

Review Article

GREEN ENERGY, LITERATURE REVIEW OF RENEWABLE ENERGY SOURCES IN INDIA

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ABSTRACT

In India, the main goals of the use of renewable energy are to reduce climate change, enhance economic development, and enhance energy security and its accessibility. Utilizing sustainable energy and ensuring that all residents have access to modern, affordable, dependable, and sustainable energy are necessary for sustainable development. India's renewable energy sector has grown tremendously in recent years, due to strong government support and a favourable economic climate. The country has set ambitious targets to increase its renewable energy capacity to 500 GW by 2030. Over a third of India's installed capacity and more than 40% of the country's power generation, including large-scale hydropower, are currently derived from renewable energy sources. People now have better access to electricity as a result of the creation of a unified national power system, and the growth of renewable energy has been crucial to this. However, there are still challenges that need to be addressed, such as the standardization of guidelines, development of stable grid and transmission networks, and steep fluctuations in solar project tariffs. This paper aims to study comprehensive information on the achievements, prospects, projections, and challenges of renewable energy in India.

Keywords: Renewable Energy, Solar Energy, Environment, Climate Change

INTRODUCTION

The need for energy sources is rising along with the population. The amount of energy required varies throughout nations worldwide. The energy requirements of established nations are higher than those of emerging nations. Any country shall have a vision for energy policy which is to meet energy demands by using clean, sustainable and affordable energy which shall be achieved in a sustainable way Nagaraju (2017). Renewable energy sources create less pollution and are easily available. Renewable energy technology like tidal energy, biomass energy, geothermal energy, wind energy, solar radiation, etc. are environment friendly in nature. For the past 20 years, renewable energy resources have been the main cause of worry for consumers. To achieve sustainable development, a variety of components are involved. The primary concern stemming from non-renewable energy sources is climate change. The major benefits of using renewable energy sources include improved energy for the environment and human health, increased energy security, social and economic growth, and a reduction in climate change.

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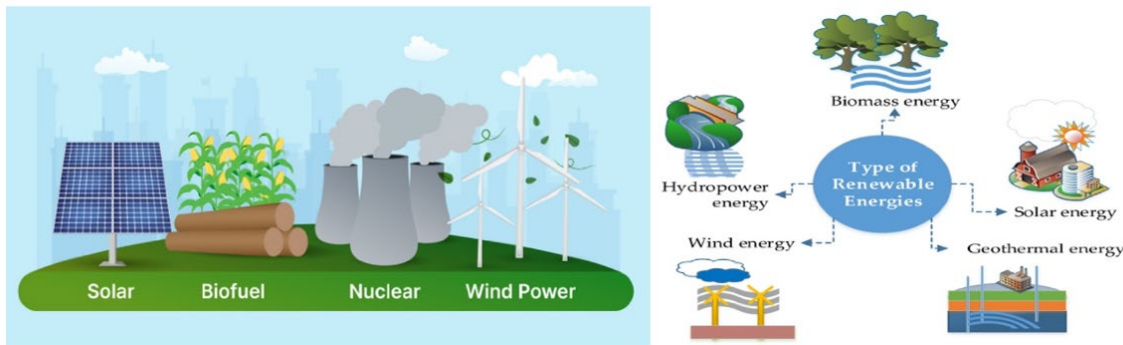
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Transparency: The authors affirm that this manuscript presents an honest, accurate, and transparent account of the study. All essential aspects have been included, and any deviations from the original study plan have been clearly explained. The writing process strictly adhered to established ethical standards.

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Figure 1**Figure 1 Types of Renewable Energy****Source Renewable Energy Present Status and Future Potentials in India: An Overview****NEED OF THE STUDY**

Research on renewable energy in India is crucial for understanding its current status, future potentials, challenges, and the policies and incentives that can favour its sustainable development. Furthermore, such research can provide insights into the untapped potential of renewable energy sources, their role in energy generation, and their contribution to reducing carbon emissions and addressing climate change. The need to study renewable energy in India is emphasized by several factors, including the country's significant and increasing energy consumption, the potential for renewable energy to contribute to energy security and the environmental benefits associated with its use. India is the fourth largest energy consumer in the world, and its energy consumption is projected to increase rapidly, with renewable energy sources expected to perform a substantial role in meeting this demand. As of December 2022, India has installed non-fossil fuel capacity, including renewable energy, stands at more than 176.49 GW, representing about 43% of the country's total capacity.

RENEWABLE ENERGY: PERSPECTIVE OF INDIA

India has several major energy-related issues, including low energy efficiency, hazards to energy security, and energy deficit. The most viable way to deal with these issues is to increase the amount of power produced using unconventional energy sources. India's 38% of installed energy capacity until 2020 is derived from renewable sources, accounting for 136 GW of the country's total of 373 GW installed energy capacity. India has become the third largest energy user and renewable energy producer after America and China. According to Ernst & Young's 2021 Renewable Energy Country Attractiveness Index (RECAI), India ranked third after America and China. India committed in 2016 to meeting the Paris Agreement's Intended Nationally Determined Contributions objectives, which call for obtaining 50% of its total energy output from renewable sources of energy by 2030. By 2030, the Central Power Authority of India wants to produce half of the nation's power using sources of renewable energy and by 2022 and 2023, India intends to generate 175 GW and 500 GW of energy from renewable sources, in succession. India has a robust manufacturing base in wind power with 20 businesses manufacturing 53 different 3 to 30 MW wind turbines of world excellence. These turbines are exported to the United States of America, Europe and other countries. With an additional 25.64 GW of projects in multiple stages of bidding and 48.21 GW of projects in multiple stages of execution, solar energy has been operating in India since September 2020. By 2020 India setup three of the largest solar parks across the globe: the 100 MW Kurnool in Andhra Pradesh, the 2,000 MW Pavagada Solar Park in Tumkur, Karnataka, and the 2,255 MW Bhadla Solar Park in Rajasthan. The states of Chhattisgarh, Punjab, Madhya Pradesh, Rajasthan and Haryana have been identified as having the highest solar radiation appropriate for use in the solar energy system to generate power. These states have an average solar radiation exceeding 6 kWh/m²/day, which makes them particularly attractive for solar energy.

Figure 2

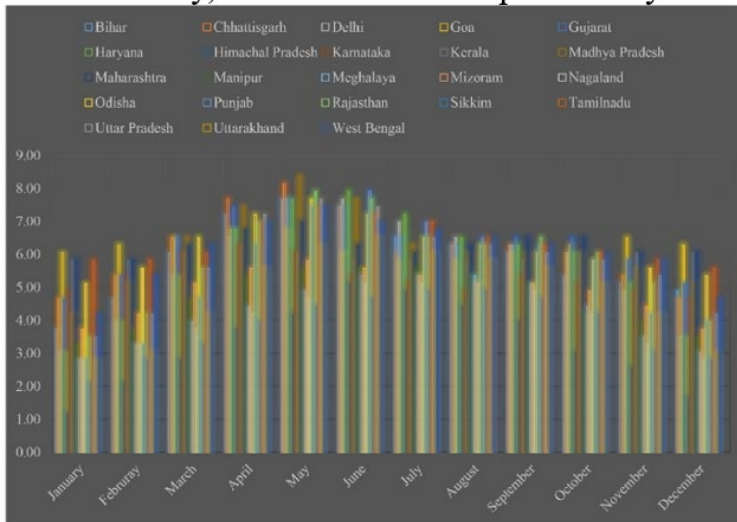


Figure 2 Month-Wise Average Solar Radiation Data Set of Different State of India (2020).

Source Path Towards Sustainable Energy Development: Status of Renewable Energy in Indian Subcontinent

TYPES OF RENEWABLE ENERGY IN INDIA

The following table presents descriptive information regarding the capability for renewable energy in different states of India. The average capacity of India's solar, wind, biomass, hydro, and ocean energy systems is 1613.07 MW, 1425.75 MW, 375.96 MW, 5399.64 MW, and 1919.82 MW respectively according to the data. With 7738 MW of solar energy, Rajasthan has the most solar energy capacity, while Tamil Nadu has 9231.77 MW of wind energy. At 2632 MW, Maharashtra is the state with the highest biomass energy capacity; Arunachal Pradesh has the most hydro energy capacity at 52128 MW; and Gujarat has the highest ocean energy capacity at 14525 MW.

	Solar	Wind	Biomass	Hydro	Ocean
State					Tidal + Wave
Andhra Pradesh	4380	4077	536	2751	100 + 6900
Arunachal Pradesh	11	0	1	52128	0
Assam	68	0	2	852	0
Bihar	190	0	126	567	0
Chhattisgarh	501	0	270	3300	0
Goa	11	0	1	60	0
Gujarat	5709	7203	100	792	10425 + 4100
Haryana	661	0	218	172	0
Himachal Pradesh	61	0	10	22000	0
Jharkhand	80	0	4	809	0
Karnataka	7469	4753.4	1902	10185	100 + 6100
Kerala	312	62.5	3	4025	100 + 4900
Madhya Pradesh	2634	2519.89	128	2790	0
Maharashtra	2445	4794.13	2632	4100	200 + 8100
Manipur	12	0	1	1861	0
Meghalaya	4	0	14	2528	0
Mizoram	8	0	1	2300	0
Nagaland	3	0	1	1634	0
Odisha	428	0	59	3267	400 + 600

Punjab	1022	0	492	1549	0
Rajasthan	7738	4299.73	125	534	0
Sikkim	2	0	1	4514	0
Tamil Nadu	4675	9231.77	1040	2297	230 + 10600
Telangana	3992	128	219	2121	0
Tripura	15	0	1	47	0
Uttar Pradesh	2020	0	2180	1124	0
Uttarakhand	552	0	139	19662	0
West Bengal	163	0	321	3221	900

State-Wise Renewable Energy Capacity (MW) in India (2020)

Source Path Towards Sustainable Energy Development: Status of Renewable Energy in Indian Subcontinent

Sources	Total installed capacity (MW)
Wind power	22,465.03
Solar energy	3063.68
Small hydro power	3990.83
Biomass power	1365.2
Bagasse power generation	2800.35
Waste to power	107.58
Total	33,791.74

Total Installed Renewable Energy Capacity (MW) in India (2020)

Source Path Towards Sustainable Energy Development: Status of Renewable Energy in the Indian Subcontinent

The main sources of electricity generation in India include power plants that use biomass, hydropower, and solar energy. In India, just 23% of power is produced by renewable sources, while 74% of CO₂ emissions may be avoided by 2050, based on the enhanced Renewable Energy Technology scenario. In comparison to the reference scenario, the percentage of renewable energy in the electrical supply elevates to 36%, while the reduction of CO₂ emissions persists at 74%.

Figure 3

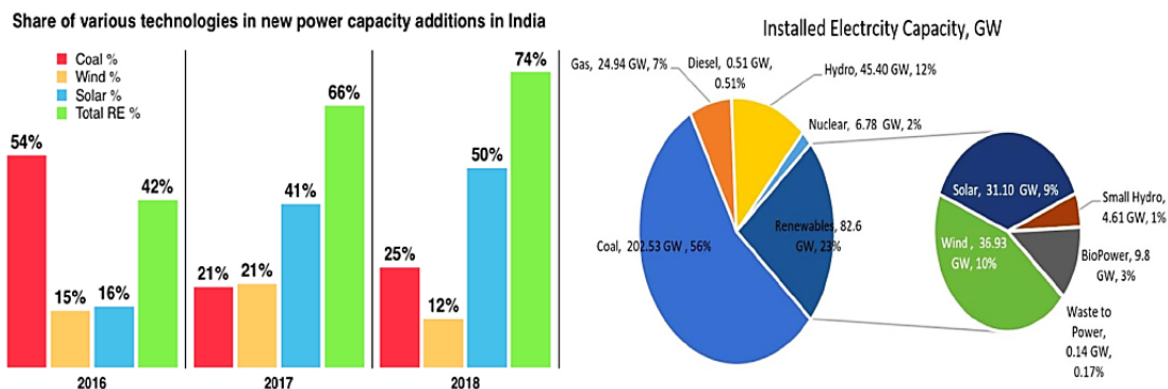


Figure 3 Renewable Energy Production and Application in India Announced by the Government of India
Source Renewable Energy Present Status and Future Potentials in India: An Overview

In the figure shown above, since 2017 India has significantly reduced the dependence on coal and increased the total generation and utilization of renewable energy. India also upgraded the efficiency of its transmission system and added additional energy capacity in order to lower transmission losses in the supply.

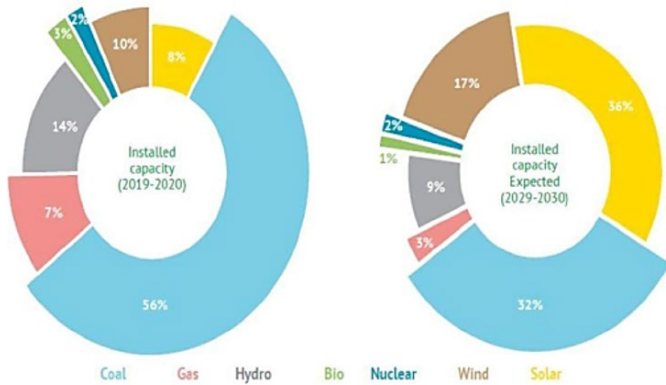
Figure 4

Figure 4 Future Perspective of India's Conventional and Non-Conventional Energy Sources
Source Renewable Energy Present Status and Future Potentials in India: An Overview

By 2030, India's energy consumption will increase at the swiftest pace of any major economy since it is the second most populated country. India's dependence of coal produced energy is more in 2019-20, hence it is expected to reduce its coal dependence and fulfil future energy demands with renewable energy sources like solar and wind energy.

GOVERNMENT INITIATIVES AND POLICIES

To speed up the switch to renewable energy, improve energy security and lower carbon emissions the Indian government has put in place a comprehensive policy framework and started a number of programs, these measures are intended to stimulate local manufacturer, guarantee the integration of renewables into the National Grid and provide a strong environment for the deployment of renewable energy. India's ambitious objective of installing 500 GW of non-fossil fuel capacity by 2030 is a pillar of its renewable energy strategy. This goal is supported by consistent investment, forward thinking policies and international obligations like net zero promise by 2070. Important government programs include the CCDC Wind Initiative which has assisted India in reaching 48 GW of wind power and the National Solar Mission, which has increased solar capacity from slightly over 9 GW in 2016 to almost 98 GW by 2025. Regulations like mandatory renewable energy targets for industries which mandate that big businesses source at least 30% of their energy from renewable sources by 2025 has been put in place to support these flagship missions. Non-compliance will result in penalties, while over achievement will be rewarded with carbon credits.

A significant step towards establishing India as a global centre for the production, use and export of green hydrogen is the National Green Hydrogen Mission which was authorized in 2023 with a budget of ₹19,744 crore. With pilot projects in industries including refineries, fertilizers and city gas the mission is being carried out in stages with an initial emphasis on generating demand and increasing domestic electrolyser production capability. The later stage seeks to build a strong regulatory and research and development environment, increase output and enter new industries like steel and transportation. It is anticipated that the mission would provide significant job opportunities. The PM Surya Ghar Muft Bijli Yojna is accelerating rooftop solar adoption by providing financial assistance and subsidies for residential solar installations which lowers electricity bills and strengthens energy self-sufficiency. In the agricultural sector the PM-KUSUM scheme supports farmers by subsidising solar pumps and decentralised solar power plants reducing diesel use and empowering rural communities. The government has also expanded the Solar Park Scheme to further promote solar energy, facilitating large scale solar installation through efficient land allocation and public-private partnerships. Grid integration is being strengthened through the Green Energy Corridor initiative, with ₹60 billion allocated for transmission infrastructure to ensure the smooth flow of renewable power. The government has also set Renewable Purchase Obligations (RPOs), mandating power distribution companies and large consumers to produce a minimum share of renewable energy.

CHALLENGES OF RENEWABLE ENERGY PRODUCTION IN INDIA

In many regions of India, the combination of energy generation is starting to include more renewable energy. The widespread implementation of renewable energy still faces significant obstacles. Some stem from different renewable energy technologies, while others are a result of the infrastructure, rules, and contemporary market conditions.

- **Cost of production**

Among the major difficulties facing the adoption of renewable energy is the significant cost linked to constructing and setting up infrastructure, such as wind or solar farms. While renewable energy sources such as solar and wind are generally less expensive to run than conventional fuels, the upfront costs of installation can make lenders wary and increase borrowing rates. As a result, investors may find it more challenging to defend their initial investment.

The expense of developing and constructing facilities like solar or wind farms is now the biggest and most well-known barrier to the adoption of renewable energy. When it comes to renewable energy sources, solar and wind power are far less expensive to run than "fuels." Installation costs account for the majority of the cost of using renewable energy. Due to the installation expenses, lenders are potentially inclined to see renewable energy sources as high-risk, which could result in higher borrowing rates and make the investment harder to defend. Interestingly, fossil fuel facilities can pass on growing fuel expenses to customers, who often take the significant price fluctuations as a fact.

- **Energy transmission**

In order to effectively use renewable energy sources, a significant amount of the latest transmission infrastructure is needed. The transmission infrastructure built during the 20th century was designed primarily for nuclear power plants and large fossil fuels. Offshore wind farms are considered one of the most promising renewable energy sources.

- **Barriers to entry**

The dominance of non-renewable energy means that the accountable facilities of these systems have substantial market influence, posing a serious challenge to renewable energy sources. Renewable energy sources like solar and wind power have to combat with well-established, well-funded infrastructure, decades of expertise, and regulations. For start-ups, the barriers to entry are even greater since they have to compete with major competitors in the industry. Start-ups need to show that they can grow in order to attract investors. This is because investors often want enormous amounts of energy output, which can be difficult to achieve. Levelling the playing field might be aided by increased government investment in renewable energy through subsidies and other initiatives.

- **Availability of power**

A major issue facing the renewable energy industry is the reliance on natural resources that are beyond human control. Solar power, for instance, can only be generated when there is adequate sunlight, and wind energy is subject to the availability of strong winds to turn the turbines. When wind speeds are low, power flow to the grid may be compromised, resulting in no energy generation.

- **Power quality issues**

For the network to remain stable and efficient, it is crucial to maintain a consistently high-power quality. When the power supply is of superior quality, the system operates with less expense and great authenticity. However, inferior power quality might have unfortunate impacts on the electrical grid and the industrial procedures, resulting in equipment failure and increased expenses.

- **Resource location**

Many renewable energy plants that provide the grid with energy demand plenty of space, which can be limiting for some users. The location of the renewable energy sources frequently determines their availability which poses challenges for adoption. Certain renewable energy sources may not be accessible in certain regions, and the distance between energy sources and the grid can impact cost and efficiency. Additionally, renewable energy sources are subject to weather patterns, climate conditions, and geographical limitations.

- **Information barrier**

Despite advancements in this area, there is still a lack of information and comprehension about the significance and benefits of renewable energy. Fortunately, funding and tax breaks have been provided to support the integration of renewable energy sources. Government organizations must play a role in guiding and advising those seeking to obtain these incentives.

- **Politics**

Billions-dollar industries can wield enormous political power and the non-renewable energy industry is no exception. The conventional electricity sector gains from tax advantages, incentives, subsidies, and regulatory loopholes in different countries. While these advantages could have improved manufacturing, they have also taken funds away from efforts to further develop renewable energy sources.

- **Oversupply of renewable energy**

In recent years, the global production of solar panels by governments and private companies has increased significantly. However, this growth has led to an oversupply situation where the supply of panels exceeds current demand. Consequently, businesses are cutting back on their long-term commitments, and some are even closing their doors, costing millions to investors. Unfortunately, this oversupply situation could have a negative impact on the future of solar energy technology, potentially disrupting its long-term adoption.

DISCUSSION

India's combined problems with energy and the environmental need is to work toward increasing the proportion of renewable energy in future energy systems. The commercial state and technology development of renewable energy technologies differ significantly. Renewable energy is only getting started in India and before these technologies take off there are still many issues that need to be tackled by businesses, consumers, industry and the government. With an extensive array of renewable energy sources like wind, biomass, solar PV, small scale hydro and solar heating, India is expected to develop and implement renewable energy projects on a massive scale. From the standpoints of long-term energy supply security, environmental benefits and climate change mitigation, India sees the growth of renewable energy as very vital. It is projected that the proportion of renewable energy in energy production alone might reach 60,000 MW in 2031-2032. Renewable energy will be the main force behind the poor's social involvement in the development process by 2031-2032. It is projected that over Rs. 300,000 crores would be invested in the renewable energy sector over the next 25 years. The Ministry of New and Renewable Energy's (MNRE) goals include energy security, a growth in the proportion of clean power, energy available and access, energy affordability and energy equity. Between March 2014 and December 2022, the installed capacity of renewable energy which includes large hydro, increased by over 2.2 times from 76.37 GW to 167.75 GW. The entire Solar Power capacity of the country increased from 2.63 GW in March 2014 to 63.30 GW in December 2022 which is 24.07 times rise. An array of public and commercial organisations such as MNRE, The Centre for Wind Energy Technology, Universities, IITs, NITs, Indian Oil Corporation Limited (IOCL) and The Energy Resource Institute (TERI) conduct research and development on renewable energy sources. In accordance with the revised Nationally Determined Contributions (NDC), by 2030 India has committed to obtain 50% of its installed capacity for electricity from non-fossil fuel-based energy sources. The nation has installed 167.75 GW of renewable energy capacity until 31st December 2022. In addition, there are 32.60 GW of projects in distinct stages of bidding and 78.75 GW of projects in various levels of implementation. India is ranked fourth in the world for installed capacity of renewable energy (renewable energy), 4th for wind power, and 4th for solar energy, according to the REN21 Renewables 2022 Global Status Report.

Figure 5

Sector	Installed capacity (GW)	Under Implementation (GW)	Tendered (GW)	Total Installed/ Pipeline (GW)
Solar Power	63.30	51.13	20.34	134.77
Wind Power	41.93	12.93	1.20	56.06
Bio Energy	10.73	---	---	10.73
Small Hydro	4.94	0.54	0.00	5.48
Hybrid/ Round the Clock (RTC)/ Peaking Power/ Thermal + RE Bundling	---	---	11.06	11.06
Sub-Total	120.90	64.6	32.6	218.10
Large Hydro	46.85	14.15	---	61.00
Total	167.75	78.75	32.60	279.10

Figure 5 Sector Wise Cumulative Achievements (As On 31.12.2022)

Source Ministry of New and Renewable Energy Annual Report 2022-23

In addition to the advancements made through the programs described in Section 2 of Ministry of New and Renewable Energy Annual Report 2022-23, in key sectors including green hydrogen, decentralized renewable energy, rooftop solar, wind repowering and offshore wind, the Ministry introduced regulatory changes and enablers to spur success. Some notable examples include:

- 1) Launch of National Portal on Rooftop Solar:** On 30th July 2022, the Ministry established the National Portal for Rooftop Solar. Through the platform, homeowners may apply for rooftop solar power from anywhere in the nation without having to wait for Discom to complete vendor empanelment and bids. More than 18 MW of projects have been approved through the platform, which has received proposals totalling 117 MW of solar power since its introduction.
- 2) Green Hydrogen:** An initial expenditure of Rs. 19,744 crores were allocated for the National Green Hydrogen Mission in January 2023. The main aim of the mission is to establish a green hydrogen production capacity of over 5 million metric

tons per annum, while simultaneously adding approximately 125 GW of renewable energy capacity in India by the year 2023.

- 3) **Energy Storage:** At the Fatehgarh III Substation of the electricity grid, the tariff-based global competitive bidding (ESS-I) procedure for the creation of 500 MW/1000 MWh standalone BESS experimental projects has been successfully completed by Solar Energy Corporation of India (SECI).
- 4) **The Ministry of New and Renewable Energy under its “Women in RE: Call for Action”:** The goal of this initiative is to encourage a favourable shift in views about women's engagement across the whole value chain, while also acknowledging the important contributions that these stakeholders make to the renewable energy sector. An Inter-Ministerial Multi-Stakeholder Committee has been formed to push policies, initiatives, and interventions focused on women's empowerment in the renewable energy sector to accomplish this. This all-inclusive strategy will support the involvement of producer and self-help groups, along with other community-based models, to successfully implement DRE schemes, improve women's renewable energy abilities and skills, and foster fusion of female-focused programs.
- 5) **India's first 24x7 solar-powered village in Gujarat:** On 9th October 2022, the Sun Temple in Modhera, Gujarat, achieved a significant milestone by becoming India's first "Suryagram" to be powered continuously by solar energy with battery storage. This achievement marks a significant step towards sustainable energy practices for India, as it demonstrates the feasibility of implementing solar-powered solutions with reliable energy storage capabilities. The successful implementation of this project showcases the potential for renewable energy sources to provide reliable and uninterrupted power supply, making them a viable alternative to traditional energy sources.
- 6) **The National Bioenergy Programme:** On November 2, 2022, a comprehensive launch occurred, consisting of three sub-themes: the Waste to Energy Programme, which focuses on generating energy from urban, industrial, and agricultural waste and residues; the Biomass Programme, which encourages the manufacturing of briquettes and pellets as well as the development of cogeneration in industries other than bagasse; and the Biogas Programme.
- 7) **On 14th February 2022,** the Ministry released a framework to help people in remote and rural areas to access renewable energy sources. This framework aims at promoting the use of Decentralized Renewable Energy (DRE) for sustainable livelihoods. This will help people in these areas to improve their quality of life by providing them with access to clean and reliable energy sources.
- 8) **Draft National Repowering Policy for Wind Power Projects:** The draft was released in October 2022 for stakeholder feedback. The aim was to maximize the energy yield (kWh) per sq. km. of the project area to optimize the exploitation of wind energy resources. To accomplish this goal, the newest and most advanced onshore wind turbine technology was used.
- 9) **Offshore Wind:** The Ministry has implemented several measures to initiate the development of the nation's offshore wind sector. Among these actions are: (i) A 37 GW offshore wind auction trajectory by 2030 was outlined in a strategy study on offshore wind energy; (ii) The Ministry approached the Ministry of Finance's Department of Expenditure for clearance regarding the Rs. 15608.65 crore Viability Gap Funding (VGF) scheme for the first 3 GW of offshore wind energy projects.

CONCLUSIONS

Renewable energy sources are environment friendly and can help us save energy, have a healthier environment and replace fossil fuels. Appropriate management of environmental resources and their consumption can minimize the negative impact on human health. In India, a total of 167.75 GW of renewable energy capacity has been installed as of December 31st, 2022. Additionally, projects of 78.75 GW capacity are being implemented and 32.60 GW capacity are being bid on. However, some challenges need to be addressed to achieve India's renewable energy targets, enhance energy security, and reduce carbon emissions. Research and policy initiatives are essential to overcome these obstacles and facilitate a successful transition to renewable energy. When it concerns producing renewable energy, imported equipment is more expensive than locally made equipment. As a result, production of renewable energy is costly, if not beyond reach. The nation should get involved in the production of renewable products in order to lower their costs. Unreliable grid connectivity is a major barrier for the growth of technology for renewable energy. Many investors start to doubt renewable energy technology as a result of this uncertainty, which makes them reluctant to invest. India should focus on creating strategies for the transmission and evacuation of renewable energy in order to overcome this obstacle.

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