WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Renewable Energy Transition in India: Achievements, Trends, and Policy Pathways for a Sustainable Future

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ABSTRACT

India's renewable energy sector has witnessed significant growth over the past decade, positioning the country as a global leader in clean energy adoption. This study analyzes India's progress in renewable energy between April 2024 and August 2024, focusing on sector-wise and state-wise installed capacities, policy interventions, and future projections. With a commitment to achieving 500 GW of non-fossil fuel capacity by 2030 and net-zero emissions by 2070, India's renewable energy expansion is driven by government initiatives, financial incentives, and regional contributions. Solar and wind energy dominate the sector, with substantial investments in bio-energy, small hydro, and waste-to-energy projects. The study also highlights key challenges, including funding, land acquisition, and grid integration, which need strategic policy interventions for sustainable energy development. Using secondary data from sources like the Ministry of New and Renewable Energy (MNRE) and the International Renewable Energy Agency (IRENA), the research provides a comprehensive assessment of India's renewable energy trajectory. The findings emphasize India's regional energy landscape, achievements, and policy recommendations to enhance energy security, affordability, and equity, ultimately supporting India's vision of a sustainable and self-reliant energy future.

Keywords: Renewable energy, Wind power, Solar power, Small hydropower, Bio-Mass, Waste to Power

Introduction

India's ambitious targets for renewable energy are driving a swift shift towards a sustainable energy future. Over the past ten years, India's renewable energy sector has expanded dramatically, making it one of the world's leaders in deploying renewable energy. The government's will to lessen reliance on fossil fuels, improve energy security, and handle the urgent issues associated with climate change is a major driving force behind this transition. India has a lot of renewable energy resources, including waste-to-energy, biomass, solar, wind, and small hydro. The industry is dominated by solar and wind power, with solar leading because of its scalability and appropriateness for a wide range of geographical locations. To encourage the use of solar energy, particularly in rural areas, the government has created several initiatives, including the National Solar Mission and the Pradhan Mantri-KisanUrja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM). The nation has also concentrated on increasing the potential for wind energy, especially in dry and coastal areas. According to the REN21 Renewables 2024 Global Status Report, India is ranked fourth in the world for installed capacity of renewable energy (including large hydro), fourth for wind power, and fifth for solar power. The nation has increased its ambition to 500 GW of non-fossil fuel-based energy by 2030 at the COP26. Under the Panchamrit, this has been a crucial commitment. This is the biggest renewable energy expansion plan in the world. With several states like Gujarat, Rajasthan, Tamil Nadu, and Karnataka setting the standard for solar and wind installations, India's journey toward renewable energy is also a regional one. This expansion has been fueled by government policy interventions, financial incentives, and an emphasis on localized energy solutions; as a result, renewable energy is now a crucial component of India's economic development and climate strategy.India aims to reach net-zero carbon emissions by 2070, 50% cumulative installed renewable power by 2030, and a reduction of less than 45% in the country's economic carbon intensity by the end of the decade. By 2030, India wants to have 500 GW of installed capacity for renewable energy. By 2030, India wants to manufacture five million tons of renewable hydrogen. A capacity of 125 GW for renewable energy will facilitate this. In India, 50 solar farms totaling 37.49 GW in capacity have been approved. By 2030, offshore wind energy is expected to reach 30 GW, with identified prospective locations. Union Budget 2024 Emphasizes The Union Budget 2024–25 allots INR 10,000 Cr to the Centrally Sponsored Scheme for Solar Power (Grid), a 110% increase over the INR 4,757 Cr allotted in the Union Budget 2023–25. PM Launched in February 2024, the Surya Ghar Muft Bijli Yojana has been allotted INR 6,250 Cr, out of a total budget of INR 75,000 Cr. It has also been stated that imports of 25 essential minerals that are vital to the renewable energy sectors will not be subject to Basic Customs Duty (BCD). However, the industry also has to deal with issues including funding, land acquisition, grid integration, and guaranteeing fair access to energy for all states. These problems need to be addressed in future policy initiatives if India is to move faster toward a cleaner, greener energy sector.

Institutions and organizations

Several institutions and organizations are actively working to develop renewable energy in India. Public sector institutions such as the Indian Renewable Energy Development Agency Limited (IREDA) and the Solar Energy Corporation of India Limited (SECI) play a key role. Autonomous institutions like the Sardar Sarovar Singh National Institute of Bio Energy, the National Institute of Solar Energy, and the National Institute of Wind Energy contribute significantly to the research and development in this field. Additionally, the Association of Renewable Energy Agencies of States (AREAS) promotes renewable energy initiatives across different states in India.

Vision of renewable energy for the sustainable development of India

To develop new and renewable energy technologies, processes, materials, components, subsystems, products, and services that meet international specifications, standards, and efficiency parameters so that the country can become a net foreign exchange earner in the sector and deploy such indigenously developed or manufactured products and services toward the national goal of energy security.

MISSION of renewable energy sources for sustainable development of India

- **Energy Security:** Development and implementation of alternate fuels such as hydrogen, biofuels, and synthetic fuels and their applications to contribute to bridging the gap between domestic oil supply and demand; less reliance on oil imports.
- **Increase the proportion of clean power:** renewables such as wind, hydro, solar, geothermal, bio, and tidal power to augment fossil fuel-powered electricity generation.
- **Increase in the share of clean power:** Renewables like wind, hydro, solar, geothermal, bio & tidal power to supplement fossil fuel-based electricity generation.
- **Energy Availability and Access:** Supplement energy requirements for cooking, heating, motive power, and captive generation in rural, urban, industrial, and commercial sectors.
- **Energy affordability:** Cost-effective, convenient, safe, economical, and dependable energy supply choices
- **Energy Equity:** By 2050, per capita energy consumption will be on par with the world average, thanks to a sustainable and diverse fuel mix.

Review of Literature

Mishra, Mukesh Kumar et,al. 2015. This study examines the current status of small hydropower development in India and identifies barriers to its growth. Researchers review potential and installed capacity, technological status, policy and regulatory support, and the process of developing small hydropower plants. Although there has been significant growth, about three-quarters of the total identified potential of 20,000MW remains untapped. The country aims to harness at least half of this potential in the next 10 years. The study found that the model simulation indicated that, at the current rate of capacity addition, the country would not be able to fully exploit the small hydropower potential even by 2050, and that efforts to accelerate growth were necessary to alleviate energy poverty in rural and remote areas.

In a 2017 study, Jha, Shibani K et al. examined renewable energy alternatives in India, discussing their techno-economic factors and environmental aspects. Researchers prioritized the alternatives based on an Energy Index parameter, which was evaluated using cumulative scores obtained for each alternative. The study concluded that geothermal energy is the most preferable alternative with the highest Energy Index, followed by hydro, wind, biomass, and solar energy sources.

K Sing (2023) reviews the development of renewable energies in India post-COP21 until December 2021. The researcher discussed the policies and roadmaps for solar, wind, biomass, hydrogen, and hydro energy sectors, highlighting challenges and India's ambitious plans to phase down coal usage by 2050 and achieve carbon neutrality by 2070. The study found that India has seen significant success in solar energy, with 80% of future investments allocated to this sector, while other renewable energy sectors have received comparatively less investment.

Puja (2023). This study delves into the current status and prospects of renewable energy in India, emphasizing its pivotal role in fostering sustainable development. The study provides a comprehensive analysis of the current renewable energy landscape, government initiatives, challenges, and potential solutions and underscores the significance of comprehensive policies, technological innovation, and international collaborations to propel India into a greener and more sustainable energy future. The study reveals that the nation strives for energy security and environmental resilience, and the evolving landscape of renewable energy in India remains a beacon of hope for a sustainable and equitable future.

Bharath Dubey (2023) study underscores significant advancements in India's power sector concerning energy security and provides an in-depth analysis of various policies and government initiatives, with a particular focus on the National Solar Mission (NSM) and its role in achieving the 2030 energy targets. The study also explores key challenges faced by developers in the industry, such as fluctuations in solar project tariffs and past trends in capacity installations. The paper outlines potential obstacles to meeting these targets, offering valuable insights for power developers, policymakers, researchers, and industry professionals and emphasizes the importance of addressing the connection between food supply and clean energy to sustain livelihoods in the current context.

Thapar (2024) examines India's renewable energy sector, emphasizing important policies, regulations, and instruments. The study focuses on three main areas: Promotional Instruments, Fiscal Instruments, and Business Enablers. It also explores the development of India's wind and solar power sectors and concludes with a comparison of energy policies in Germany, Japan, and the United States.

Objectives

- To evaluate the achievements of renewable energy sources in India between April 2024 and August 2024.
- To analyze year-wise trends in installed renewable energy capacities since 2014.
- To explore state-wise contributions to India’s renewable energy landscape.
- To provide policy suggestions for improving renewable energy adoption.

Methodology

The study uses secondary data based on reports from the International Renewable Energy Agency (IRENA), the Ministry of New and Renewable Energy (MNRE). The data were evaluated to assess the amount of money allocated in the Union Budget and the advancement of renewable energy installations in various states and industries (solar, wind, biomass, etc.).

Physical Achievement of Renewable Energy

Year-wise achievement of Installed Renewable Energy Capacity(MW)

Table 1.1 : Installed Renewable Energy Capacity(MW) (Excluding Large Hydro Power)

Sector	**Cumulative Achievements (till-31.03.2014)**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**	**Cumulative Achievements(till-31.08.2024)**
Wind Power	21042.58	2311.77	3423.05	5502.37	1865.23	1480.97	2117.79	1503.3	1110.53	2275.55	3253.38	47192.33
Solar Power	2821.91	1171.62	3130.36	5658.63	9563.69	6750.97	6510.06	5628.8	12760.5	12783.8	15033.24	89431.98
Small Hydro Power	3803.68	251.68	218.11	106.38	105.95	107.34	90.01	103.65	62.09	95.4	58.95	5070.75
Biomass (Bagasse) Cogeneration	7419.23	295.67	304.85	161.95	519.1	402.7	97	173.37	59.69	0.00	0.00	9433.56
Biomass(Non-bagasse) Cogeneration	531.82	60.05	59.s24	2.2	9.5	12	0.00	97.24	0.00	42.4	107.34	921.79
Waste to Power	90.58	0.00	0.00	23.5	24.22	0.00	9.34	21	54.5	25	1.60	249.74
Waste to Energy (Off-grid)	139.79	9.71	5.69	11.77	5.55	6.58	19.11	20.75	34.66	52.28	30.17	354.33
Total	**35849.59**	**4100.5**	**7141.3**	**11466.81**	**12093.24**	**8760.56**	**8843.31**	**7548.11**	**14081.97**	**15274.43**	**18484.68**	**152654.48**

Source: Ministry of New & Renewable Energy

Table 1. 2 displays the year-by-year performance of India's renewable energy industry (barring major hydropower) from August 31, 2024, to March 31, 2014. It demonstrates a consistent increase in several sectors, with wind and solar power exhibiting the most growth. According to the report, wind power started at 21,042.58 MW in 2014 and increased gradually, adding nearly 3,000 MW in 2023–2024 alone, for a total capacity of 47,192.33 MW by August 2024. The fastest-growing energy source was solar power, which increased from 2,821.91 MW in 2014 to an astounding 89,431.98 MW by August 2024. The two years 2021–2022 and 2022–2023 saw the largest increases, each contributing over 12,700 MW. Small hydropower growth has been slower, with small annual additions accounting for the increase from 3,803.68 MW in 2014 to 5,070.75 MW by August 2024. Biomass (Bagasse) Cogeneration saw significant growth from 2014 to 2024, rising from 7,419.23 MW to 9,433.56 MW. After that, additions halted. Cogeneration of Non-Bagasse Biomass The industry experienced very little growth, peaking at 531.82 MW in 2014 and reaching a cumulative capacity of 921.79 MW by August 2024.waste to power With little but steady annual increases, this sector expanded from its initial 90.58 MW in 2014 to 249.74 MW by August 2024. Since its inception in 2014, Waste to Energy (Off-Grid) has grown steadily, with a cumulative capacity of 354.33 MW by August 2024. Its initial capacity was 139.79 MW. Overall, expansions in solar and wind power were a major factor in India's remarkable increase in renewable energy capacity, which rose from 35,849.59 MW in 2014 to 152,654.48 MW by August 2024. This expansion demonstrates India's ongoing advancements in renewable energy, with a current emphasis on solar projects.

State-wise installed capacity of Small Hydro- Power

Table 1.2:State-wise installed capacity of Small Hydro-Power as of 31-08-2024

Sl.no	**Small hydro**	**Megawatt**
1.	Andhra Pradesh	163.31
2.	Arunachal Pradesh	140.61
3.	Assam	34.11
4.	Bihar	70.70
5.	Chhattisgarh	70.00
6.	Goa	0.05
7.	Gujarat	91.64
8.	Haryana	73.50
9.	Himachal Pradesh	993.71
10.	Jammu and Kashmir	183.93
11.	Jharkhand	4.05
12.	Karnataka	1284.73
13.	Kerala	276.52
14.	Ladakh	42.99
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	228.82
30.	West Bengal	98.50
31.	Andaman and Nicobar	5.25

Source: Ministry of New & Renewable Energy

The table1.3 shows the state-wise installed capacity of small hydroelectric power by observation the study shows that the Top Three States like Karnatakahave the highest installed small hydro capacity at 1,284.73 MW. This suggests a significant focus on small hydropower development in the state, and thenHimachal Pradesh follows with 993.71 MW, which is understandable given its mountainous terrain, ideal for small hydro projects. And Maharashtra comes third with 384.28 MW, showcasing its efforts to diversify renewable energy sources. High Potential in Himalayan and Hilly Regions States like Himachal Pradesh, Uttarakhandwith 228.82 MW, Jammu and Kashmirwith 183.93 MW, and Arunachal Pradeshwith 140.61 MW show substantial capacities. These regions, with abundant rivers and elevation changes, are naturally suited for small hydro installations. Lower Capacity in Plains and Smaller States like Goawith 0.05 MW, Tripurawith 16.01 MW, and Nagalandwith 32.67 MWshow much lower capacities, which could be due to limited water resources and less geographical suitability for small hydro projects.Smaller Contributions from Certain Big States like Gujaratwith 91.64 MW, Tamil Naduwith 123.05 MW, and Madhya Pradeshwith 123.71 MW show moderate capacities. While these states are leaders in solar and wind energy, their small hydro contributions are relatively modest. Eastern States' Modest Development States like Biharwith 70.70 MW, Odishawith 115.63 MW, and West Bengalwith 98.50 MW have developed some capacity, but they are still far from their potential. Assam and other northeastern states remain underdeveloped in this sector, except for Arunachal Pradesh. And also find that Geographical Factors States with more rivers and mountainous terrains, such as Himachal Pradesh and Karnataka, have naturally higher capacities for small hydropower. On the other hand, flatter regions with fewer water bodies show less capacity.

State-wise installed capacity of Bio-Power

Table 1.3: State-wise installed capacity of Bio-Power 31- 08-2024

Sl. no	**State**	**Biomass power**	**Biomass non-bagasse**	**Waste energy**	**Waste energy (off-grid)**	**Biopower total**
01.	Andhra Pradesh	378	113	53.16	29.56	573.72
02.	Assam	-	2.00	-	-	2
03.	Bihar	112	26.40	-	1.32	139.72
04.	Chattisgarh	272.09	2.50	-	0.41	275
05.	Goa	-	-	1.94	-	1.94
06.	Gujarat	65.30	12.00	7.50	28.18	112.98
07.	Haryana	151.40	111.26	11.20	14.38	288.24
08.	Himachal Pradesh	-	9.20	-	1.00	10.2
09.	Jarkand	-	19.10	-	-	19.1
10.	Karnataka	1867.10	20.20	1.00	19.42	1907.72

11.	Kerala	-	2.27	-	0.23	2.5
12.	Madya Pradesh	92.50	14.85	15.40	12.19	134.94
13.	Maharashtra	2568	16.40	12.59	47.76	2644.75
14.	Meghalaya	-	13.80	-	-	13.8
15.	Odisha	50.40	8.82	-	-	59.22
16.	Punjab	299.50	231.79	10.75	25.21	567.25
17.	Rajastan	119.25	2.00	-	4.81	126.06
18.	Tamil Nadu	969.10	43.55	6.40	26.40	1045.45
19.	Telangana	158.10	3.30	45.80	14.47	221.67
20.	Uttar Pradesh	197.50	165.26	-	114.63	477.39
21.	Uttarkand	72.72	60.00	-	9.52	142.24
22.	West Bengal	300	43.52	-	4.84	348.36
23.	Delhi	-	-	84	-	84

Source: Ministry of New & Renewable Energy

Table 1.4 provides an overview of state-wise installed capacity for bio-power in India as of August 31, 2024. It breaks down bio-power generation into four categories like biomass power, biomass non-bagasse, waste energy, and waste energy (off-grid), with the total bio-power for each state.According to the findings, Maharashtra is among the top producers of biopower, with a total installed capacity of 2,644.75 MW, which includes a sizeable 2,568 MW of biomass power. Maharashtra's high biomass capacity can be explained by the size of its sugarcane sector. Karnataka comes in second with 1,907.72 MW, mostly from 1,867.10 MW of biomass electricity. At 1,045.45 MW, Tamil Nadu boasts the third-highest capacity among all states. Its biopower sources include waste energy and biomass power. Delhi stands out in terms of Waste Energy Capacity since it has 84 MW of waste energy but no biomass power, meaning it must rely on waste-to-energy conversion to cover its bio-power needs. Significant amounts of biopower is generated from waste energy in states like Gujarat with 7.50 MW and Telangana with 45.80 MW. The agricultural economies of Punjab with 299.50 MW, Andhra Pradesh with 378 MW, Uttar Pradesh with 197.50 MW, and Haryana with 151.40 MW, as well as their capacity to employ crop leftovers for power generation, are indicative of states with high biomass power capacities. Several states, including Uttar Pradesh with 114.63 MW, Maharashtra with 47.76 MW, and Andhra Pradesh with 29.56 MW, have installed additional off-grid waste energy facilities. Certain localized energy needs can be met by these systems.States with comparatively low installed bio-power capabilities are those with modest or minimal bio-power capacities, such as Goa at 1.94 MW, Assam at 2 MW, Himachal Pradesh at 10.2 MW, and Meghalaya at 13.8 MW. These states might have less waste-to-energy initiatives or limited access to biomass resources.Strong biopower potential is shown in the agricultural states of Punjab with 567.25 MW and Uttar Pradesh with 477.39 MW, both of which are largely dependent on agriculture. This potential is particularly evident in biomass non-bagasse and waste energy, demonstrating the possibility of using crop waste for electricity. Bio-power portfolios with a greater degree of diversity, such as those in Telangana with 222.67 MW, and Gujarat with 112.98 MW, combine waste energy sources with biomass. Increasing the capacity for renewable energy is the goal of this strategic diversification.The table indicates that Karnataka and Maharashtra are top producers of biomass power due to their strong agricultural backgrounds, particularly in the sugar industry. Tamil Nadu and Punjab are also entering the biomass and waste-to-energy sectors, while urban states like Delhi are utilizing waste-to-energy initiatives. This trend is also observed in Telangana, Uttar Pradesh, and Gujarat. States with potential for biopower growth include Goa, Assam, and Meghalaya, with opportunities for future growth in areas with lower levels of industrial or agricultural activity.

State-wise installed capacity of Solar

Table 1.4 : State-wise installed capacity of Solar 31- 08-2024

Sl.No	**State**	**Ground mounted solar**	**PM-Surya GharYojna**	**Hybrid solar**	**Off-grid solar KUSUM**	**Solar power total**
1.	Andhra Pradesh	4321.76	217.37	0.00	88.34	4627.47
2.	Arunachal Pradesh	1.27	6.68	0.00	6.70	14.65
3.	Assam	126.00	43.80	0.00	9.44	179.24
4.	Bihar	146.06	71.89	0.00	21.28	239.23
5.	Chhattisgarh	776.60	96.99	0.00	390.73	1264.32
6.	Goa	0.95	44.72	0.00	1.41	47.08

7.	Gujarat	9851.29	4195.07	610.95	87.90	14745.21
8.	Haryana	266.80	703.14	0.00	902.68	1872.62
9.	Himachal Pradesh	79.91	20.73	0.00	34.58	135.22
10.	Jammu and Kashmir	2.49	39.92	0.00	27.78	70.19
11.	Jharkhand	21.00	92.22	0.00	58.15	171.37
12.	Karnataka	8189.36	603.94	0.00	36.55	8829.85
13.	Kerala	323.21	882.23	0.00	24.93	1230.37
14.	Ladakh	6.00	1.80	0.00	0.00	7.8
15.	Madhya Pradesh	3624.22	402	0.00	102.04	4128.26
16.	Maharashtra	4354.38	2487.73	0.00	541.23	7383.34
17.	Manipur	0.60	6.36	0.00	6.08	13.04
18.	Meghalaya	0.00	0.21	0.00	4.07	4.28
19.	Mizoram	22.00	1.96	0.00	6.35	30.31
20.	Nagaland	0.00	1.00	0.00	2.17	3.17
21.	Odisha	419.16	56.37	0.00	40.97	516.50
22.	Punjab	886.27	408.16	0.00	81.35	1375.78
23.	Rajasthan	20047.17	1269.59	1980.00	805.45	24102.21
24.	Sikkim	0.52	5.12	0.00	1.92	7.56
25.	Tamil Nadu	8179.87	747.56	0.00	65.99	8993.42
26.	Telangana	4360.49	447.54	0.00	8.71	4816.74
27.	Tripura	5.00	4.78	0.00	10.48	20.26
28.	Uttar Pradesh	2700.02	265.10	0.00	315.03	3280.15
29.	Uttarakhand	298.40	273.71	0.00	19.96	592.07
30.	West Bengal	117.70	67.13	0.00	13.14	197.97
31.	Andaman and Nicobar	25.05	4.59	0.00	0.27	29.91
32.	Chandigarh	6.34	66.43	0.00	0.81	73.58
33.	Dadar Nagar haveli / Diu &Daman	12.64	33.82	0.00	0.00	46.46
34.	Delhi	9.84	269.85	0.00	1.46	281.15
35.	Lakshadweep	2.45	0.00	0.00	2.52	4.97
36.	Pandichery	0.88	50.68	0.00	0.18	51.74
37.	others	0.00	0.00	0.00	45.01	45.01
	Total	**69185.7**	**13890.19**	**2590.95**	**3765.66**	**89432.5**

Source: Ministry of New & Renewable Energy

The table provides the state-wise installed solar power capacity in India as of August 31, 2024, split into four categories: Ground Mounted Solar, a traditional large-scale solar facility. The PM-Surya GharYojna is a government-sponsored plan for rooftop solar systems. Hybrid Solar refers to systems that combine solar and other renewable energy sources, such as wind. Off-grid Solar KUSUM is an off-grid installation offered by the KUSUM program, which focuses on decentralized solar for rural and agricultural applications.This report finds that India's total installed solar capacity is 89,432.5 MW, indicating considerable solar energy penetration. Top States by Installed Capacity: Rajasthan leads with 24,102.21 MW, driven by ground-mounted solar

(20,047.17 MW) and hybrid solar (1,980.00 MW). Gujarat has the second-highest capacity at 14,745.21 MW, thanks to a significant rooftop solar program of 4,195.07 MW.Karnataka follows with 8,829.85 megawatts. Smaller Contributors Due to geographical and infrastructure constraints, states such as Goa at 47.08 MW, Nagaland at 3.17 MW, and Meghalaya at 4.28 MW make small contributions. Union territories with smaller capabilities include Lakshadweep at 4.97 MW and Andaman and Nicobar at 29.91 MW. The PM-Surya GharYojna program plays a significant role in states like Kerala, promoting urban solar rooftop adoption. In these states, the program has achieved notable success, with Kerala leading the way at 882.23 MW, followed by Haryana at 703.14 MW, and Delhi at 269.85 MW. Hybrid solar energy is primarily concentrated in Rajasthan, with 1,980 MW, and Gujarat, with 610.95 MW, showcasing efforts to integrate different energy sources. In the realm of off-grid solar, KUSUM Haryana leads the way with 902.68 MW, followed by Chhattisgarh at 390.73 MW, and Maharashtra at 541.23 MW. These states' adoption of off-grid solar power reflects its significant impact in rural and agricultural areas. This data demonstrates India's substantial progress in expanding solar energy, with varying contributions from different states depending on geographic and policy factors.

State-wise installed capacity of Large hydro power

Table 1.5 : State-wise installed capacity of Large hydro power 31- 08-2024

Sl no	State	Large hydropower MW
1.	Andhra Pradesh	1610.00
2.	Arunachal Pradesh	1115.00
3.	Assam	350
4.	Chhattisgarh	120
5.	Gujarat	1990.00
6.	Himachal Pradesh	10281.02
7.	Jammu and Kashmir	3360.00
8.	Jharkhand	210
9.	Karnataka	3689.20
10.	Kerala	1864.15
11.	Ladakh	89.00
12.	Madhya Pradesh	2235.00
13.	Maharashtra	3047.00
14.	Manipur	105.00
15.	Meghalaya	322
16.	Mizoram	60
17.	Nagaland	75
18.	Odisha	2154.55
19.	Punjab	1096.30
20.	Rajasthan	411.00
21.	Sikkim	2282.00

22.	Tamil Nadu	2178.20
23.	Telangana	2405.60
24.	Uttar Pradesh	501.60
25.	Uttarakhand	4035.35
26.	West Bengal	1341.20
	Total	**46928.17**

Source: Ministry of New & Renewable Energy

Table 1.5 provides the information about State-wise installed capacity of Large hydro power here Northern Statesof Himachal Pradesh with a capacity of 10,281.02 MW, Jammu & Kashmir with 3360.00 MW, Uttarakhand with 4035.35 MW, and Sikkim at 2282.00 MW collectively account for over 50% of India's total large hydropower capacity. This dominance can be attributed to their mountainous terrains, abundant rainfall, and well-developed hydropower infrastructure. Southern States with Significant Capacity, such as Kerala at 1864.15 MW, Karnataka at 3689.20 MW, Tamil Nadu at 2178.20 MW, and Telangana at 2405.60 MW, also contribute substantially to the national total. These states benefit from their geographical location and well-managed water resources. The northeastern states of Arunachal Pradesh, with 1115.00 MW, and Sikkim, with 2282.00 MW, possess significant untapped hydropower potential due to their mountainous landscapes and abundant rainfall. However, challenges such as difficult terrain, remote locations, and environmental concerns have hindered their development. Central and western states like Madhya Pradesh, with 2235.00 MW, Maharashtra with 3047.00 MW, Rajasthan with 411.00 MW, and Gujarat with 1990.00 MW, have relatively lower installed capacities of large hydropower due to their geographical characteristics and alternative energy sources like solar and wind power.

Findings

From 2014 to 2024, India's installed renewable energy capacity rose significantly. This studypresents the sector's annual achievements in megawatts (MW). The analysis indicated that wind energy Wind energy has consistently increased, rising from 21,042.58 MW in 2014 to 47,192.33 MW by August 2024, with significant growth in recent years. Solar Power Solar energy has fast growth, increasing from 2,821.91 MW in 2014 to 89,431.98 MW by August 2024. Solar has emerged as the leading renewable energy source, thanks to significant government efforts and technological advancements.Small Hydropower This industry has grown more modestly, from 3,803.68 MW in 2014 to 5,070.75 MW by 2024, showing regional problems in scaling these projects. Biomass and Waste-to-Power While biomass power has progressively increased from 7,419.23 MW to 9,433.56 MW (bagasse cogeneration), waste-to-power has made relatively little progress. Overall, India's total renewable energy capacity (excluding large hydro) increased from 35,849.59 MW in 2014 to 152,654.48 MW by August 2024, with solar energy being the most significant contributor to this growth.Furthermore, the investigation discovered Physical Achievement of Renewable Energy of State-wise. Installed Capacity of Small Hydro and Biomass Power for Small Hydro Power Karnataka leads with 1,284.73 MW, followed by Himachal Pradesh (993.71 MW) and Maharashtra (384.28 MW). The natural advantage of mountainous and river-rich regions such as Himachal Pradesh and Uttarakhand (228.82 MW) makes them important players in this industry. In contrast, states such as Goa (0.05 MW) and Tripura (16.01 MW) have low capacity, owing to topographical constraints. Maharashtra dominates biomass power with 2,568 MW, thanks to its huge agricultural sector, particularly sugarcane. Karnataka and Tamil Nadu follow closely behind, with capacities of 1,867.10 MW and 969.10 MW, respectively. Waste-to-energy programs have gained pace in cities like Delhi at 84 MW, focusing on energy generation from waste. Then, state-wise installed capacity of solar power Gujarat leads the way in solar power generation with 14,745.21 MW, owing to large-scale ground-mounted solar plants. Rajasthan, Andhra Pradesh, and Tamil Nadu are also big contributors, with each state investing in solar energy infrastructure across a range of sub-sectors, including off-grid and hybrid solutions.

Suggestions for Improving Renewable Energy Adoption in India

To boost renewable energy adoption in India, a stable policy framework is crucial. This should include long-term policies, tax incentives, and stricter enforcement of Renewable Purchase Obligations. Encouraging decentralized renewable energy solutions, such as rooftop solar, is also important, along with strengthening schemes like PM-KUSUM for solar pumps to achieve rural electrification. Encouraging decentralized renewable energy solutions like rooftop solar is gaining momentum, especially in urban areas. Implementing policies to facilitate access to net metering, financing options, and simplified grid integration for small consumers will drive widespread adoption. Strengthening schemes like PM-KUSUM for solar pumps and expanding them to include other decentralized renewable applications is crucial for rural electrification. Enhanced financing mechanisms, such as green bonds, encourage more investment in renewable energy projects. Subsidized loans and grants provide financial support to companies working on renewable energy startups and research and development. Risk mitigation involves setting up insurance mechanisms for renewable energy projects to mitigate financial risks related to weather uncertainties. The deployment of battery storage systems is crucial for handling intermittent renewable energy sources. It is essential to prioritize investments in large-scale storage and upgrade India’s transmission and distribution infrastructure. Additionally, introducing more microgrids can improve energy access, especially in remote areas. Let's focus on advancing emerging technologies like the Hydrogen Economy and green hydrogen

production in India. We should also prioritize the development of offshore wind projects and invest in smart grids that leverage advanced technologies such as AI and IoT. Additionally, fostering public-private partnerships will be crucial for streamlining the acquisition process for renewable energy projects. Skill Development and Local Manufacturing: - Implement specialized training programs for renewable energy workers and provide incentives for domestic production of renewable energy components. Public Awareness and Incentives: Promote public awareness about the benefits of renewable energy and offer tax rebates and financing options for residential renewable energy solutions. Consider introducing further incentives for industries that adopt clean energy. Collaboration with States and Localized Solutions: Establish state-specific renewable energy targets and prioritize region-specific renewable energy projects. By implementing these measures, India can expedite its transition to a cleaner energy future, meet its climate goals, ensure energy security, create jobs, and reduce reliance on fossil fuel imports.

Conclusion

India's renewable energy sector has made impressive strides in recent years, establishing the country as a global leader in the transition to sustainable energy. Solar and wind energy have emerged as the cornerstones of this transformation, with government initiatives, policy interventions, and financial incentives playing pivotal roles in propelling the sector forward. The ambitious targets of achieving 500 GW of non-fossil fuel energy by 2030 and committing to net-zero carbon emissions by 2070 demonstrate India's unwavering commitment to combating climate change and ensuring energy security. An analysis reveals a consistent year-on-year increase in installed renewable energy capacity, particularly in solar and wind power, which have experienced the most significant growth. While solar power has witnessed exponential expansion, wind energy continues to grow steadily, contributing to India's overall renewable energy capacity. Progress has also been made in the small hydropower and bioenergy sectors, albeit at a slower pace. Nevertheless, challenges persist. Issues such as land acquisition, grid integration, financing, and ensuring equitable access to clean energy across states need to be addressed. States with geographical advantages, such as Karnataka, Himachal Pradesh, and Maharashtra, have capitalized on their natural resources, while others, particularly in the plains and smaller states, have faced obstacles. Looking ahead, India must continue to strengthen its policy framework, improve infrastructure, and foster innovation in renewable technologies. With focused efforts on overcoming existing barriers and optimizing resource utilization, India is well on its way to achieving its renewable energy goals and setting a global example for sustainable development. This trajectory not only contributes to national energy security but also plays a crucial role in the global fight against climate change.

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