Sustainable Development through Renewable Energy Sources in Rajasthan

AJAY PAL, DR B.L. SONI
Research Scholar, Department of Accounting, Jai Naryan Vyas University Jodhpur Rajasthan
Assistant Professor, Government P.G. College, Barmer Rajasthan

***Abstract*—The growth of the economy, the increasing industrialization of the domestic sector, and the increased degree of comfort in homes are all contributing factors to the global increase in energy consumption. Furthermore, it is becoming more widely accepted that energy plays a crucial role in a nation's ability to achieve sustainable development. Utilising the enormous potential offered by renewable energy sources may be one way to avoid being totally dependent on traditional energy sources. Environmental problems have received a lot more attention as a result of the drastic climatic changes that have taken place all over the world, including the melting of ice caps, the abundance of greenhouse gases, global warming, and other similar events. Due to the scarce population spread over a vast geographic area, the Indian government sometimes struggles to provide electricity to its citizens via a centralised national infrastructure. Utilising renewable energy sources in the form of autonomous distributed generating systems might be very beneficial within these constraints. This article aims to provide a succinct overview of Rajasthan's renewable energy potential and current state of affairs. A summary of the current resources will be provided by researchers, entrepreneurs, developers, and investors to help assess the viability of improving the technologies that have been established to capture renewable energy and to map the future development of renewable energy production.**

***Key words*—Renewable energy, Wind power, Solar power, Biomass power**

I. INTRODUCTION

A global multinational effort to address environmental issues began with the United Nations Framework Convention on Climate Change. Following that, other countries, including India, have pledged to reduce their carbon emissions and switch to greener energy sources. China is now the world's most populated country, with India coming in second. Nevertheless, despite this fact, the Indian government is doing a great job of increasing the quantity of electricity produced to meet the current demand. As a result, in the context of the country's general development, the Indian government is making notable strides in the per capita use of electricity, a kind of clean energy. Furthermore, by 2021, India wants to have 100 gigawatts (GW) of renewable energy generation capacity operational. The country presently ranks third in the world, behind only Brazil and the United States, in terms of the total capacity of installed renewable energy sources. Given its remarkable rate of economic development, India will surely see a sustained increase in per capita energy consumption in the near future, which would hasten the production of energy closer to the goals. India has already installed about 89.22 GW of renewable energy, and as a result, the nation's energy consumption is probably going to continue to rise.

Twenty-four percent of India's total energy consumption is used inside its boundaries. A third of the world's energy is produced by coal, according to the 2017 Report of the International Energy Agency. Forty percent of this is used to produce power, while the other forty percent is used for industrial purposes. The requirement for producing capacity to be developed is exacerbated by the demand for energy, and more use of coal leads to higher emissions of harmful gases and carbon. There is still a large dependence on coal to generate electricity, but switching to alternative natural sources would need infrastructural changes, which would cost more money and cause delays. The many power generation sources in India are shown in Figure 1 according to their megawatt (1 MW) capacity.

With a total installed capacity of $900, the ability to produce power from renewable energy sources started in 1997. In the end, this capacity grew to $7,760 MW in 2027, $57,244 MW in 2017, $69,022 MW in 2018, and $87,027.68 MW in 2020.

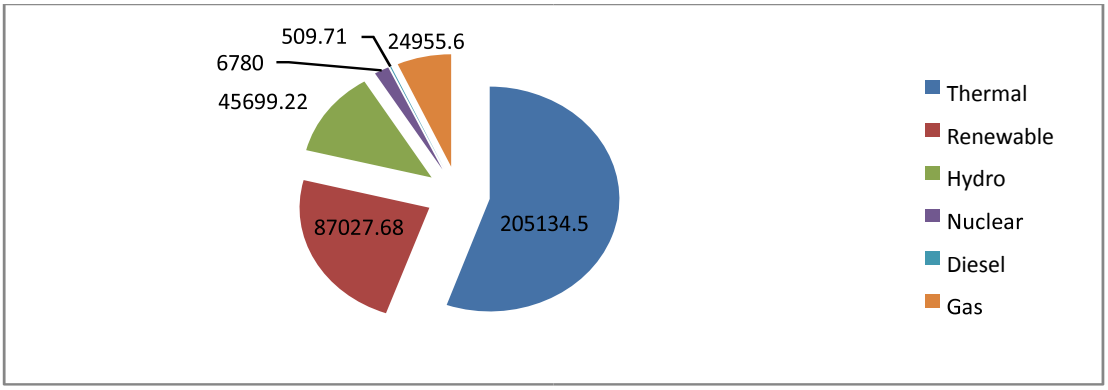

Fig. 1 Conventional and Renewable energy Generation Capacity of India in MW (31 March 2020)

The top five Indian states in terms of installed renewable energy capacity are Karnataka, Tamil Nadu, Maharashtra, Gujarat, and Rajasthan. About 66.991% of the total capacity in these five states may be used for renewable energy. With 12,953.24 MW (17.485%), the state of Karnataka leads the field, followed by Tamil Nadu with 11,934.38 MW (16%). Gujarat ranks fourth with 7,882.5 MW (10.6%) while Maharashtra ranks third with 9,238.78 MW (12.532%) in terms of electricity production. With 7,573.86 MW (10.224%), the state of Rajasthan ranks sixth [60]. Together with these five states, Andra Pradesh, Madhya Pradesh, Telangana, and Uttar Pradesh are the other Indian states with the most installed capacity for renewable energy sources. These nine states together account for 91.655% of India's total renewable energy production.

India's total grid-connected installed capacity increased between 2019 and 2020, as seen in Table 1.

TABLE 1 Growth in Grid Connected Renewable Power

Renewable sources	Total capacity (2019)	Total capacity (2020)
Wind power	37505.18	38433.55
Solar power Ground mounted	31379.30	33508.31
Solar power Rooftop	2333.23	3402.18
Small hydropower	4671.55	4740.47
Biomass power	9861.31	10145.92
Waste to energy	139.80	168.64
Total	85908.37	90399.07

II. RENEWABLE ENERGY IN RAJASTHAN

As India's renewable power production grows and the energy grid shifts to a more economical, ecologically friendly, and sustainable electrical system, Rajasthan is taking the lead. In addition to having the largest land area in the country, Rajasthan also stands out on the country's solar map since it receives between 300 and 330 days of pure sunshine. Due to many factors, including as its high radiation levels, wind speeds, and the availability of huge tracts of land free of vegetation, the state of Rajasthan is a good location for commercial solar parks. With a 2.25 gigawatt capacity, the Bhadla Solar Park, which is situated near Jodhpur, is the largest solar park globally. Figure 2 illustrates that 9.8 gigawatts of non-conventional capacity, or 45% of the total power generation capacity, are present in Rajasthan. Of the entire output linked to the grid, 56.5% is attributed to this capacity. Additionally, 17.6% of all on-grid power is derived from renewable energy sources, which account for 43.5% of installed capacity. In order to meet the ambitious target of 175 gigawatts (GW) of renewable power by 2030, the state of Rajasthan may provide 22.6 GW. This expansion will include 4 gigawatts of new onshore wind energy and 18 gigawatts of new solar electricity. The 2019–20 Rajasthan economic assessment states that the state's total installed generating capacity is 21,175.90 megawatts (MW). A 736.96 MW increase over the previous year, 2018–19, is shown by this.

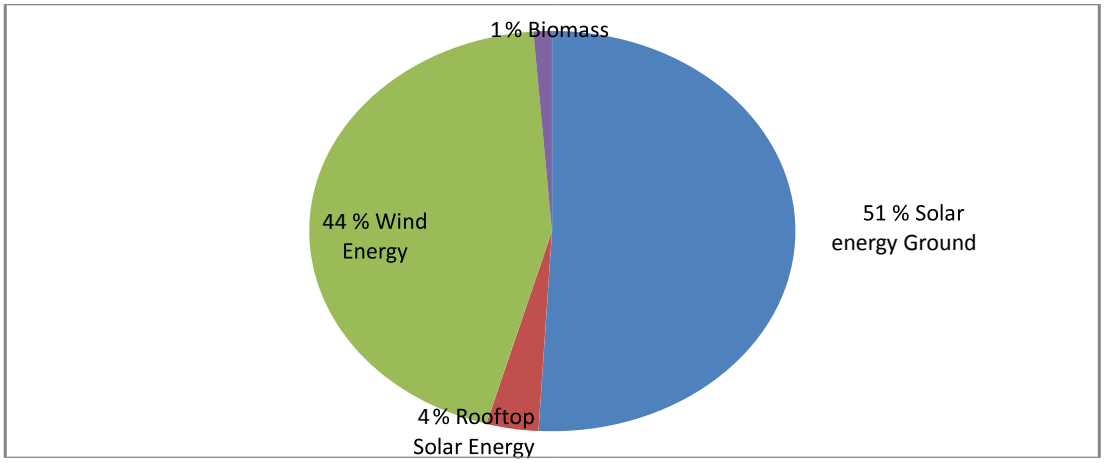

Fig. 2 Source wise total renewable Capacity of Rajasthan 2019-20

a) Solar energy

Karnataka is the only state that offers a higher capacity for solar power generation than Rajasthan. The entire amount of electricity generation capacity constructed in the state of Rajasthan as of 2020 is 22,268.27 megawatts. According to Table 2, the state of Rajasthan's solar power producing capacity, which stands at 5,137.19 megawatts (MW), accounts for around 21.06% of the total capacity. Several Indian governments are considering solar parks as possible sites for upcoming solar project launches. The core region consists of the cities of Barmer, Jaisalmer, Bikaner, and Jodhpur. Among the many underutilised resources found in the state of Rajasthan are a large area of flat land and a high level of solar radiation. In Rajasthan, there are now 4,996.96 MW of operational ground-mounted solar power plants and 356.8 MW of rooftop-mounted plants, up from 726 MW in 2014. Rajasthan's solar power potential is estimated by the Ministry of New and Renewable Energy (MNRE) to be 142 GW.

By 2020, the state of Rajasthan will have access to 5,137.19 megawatts of solar energy. Additionally, the state is home to the largest Fresnel-type CSP power facility in the world, the Dhirubhai Ambani Solar Park, which has a 125-megawatt electrical capacity. The Jodhpur district has 1,500 MW of installed capacity, followed by the solar farms. These solar farms span more than 2,500 hectares and are scattered across Bikaner and Jodhpur.

The Bhadla solar farm, which has a 2245 megawatt (MW) total capacity, is now the most widely distributed plant in the world as of March 2020. The Bhadla solar farm, situated in the Bikaner region, uses a tower-type solar thermal power plant with a 2.5-megawatt output as its only kind of solar power plant. Furthermore, the project's pricing of 2.48 per kilowatt-hour is the lowest tariff available in India for a 750-megawatt solar power facility.

TABLE 2 Growth in Installed solar power in Rajasthan

Year	Capacity Added (MW)	Cumulative capacity (MW)
2014-15	942.10	942.10
2015-16	327.83	1269.93
2016-17	543.00	1812.93
2017-18	519.84	2332.77
2018-19	894.02	3226.79
2019-20	1911.12	5137.19

Bhadla Solar Par:

The Rajasthan region benefits from higher solar potential of 142GW and more sun irradiation of 5.72 kWh/m2/day. This is due to the region's abundance of solar radiation and the vast quantity of cheap, undeveloped land that is accessible. The Bhadla Solar Park is located near Phalodi, which is in the Rajasthani district of Jodhpur. Covering an area of around 40 km squared, or more than 10,000 hectares, it is one of India's largest solar parks. This park was originally intended to have a 2000 megawatt (MW) capacity, but it has now been expanded to 2250 megawatts (2.25 gigawatts). The development of the

project was conducted in four phases starting in July 2015.

Phase I: The Rajasthan Renewable Energy Corporation Limited (RRECL), in collaboration with the Rajasthan State Power Development Corporation (RSPDCL), began the Phase I development in October 2018. Among its components were seven solar power facilities, totalling 75 megawatts in installed capacity.

Phase II: The second stage of the Bhadla Solar Park, which is being constructed by RSDCL and is located in the Jodhpur hamlet of Bhadla, began construction in April 2019. It is made up of 10 solar generating installations with a combined installed capacity of 680 megawatts. This phase, which was established as part of the MNRE program for solar park development, gives solar parks access to necessary facilities such power evacuation systems, office buildings, water, and light, among other things. Both operations and maintenance were within the purview of the RSDCL.

Phase III: The Surya Urja Company, based in Rajasthan, is now working on Phase III of the Bhadla Solar Park. Ten solar power plants totalling one thousand megawatts (MW) of installed capacity are in operation during this phase. The solar power plants now being built in the third phase of the Bhadla solar park installation are manufactured by Hero Future Energies (300 MW), Softbank Group (200 MW), ACME Solar (200 MW), and SB Energy (300 MW).

Phase IV: Additionally, the fourth phase of the Adani renewable energy project in Rajasthan was built. It consists of ten solar power plants, each of which has a capacity of 500 megawatts (MW).

Sambhar Ultra-Mega Green Solar Power Project
Their goal was to develop four thousand megawatts of solar power installations in Rajasthan's Sambhar Lake, which is near Jaipur. The design for the Sambhar Ultra Mega Green Solar Power Project was introduced by Sprint Energy in 2013. Sambhar Salts Ltd. has 9308 hectares of land, which was supposed to be the site of the finished solar project's installation. The first phase of the project was expected to be activated by the end of 2016 and the first part of the plant was expected to be able to generate a total of one thousand megawatts (MW). According to the planned capacity that has been set up, the power plant is anticipated to have a 6,000 million unit generating capacity when the commissioning of 4,000 megawatts is completed. Bharat Heavy Electricals Ltd (BHEL), Solar Energy Corporation of India, Power Grid Corporation of India Limited (PGCIL), Satluj Jal Vidyut Nigam Limited, and REIL formed a joint venture with Sambhar Salts Ltd. to complete the project's first phase.

Nokh solar park
Located in Rajasthan, the Nokh Solar farm is the second largest solar farm. This location, which is in the northern Jaisalmer region, provides the state with around 300 sunny days annually; as a result, the state has a huge capacity to produce solar power. In Rajasthan's districts, the maximum amount of solar radiation is above 7.2 kilowatt-hours per square meter per day. This solar park, which spans over 1850 hectares, is located in the Jaisalmer district's Nokh locality. The Rajasthani government and NTPC Ltd. have approved the solar farm's capacity to generate 925 megawatts of solar power after signing a Memorandum of Understanding (MOU). An approximate sum of four thousand crores of rupees is the expected cost. Super mega renewable energy parks are to be built by Renewable Energy Corporation Limited (RRECL) in collaboration with other related developers such Power Finance Corporation, Solar Energy Corporation, and National Hydro Power Corporation. It is anticipated that these parks will be built concurrently with the creation of solar parks. 980 megawatts is the current operational capacity level.

Fatehgarh Solar Parks
The Fatehgarh Solar Park project is located close to Jaisalmer and spans 9981 acres. It has an installed capacity of 421 megawatts (MW). This project is the result of a collaborative effort between Rajasthan Renewable Energy Corporation Limited and Adani Renewable Energy Park Limited. Additionally, a 1500 megawatt (MW) phase 1 solar park at Fatehgarh, Jaisalmer, has been planned by the Adani Group and is now under development. The state of Rajasthan intends to build solar parks in the established areas of Jodhpur, Jaisalmer, Bikaner, and Barmer, each with an additional capacity of 1,000 megawatts (MW). To support the development of solar parks in Rajasthan, RREC would act as a nodal agency.

b) Wind energy

Located close to Jaisalmer, the 9981-acre Fatehgarh Solar Park project has an installed capacity of 421 megawatts. This project is the result of a collaborative effort between Rajasthan Renewable Energy Corporation Limited and Adani Renewable Energy Park Limited. A 1500 megawatt (MW) phase 1 solar park at Fatehgarh, Jaisalmer, has also been planned by the Adani Group and is now under development. It is anticipated that the state of Rajasthan would create solar parks in the identified areas of Jodhpur, Jaisalmer, Bikaner, and Barmer, with an additional capacity of one thousand megawatts. RREC will be in charge of building solar parks across the state of Rajasthan in its capacity as a nodal authority.

Table 3 shows district-wise wind installed capacity of Rajasthan.

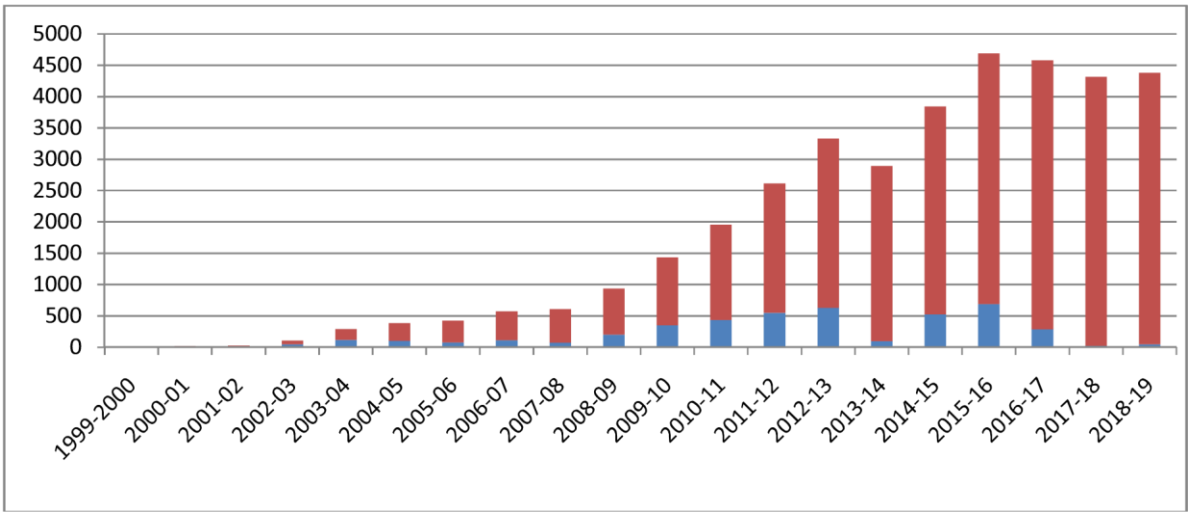

Fig. 3 Growth of Installed Wind Capacity of Rajasthan yearly

TABLE 3: District-wise Status of Wind power projects commissioned in Rajasthan

District	Total Capacity Commissioned (MW)
Jaisalmer	3464.32
Jodhpur	416
Sikar	7.2
Barmer	49.6
Chhittorgarh	355.425
Total (MW)	4337

c) Biomass Energy

India's economy is heavily dependent on agriculture, and the country's tropical location, abundant sunshine, and rainfall make it a perfect location for biomass production with favourable conditions. In India, the installed capacity of biomass energy is now one gigawatt (GW), and initiatives are underway to raise that capacity to 10 GW. Several states are among the top producers of biomass-based electricity, including Andhra Pradesh, Maharashtra, Tamil Nadu, Karnataka, and Rajasthan. The states of Chhattisgarh and Punjab have been working to increase their biomass production.

The Rajasthani government has taken the lead in implementing electrical projects that don't follow conventional guidelines. In 1999, the Rajasthani government released a document called "Policy for Promoting Generation of Electricity from Non-Conventional Energy Sources" to promote the growth of renewable energy sources. The Rajasthani government then unveiled a second "Policy for Promoting for Generation of Electricity from Biomass" in 2010.

The two main biomass energy crop kinds used in Rajasthan are mustard husk and Julie Flora. Remainders and waste products from the production of mustard, cotton, gaur, and Prosopis Juliflora might be used as fuel in a biomass power plant. These leftovers and agricultural waste may be used to prepare the fuel. Crop residue output for cotton, mustard, and gaur exhibits a notable level of reliability and consistency.

The most crucial areas for mustard farming in the state of Rajasthan are the districts of Tonk, Bharatpur, Ganganagar, Alwar, and Modhopur. There are 61.46 lakh (6164066) tonnes of mustard husk produced annually in Rajasthan, and there are 27.58 lakh (2758894) tonnes of surplus available, annually. The Prosopis Juliflora plant is grown in a few areas in Jaisalmer, Bikaner, Barmer, and Jodhpur. A total of 2.92 crore (29262740) tonnes of Juliflora wood are produced yearly, and 36.32 lakh

(3632967) tonnes of surplus are made accessible annually. Eleven biomass power plants with a total capacity of 121.3 megawatts are located in the state of Rajasthan, according to data provided by the state's biomass project developers.

d) Small Hydropower

India ranks sixth in the world for the quantity of hydroelectric power capacity that has been constructed. India now has 45699 megawatts (MW) of utility-scale hydroelectric facilities, or 12.35% of the country's total capacity. A further 1.3% of the total production capacity is made up of 4380 megawatts (MW) of small hydroelectric power units that have been installed. Projects with producing capacities between 2 and 25 megawatts (MW) are referred to as SHP. India has a great deal of potential for small hydro projects. The MNRE has set a target of 5 GW by 2022, whereas the SHP's capacity has been assessed at 20 GW. Four and a half gigawatts (GW) of these were finished before 2020 ended. A small hydroelectric capacity of around 24 megawatts (MW) has also been created in the state by the Rajasthani government.

TABLE 4 shows small hydropower projects of Rajasthan.

S.No.	Name of Power House	Capacity (MW)
1	Anoopgarh PH-I	4.50
2	Anoopgarh PH-II	4.50
3	Pugal PH-I	1.50
4	Pugal PH-II	0.65
5	RMC Mahi-I	0.80
6	RMC Mahi-II	0.165
7	Mangrol	6
8	Suratgarh	4
9	Charanwala	1.20
10	Birsalpur	0.535
	Total	23.85

Current achievements:

An interstate solar power auction using the inverted bidding technique was held by the Solar Energy Corporation of India (SECI) in June 2020. This was higher than the previous record of INR 2.44 per unit, which was established in 2018. It was subsequently lowered to INR 2.36 per unit, a 3.3% decline. Six solar parks in Rajasthan are fully operating, including the newly completed Bhadla-II project, which has a 680 megawatt (MW) capacity. Rajasthan has been able to outperform other Indian states as a result. The Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM) initiative was launched in India in February 2019 with the aim of giving farmers access to suitable water supplies and maintaining their financial stability. This project will increase the total capacity of solar electricity by an additional 25.75 gigawatts (GW). The state government is working hard to ensure that the project is executed by the right people in accordance with the Rajasthan State Solar Energy Policy 2019 framework. The program encourages the use of solar-powered irrigation pumps, which are a crucial part of sophisticated agricultural methods, while also lowering the total cost of farming.

As part of the "Make in India initiative," the solar parks sub-program expanded the parks' capacity from 20,000 megawatts to 40,000 megawatts, with the goal of establishing 50 solar parks by 2019–20. The selection process for private marketers has become more open and competitive. This has been made feasible by the introduction of new criteria that provide more insight into the process and the modification of the previously established selection criteria.

To put the state ahead of all other Indian states in terms of renewable energy, a new policy that integrates solar and wind energy was put into effect in 2019.

Since it helps to provide employment opportunities for people with different levels of competence, it is advantageous to the development of legislation for the use of renewable energy.

III. CONCLUSION

In order to achieve its long-term sustainable power goals, India will need to invest appropriately in eco-friendly innovations. Rajasthan is pursuing considerably more ecologically friendly energy

initiatives at the state level, which are crucial to helping the country make the transition to a fully sustainable energy system. A more optimistic scenario within the state of Rajasthan indicates that by 2030, the country may have 860 GW of installed power capacity for renewable energy sources. We believe that India's renewable energy advancements will increase the usage of electric cars and lead to the establishment of new employment opportunities, such as electrifying rural regions. Nonetheless, the use of renewable energy sources continues to present several difficulties. These issues include a misalignment of supply and demand, a lack of governmental support, a lack of political regulations that encourage credits, a sense of risk, and insufficient financial aid for off-grid applications. If the power produced from renewable resources is not used effectively, the lofty goals that India has set for itself are going to seem unsupportable. An overview of the potential and applicability of renewable energy sources in the state of Rajasthan is what this research aims to deliver. This page discusses the installed capacity as it is now, government initiatives aimed at promoting its adoption, the progress made in reaching key milestones, and future development plans.

The information gathered in this study will be very helpful to academics and developers as they decide how to improve and expand upon renewable energy technologies. We may draw the following conclusions by taking into account the current state of circumstances, as previously discussed:

The quantity of energy that can be produced from renewable sources is limited by a number of factors. Because it necessitates the upgrade of transmission and distribution networks, widespread adoption of this technology is a challenging undertaking.

The state won't be able to satisfy its future energy demands unless the optimal ratio of renewable and non-renewable energy sources is thoroughly examined and all technological options are implemented.

The public's attitude towards the use of renewable energy sources is still lacking in India's cities. Raising awareness is one of the biggest barriers to the broad use of renewable energy strategies.

Information that has been created on the advantages of renewable technology and their environmental impacts has to be shared. This is required to illustrate how efficiency may be pursued in order to secure renewable energy's rapid approval.

Renewable energy improves energy diversity, which means private industry must utilise renewables. The government actively promotes various state ideas at the same time that interdisciplinary collaboration allows manufacturing innovations to flood in from policymakers.

The development of these resources will lead to the most efficient energy transmission feasible via the deployment of hybrid projects, which combine conventional and renewable energy sources with battery storage systems.

In addition to optimising expenses, it will provide power at competitive prices.

Even though it is being expanded, the government is only offering a little amount of financial support to increase the capacity of renewable electricity generation. To encourage the development of ecologically friendly energy sources in a way that is acceptable, the government must provide funds.

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