels to renewable sources like wind, solar, and hydro, and exploring nuclear and hydrogen options.
- Promotion of Electric Vehicles: Encouraging the adoption of electric vehicles to lessen oil consumption in the transportation sector, leading to reduced carbon emissions and offering substantial investment opportunities.
- Addressing Energy Storage Costs: Acknowledging the high capital requirements for energy storage technology, a critical factor in achieving variable renewable energy targets. Addressing these costs is essential for the financial feasibility of reaching net-zero emissions.

- Afforestation Initiatives: Implementing substantial afforestation efforts to absorb carbon, balancing emissions from fossil fuel-dependent sectors and rapidly growing industries.
- Hydrogen as Alternative Fuel: Increasing the use of hydrogen, especially in heavy-duty transportation and industrial applications, to reduce reliance on conventional fossil fuels.

Implementing these strategies is pivotal for India to meet its climate commitments and set a precedent for sustainable and eco-friendly growth.

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