International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

A Comprehensive Study on Transition and Impact of Green Electricity in India

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ABSTRACT

Fossil fuel-based power plants generate about 60% of global electricity and over 40% of carbon dioxide emissions. India mirrors this trend, with 56% of its electricity sourced from fossil fuels, making it the third-largest emitter of greenhouse gases after China and the United States. In response to climate change, global warming, and resource depletion, India has committed to transitioning toward renewable energy. At COP26 in Glasgow, under the "Panch Amrit" framework, India pledged to achieve 500 GW of non-fossil fuel capacity and meet 50% of its energy needs from renewables by 2030—building on earlier COP21 commitments, including a 40% non-fossil energy target, which was surpassed by 2022.

This study evaluates the current adoption of green electricity sources in India—solar, wind, hydroelectric, and biomass—and assesses projected capacities through 2030. It investigates opportunities and challenges in achieving India's 2030 renewable targets and its long-term goal of net-zero emissions by 2070. Using secondary data from the Ministry of Power and the Ministry of New and Renewable Energy (2013–2023), the research applies qualitative and quantitative analyses, including trend assessments with Excel and SPSS.

The findings highlight positive momentum, supported by progressive policies and declining renewable energy costs. However, challenges such as renewable energy intermittency, grid flexibility, and the need for large-scale energy storage remain significant. Despite these hurdles, the study concludes that India's decarbonization targets are realistic, provided there is sustained policy support, infrastructure development, and technological innovation. Overall, the research offers key insights into India's energy transition aligned with global climate objectives.

Keywords: Green electricity, Renewable energy, Fossil fuels, Climate change, Global warming, Net-zero emissions, COP26, Paris Agreement, Panch Amrit, Nationally Determined Contributions (NDCs), Ministry of Power, Ministry of New and Renewable Energy (MNRE)

1. Introduction

Globally, almost 60% of electricity comes from fossil fuel-based power plants that burn fossil fuels like coal and natural gas to produce electricity. These non-renewable energy sources are generally expensive, exhaustible, polluting, and insecure because of their uneven distribution and account for over 40% of CO_2 emissions. In India, 56% of electricity comes from fossil fuel-based power plants (Ministry of Power), and India is the third-largest producer of GHGs after the United States and China. Thus, there is a growing need to transition from fossil fuel-based to renewable and sustainable energy sources as the world faces global warming, climate change, and the depletion of non-renewable resources. Electricity produced from renewable sources, such as water, wind, solar, biomass, and small hydroelectric sources, with a much lower environmental impact, is called green electricity.

India's New 2030 Decarbonization Targets:

India has been a pioneer in the fight against climate change and is committed to completing the switch to clean energy. The Indian Prime Minister unveiled Panch Amrit, or "The Gift of Five Elixirs," the five nectar ingredients, during COP26 in Glasgow. The following five goals are to be accomplished by 2030:

1. India will reach its non-fossil energy capacity of 500 GW by 2030.
2. India will meet 50% of its energy requirements with renewable energy by 2030.
3. India will reduce total projected carbon emissions by one billion tonnes by 2030.
4. India will reduce its carbon intensity by less than 45% by 2030.
5. India aims to reach net zero by the year 2070.

When India announced its Nationally Determined Contributions (NDCs) at COP21 in 2015 in Paris, it made a historic commitment in 2015 to install 175 gigawatts (GW) of renewable energy by 2022 and expand its non-fossil fuel power production capacity to 40% by 2030, which marked a turning point in the country's low-carbon transition. As of April 2022, India had 165 GW of total non-fossil fuel capacity, including nuclear. It equals 41% of the 401 GW installed power capacity (MNRE, 2022). By 2030, the goal of having 40% of electricity capacity come from non-fossil fuels has already been met. India is expected to surpass its NDC obligations well before 2030, having already achieved a 28% decrease in emissions above 2005. India's aspirations for the climate have grown significantly between Paris (COP21) and Glasgow (COP26). The figure below shows India's commitments at COP21 and COP26.

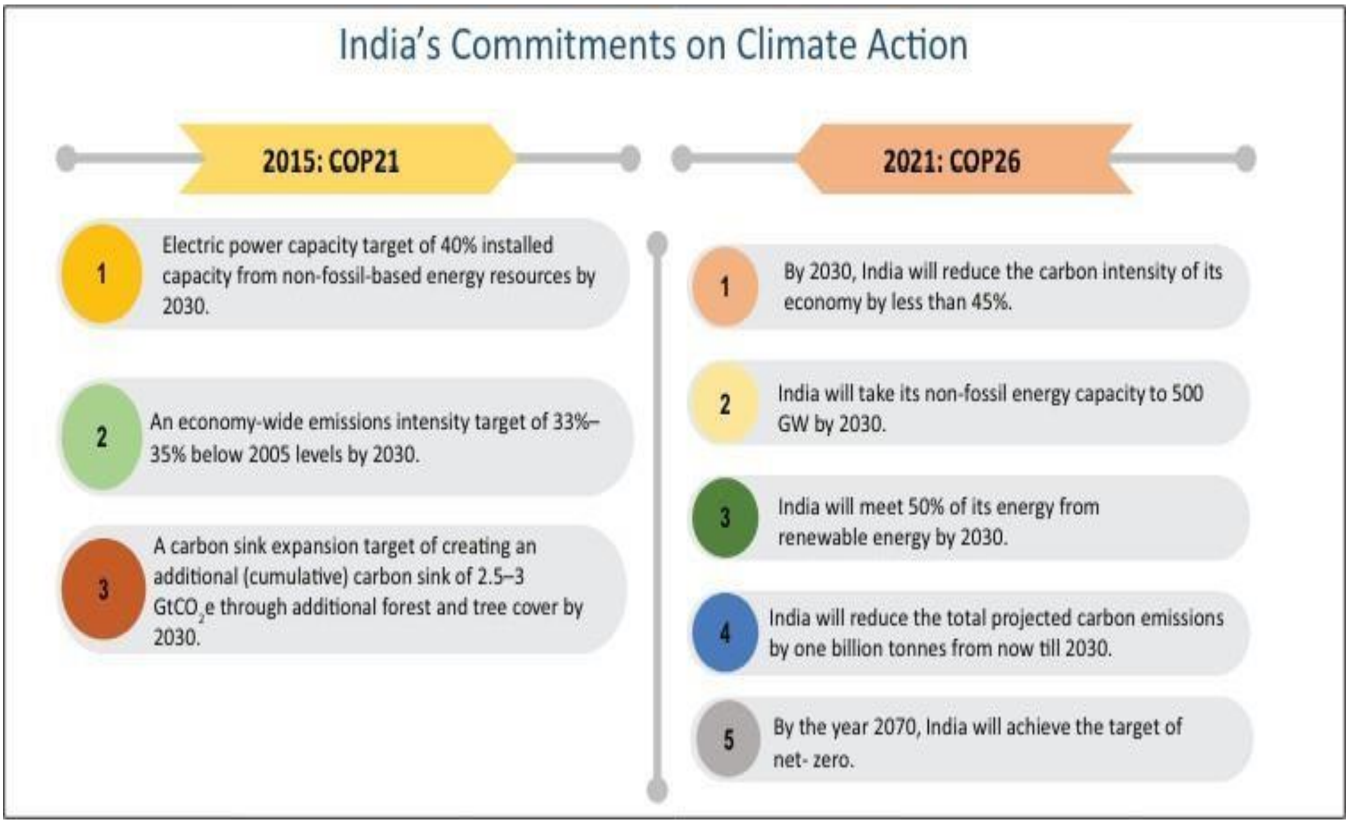

Figure 1. India's commitment to Climate Action at COP21 and COP26 (pib.gov.in/PRID=1795071)

Massive, in-depth decarbonization initiatives would be required to meet these aggressive targets. India would need to install an extra 340 GW of non-fossil fuel energy capacity this decade to meet its new

2030 targets. Over the past seven years, India has experienced the greatest growth rate in the addition of renewable energy capacity among the major economies. India will need to increase its renewable energy capacity by 40–43 GW annually on average. Glasgow's announcements of 500 GW of non-fossil fuel energy could be achieved, according to Central Electricity Authority (CEA) projections, by roughly combining 435 GW from wind, solar, and other RE sources; 61 GW from large hydro; and 19 GW from nuclear energy capacity (CEA, 2020). Reaching 500 GW of non-fossil fuel capacity and 50% Renewable energy generation is both doable and inexpensive, but it would be exceedingly difficult to reach these goals. The main challenges will be increasing the flexibility of the generating resources and deploying large-scale energy storage capacity. These are necessary to guarantee the grid's seamless operation, maximize the renewable energy (RE) capacity, and ensure high reliability around the clock. In addition to facilitating this shift, a stronger emphasis on expanding decentralized power from renewable sources would prove more economical. The percentage of renewable energy in electricity generation would rise quickly from about 10%, posing new operational issues. Renewables only generate electricity when the sun shines and the wind blows, which is variable and intermittent. It needs to be fully utilized, and at the same time, the grid has to be stable, with the supply meeting demand continuously. Globally, there is a growing understanding of how to run power systems efficiently while keeping in mind the security and stability of the grid and integrated resource planning for power with a higher share of renewables. India should be able to use the knowledge and adapt it to handle the transition smoothly. This project aims to study the current level of adoption of various green electricity sources in India, such as solar, wind, water, and biomass, while considering future green electricity plant capacities. It also aims to assess opportunities and challenges in achieving India's interim target of 50% of its energy requirement from renewable energy by 2030, considering the latest trends, developments, and policy outlook given the latest proposed Nationally Determined Contribution (NDCs) for the Paris Agreement.

Background of the study: India ratified the 2030 Agenda during the United Nations Summit held in September 2015 to limit global warming to no more than 1.5°C—known as the Paris Agreement—greenhouse gas (GHG) emissions to be reduced by 45% by 2030 and brought to net zero by 2050. The literature review highlights previous studies and analyses on renewable energy sources in India, like solar, wind, water, and biomass, as well as their CO_2 reduction potential over the past decade, and extrapolates them to 2030 and 2050. As we approach 2025, recent trends and deviations necessitate a more relevant and detailed analysis of the latest developments and policies to provide valuable insights into more efficient adoption of green electricity for India's 2050 net zero target. This study delves deeper and focuses on the current level of adoption of various green electricity sources in India, such as solar, wind, and water, including upcoming green power plant capacities. It also considers opportunities and challenges in achieving India's 2050 Net Zero target, including India's latest proposed Nationally Determined Contributions (NDCs) and policy scenarios for the Paris Agreement.

Problem Statement: This study uses secondary data from the Ministry of Power and the Ministry of New & Renewable Energy from 2013-14 to 2022-23 for various green electricity sources in India, such as solar, wind, water, and biomass. The study conducted both qualitative and quantitative analyses of the green electricity mix in India from 2015 to 2023. The study also conducted statistical analysis using Microsoft Excel or the Statistical Package for the Social Sciences (SPSS) software to identify trends, patterns, and correlations. The aim was to gain insights into the current level of adoption of various green electricity sources in India. Furthermore, we will extrapolate this data to 2030, taking into account the most recent trends, the capacities that are planned or under construction, and the policy outlook in light of the recently proposed Nationally Determined Contributions (NDCs) for the Paris Agreement.

Research Objectives

1. To assess the current level of adoption of various green electricity sources in India, such as solar, wind, water, and biomass, consider upcoming green electricity plant capacities.
2. The aim is to assess opportunities and challenges in achieving India's 2050 Net Zero target, taking into account the latest trends, developments, policy scenarios, and Nationally Determined Contributions (NDCs) for the Paris Agreement.

Literature Review: A study by Jacobson (2020) depicts an over 49% reduction of the projected 2050 end-use load for Indian metros—Delhi and Mumbai—through wind, water, and solar renewable energy. A study by Ram et al. (2022) looks at how the power, heat, and transportation sectors can switch to 100% renewable energy by 2050 under the best policy conditions and shows that Delhi could cut its energy use by nearly 50% just by using photovoltaic (PV) by that year.

The literature review highlights previous studies and analyses on renewable energy sources in India, such as solar, wind, water, and biomass, their CO2 reduction potential over the past decades, and extrapolates them to 2030 and 2050. However, as we approach 2025, recent changes and differences in data require a closer look at the latest developments and new green power plants that could help us understand how much India is using different green electricity sources. Moreover, the latest trends, policy scenarios, and proposed Nationally Determined Contributions (NDCs) for the Paris Agreement present both opportunities and challenges in achieving India's 2050 net-zero target.

Research Methodology

Research Design

This study uses secondary data from the Ministry of Power and the Ministry of New & Renewable Energy from 2013-14 to 2022-23 for various green electricity sources in India, such as solar, wind, water, and biomass. We conducted qualitative and quantitative analyses of the electricity mix in India from 2015 to 2023, utilizing Microsoft Excel for statistical analysis. This analysis aimed to identify trends, patterns, and correlations, providing valuable insights into the current level of adoption of various green electricity sources in India, including upcoming green power plant capacities. Moreover, we will extrapolate this data to 2030, considering the latest trends, the planned or under-construction capacities, and the policy outlook in light of the recently proposed Nationally Determined Contributions (NDCs) for the Paris Agreement.

Data Collection Method

This secondary data is readily available as reports, executive summaries (monthly, yearly), dashboards, and APIs from (https://cea.nic.in/api). The API sample datasets for All India Installed Capacity and All India Installed Capacity (Renewables) are below.

{"id": 49, "month": "Jan-2023", "coal": "204435.5", "gas": "24824.2", "diesel": "589.2", "thermal_total": "236468.91000000003", "nuclear": "6780", "hydro": "46850.170000000006", "res": "121549.52", "grand_total": "411648.6"},
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{"id": 52, "month": "Apr-2023", "coal": "205235.5", "gas": "24824.2", "diesel": "589.2", "thermal_total": "237268.91000000003", "nuclear": "6780", "hydro": "46850.170000000006", "res": "125692.30000000002",
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API sample Dataset – All India Installed Capacity (RES) from www.cea.nic.in
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Data Analysis and Presentation

The monthly data for total installed and installed renewable was converted into total yearly financial and cumulative data for total generation from all sources as shown in Table 1 below, and analysed with Microsoft Excel to find trends, patterns, and connections to understand how much different green electricity sources are being used in India, including new green power plant capacities. Moreover, we will extrapolate this data to 2030, considering the latest trends, the planned or under-construction capacities, and the policy outlook in light of the recently proposed Nationally Determined Contributions (NDCs) for the Paris Agreement.

Table 2: Total Power Generation from all sources

Total Generation from all sources (MW)								
Sector	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**
Wind Power	32279.77	34145.00	35625.97	37693.75	39247.06	40357.59	42633.14	45886.51
Solar Power	12782.52	22346.21	28180.71	34627.82	40085.37	53996.54	66779.37	81813.60
Small Hydro Power	4379.85	4485.80	4593.14	4683.15	4786.80	4848.89	4944.29	5003.25
Biomass	9116.05	9674.42	9241.80	10022.95	10314.56	10682.36	10802.04	10845.86
Green (excl. Large Hydro)	57260.23	69022.00	77641.62	87027.67	94433.79	109885.38	125159.81	143644.51
RE (incl. Large Hydro)	44478.42	45293.42	45399.22	45699.22	46209.22	46722.52	46850.17	46928.17
Coal	192162.88	197171.50	200704.50	205344.50	209294.50	210699.50	211855.50	217589.46
Gas	25329.38	24897.46	24937.22	24955.36	24924.00	24899.51	24824.21	25038.21
Diesel	837.63	837.63	637.63	509.71	509.71	509.71	589.20	589.20
Nuclear	6780.00	6780.00	6780.00	6780.00	6780.00	6780.00	6780.00	8180.00
Total Gen. (all sources)	326848.54	344002.01	356100.19	370316.46	382151.22	399469.62	416058.89	441969.54
Year	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**
% RE Generation (Excl. Large Hydro)	17.52	20.06	21.80	23.50	24.71	27.51	30.08	32.50

% RE Generation (Incl. Large Hydro)	31.13	33.23	34.55	35.84	36.80	39.20	41.34	43.12

Scope of the Study

The scope of this study is limited to an assessment of the current level of adoption of various green electricity sources in India, such as solar, wind, water, and biomass, considering upcoming green electricity plant capacities. Moreover, it will assess opportunities and challenges in achieving India's 2050 Net Zero target, considering the latest trends, developments, policy scenarios, and Nationally Determined Contributions (NDCs) for the Paris Agreement.

Limitations of the Study: Although the proposed study can provide valuable insights, it is essential to acknowledge its limitations to ensure a balanced interpretation of the results. Some potential limitations of this study include:

1. Data availability and quality: Data availability and quality depend on the secondary data sources.
2. Generalizability: The data values for installed capacity and installed capacity of renewables are for India overall and may not be exactly representative of states, regions, or grids in parts.
3. Scope of Study: A single study's scope is limited to certain aspects of the adoption of green electricity in India and may leave out other critical factors, such as customer perception.
4. External factors, such as weather conditions and events, may not be adequately accounted for in the study's design.
5. Limited representation of stakeholders: The study might not involve the participation of all relevant stakeholders, which could lead to an incomplete understanding of the issue.
6. Changes over Time: The dynamic nature of urban environments might impact adoption patterns, and regulatory conditions might change over time, potentially affecting the relevance of the study's conclusion.

1. Data Analysis and Discussions:

1.1 India’s Generation Capacity Mix over the past years

Exhibit 1 below shows India's RE generation capacity mix over the years in MW. As can be seen, the country's generation capacity mix in MW has significantly changed due to increased electricity demand. The share of wind and solar capacity have increased significantly.

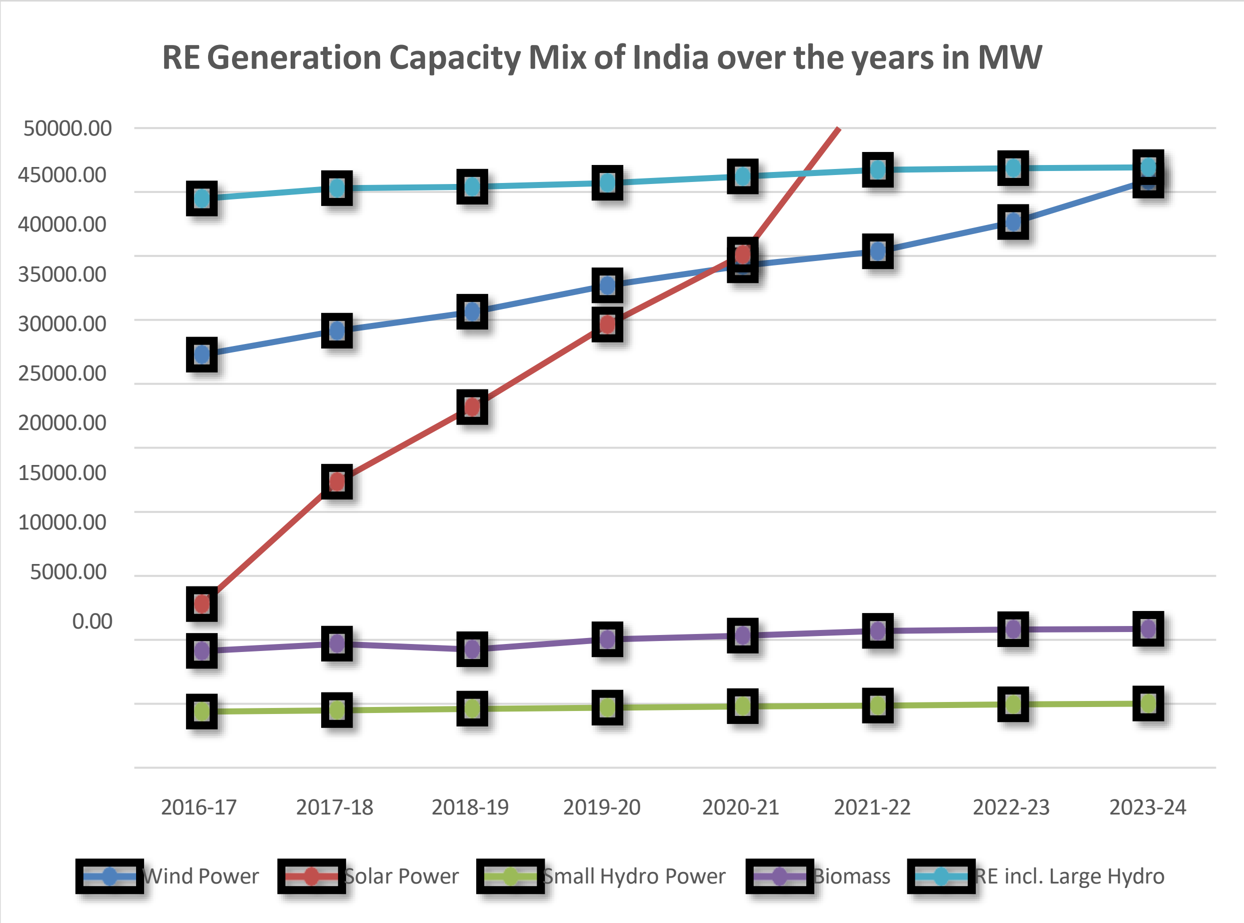
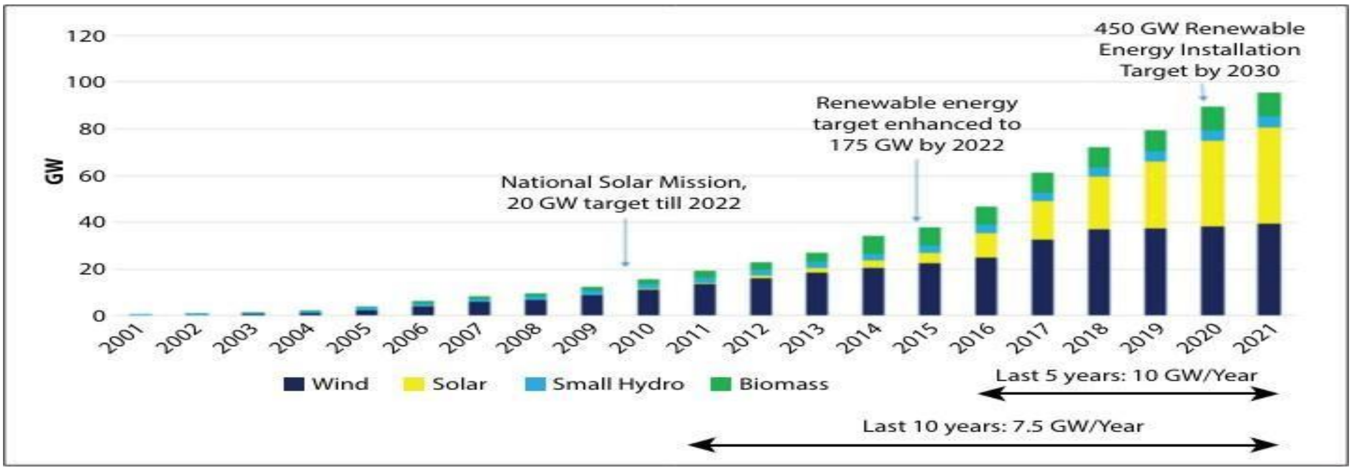


Exhibit 1: RE Generation Capacity mix of the country over the past years in MW (based on Table 2)

2.2 Growth of Green Electricity

Over the past ten years, it has expanded quickly, instilling confidence in all parties involved. Due to innovative policies and a competitive market structure, private investors and developers have created capacities. India has been able to take full advantage of the phenomenal global decline in the costs of renewables. Figure 2 shows the country's green electricity growth over the last two decades.

Figure 2. The Growth trajectory of green electricity in India (*TERI's analysis*)



Following the initiation of the National Solar Mission in 2010, there has been a notable acceleration in growth, particularly after India made its NDC commitments in Paris. Over the last five years, India's renewable capacity has grown at a compound annual growth rate (CAGR) of 10% and over 20% over the past decade. The costs associated with generating renewable energy have sharply declined in the past ten years due to significant advancements in manufacturing technologies, increased economies of scale, and improved supply chains. Solar and wind energy have shifted from being relatively expensive options to the most affordable sources of electricity whenever sunlight or wind is available.

2.3. Present Installed Capacity (MW) as of 31.03.2023

The current installed capacity of the country, as of 31.03.2023, is 415.4 GW, which comprises 236.68 GW from thermal (211.8 GW coal & lignite and 24.8 GW gas), 6.78 GW from nuclear, 167.2 GW from RES (42.1 GW hydro, 66.8 GW solar, 42.6 GW wind, 4.7 GW small hydro, and 10.8 GW bio power), and 4.75 GW from PSP (excluding 0.589 GW diesel- based capacity). The region-wise and fuel-wise details of installed capacity as of 31st March 2022 are given in Table 3 below.

Resource	Capacity (MW)	Percentage
Hydro	46850	11.26
Small Hydro	4944	1.19
Solar PV	66780	16.05
Wind	42633	10.24
Biomass	10802	2.59
Nuclear	6780	1.62
Coal+ Lignite	211855	50.91
Gas	24824	5.96
Diesel	589	0.14
Total	416,057	100

Table 3: Present Installed Capacity (MW) as of 31.03.2023

2.4 Retirement of coal-based capacity

The coal-based capacity of 2,121.5 MW, which is likely to be retired due to the non-submission of any Fuel Gas Desulphurization (FGD) installation plan to abide by the new environmental reforms, has been considered to be retired until 2029-30. It may be noted that out of this, the year 2022-23 saw the retirement of a capacity of 304 MW (CEA).

2.5 Planned or Under Construction Capacities (CEA):

Planned Capacities that are likely to yield benefit during the period 2023 - 30:

Coal

The latest assessment by CEA estimates that the coal capacity under construction and anticipated for commissioning during 2022-30 is approximately 26,900 MW. Pit head-based potential supercritical coal capacity totals 21,240 MW, and the coal-based capacity of central and state sector utilities totals 9,420 MW.

Hydro (including PSP)

The latest assessment by CEA estimates the hydropower capacity, which is under construction and likely to yield benefits during 2022–30, to be around 11,494 MW. The hydro and PSP projects have a combined capacity of 502 MW and 2780 MW, respectively.

Nuclear

According to the latest assessment by the Department of Atomic Energy (DAE), 8700 MW of capacity is under construction, and the same has been considered for the studies for 2022-30.

Solar and Wind-based Capacity

In the studies, region-wise solar and wind-based candidate capacity has been considered based on the latest state-level potential furnished by the Ministry of New and Renewable Energy. MNRE has indicated that wind-based projects may achieve a cumulative installed capacity of up to 100 GW by 2029 - 30 (MNRE).

Resource	Capacity (MW)	Percentage
Hydro	11494	6.69
PSP	2780	1.61
Small Hydro	502	0.29
Solar	92580	53.89
Wind	25000	14.55
Biomass	3818	2.22
Nuclear	8700	5.06
Coal+ Lignite	26900	15.66
Gas	0	0
Total	171,774	100

Table 4: Planned/Under Construction Capacity Addition 2022-30 (MW), CEA

2.6 Optimal Generation Mix for Projected Installed Capacity in 2029-30

Considering all the factors and the latest demand predictions for the five regional grids (NR, WR, SR, ER, and NER), the updated Optimal Generation Mix for 2030, released in April 2023, estimated that the best combination of power generation capacity for 2029-30 would be 777,144 MW. This total includes 53,860 MW from hydro (not counting 5,856 MW from hydro imports), 18,986 MW from pumped storage, 5,350 MW from small hydro, 251,683 MW from coal, 24,824 MW from gas, 15,480 MW from nuclear, 292,566 MW from solar, 99,895 MW from wind, and 14,500 MW from biomass, plus a battery energy storage capacity of 41,650 MW/208,250 MWh to meet the expected peak electricity demand of 334.8, according to the 19th EPS report. The installed capacity from renewable energy sources, excluding large hydro (solar, wind, biomass, and small hydro), is expected to be 435 GW in 2029 - 30 (CEA).

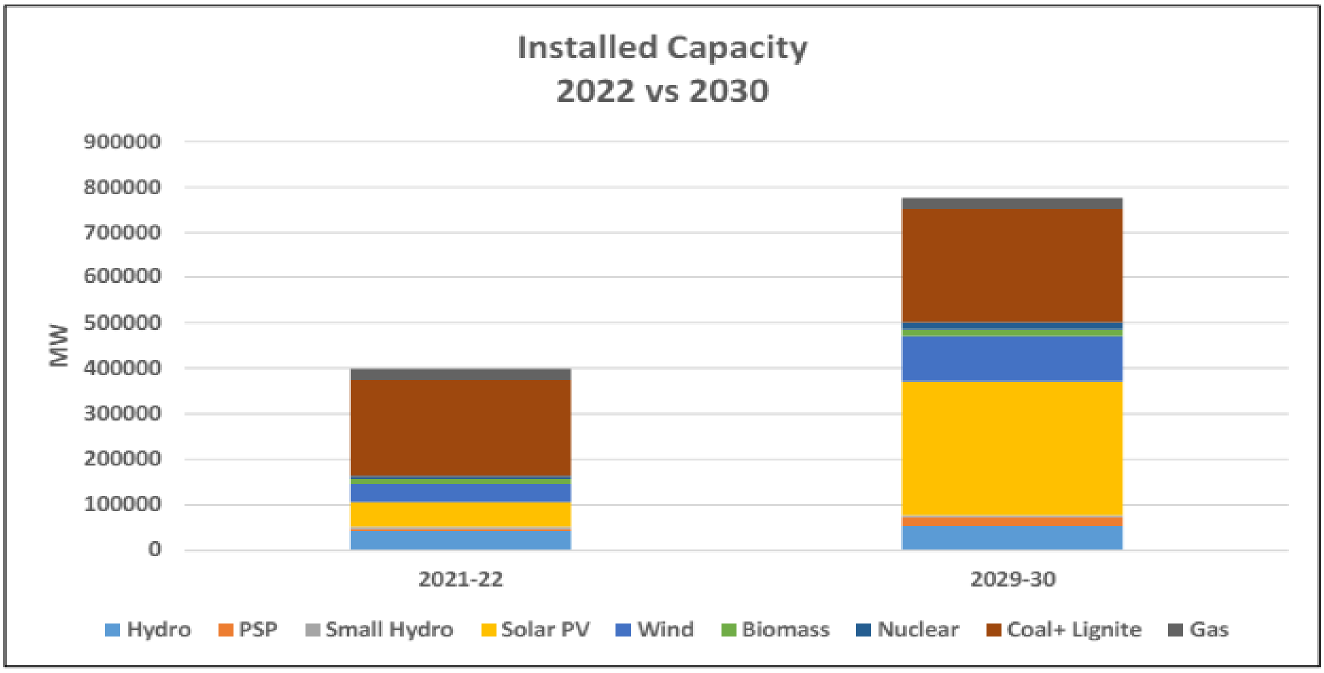
The likely installed capacity (MW) in 2029-30 is given in Table 5 below.

Resource	Capacity (MW)	Percentage
Hydro	53860	6.93
Small Hydro	5350	0.69
PSP	18986	2.44
Solar PV	292566	37.65

Wind	99895	12.85
Biomass	14500	1.87
Nuclear	15480	1.99
Coal+ Lignite	251683	32.38
Gas	24824	3.19
Total	777144	100
BESS(MW/MWh)	41650/208250	

Table 5: Likely Installed Capacity (MW) in 2029-30, CEA

The resource-wise details of likely installed capacity in 2029-30 are given in Exhibit 2. The resource-wise details of likely installed capacity in 2029-30, CEA



Graphs are indicative and are not to the scale.

2.7 Additional Capacity required to meet likely Installed Capacity in 2029-30

Resource	Present Installed Capacity (MW) 31.03.2023	Planned Capacity 2022 - 30	Likely Installed Capacity 2029 - 30	Additional Capacity required
Hydro	42104	11494	53860	262
PSP	4746	2780	5350	(included in psp growth)
Small Hydro	4944	502	18986	13540
Solar PV	66780	92580	292566	133206
Wind	42633	25000	99895	32262
Biomass	10802	3818	14500	(included in planned)
Nuclear	6780	8700	15480	0
Coal+ Lignite	211855	26900	251683	12928
Gas	24824	0	24824	0

Diesel	589	0	0	(phased out)
Total	416057	171774	777144	192198
BESS (MW/MWh)	0	0	41650/208250	0

Table 6: Additional Capacity required to meet likely Installed Capacity in 2029-30, CEA

3.0 Conclusion & Summary

India's energy sector net CO2 emissions pathways

During the climate conference COP26 held in Glasgow in 2021, India announced that it would reach net zero by 2070, but its current emissions trajectory is significantly off course. In our basic scenario, emissions will nearly triple by 2040 and only slightly decrease by 2070; fossil fuels are essential to India's robust economic growth. Our scenario for Net Zero 2070 lays out an entirely different result. This scenario, which calls for a radical rethinking of the economy, is based on massive investments in clean energy, decarbonizing India's quickly developing infrastructure and industrial sectors, and fully utilizing the country's exceptional human resources (WoodMac)

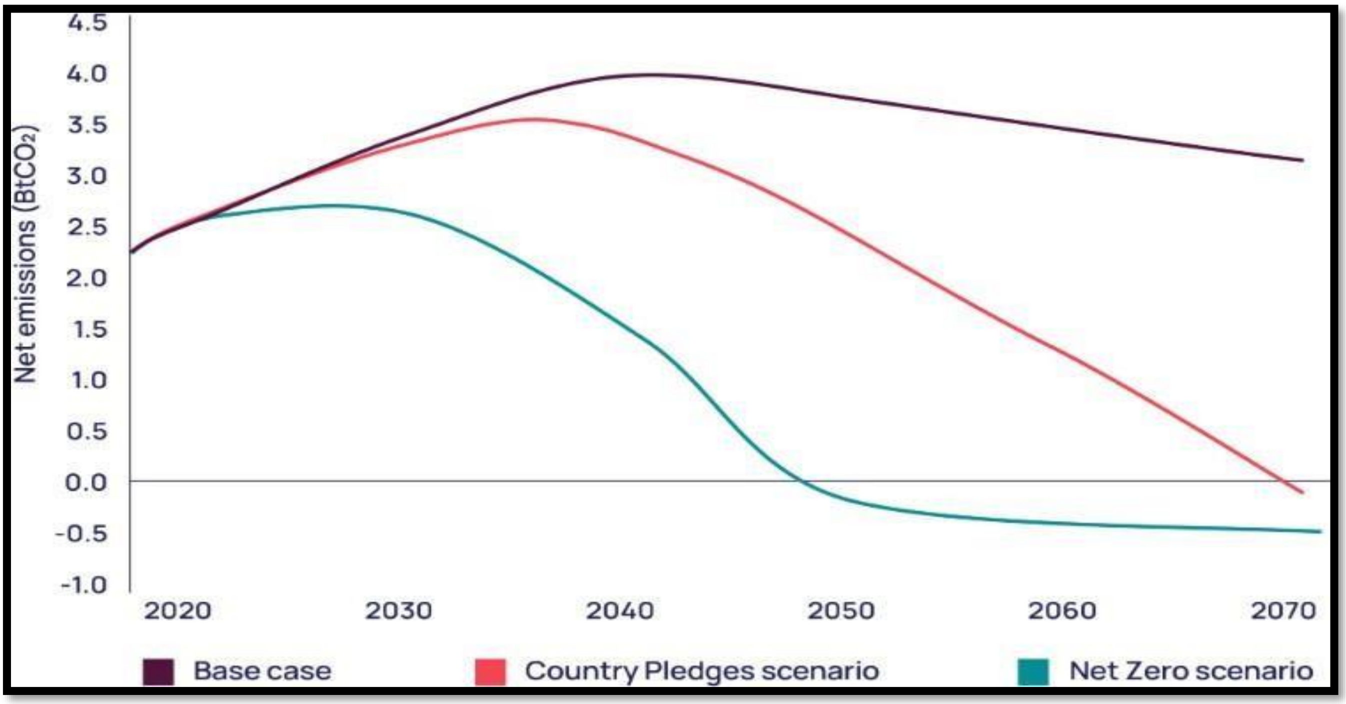


Figure 3: India's energy sector net CO2 emissions pathways, WoodMac

India's 2030 Decarbonization Roadmap

- A coal-based capacity addition of 16,204.5 MW is required to meet the electricity demand requirement in 2029-30, apart from the coal-based capacity of 26,900 MW currently under construction (for likely benefits during 2022-23 to 2029-30).
- By 2030, an additional 180.4 GW of RE-based capacity (145.9 GW solar and 34.5 GW wind) is required in addition to the 117 GW (92.5 GW solar and 25 GW wind) currently in the planning/implementation stage.
- A prospective addition of 389 MW of large hydroelectric capacity is required until 2030, apart

from the capacity of 11,494 MW of hydroelectric projects currently under construction (for likely benefits from 2022–23 to 2029–30).

- The likely share of thermal installed capacity will reduce from 57 % of the total installed capacity as of March 2023 to 35.5 % in 2029–30, while the RE-based installed capacity in 2029–30 (including large hydro) will increase to 62.4% of the total installed capacity, compared to 41.4 % as of March 2023.
- By the end of 2029-30, the non-fossil fuel-based installed capacity will likely be 500.6 GW, comprising about 64% of the total capacity mix.
- The energy storage capacity required for 2029-30 is likely to be 60.63 GW (18.98 GW PSP and 41.65 GW BESS) with storage of 336.4 GWh (128.15 GWh from PSP and 208.25 GWh from BESS).
- As of 31.03.2023, the country has a PSP-based capacity of 4746 MW. PSP projects totaling 2780 MW are under construction and will likely benefit the country until 2030. In addition to these projects, a PSP capacity of 11,460 MW is required until 2030 to meet the country's electricity storage requirements.

Opportunities and Challenges:

Electrifying India: Policymakers hold the key

Renewables must grow quickly to electrify India's economy in the future. The nation currently holds the fourth position globally for installed renewable capacity; since 2014, renewable energy has increased fourfold, making up approximately 43% of the nation's overall power generation capacity (including large hydro). While a start is a good beginning, much more is required. Policy is crucial in the Indian economy, as in every other sector. The government's Panch Amrit project, which outlined its first climate targets at COP26 in 2021, created the conditions for the renewable energy industry to flourish quickly. India will need to nearly quadruple its non-fossil fuel capacity in just six years. With this effort, non-fossil fuel sources will meet 50% of India's energy needs by 2030. If the strategy is effective, there might be a cumulative decrease in carbon emissions of one billion tons by 2030, which would lead to a GDP with a carbon intensity of less than 45% and net zero emissions by 2070. The 2070 net-zero target will need resolute political leadership for many years. Despite the growing demand for fossil fuels, Prime Minister Narendra Modi's goal of rapidly deploying low-carbon technologies at scale is supported by his enormous political capital at home. It will be incumbent upon future leaders to adopt the vision of Prime Minister Modi and exert greater pressure to garner backing for sustainable energy and the potential economic revolution it offers. Politicians need to ensure that consumers know the reasons for India's plans to impose a domestic carbon tax.

Building Indian Renewable Supply Chains

India has made excellent progress so far, but we still need to do more to meet our target of nearly 80% non-fossil fuel electricity output by 2050. By doing this, India can improve job creation, cost control, energy security, and indigenous supply chains. For instance, the nation's insufficient capacity to produce solar wafers hinders India's manufacturing aspirations and net-zero targets. Although policy measures to support the expansion of the local photovoltaic (PV) supply chain have quickened, the industry still depends on imports for PV machinery, ingots/wafers, polysilicon, and ancillaries. With significant grid and storage capacity upgrades needed to support a substantial growth in renewable energy, battery storage is essential to India's goal of being net-zero. Government incentives are available for capital projects, and battery storage installation is required in variable renewable energy projects above 5 MW.

However, battery storage investment is falling behind the growth in renewable capacity. India requires gigawatt-scale battery manufacture to guarantee energy security and lower production costs. Another difficulty is accessing the essential minerals needed to increase domestic battery capacity. The 208 GWh capacity for battery energy storage by 2030 is significantly more than what the government is willing to support through the production-linked incentive program to establish a battery manufacturing capacity of about 50 GWh.

Unlocking India's internal potential

Due to its size, population, and economic development, India has several special opportunities to reduce its carbon footprint. However, its potential for producing bioenergy is mainly unrealized, with an annual biomass residual production of about 750 million tonnes (Mtpa). Using bioenergy in the transportation and industrial sectors instead of residential areas could help reduce air pollution from stubble burning and oil imports. India already leads the world in the areas of compressed biogas, biomass pelleting, and bioenergy in thermal power plants and road transportation. Its development of in-house solutions and abundance of bio-feedstock reveal its tremendous promise in sustainable aviation fuel (SAF). The Mangalore Refinery's SAF unit is scheduled to begin operations in early 2025, and approval for an indigenous SAF manufacturing process is anticipated this year. To accelerate these developments, India has to increase regulations to guarantee the development of the biomass supply chain and offer federal funding support for contemporary biofuel production facilities that use regional resources. India possesses the scientific capacity and expertise in pressurized heavy water and submarine reactors, which positions it as a leader in small modular reactors (SMRs) with a maximum power of 300 MW or less. The recent alliance between the National Thermal Power Corporation and the Nuclear Power Corporation of India to expedite nuclear deployment may accelerate SMR development. However, the Atomic Energy Act of 1962 is under review to allow for greater participation, and private-sector investment will also be necessary.

Realizing India's Green Hydrogen Potential

A key component of decarbonizing India's most difficult sectors is low-carbon hydrogen. By 2030, 4 Mt of low-carbon hydrogen would likely be produced, representing 5% of the world's total. In addition to decarbonization, India needs 125 GW of clean power from renewable sources to meet its 2030 aim of producing 5 Mt of green hydrogen and 55 Mt of green hydrogen to achieve net zero by 2070. We estimate that India can manufacture up to 35 Mtpa of this green hydrogen locally, with imports covering the remaining amount.

Carbon Capture and Storage requires urgent support

India is well-positioned to benefit from low-carbon hydrogen due to its cost- cost-effectiveness and governmental support, but more needs to be done by the government to encourage other industries, such as carbon capture, utilization, and storage (CCUS). Despite acknowledging the significance of CCUS, the government's approach is nevertheless unduly conservative. The powerful think tank of the Indian government, NITI Aayog, has noted a significant amount of CCUS potential; nonetheless, the nation lacks funding and a clear timetable. The carbon price system that India will implement by 2026 will be beneficial, but more action is still needed. Incentives should be provided by using captured CO_2 to create methanol for India's road fleet, diesel generators, tractors, and urea for the country's massive fertilizer industry. The lack of progress is concerning because our Net Zero 2050 model calls for more than one gigatonne of CCUS capacity.

Tackling India's hard-to-abate sectors

Economic growth must be correlated with sustainability to achieve the Net Zero target, particularly in hard-to-abate sectors, such as petrochemicals, cement, iron, and steel, which together account for three-quarters of India's total industrial emissions. Cement manufacturing is responsible for around 25% of India's industrial emissions. Major cement players should benefit from the fast-paced construction industry by investing in a low-carbon value chain. For example, JSW Cement wants to source agricultural waste for use as biomass fuel at its manufacturing plants to decrease its carbon emissions. Newer technologies, including cofiring hydrogen, electrifying kilns, harnessing waste heat from industry and agriculture, and CCUS, can support long-term decarbonization initiatives for cement producers in India. India is the country that produces the most steel worldwide, but it also produces the most industrial pollution. First and foremost, steel producers need to lessen their reliance on extremely polluting induction furnaces and coal-fired direct reduction furnaces. One way to cut down on carbon emissions is to switch to low-carbon electric arc furnaces and use greener metals, like scrap and direct reduction iron (DRI) made with gas or hydrogen. The swift escalation of petrochemical demand in India warrants the provision of decarbonization initiatives. India has to decarbonize its ethylene-producing industry because it uses more energy and generates more emissions. Expanding the circular economy for plastics to lower demand by 10% by 2050 compared to our base case, electrifying crackers, switching to low-carbon feedstock, and using hydrogen cofiring furnaces are important milestones in our Net Zero 2050 scenario.

Energy Efficiency: Leading the way

India is a leader in national policy with local impact, as demonstrated by the Unnat Jeevan by Affordable LEDs and Appliances for All (UJALA) program, the largest zero-subsidy LED bulb project in the world for residential consumers. In addition to cutting energy use by 35 TWh a year (a remarkable 3% of India's total electricity demand), UJALA spurred significant investments in the production of LED bulbs, which resulted in a significant drop in retail pricing. The Perform, Achieve, and Trade initiative has been instrumental in promoting efficiency improvements in energy-intensive businesses. Designated consumers can be given personalized energy-saving goals, and certificates obtained by exceeding these goals can be exchanged, offering a special incentive to adopt energy-saving practices. The building industry must address energy efficiency, especially in cooling. It is also essential to fully enforce national building norms and improve appliance standards and ratings.

Building an Indian Carbon Market:

India intends to develop a voluntary system concurrently and operate as a compliant carbon market. India, a nation known for its price sensitivity, must set its carbon price at US$154 per tonne of CO_2 by the year 2050 to achieve net zero. Development of the carbon market could incentivize businesses to profit from their investments in green hydrogen, bioenergy, CCUS, and renewables, which might not otherwise appear feasible due to their high initial capital expenditures.

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