**India's Transition to Clean Energy: A Review of Current Contributions from Renewable Energy Sources**

**Abstract**

Energy is a key catalyst for the economic growth of any nation. Lack of power acts as a development impediment in developing nations like India. India has seen a rather rapid increase in energy consumption in recent years due to both economic development and population expansion. India can address its energy constraint by utilizing renewable energy sources as wind, solar, geothermal, ocean, biomass, and fuel cell technologies. There is a high demand for electricity due to the Indian economy's rapid expansion. The majority of today's electricity demand is met by coal-fired power plants, which puts pressure on fossil fuels. Local and regional environmental deterioration and greenhouse gas emissions, which contribute to climate change. Therefore, in addition to lowering greenhouse gas emissions, energy security must be improved. One of the greener energy sources is renewable energy. In the current energy context, it is increasingly necessary to use renewable resources in an efficient manner in order to reduce the negative environmental effects of fossil fuels and ensure a sustainable power supply. This review paper explores the current status and growth trends of renewable energy sources in India, including solar, wind, hydro, and bioenergy. It assesses their contributions to the national energy mix, highlights key policies driving the clean energy transition, and discusses challenges and opportunities in scaling up renewable adoption for a sustainable energy future.

**Keywords**: Electricity, Energy, Fossil fuels, Greener energy, Renewable energy.

**Introduction**

India consumes the fourth most energy globally, behind China, Russia, and the United States [1]. India's population growth and rising living standards have contributed to a relatively rapid increase in the country's energy usage. For energy needs, India's current centralized energy planning mostly relies on thermal power plants, which account for close to 70% of all existing power plant capacity [2]. This over-reliance puts a strain on fossil fuels. The primary issue is how to preserve fossil fuels for future generations while employing various energy sources to support rapid and steady economic expansion. Thermal power plants have a negative impact on the environment. It's also important to remember that thermal power plants emit a significant quantity of carbon dioxide (CO2) (0.9 0.95 kg/kwh) and SOx and NOx, which contribute to global warming and climate change [3]. Global temperatures in 2023 were more than 1.5°C above pre-industrial levels for about half of the year, making it the hottest year on record [4]. Global CO2 emissions from energy sources were over 14.7 billion metric tons in 2022. About 3.6 billion people reside in regions that are particularly vulnerable to the effects of climate change [5]. India has made substantial investments in solar, wind, and other renewable energy sources to lessen its reliance on coal and other fossil fuels, placing it in the top five nations in terms of renewable energy capacity (International Energy Agency [IEA] [6]. The amount of renewable energy in India's energy mix has significantly increased, rising from 87.66 GW in 2015 to over 160 GW in 2023 [7]. The National Action Plan on Climate Change (NAPCC) and the National Solar Mission have established ambitious goals that have propelled this growth, positioning India as a worldwide leader in renewable energy. By 2030, India hopes to attain 280 GW of solar capacity under the National Solar Mission, which would help the country accomplish its larger goal of 500 GW of renewable energy capacity by the same year [8]. The private sector has become heavily involved as a consequence of government regulations and strategic investments, which have decreased the cost of renewable energy technology and increased its accessibility. For instance, between 2010 and 2022, solar power costs in India dropped by more than 80%, making it one of the least expensive energy sources in the nation [9]. Rural electrification has also been successfully accomplished by community-driven projects like microgrids and decentralized solar farms, which improve energy availability and promote economic development in isolated regions [10]. Initially, India set a goal to elevate its renewable energy capacity to 175 GW by 2022, including contributions from solar (100 GW), wind (60 GW), biomass (10 GW), and small hydropower (5 GW). In 2018, this ambition was expanded to achieve 225 GW of renewable capacity by 2022 and 275 GW by 2027. India remains dedicated to meeting its Nationally Determined Contribution (NDC) target of achieving a 40 percent share of renewable energy in its total energy mix by 2022. During COP 21, India pledged under its Nationally Determined Contributions (NDCs) to source 40% of its electricity capacity from non-fossil fuels by 2030. This goal was met by November 2021.India has 150.54 GW of renewable energy (RE) capacity as of November 30, 2021, which is divided into solar (48.55 GW), wind (40.03 GW), small hydro power (4.83 GW), bio-power (10.62 GW), and big hydro (46.51 GW). There is also 6.78 GW of nuclear energy. Thus, 157.32 GW of installed capacity from non-fossil fuels accounted for 40.1% of the 392.01 GW of total power capacity. India has had the most remarkable expansion in renewable energy capacity among major nations over the last seven and a half years. The solar energy industry has grown more than eighteen times, and the renewable sector, which includes substantial hydro, has nearly doubled [11]. The Indian government also makes an effort to reconcile the nation's need for power with environmental preservation by avoiding the usage of coal and other energy sources for electricity production. New energy sources are therefore required. In these situations, renewable energy is the best choice. To fulfill the need for energy, the potential of renewable energy sources may be investigated and used. In order to address the energy issue, there are several renewable energy sources found in nature, such as hydro, solar, wind, and biomass energy. These renewable energy sources have a lot of power potential and will solve the future electricity generating issue.

This paper primary goals is to first investigate potential solutions for supplying electricity to everyone, even in the most remote parts of the nation; second, lessen the demand on fossil fuels and preserve them for future generations; and third, protect the environment from natural disasters and global warming.

**Current energy scenario of India:**

One of the world's most varied electricity sectors is India. Through both traditional sources like coal, lignite, gas, hydro, and nuclear power, as well as non-conventional sources like wind,

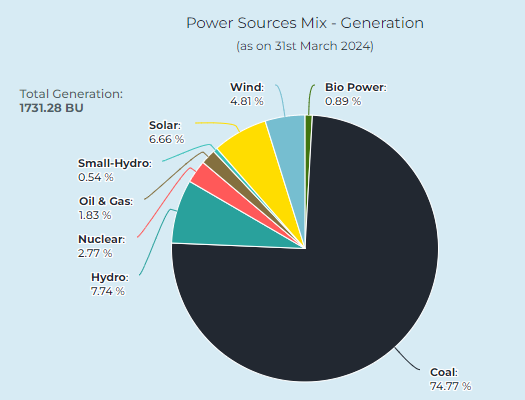
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Fig.1. India’s Energy Basket [12]

solar, small hydro, and biomass, this sector has been steadily increasing its generation capacity.

Coal contributes a massive 74.77% of the total power generation. This indicates a heavy reliance on fossil fuels. Solar (6.66%), Wind (4.81%), and Hydro (7.74%) collectively contribute a notable portion of the power generation. Nuclear (2.77%), Oil & Gas (1.83%), Bio Power (0.89%), and Small-Hydro (0.54%) have relatively small shares. The total generation is 1731.28 BU, providing a quantitative measure of India's power output(Fig-1)[13].

**Renewable energy:**

Natural processes that are continuously renewed provide renewable energy. Biomass, biogas, solar, wind, geothermal, tidal, and minor hydro power are among the many renewable energy sources that India is endowed with. Although large hydropower has been used for many decades worldwide and is considered a renewable energy source, it is typically excluded from the list of new and renewable energy sources. One of the world's most active users of renewable energy, particularly wind energy, is the Indian electrical industry(Table-1) [14].

**Table-1** Installed Renewable Energy Capacity in India as on 28.02.2025Source: [MNRE]. [15]

|  |  |  |
| --- | --- | --- |
| S no | Renewable sources of energy | Installation capacity (MW) |
| 1 | Wind Power | 48588.56 |
| 2 | Solar Power | 102566.02 |
| 3 | Small Hydro Power | 5100.55 |
| 4 | Biomass (Bagasse) Cogeneration | 9821.32 |
| 5 | Biomass(non-bagasse) Cogeneration | 921.79 |
| 6 | Waste to Power | 309.34 |
| 7 | Waste to Energy (off-grid) | 401.95 |
| 8 | **Total** | **167709.53** |

**The necessity of renewable energy**

One of the main issues with using renewable energy is climate change. A combination of the domestic coal dilemma, which is ongoing and predictable, and greenhouse gas emissions, including CO2, CH4, CFCs, halons, N2O, ozone, and peroxy acetyl nitrate [16]. Which are in charge of trapping heat radiated from the Earth's surface in the atmosphere, eventually raising the surface temperature, forcing India and the rest of the world to rethink and restructure their power infrastructure and energy dependencies. The rising global temperature and energy demand ultimately force India to turn to sustainable and cost-effective renewable energy resources in addition to improved energy efficiency measures. The renewable energy system has a vast amount of potential that can be explored and harnessed to meet the energy demand. The potentially most significant environmental issue is that India is facing alarming difficulties in expanding its energy infrastructure to meet its economic and social targets because of the rising electricity demand.

**Wind energy**

The domestic wind power industry leads India's wind energy sector, which has made steady advancements. The wind industry's growth has produced a robust ecosystem, project operation skills, and a manufacturing base that produces roughly 18,000 MW annually. As of right now, the nation has the fourth-highest installed capacity for wind power worldwide [17]. India is a significant participant in the worldwide wind energy industry today. Gujarat, Rajasthan, Karnataka, Maharashtra, and Tamil Nadu are the main Indian states that have been concentrating on the development of wind energy. The initial cost per megawatt (MW) of installed capacity is higher for wind turbines than for traditional fossil fuel generators. Because regulatory incentives are focused on plant building rather than operation, India's real wind power usage is low despite the huge installed capacity. This explains why, despite the installed capacity being 8.6%, wind power only accounts for 1.6% of India's total electricity generation [18]. Wind power generation variability is impacted by wind speed or lack of wind. A significant barrier in this instance is the whole reliance on weather patterns.

Since wind is a site-specific and intermittent energy source, choosing possible locations requires a thorough Wind Resource Assessment. More than 900 wind-monitoring stations have been placed nationwide by the government through the National Institute of Wind Energy (NIWE), and wind potential maps at elevations of 50, 80, 100, 120, and 150 meters have been released. A gross wind power potential of 695.50 GW at 120 meters and 1163.9 GW at 150 meters above ground level is indicated by the most recent evaluation(Table-2).

**Table-2** The eight windy states listed below have the highest wind energy potential [17]. 28.02.2025

|  |  |  |  |
| --- | --- | --- | --- |
| SI no | State | Wind Potential at 120 m (GW) | Wind Potential at 150 m (GW) |
| 1 | Andhra Pradesh | 74.90 | 123.3 |
| 2 | Gujarat | 142.56 | 180.8 |
| 3 | Karnataka | 124.15 | 169.3 |
| 4 | Madhya Pradesh | 15.40 | 55.4 |
| 5 | Maharashtra | 98.21 | 173.9 |
| 6 | Rajasthan | 127.75 | 284.2 |
| 7 | Tamil Nadu | 68.75 | 95.1 |
| 8 | Telangana | 24.83 | 54.7 |
|  | Total 8 windy states | 676.55 | 1136.7 |
| 9 | Others | 18.95 | 27.1 |

**Environmental impact of solar energy-** Wind turbines generate mechanical noise primarily from the generator and gearbox, as well as aerodynamic noise from the blades, experimentation with changing wind speed as they pass the tower and other moving parts. Modern turbines produce very little noise; at a distance of 40 meters, a single turbine produces about 50–60 dB [19,20]. However, the noise pollution caused by wind turbines is negligible because the CPCB's suggested tolerable noise levels for household appliances are far greater than the noise produced by wind farms.

**Solar energy**

The Sun has been revered since ancient times as the source of life on Earth. Our awareness of sunlight as an energy source came about throughout the industrial era. India has a wealth of solar energy resources. India receives over 5,000 trillion kWh of energy annually, with 4–7 kWh per square meter per day in the majority of its regions. India can efficiently use solar photovoltaic electricity, offering enormous scalability [21]. The National Solar Mission is now being implemented to achieve 20,000 MW of grid solar power, 2000 MW of off-grid capacity, which includes 20 million solar lighting systems and 20 million square meters of solar thermal collector area by 2022 (Table-3)[22].

**Table-3:** Installed capacity of Solar Power as on 28.02.2025 [21].

|  |  |  |
| --- | --- | --- |
| SI no | State | Solar Power (MW) |
| 1 | Andhra Pradesh | 5179.23 |
| 2 | Arunachal Pradesh | 14.85 |
| 3 | Assam | 192.34 |
| 4 | Chhattisgarh | 319.44 |
| 5 | Goa | 1340.54 |
| 6 | Bihar | 55.44 |
| 7 | Gujarat | 18125.41 |
| 8 | Haryana | 2025.18 |
| 9 | Himachal Pradesh | 170.26 |
| 10 | Jammu & Kashmir | 74.49 |
| 11 | Jharkhand | 199.87 |
| 12 | Karnataka | 9312.71 |
| 13 | Kerala | 1482.14 |
| 14 | Ladakh | 7.80 |
| 15 | Madhya Pradesh | 5012.88 |
| 16 | Maharashtra | 9881.37 |
| 17 | Manipur | 13.79 |
| 18 | Meghalaya | 4.28 |
| 19 | Mizoram | 30.39 |
| 20 | Nagaland | 3.17 |
| 21 | Odisha | 621.84 |
| 22 | Punjab | 1421.43 |
| 23 | Rajasthan | 27636.75 |
| 24 | Sikkim | 7.56 |
| 25 | Tamil Nadu | 9723.95 |
| 26 | Telangana | 4842.10 |
| 27 | Tripura | 21.24 |
| 28 | Uttar Pradesh | 3357.51 |
| 29 | Uttarakhand | 593.07 |
| 30 | West Bengal | 320.62 |
| 31 | Andaman & Nicobar Islands | 29.91 |
| 32 | Chandigarh | 78.85 |
| 33 | Dadra & Nagar Haveli and Daman & Diu | 48.12 |
| 34 | Delhi | 313.40 |
| 35 | Lakshadweep | 4.97 |
| 36 | Puducherry | 54.11 |
| 37 | Others | 45.01 |
|  | **Total (MW)** | **102566.02** |

**Environmental impact of small hydro energy-** The solar projects don't have zero emissions. If such projects are situated on land with vegetation, the emissions from them might rise much more. One hundred megawatt

solar power plants emit 15.6 gCO2/kWh of greenhouse gases. Solar power plants are linked to mercury and cadmium emissions in addition to greenhouse gas emissions. These components are employed in the production of solar panels. Cadmium emissions from Cd-Te PV cells are around 0.02 g Cd/GWh, while mercury emissions from solar power plants are about 0.1 g Hg/GWh [19]. The land space needed for photovoltaic systems is minimal since they are usually installed on already-existing structures. In contrast, depending on the type of solar-thermal technology being employed, a sizable area of land may be needed.

**Small hydro energy**

In India, hydropower plants with a capacity of less than 25 MW are categorised as "small hydropower" and are regarded as "renewable" energy sources. Over the past ten years, the industry has experienced remarkable growth. In India, SHP is by far the most traditional renewable energy technique for producing power. There are now 5100.55 MW of installed capacity from small hydropower projects [23]. For many years, the energy of flowing water has been used for commercial purposes. Hydro projects, however, may not be dependable during protracted droughts and dry seasons when rivers dry up or decrease in size (Table-4).

**Table-4:** Installed capacity of Renewable Power as on 28.02.2025.[23]

|  |  |  |
| --- | --- | --- |
| SI no | State | Small Hydro Power (MW) |
| 1 | Andhra Pradesh | 163.31 |
| 2 | Arunachal Pradesh | 140.61 |
| 3 | Assam | 34.11 |
| 4 | Chhattisgarh | 70.70 |
| 5 | Goa | 76.00 |
| 6 | Bihar | 0.05 |
| 7 | Gujarat | 106.64 |
| 8 | Haryana | 73.50 |
| 9 | Himachal Pradesh | 1000.71 |
| 10 | Jammu & Kashmir | 189.93 |
| 11 | Jharkhand | 4.05 |
| 12 | Karnataka | 1284.73 |
| 13 | Kerala | 276.52 |
| 14 | Ladakh | 45.79 |
| 15 | Madhya Pradesh | 123.71 |
| 16 | Maharashtra | 384.28 |
| 17 | Manipur | 5.45 |
| 18 | Meghalaya | 55.03 |
| 19 | Mizoram | 45.47 |
| 20 | Nagaland | 32.67 |
| 21 | Odisha | 115.63 |
| 22 | Punjab | 176.10 |
| 23 | Rajasthan | 23.85 |
| 24 | Sikkim | 55.11 |
| 25 | Tamil Nadu | 123.05 |
| 26 | Telangana | 90.87 |
| 27 | Tripura | 16.01 |
| 28 | Uttar Pradesh | 49.10 |
| 29 | Uttarakhand | 233.82 |
| 30 | West Bengal | 98.50 |
| 31 | Andaman & Nicobar Islands | 5.25 |
|  | **Total (MW)** | **5100.55** |

**Environmental Small hydro energy impact**: Small hydro energy has no discernible, significant negative effects on the environment. Small hydropower projects are often promoted as a cleaner alternative to large dams, with relatively lower environmental footprints; however, their ecological impacts are not negligible [49]. Despite being a renewable source, small hydro can disrupt aquatic ecosystems, particularly by altering river flow, affecting fish migration, and modifying sediment transport [50]. Run-of-the-river systems, commonly used in small hydro projects, may still lead to habitat fragmentation and changes in water quality downstream [51]. The cumulative environmental impact of multiple small hydro projects in a single river basin can be substantial, often overlooked in environmental assessments [52]. While greenhouse gas emissions from small hydro are significantly lower than fossil-based energy sources, the flooding of land and organic matter decomposition can contribute to localized methane emissions [53]. Proper site selection, environmental flow maintenance, and fish passage mechanisms are critical to minimizing the ecological impacts of small hydro installations [54]. There remains a need for standardized environmental impact assessment frameworks specifically tailored to small hydro projects, especially in ecologically sensitive areas [55]. Small hydro projects are often perceived as benign due to their scale, but even low-head installations can have lasting effects on biodiversity and riverine health [56].

**Biomass energy**

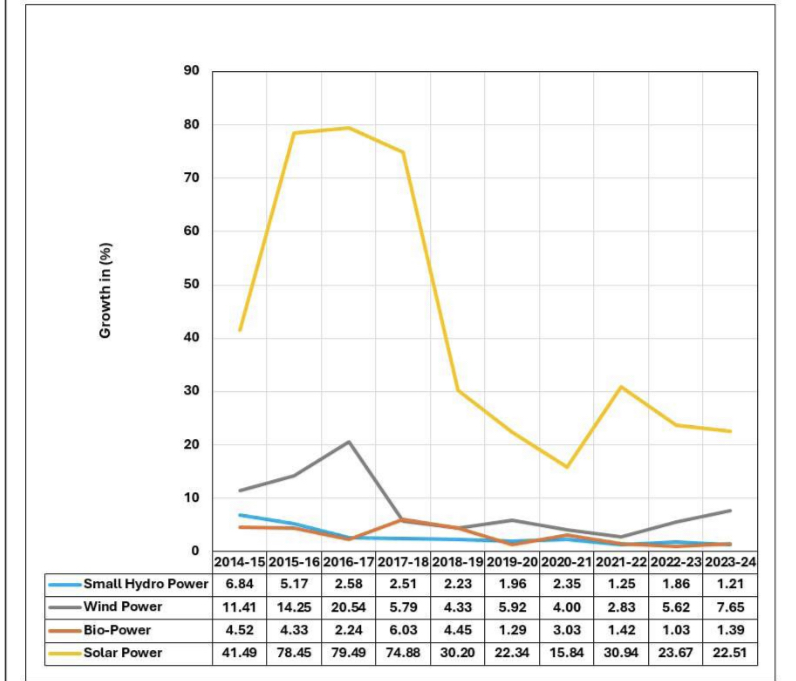
Solar, wind, and geothermal energy are examples of renewable energy sources that now account for a very small portion of the world's energy consumption, aside from hydropower. The most often used energy source is biomass. Biological material obtained from live or recently living things is known as biomass. Specifically, it refers to ligno-cellulosic biomass, which is made up of plants or plant-based components [24]. Biomass includes things like wood, sawdust and logging debris, animal manure, vegetable matter like leaves, crop residue, and agricultural waste. As of mid-2013, India has at least 3.4 GW of utility-based installed capacity in bagasse-based cogeneration and biomass power plants, according to the CEA. India has 18 GW of potential biomass energy generation capacity and 5 GW of potential bagasse-based generation, according to the Ministry of New and Renewable Energy. Bagasse, or crushed sugarcane or sorghum stalks, is a significant source of biomass used to generate energy and may be fed into combustion-powered generators. In India, biomass programs have aided in bringing energy to the underserved interior population and are primarily designed to address the demands of rural and isolated areas. Biomass fuels provide 13% of the world's overall energy needs. One such source is biomass, which may be burned directly or converted into biogas, vegetable oil, biodiesel, and producer gas to offer a steady supply of the energy needed. Various conversion technologies can be used to transform biomass into an appropriate type of energy. In India, the biomass power production sector generates over 5000 million units of energy annually, employs over 10 million man-days in rural regions, and draws investments totalling over Rs. 600 crores(Table-5) [26].

**Table-5:** Installed capacity of Biomass Power/ Bagasse Cogeneration 28.02.2025 [27]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SI no | State | Biomass Power (MW) | Biomass Cogeneration (Non-Bagasse) | Waste to Energy | Waste to Energy (Off-grid) | Bio Power Total |
| 1 | Andhra Pradesh | 378.10 | 113.57 | 53.16 | 29.56 | 574 |
| 2 | Arunachal Pradesh | - | - | - | - | 0.00 |
| 3 | Assam | - | 2.00 | - | - | 2.00 |
| 4 | Chhattisgarh | 272.09 | 2.50 | - | 2.50 | 277.09 |
| 5 | Goa | - | - | 1.94 | - | 1.94 |
| 6 | Bihar | 112.50 | 26.40 | - | 1.32 | 140 |
| 7 | Gujarat | 65.30 | 12.00 | 7.50 | 33.30 | 118.10 |
| 8 | Haryana | 151.40 | 111.26 | 11.20 | 18.76 | 292.62 |
| 9 | Himachal Pradesh | - | 9.20 | - | 1.00 | 10.20 |
| 10 | Jammu & Kashmir | - | - | - | - | 0.00 |
| 11 | Jharkhand | - | 19.10 | - | 1.04 | 20.14 |
| 12 | Karnataka | 1868.91 | 20.20 | 1.00 | 19.84 | 1909.95 |
| 13 | Kerala | - | 2.27 | - | 0.23 | 2.50 |
| 14 | Ladakh | - | - | - | - | 0.00 |
| 15 | Madhya Pradesh | 92.50 | 14.85 | 15.40 | 28.13 | 150.88 |
| 16 | Maharashtra | 2907.30 | 16.40 | 12.59 | 58.28 | 2992.57 |
| 17 | Manipur | - | - | - | - | 0.00 |
| 18 | Meghalaya | - | 13.80 | - | - | 13.80 |
| 19 | Mizoram | - | - | - | - | 0.00 |
| 20 | Nagaland | - | - | - | - | 0.00 |
| 21 | Odish | 50.40 | 8.52 | - | 0.83 | 60.05 |
| 22 | Punjab | 299.50 | 231.79 | 10.75 | 2621 | 568.25 |
| 23 | Rajasthan | 134.15 | - | 59.60 | 4.81 | 200.56 |
| 24 | Sikkim | - | 2.00 | - | - | 2.00 |
| 25 | Tamil Nadu | 969.10 | 43.55 | 6.40 | 26.40 | 1045.45 |
| 26 | Telangana | 158.10 | 3.30 | 45.80 | 14.47 | 221.67 |
| 27 | Tripura | - | - | - | - | 0.00 |
| 28 | Uttar Pradesh | 1985.50 | 165.26 | - | 122.91 | 2273.67 |
| 29 | Uttarakhand | 72.72 | 60.00 | - | 9.52 | 142.24 |
| 30 | West Benga | 300.00 | 43.52 | - | 4.84 | 348.36 |
| 31 | Andaman & Nicobar Islands | - | - | - | - | 0.00 |
| 32 | Chandigarh | - | - | - | - | 0.00 |
| 33 | Dadra & Nagar Haveli and Daman & Diu | 3.75 | - | - | - | 3.75 |
| 34 | Delhi | - | - | 84.00 | - | 84.00 |
| 35 | Lakshadweep | - | - | - | - | 0.00 |
| 36 | Puducherry | - | - | - | - | 0.00 |
| 37 | Others | - | - | - | - | 0.00 |
|  | **Total (MW)** | **9821.32** | **921.79** | **309.34** | **401.95** | **11454.40** |

**Environmental Biomass energy impact:** In comparison to thermal power plants, biomass emits extremely little sulfur oxide and nitrogen oxide since it contains very little of these elements. As a component of the earth's natural carbon cycle, burning biomass also releases carbon dioxide, the main greenhouse gas. There is no net increase in the amount of carbon dioxide in the atmosphere since the plants absorb it from the environment during their growth and release it back into the atmosphere after combustion. Water is needed in the cooling system and boiler of biomass power plants. When returned to the lake or river, the cooling water is significantly warmer than when it was taken out. In the lake or river where the power plant water is released, pollutants and the warmer water can damage fish and vegetation

**Fig-2** Annual Growth (%) in Installed Capacity

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From 2014-15 to 2023-24, in the renewable energy sector, solar power exhibited exceptional growth over the years. It achieved a high CAR of 78.97% from 2014-15 to 2016-17, then faced a slowdown with a CAGR of 34.03% from 2016-17 to 2020-21, and 25.65% from 2020-21 to 2023-24, highlighting its resilience and potential despite short-term fluctuations. Wind energy also grew significantly, with a CAGR of 17.55% from 2014-15 to 2016-17, and 5.15% from 2016-17 to 2023-24(Fig-2).

**Comparison between present and previous situation of renewable energy**

Between 2020 and 2025, India witnessed a remarkable transformation in its renewable energy sector, marked by a significant increase in capacity, policy evolution, and investment growth. In 2020, India had an installed renewable energy capacity of approximately 85.9 GW, including around 34 GW from solar, 38 GW from wind, 10 GW from bio-power, and about 45 GW from small hydro projects [28][29]. By February 2025, this capacity had more than doubled, reaching around 214.68 GW Solar energy made the most substantial leap, rising to 102.57 GW, followed by wind at 48.59 GW, hydro at 52.07 GW, and bio-power at 11.45 GW [30].

This growth was underpinned by robust government initiatives. One of the major policy instruments was the waiver on inter-state transmission system (ISTS) charges for renewable projects, which was originally introduced for projects commissioned by June 30, 2025. This waiver helped attract investments by lowering project costs. Furthermore, in 2024–2025, the government extended this benefit to green hydrogen and green ammonia projects, signalling a shift toward integrating advanced renewable technologies into the mainstream energy mix [29]. Additionally, domestic manufacturing of solar modules received a boost through production-linked incentive (PLI) schemes, aiming to reduce dependence on imports and build a self-reliant green energy infrastructure.

From a financial perspective, India's investment in renewable energy also surged. Over $30 billion was allocated in the five years leading up to 2025, reinforcing India’s position as one of the fastest-growing renewable energy markets globally [30]. However, despite this progress, the sector faced several challenges. A 2025 Reuters report highlighted issues such as weak demand for renewable tenders, delays in power purchase agreements (PPAs), and high project cancellation rates. The sector also grapples with a shortage of skilled labor, particularly in the solar segment, and continues to struggle with the country’s ongoing dependence on coal [31,32].

Overall, the comparison between the 2020 and 2025 scenarios reveals a dramatic scaling up of India's renewable energy efforts, backed by targeted policies and financial commitment. Yet, persistent structural and implementation challenges remain, which must be addressed to fully realize India's clean energy potential and long-term sustainability goals.

**Future of renewable energy**

India, characterized by its burgeoning population and finite conventional energy resources, must pursue sustainable pathways to meet its escalating energy demands while maintaining economic growth. In this context, renewable energy emerges as the most viable and strategic alternative. The depletion of fossil fuel reserves, coupled with growing environmental concerns such as global warming, has intensified the global and national focus on clean energy production. Consequently, the adoption and integration of renewable energy sources are expected to rise progressively in the coming years.

Projections indicate that the share of renewable energy in India’s total installed capacity is anticipated to increase from the current 12% to approximately 33% by the year 2030. In terms of electricity generation, the contribution of renewables is expected to grow from around 6% to 16% within the same period. This significant increase positions renewable energy as the second-largest source of power generation, following coal. Furthermore, due to both a projected decline in coal availability and strategic policy shifts towards environmentally sustainable development, the reliance on coal-based electricity is expected to decrease from 70% to 58% by 2030 [33,34].

According to a report by the Planning Commission of India,[35] the projected installed capacity of renewable energy-based power generation by 2031–2032 is estimated to be 243,494 MW, out of a total projected generation capacity of 700,703 MW. The total contribution from new renewable energy sources is expected to reach 122 Million Tonnes of Oil Equivalent (Mtoe), with hydropower accounting for 35 Mtoe and other renewable sources contributing 87 Mtoe.[36].

**India’s current energy policies**

The National Electricity Policy was launched in 2005 to access the power, power demand availability, to meet the energy and peaking deficits, to provide reliable quality power at reasonable prices, to raise the per capita electricity availability by 1000 units, and also to make the electricity sector commercially feasible to look after consumers' interests [37].Thus, the main objective of the renewable energy policy framework is to greatly expand the contribution of renewable sources to India's energy mix. The following outlines different energy policies enacted by the Indian government to promote power generation from both conventional and renewable sources, especially highlighting renewable energy.

1. National electricity policy 2005

In order to meet the needs of the consumers, the National Electricity Policy was established in 2005. Its aim was to increase the per capita electricity availability by 1000 units, make the power sector commercially viable, eliminate peaking and energy shortages, and provide reliable, quality power at affordable prices [38,39].

1. Electricity Act 2003

The Indian Electricity Act (1910), the Electricity (Supply) Act (1948), and the Electricity Regulatory Commissions Act (1998) were the three earlier acts that governed the electricity sector before the Electricity Act of 2003 was created. The electricity act has various sections that address rural electrification, transmission and distribution, cogeneration, and the production of electricity from renewable energy sources by offering appropriate measures for grid connectivity and electricity sales to individuals. These sections also outline the principles of tariffs, the establishment of the CEA, trading development, measures against electricity theft, restructuring of state electricity boards (SEBs), and other topics related to the purchase of electricity from such sources [38-41].

1. Tariff policy 2006

The Tariff Policy, which was announced in January 2006, set a minimum percentage for energy purchases while taking into account resource availability, distribution companies' purchases at preferential tariffs, etc [38,39].

1. National rural electrification policies 2006

The National Rural Electrification Policies were created in 2006 with the goals of giving all households access to electricity (a dependable, high-quality power supply) by 2009 and supplying energy to every village via off-grid options like standalone systems or grid-connected options [38,39].

1. National action plan on climate change 2008

India's first National Action Plan on Climate Change (NAPCC), which outlines current and upcoming policies and programs addressing climate reduction and adaptation, was launched on June 30, 2008, by Prime Minister Manmohan Singh. The National Mission for Enhanced Energy Efficiency (NMEEE) and the Jawaharlal Nehru National Solar Mission (JNNSM) are the two main energy-related missions among the eight missions that make up the NAPCC. Making solar energy competitive with fossil fuel-based energy is JNNSM's goal. Demand management is one of the NMEEE's goals, with a minimum of 10 GW of energy savings by the end of 2012 [38,42].

1. National Solar Mission (NSM) – 2010

The NSM was established in January 2010 as part of the National Action Plan on Climate Change with the goal of promoting solar energy for power generation and other applications. Since its initial goal of 20 GW of solar capacity by 2022 was revised to 100 GW in 2015, the mission has made a significant contribution to India's renewable energy capacity, with utility-scale and rooftop solar installations growing significantly [43].

1. Pradhan Mantri Ujjwala Yojana (PMUY) – 2016

PMUY was established in May 2016 with the goal of delivering LPG connections to women from Below Poverty Line (BPL) families so they may have clean cooking fuel. More than 58 million connections had been made by December 2018, increasing access to cleaner cooking fuels and lowering the health risks connected to conventional cooking techniques [44].

1. National Energy Policy (NEP) – 2017

A comprehensive framework for India's energy industry with an emphasis on affordability, sustainability, and energy security was offered by the NEP, which was introduced in 2017. Enhancing energy efficiency, expanding the capacity of renewable energy sources, and guaranteeing universal access to power were the main points of emphasis [45].

1. Pradhan Mantri Surya Ghar Muft Bijli Yojana – 2024

This program, which was unveiled in February 2024, intends to encourage rooftop solar installations by giving people financial aid and favorable loans. It aims to enable 1 crore residential homes to produce their own electricity and get up to 300 units of free power per month with an investment of more than ₹75,000 crore [46].

1. Amendments to Civil Nuclear Liability Laws – 2025

India proposed changes to its 2010 Civil Nuclear Liability Damage Act in April 2025 to limit nuclear equipment providers' liability for accidents. In accordance with international standards and to facilitate trade talks, this action seeks to draw in foreign companies and increase India's nuclear power capacity to 100 GW by 2047 [47].​

1. Legislation to Boost Oil and Gas Exploration – 2025

To encourage oil and gas development, India amended the 1948 law on oil extraction with new laws in early 2025. The measure aims to lessen India's significant reliance on imported crude oil by stabilizing rules, permitting international arbitration, and extending lease durations in order to draw in additional investors [48].

**Promotional Centre of Renewable Energy**

The Ministry of New and Renewable Energy (MNRE) serves as the central authority within the Government of India responsible for the promotion and advancement of new and renewable energy sources. Its primary objective is to facilitate the development and deployment of renewable energy technologies to supplement the nation’s growing energy demands. India was among the pioneering nations to establish a dedicated ministry—MNRE—at the national level to oversee renewable energy initiatives.

To further its objectives, several specialized institutions have been established across the country. These include the Solar Energy Centre, the Indian Renewable Energy Development Agency (IREDA), the Centre for Wind Energy Technology (C-WET), the Alternate Hydro Energy Centre (AHEC), and the Sardar Swaran Singh National Institute of Renewable Energy (SSS-NIRE). Each of these organizations plays a pivotal role in supporting the adoption and implementation of renewable energy technologies.

At the sub-national level, State Nodal Agencies (SNAs) have been constituted to execute the Ministry’s policies and implement various programmes and projects. A significant initiative in this domain is the Jawaharlal Nehru National Solar Mission (JNNSM), which was launched to accelerate the generation of solar power across the country.

**Conclusion**

In the face of escalating greenhouse gas emissions from the power sector and the continued depletion of fossil fuel reserves, the development and promotion of renewable energy sources have become more critical than ever. As of 2025, renewable energy is playing an increasingly significant role in India's energy mix, contributing not only to reducing the dependency on conventional energy sources but also in addressing energy deficits and improving access in remote and underserved areas. Recent assessments show that with sustained efforts, greenhouse gas emissions can be significantly reduced—by up to 45%—with approximately 14% achievable through the replacement of coal with renewable alternatives. India's renewable energy potential is immense; however, the effective harnessing of this potential depends on the synergy between technological advancement and proactive human behavior. No technology is without limitations, which underscores the need for context-appropriate solutions.

To achieve long-term sustainability and efficiency, there must be an increased focus on research and development (R&D), innovation, and the benchmarking of best practices. Furthermore, government support remains essential in accelerating the transition. Policy tools such as subsidies, tax exemptions, feed-in tariffs (FITs), green certificates (GC), production and investment tax credits (PTC/ITC), and soft loans should be expanded and tailored to empower local entrepreneurs and renewable energy developers. Strengthening institutional frameworks, ensuring community participation, and promoting public awareness are equally important in fostering a culture that supports clean and sustainable energy. In conclusion, with continued commitment and the right policy ecosystem, renewable energy can not only mitigate climate change but also drive inclusive growth and energy security for the future.

**Disclaimer (Artificial intelligence)**

We, Geetesh Kumar and Dr. Ayushi Trivedi, hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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