



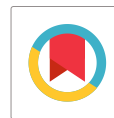
Current Scenario and Future Perspectives of Renewable and Sustainable Energy in India: Progress and its Challenges

A. S. Sikarwar^{1*}, N. A. Ansari¹ and P. Singh¹

Department of Mechanical Engineering, Delhi Technological University, Delhi, India

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*ajeetsinghsikarwar_2k22phdme507@dtu.ac.in



ABSTRACT

Energy is a key force behind both social and economic advancement. The scientific advancements in numerous industrial, governmental, and municipal activities have significantly increased the energy demand. The main reasons behind the efficient utilization of renewable energy sources (RESs) are the rapidly increasing rates of energy demand and fuel prices, as well as the requirement to control greenhouse gas emissions. In reality, meeting the world's growing energy requirements and preventing climate change are now of greatest concern. This review paper provides a thorough overview of the creation and growth of renewable and sustainable energy sources, including information on their types, traits, benefits, and drawbacks. This review specifically discusses the situation and future potential of renewable and sustainable energy sources in India. The growth of RESs can have a substantial impact on the economic development of India, in addition to creating employment possibilities related to harnessing energy from RESs.

Keywords: Solar energy; Hydrogen energy; Greenhouse gas emissions; Electricity; Renewable energy.

1. INTRODUCTION

The most difficult issues of the twenty-first century are how to power the globe. Energy demand has spread to all walks of life. So, maintaining the energy supply is crucial on a global scale. However, a sizable portion of people live without access to power in rural areas (Azarpour *et al.* 2022). India has made considerable stride towards increasing its capacity for renewable energy. These developments are mostly fuelled by solar and wind energy. The nation has high goals to reach 450 GW of renewable energy generation by 2030. These objectives included minor hydropower, biomass, solar, and wind energy projects. India has now decided to increase the production of solar modules. The production linked incentive plan for the production of high-efficient solar PV modules has just been introduced by the Indian government. Over the following five years, we anticipate increasing solar PV production capacity by 10 GW. Private sectors are instrumental in achieving production of energy from non-conventional sources., This is as a result of India's favourable public policy.

According to research conducted on both laboratory and industrial scales, maintaining the balance between crucial factors such as non-polluting or extremely low-polluting energy sources and energy efficiency is not as simple to achieve. As a result, the main goal of finding an alternative was to reduce carbon dioxide emissions or other atmospheric pollutants

like nitrogen oxides, sulphur dioxide, PM₁₀, and PM_{2.5} associated with transportation to the environment that are playing a significant role in the deterioration of air quality and directly affect the health of humans as well as other living species on the planet (Krishna *et al.* 2022).

Due to India's poor exploitation of natural energy and its predominant dependency on coal for its energy needs, the country is significantly dependent on imports for its oil and natural gas needs. According to the most recent assessment from the International Energy Agency, by 2040, India will depend 90% more on oil imports. India's energy security is currently very much threatened by changes in oil prices. India continues to have a significant electricity shortage. The statistics tell us that 5.4% of Indians, the majority of who live in rural or remote locations, did not have access to electricity as of 2018. In addition to the issues, brought by the imbalance between supply and demand, India ranks third in greenhouse gas emissions due to its low energy efficiency (Wang and Liu, 2021).

According to a CO₂ emission assessment undertaken by the Delhi-based Centre for Science and Environment, the quantity of CO₂ emitted on Indian roads might rise from 208 million tonnes in 2005 to 1212 million tonnes by 2035. The extensive usage of imported oil, gasoline, and diesel by Intercontinental Exchange is another significant negative consequence. By 2030, it is predicted that India's energy import bill will have doubled, from about \$150 billion to \$300 billion. These

scary numbers can be diminished by the fact that electric vehicles have a good chance of succeeding. Tesla is the world’s top EV manufacturer. Battery technology was judged unsuitable for India since it is extremely expensive. Even if the idea of electric vehicles is fantastic, the main challenge we face is implementing it.

The National Electricity Plan, which was announced this year, anticipates a significant rise in the nation’s overall electricity demand and calls for a more than doubling of built capacity by 2031–2032, from the current 431 GW to 900 GW, and in addition, 596 GW will come from renewable sources and 615 GW from non-fossil sources. As a result, renewable energy capacity will increase from its present 42 percent to 55 percent by 2026–2027 and 66 percent by 2031–2032. Solar and wind energy will be the main drivers of this growth.

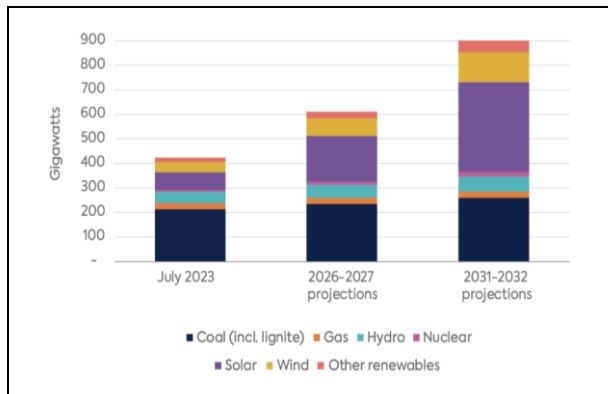


Fig. 1: Production of electricity using different sources (Source: Ministry of Power, India)

Figure 1 depicts the current share of electricity generation from various sources, which is approximately 42.5%, with the share of non-fossil-based capacity expected to climb to 57.4% by the end of 2026-2027 and further to 68.4% by the end of 2031-2032. An extra of Rs. 33.60 lakh crore will be required for electricity generation capacity from 2022 to 2032.

2. VARIOUS ATTRIBUTES OF RENEWABLE AND SUSTAINABLE ENERGY RESOURCES

In 2022, the energy crisis has prompted the development and use of solar PV cells and wind energy, which will continue to expand in the future. These renewables are critical for reducing pollution, producing unpolluted energy, and addressing energy security concerns. Furthermore, the energy generated will be less expensive and more accessible. Exploiting the enormous potential of solar, wind, and hydropower will boost the energy budget. Green energy is not only environmentally good, but also inexpensive and creates jobs. It will transform sustainable energy systems. Figure 2 depicts the global energy investment in clean energy and fossil fuels during 2015-2023.

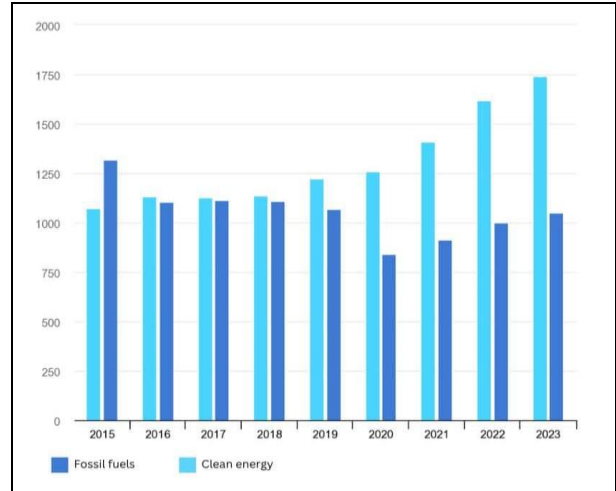


Fig. 2 Global energy investment in clean energy and fossil fuels during 2015-2023 (Source: IEA)

A pre-feasibility assessment of a hybrid energy system is often performed before installation and operation. The feasibility analysis involves a study of climatic conditions of the proposed sites, the accessibility of RESs, and an assessment of the prospective load and load demand of the application site (Khare et al. 2016). There are nine major energy sources, which are divided into renewable and non-renewable categories. All RE resources are now used to generate electricity, but only geothermal, solar, and biomass are used to generate heat (Azarpour et al. 2022).

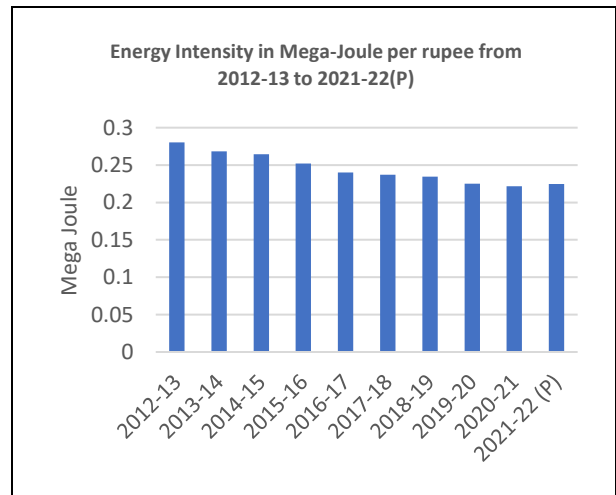


Fig. 3: Energy intensity in megajoule per rupee from 2012-2013 to 2021-2022 (Source: Ministry of Statistics and Programme Implementation, India)

The Sustainable Development Goals include making inexpensive, dependable, and modern energy available to everyone as one of its targets. India has been concentrating on making energy accessible to all of its residents to guarantee the same. As can be seen, the percentage of villages in each state that are electrified as of 31 March 2022 has reached 100% (compared to census

data from 2011 for the total number of villages in the nation). As Fig. 3 shows the energy intensity dropped from 0.2801 Mega Joules per rupee in 2012–13 to 0.2245

Mega Joules in 2021–22 (at prices from 2011–12) and Fig.4 shows energy sector capacity of India between 2022-2047.

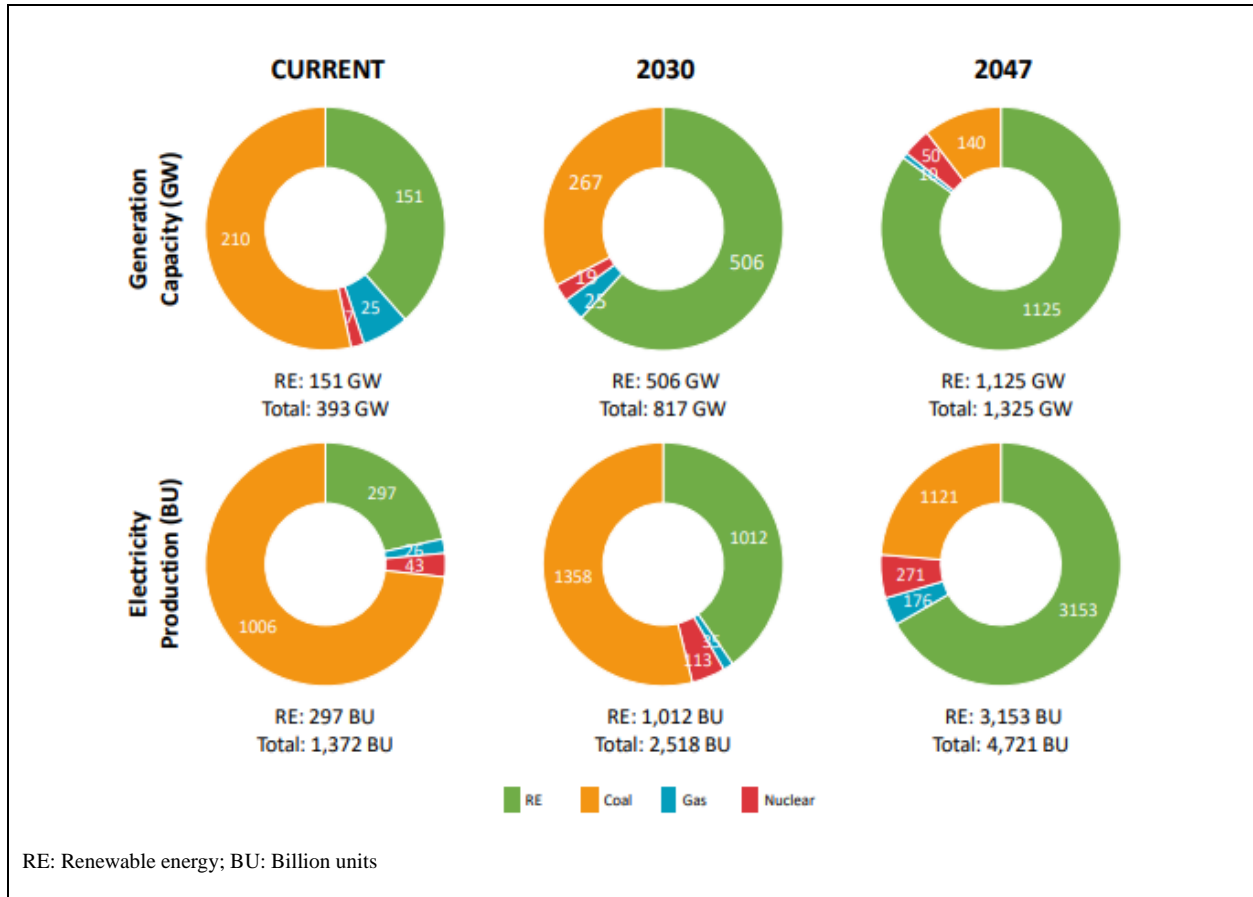


Fig. 4: Energy Sector capacity of India 2022-2047 (Source: Ministry of New and Renewable Energy, India)

This paper focuses on electricity generation since it is a convenient secondary kind of energy that can be efficiently exploited to provide numerous end-uses. Traditional biomass, which is currently used for cooking, accounts for the majority of renewables. We analyse the status of various renewables in India, and their potential, and highlight challenges and methods for expedited implementation.

2.1 Solar Energy

India being one of the global leaders in terms of solar energy installations, it has undertaken several solar projects and initiatives, including the Jawaharlal Nehru National Solar Mission to promote the use of solar electricity. Solar parks, rooftop solar installations, and

solar-wind hybrid projects are becoming increasingly popular. India has implemented various policy changes to solve its energy trilemma of assuring energy security, energy affordability, and environmental sustainability.

India is the world’s most populated nation, the fifth-largest economy, and the third-largest emitter of CO₂. In order to mitigate CO₂ emission, India has taken big leaps towards energy production from renewable sources. The country had 61.97 GW of installed solar capacity as of November 30, 2022, ranking fourth in the world for solar photovoltaic (PV) deployment. Solar rates in India are currently highly competitive and have reached grid parity. Figure 5 shows the overall target and installed capacity as on 31st March 2021.

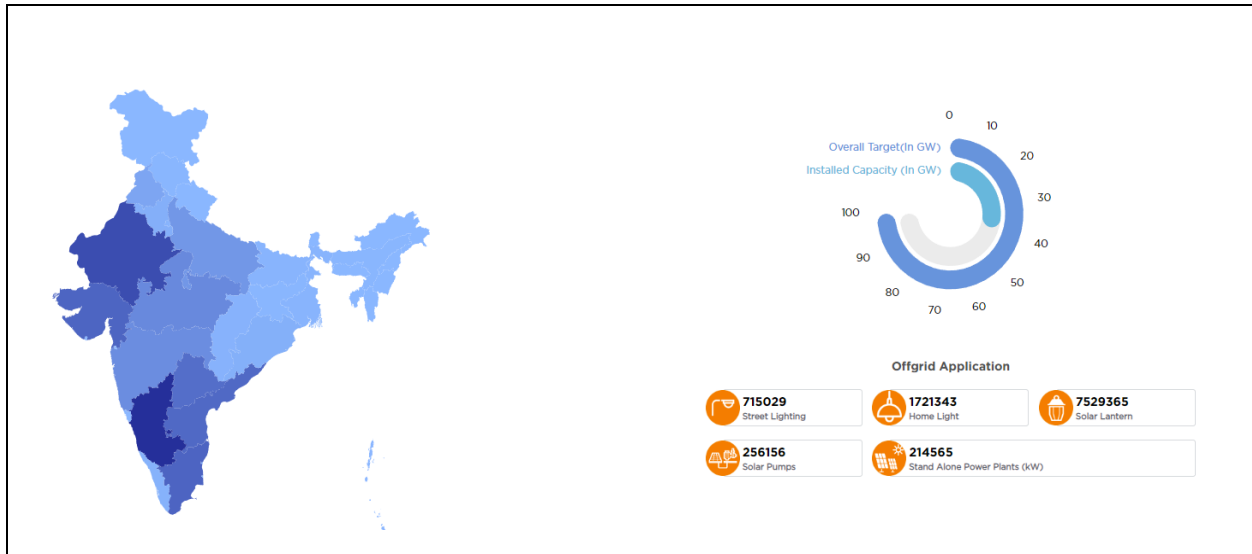


Fig. 5: Overall target and installed capacity as on 31st March 2021 (Source: solarfeeds.com)

Rajasthan has the largest potential for solar energy generation compared to any state in India. Rajasthan had installed over 16,060 MW of solar energy capacity as of December 2022, surpassing Karnataka. Rajasthan intends to install 30,000 MW of solar energy capacity by 2025. Table 1 gives the data of top Indian cities having prominent solar plants.

Table 1. The top Indian cities for solar energy in 2022 (Source: ornatesolar.com)

Rank	State	Solar Capacity	Prominent Solar Plant
1	Tamil Nadu	6.2 GW	Kamuthi Solar Power Project
2	Gujarat	8 GW	Charanka Solar Park
3	Karnataka	7.8 GW	Pavagada Solar Park
4	Telangana	4.6 GW	Ramagundam Floating Solar Project
5	Rajasthan	16.06 GW	Bhadla Solar Park

Between the fiscal years 2011–12 (FY12) and FY20, economy of Rajasthan (gross state domestic product), grew at a compound annual growth rate (CAGR) of 9.68%. With energy supply increasing at a CAGR of 5.66% during the same period, the availability of power has been a major factor in fostering economic growth (Azarpour *et al.* 2022). As a result, the per-capita electricity availability of the state reached 1,241 kWh in FY21, an increase of 72% over 721 kWh in FY12.

Rajasthan is in a good position to pursue a sustainable development route because the state has a lot of renewable energy resources and undeveloped territory. The state enjoys high sun insolation levels of 5.2 to 5.7 KWh/sq.m/day, with the western regions experiencing the highest amounts. The 41,949 sq. km. of total

wasteland area is suitable for renewable energy deployment and is almost entirely comprised of the four western districts of Barmer, Bikaner, Jaisalmer, and Jodhpur. As shown in Fig. 6, only a small portion (0.5%) of the state’s land area will be necessary to reach the 90 GW goal by 2030 to cover the state’s own energy needs as well as export electricity to other states. Hence, Rajasthan has some of the least expensive renewable electricity in India. The weighted average rates for solar PV projects awarded in the state between November 2020 and December 2021 ranged from INR 2.00 to 2.25 per unit.

2.2 Wind Energy

Wind energy is another significant source of India’s renewable resources. There are many wind farms and wind turbine producers in the nation. To make use of the enormous wind potential along its coastlines, wind energy projects are actively being investigated in India. A substantial effort is being made to increase India’s technological toolkit to facilitate the energy transition. India will bid out offshore wind energy blocks off the shores of Gujarat and Tamil Nadu for the first time, starting with 4 GW per year for three years up to 2024–2025 and increasing to 5 GW per year for five years up to 2029–2030 with no evacuation or transmission expenses. Over the next seven years, India will install 58 GW of wind energy capacity at a cost of more than 4 lakh crore. With this, onshore wind energy would have a total installed capacity of 100 GW as part of the India’s mission to develop 500 GW of non-fossil fuel-based power by 2030. At the moment, 42.8 GW of onshore wind power is operational. Five GW and three GW of the 58 GW of wind energy are proposed to be installed in 2023–2024 and 2024–2025, respectively. The capacity of 58 GW of onshore wind energy will be operational by 2030. The amount needed to spend in one GW of wind energy is between Rs 7,000 and Rs 8,000 crore.

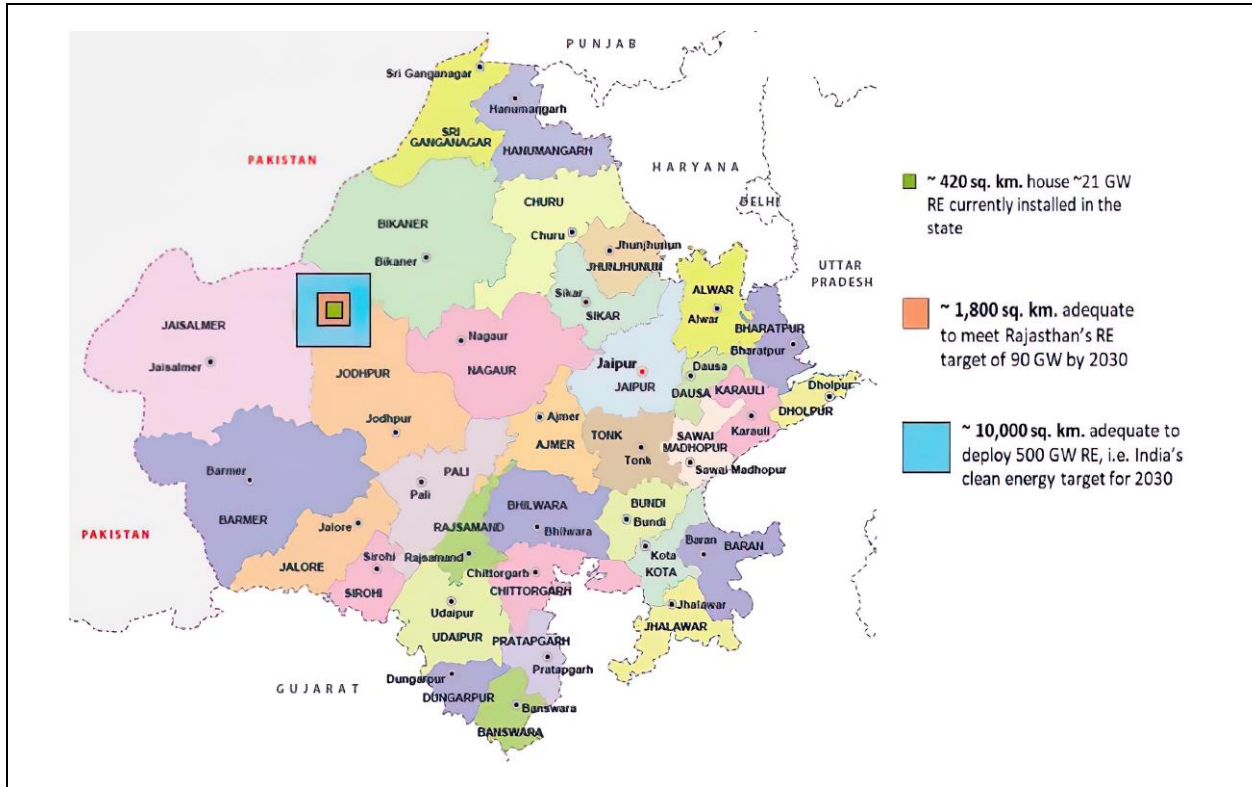


Fig. 6: Renewable energy resources in Rajasthan (Source: Department of Land Resources, India)

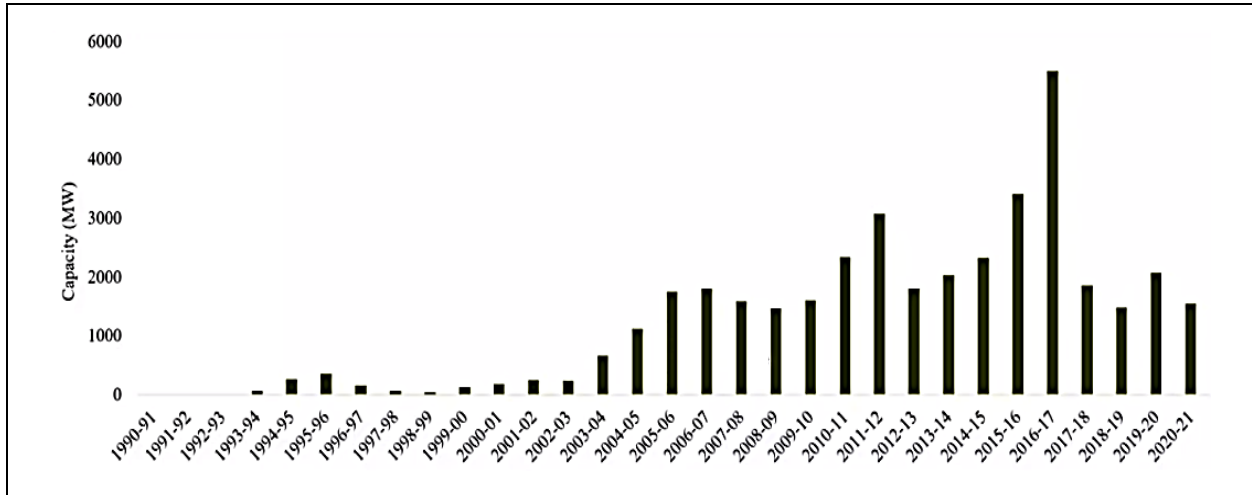


Fig. 7: Timeline of increased wind capacity of India (Source: MNRE, India)

The top six states for wind energy production are Tamil Nadu, Gujarat, Karnataka, Maharashtra, Rajasthan, and Andhra Pradesh. Renewable energy sources (excluding large hydro power stations) currently account for 30.08% (125160 MW) of India's total installed power capacity of 416059 MW (March 31, 2023), with wind energy accounting for 42633 MW. Wind energy continues to be the main source of clean energy, accounting for 34.06% of all renewable energy

capacity. Indian government has set a goal of 500 GW of renewable energy by 2030, of which 140 GW is expected to come from wind. The National Institute of Wind Energy (NIWE) first calculated the wind potential in India at 50 m hub height or 49 GW, but the survey shows that at 80 m hub height, the potential increases to 102 GW, and at 100 m hub height, it increases to 302 GW. Additionally, a recent NIWE research at 120 m height suggested a potential 695 GW. One of the primary

advantages of wind energy is its natural ability to support rural jobs and enhance the rural economy. Figure 7 depicts the timeline of increased wind capacity of India. According to a study, 18% of India's 34000 wind turbines are more than 15 years old. Additionally, 1 MW or smaller turbines make up about 10.5 GW of India's

installed wind capacity. In India's most recent wind atlas at 150 m, Rajasthan has the potential to deploy 284 GW of wind capacity, 45 GW of which can be built in high wind-speed sites with a capacity factor of 30-32%. Figure 8 depicts GIS mapping of various government-funded wind power plants.

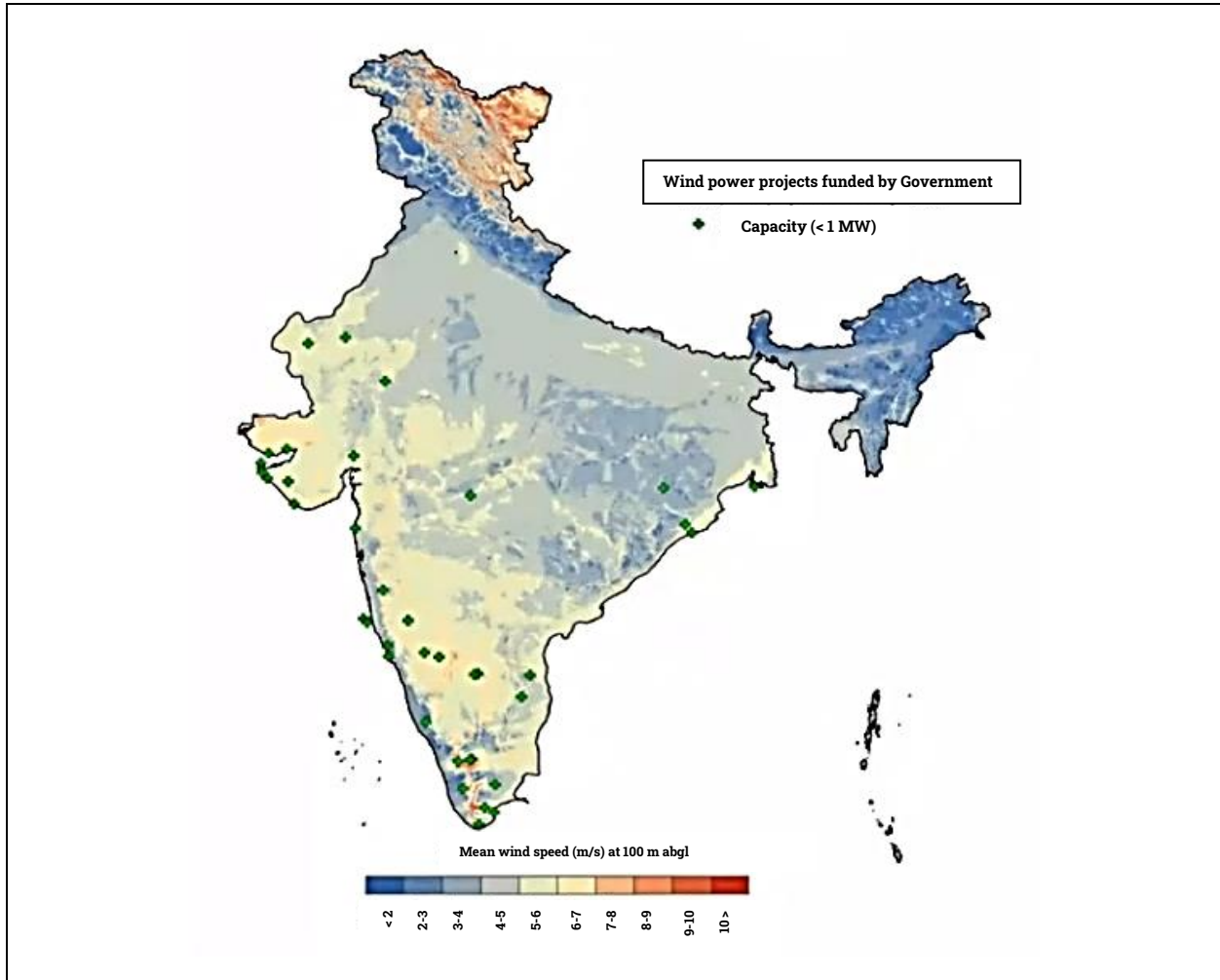


Fig. 8: Government-funded wind power plants on GIS mapping

2.3 Green Hydrogen

The government has published guidelines for programs that offer incentives for electrolyzer manufacture and green hydrogen generation as part of the Green Hydrogen Mission, which intends to produce 5 million metric tons (MMT) by 2030. By producing and using the intended amount of green hydrogen, it is predicted that close to 50 MMT of annual CO₂ emissions can be avoided. As one of the most promising solutions for the long-term storage of electricity, the 2020s are a vital decade for the development of green hydrogen technology. The decarbonized energy future envisioned by the Paris Agreement would likely be fulfilled if the

target of 40% of electricity in the global energy portfolio in 2050 were achieved (Rabiee *et al.* 2021).

A two-stage stochastic optimization technique with forecast updating is proposed from an economic standpoint for the best scheduling of a real multi-energy system with hydrogen-based automobile applications. According to simulation results, the proposed scheduling technique can assist in quantifying daily operating costs, matching real-time power demands with PV output solar electricity, and achieving significant operating cost savings by effectively arranging and using all system elements (Mei *et al.* 2021). Figure 9 shows the important advancements in hydrogen development in various nations in MMT.



Fig. 9: Advancements in hydrogen development in various nations (Source: IEA)

India now imports energy for more than \$160 billion annually. Hydrogen can be used in India to replace fossil fuels in transportation, iron and steel and gas distribution sectors. By substituting locally produced green hydrogen for imported fossil fuels, India can save \$15–20 billion annually.

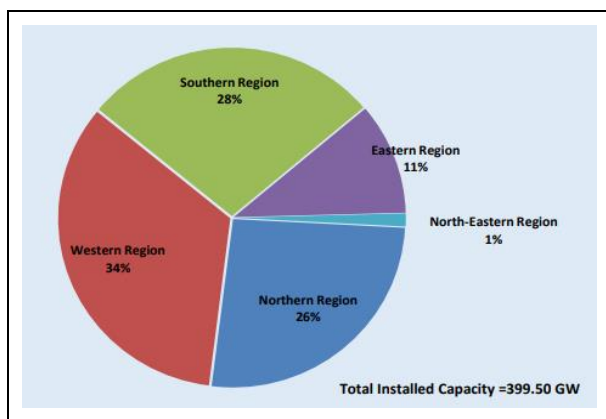


Fig. 10: Established regional power generation capacity as on March 31, 2022 (Source: MOSPI, India)

2.4 Hydropower and Biomass

The production of energy from biomass and hydropower was included in India’s mix of RESs. Despite the relative stability of these sources, attention has mostly switched to solar and wind because of their higher development rates and less negative

environmental effects. The western region accounted for the biggest share (34%) of installed capacity for generating electricity as of 31.03.2022, followed by the southern region (28%) and northern region (26%), which are also accounted for the highest percentage of hydro energy. Karnataka has the biggest share of installed hydro capacity among the states, with 3.63 GW, and Rajasthan has the highest percentage of other renewable resources with 16.70 GW. Figure 10 shows the established regional power generation capacity as on March 31, 2022 and Fig. 11 depicts the trends in India’s installed utility-generated electricity production capacity (MW) from 2012–13 to 2021–22.

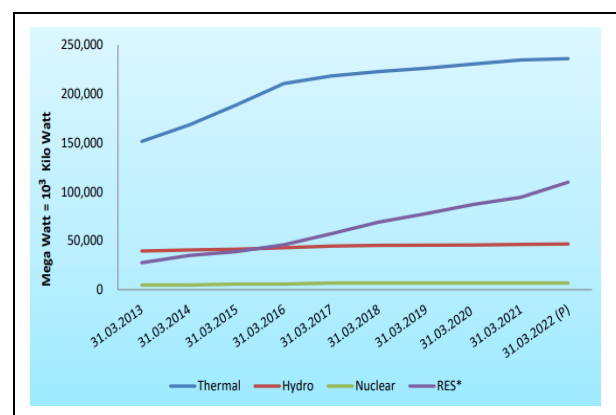


Fig. 11: Trends in India’s installed utility-generated electricity production capacity (MW) from 2012–13 to 2021–22 (Source: MOSPI, India)

3. FUTURE INDUSTRIES WITH HIGH POTENTIAL FOR JOBS IN THE GREEN ECONOMY

The Rozgar Portal, developed by the Skill Council for Green Jobs, is a cutting-edge technological innovation that connects qualified professionals with sought businesses all over India, opening up career prospects in the green energy sector. The Skill Council for Green Jobs developed this cutting-edge solution, which automates the entire talent acquisition process for employers, offers employment opportunities to skilled workers, and enables SCGJ to intervene as needed in skill development activities to meet industry needs. Rozgar Portal will assist SCGJ in achieving its goal of creating 10 lakh jobs by 2030 and by 2047, various sectors will add 3–3.50 crore new jobs. Figure 12 shows various factors influencing employment possibilities and skill development in a low-carbon Indian economy. Table 2

gives detailed state-by-state description about various types of installed renewable energy capacity on September 30, 2023. New job opportunities are expected in the following green business sectors.

- Off Shore Wind Power Plants
- Hybrid Solar Wind and other Renewable Energy Systems
- Green Hydrogen Energy
- Floating Solar Power Plants
- Biomass /Biofuels/ Bio CNG Production and Supply Chain
- Large Size Energy Storage
- E-waste Management
- De-Carbonization of Energy-intensive Sectors
- EV Charging Through Solar Energy Plants
- Pollution Prevention and Control Network



Fig. 12: Employment possibilities and skill development in a low-carbon Indian economy (Source: sscgj.in)

Table 2. State-by-state installed renewable energy capacity on September 30, 2023 (Source: MNRE, India)

P&C Division															
State-wise installed capacity of Renewable Power including Off-grid as on 29.02.2024															
#	STATES / Uts			Bio-Power					Solar Power						
		Small Hydro Power	Wind Power	BM Power/Bagasse Cogen.	BM Cogen. (Non-Bagasse)	Waste to Energy	Waste to Energy (Off-grid)	Bio Power Total	Ground Mounted Solar	Rooftop Solar	Hybrid Solar Comp.	Off-grid Solar/ KUSUM	Solar Power	Large Hydro Power	Total Capacity
		(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
1	Andhra Pradesh	163.31	4096.65	378.10	105.57	53.16	29.56	566.39	4298.52	179.99	0.00	88.34	4566.85	1610.00	11003.20
2	Arunachal Pradesh	133.11						0.00	1.27	4.34	0.00	6.18	11.79	1115.00	1259.90
3	Assam	34.11			2.00			2.00	105.00	41.36	0.00	9.44	155.80	350.00	541.91
4	Bihar	70.70		112.50	12.20		1.32	126.02	146.06	56.21	0.00	21.28	223.55		420.27
5	Chhattisgarh	76.00		272.09	2.50		0.41	275.00	747.96	68.32	0.00	387.73	1204.01	120.00	1675.01
6	Goa	0.05				1.94		1.94	0.95	33.69	0.00	1.12	35.76		37.75
7	Gujarat	91.64	11249.02	65.30	12.00	7.50	27.68	112.48	7217.55	2898.16	590.96	54.30	10760.97	1990.00	24204.11
8	Haryana	73.50		151.40	93.26	11.20	9.84	265.70	265.80	486.23	0.00	571.58	1323.61		1662.81
9	Himachal Pradesh	969.71			9.20		1.00	10.20	40.85	37.87	0.00	34.07	112.79	10281.02	11373.72
10	J & K	161.43						0.00	2.49	27.20	0.00	25.29	54.98	3360.00	3576.41
11	Jharkhand	4.05			14.10			14.10	21.00	53.19	0.00	49.53	123.72	210.00	351.87
12	Karnataka	1280.73	5918.26	1867.10	20.20	1.00	19.42	1907.72	7906.32	1562.11	0.00	30.31	9498.74	3689.20	22294.65
13	Kerala	276.52	63.50		2.27		0.23	2.50	322.79	512.67	0.00	24.64	860.10	1864.15	3066.77
14	Ladakh	42.99						0.00	6.00	1.80	0.00	0.00	7.80	89.00	139.79
15	Madhya Pradesh	123.71	2844.29	92.50	14.85	15.40	12.19	134.94	2900.33	296.02	0.00	99.03	3295.38	2235.00	8633.32
16	Maharashtra	382.28	5195.38	2568.00	16.40	12.59	46.20	2643.19	3680.55	1716.30	0.00	317.00	5713.85	3047.00	16981.70
17	Manipur	5.45						0.00	0.60	6.36	0.00	6.08	13.04	105.00	123.49
18	Meghalaya	55.03			13.80			13.80	0.00	0.21	0.00	3.98	4.19	322.00	395.02
19	Mizoram	45.47						0.00	22.00	2.07	0.00	6.35	30.42	60.00	135.89
20	Nagaland	32.67						0.00	0.00	1.00	0.00	2.17	3.17	75.00	110.84
21	Odisha	115.63		50.40	8.82			59.22	419.16	33.42	0.00	28.25	480.83	2154.55	2810.23
22	Punjab	176.10		299.50	196.65	10.75	25.21	532.11	886.27	298.92	0.00	81.35	1266.54	1096.30	3071.05
23	Rajasthan	23.85	5195.82	119.25	2.00		4.39	125.64	15907.97	1002.43	1980.00	620.20	19510.60	411.00	25266.91
24	Sikkim	55.11						0.00	0.00	2.76	0.00	1.92	4.68	2282.00	2341.79
25	Tamil Nadu	123.05	10458.35	969.10	43.55	6.40	24.65	1043.70	6992.66	449.22	0.00	65.85	7507.73	2178.20	21311.03
26	Telangana	90.87	128.10	158.10	2.00	45.80	14.47	220.37	4360.49	343.78	0.00	8.71	4712.98	2405.60	7557.92
27	Tripura	16.01						0.00	5.00	4.78	0.00	8.68	18.46		34.47
28	Uttar Pradesh	49.10		1957.50	160.76		103.38	2221.64	2347.96	265.10	0.00	219.77	2832.83	501.60	5605.17
29	Uttarakhand	218.82		72.72	57.50		9.52	139.74	298.40	262.71	0.00	14.42	575.53	4035.35	4969.44
30	West Bengal	98.50		300.00	38.62		4.84	343.46	113.80	67.13	0.00	13.14	194.07	1341.20	1977.23
31	AN	5.25						0.00	25.05	4.59	0.00	0.27	29.91		35.16
32	Chandigarh							0.00	6.34	56.90	0.00	0.81	64.05		64.05
33	Dadar & Nagar Haveli/ Daman & Diu							0.00	12.64	33.83	0.00	0.00	46.47		46.47
34	Delhi					84.00		84.00	9.84	225.99	0.00	1.46	237.29		321.29
35	Lakshadweep							0.00	2.45	0.00	0.00	2.52	4.97		4.97
36	Pondicherry							0.00	0.88	42.28	0.00	0.18	43.34		43.34
37	Others		4.30					0.00	0.00	0.00	0.00	45.01	45.01		49.31
	Total (MW)	4994.75	45153.67	9433.56	828.25	249.74	334.31	10845.86	59074.95	11078.94	2570.96	2850.96	75575.81	46928.17	183498.26

MW = Megawatt

4. CHALLENGES IN IMPLEMENTATION OF THE RENEWABLE ENERGY

Despite its enormous commitment, renewable energy implementation presents unique hurdles for India. The integration of renewable energy sources was not initially intended for the current Indian power grid. One of the biggest challenges is balancing the demand on the grid with the intermittent nature of renewable energy. India has made progress in supporting renewable energy sources through its policies, although implementation and consistency can be difficult. Project implementation can be slowed down by bureaucratic roadblocks, land acquisition problems, and regulatory obstacles. It may be challenging to find reasonably priced funding for renewable energy initiatives. Even if prices are going down, starting a business still requires money, particularly for smaller businesses or in rural areas. It is critical to develop the infrastructure required, particularly for transmission and storage. More economical and efficient systems require technological developments. Obtaining land for significant renewable energy projects can be difficult, and local communities may oppose them.

It is difficult to strike a balance between the need for energy and social and environmental concerns. The potential for renewable energy and the preparedness of the infrastructure varies throughout Indian states. In the larger national energy framework, coordinating and balancing these differences is crucial.

India still primarily relies on coal for energy production since it is plentiful and cheap. Making the switch from this conventional source to renewables calls for significant preparation and financial outlays. The potential for renewable energy in India is mostly based on weather-dependent resources, such as wind and solar power, which can vary greatly between locations and seasons. It is still difficult to train workers with the knowledge and abilities needed for the renewable energy industry. It is essential to build a skilled labour force for the management, upkeep, and installation of renewable energy infrastructure. The development of renewable energy in India may be impacted by external variables such as changes in the worldwide market that impact the cost and accessibility of technology and components for renewable energy.

For successful adoption and integration of renewable energy into India's energy mix, addressing these issues calls for an all-encompassing strategy that includes public-private partnerships, infrastructural investments, legislative reforms, technological innovation, and community engagement.

5. CONCLUSION

In the contemporary context, renewable energy is used not only to generate power but also for other reasons such as investment, policy stabilization, environmental sustainability, and job opportunities. By 2030, India's shift to a green economy might result in the creation of 3 million new jobs in the renewable energy sector alone. Through the utilization of renewable energy, the environmental health must be enhanced, preserved, and maintained. The use of non-renewable fossil fuels must be entirely replaced by renewable energy. There are numerous safety benefits associated with using renewable resources, both for the environment and for human beings. Several obstacles need to be removed in order to achieve the above goals. Some of these problems include outdated infrastructure, legislative rules, political pressures, public acceptance, plant development costs, excess supply capacity, and corporate influence.

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AVAILABILITY OF DATA AND MATERIALS

All data given in either table or figure.

COMPETING INTERESTS

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