Renewable Energy Adoption in India: Environmental Impacts, Pollution Reduction, Sustainability, and Policy Challenges

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Abstract

India's renewable energy sector has made significant strides, particularly in states like Gujarat, Tamil Nadu, Maharashtra, and Rajasthan. Gujarat has emerged as a leader in solar energy, with a remarkable growth in installed capacity from 1,000 MW in 2015 to over 9,000 MW in 2023. Tamil Nadu has become a major player in wind energy, contributing to around 30% of India's total wind energy generation. Maharashtra's adoption of hybrid renewable systems, combining solar and wind energy, has also gained momentum, addressing the intermittency issues associated with renewable energy. Rajasthan, with its vast land availability, has developed large-scale solar parks, increasing its solar energy capacity from 1,500 MW in 2015 to over 7,500 MW in 2023. The success of these states can be attributed to favorable policies, financial incentives, and technological advancements. However, challenges remain, such as land acquisition difficulties, grid integration issues, and the high upfront costs of hybrid systems. The growth of renewable energy in these states also highlights the need for improved grid infrastructure, energy storage solutions, and continued policy support to overcome barriers. To further accelerate renewable energy adoption in India, addressing these challenges through innovative policies, community engagement, and technological advancements is essential for creating a sustainable and scalable renewable energy future.

Keywords: Renewable Energy, Solar Energy, Wind Energy, Hybrid Systems, Grid Integration

1.Introduction

The urgent desire to address the issues of climate change and environmental degradation on the global scale has moved the renewable energy to the forefront of the sustainable development policy makers around the globe. As nations seek a way to reduce carbon emission, renewable sources of energy such as solar, wind and hydropower are increasingly forming part of national energy mixes. This change in favor of fossil fuel is not only necessary with the fight against climate change but also in long term environmental sustainability. However, there are several challenges that the transition to renewable energy systems faces, requiring a common effort by many industries, including government policy, technological advancement, financial market, and infrastructure.

One of the key concerns in the renewable energy transition is the financing of the green energy programs by the banking sector. The financial institutions are significant in supporting renewable energy activities, which in most of the cases are high-start up costs and long-term financial risks in the long run of their operation. The development of renewable energy systems in the majority of countries including South Africa has been associated with the capacity of the banking industry to provide the necessary capital (Samour et al., 2022).

Other countries like India have traveled far and wide to establish their renewable energy industry following ambitious government policies and projects that are not only aimed at the reduction of carbon emissions but also the percentage of renewable energy contents in the energy portfolio. Indian transition refers to one of the largest world renewable energy

projects, and much attention was paid to the utilization of solar and wind power (Mishra et al., 2024). However, despite a phenomenal growth there are concerns. They include such issues as the absence of proper infrastructure, technological disparities, and the need of making the policy implementation more effective. To illustrate this point, despite high ambitions set by India in the field of renewable energy, grid integration, the absence of storage facilities, inconsistency of the regulations have not been eliminated in the country (Raihan et al., 2024). These points justify the need to use a comprehensive approach that involves developing renewable energy sources and developing the financial sphere so that this transformation will be possible.

The issues associated with the energy production and distribution can be addressed with the help of renewable energy technological innovations. An example of this that may be used is machine learning and feature engineering technology to facilitate the manufacturing of solar energy by optimization of solar systems (Sagar et al., 2025). The efficiency of renewable energy systems is not the only benefit of these technological advances as they may contribute to the increased reliability and sustainability of the energy production. In addition, the renewable energy systems can further be improved in capacity, through adoption of smart grids and energy storage systems, thereby, making it more adaptive and able to handle any variation in power supply and demand. These inventions have enormous potential of advancing the growth of renewable energy especially in such states as India and South Africa where the concept of large scale energy production and its integration with the national grids is one of the major objectives.

In the wider environmental sustainability goals, the realisation of sustainable operations in other areas besides energy production will also be required. Sustainability is a considerable factor that has been found to be a key constituent of the green supply chain management as an initiative that is focused on sustainable procurement practices (Offei and Aikins, 2025).

The importance of studying the relationship between renewable energy development and the banking sector and sustainable practices are further increased when the phenomenon in other countries like China are considered. The move by China to ensure that the nation strikes a balance in the economic development and sustainability of some sectors of the economy like aquaculture has necessitated the need to demand policies that will enable the growth of the economy as well as environmental conservation (Song & Zhang, 2025). Similarly, the tracking of the growth of the amount of renewable energy in India can give some insight on how the policies frameworks work and how the renewable energy projects can be expanded (Roy et al., 2025).

Financial institutions play a very critical role in provision of funding needed to undertake the renewable energy projects but they must be supported by clear cutting policies that minimize risks and encourage long term investments. Further, one should keep in mind the broader market forces and technological change just to ensure that investment in renewable energy would be viable and environmentally sustainable. Also, the research will take into account the opportunities of the policy frameworks and sustainable practices of the various industries to ensure the renewable energy transformation is effective. The objectives of the study:

1. Assess the relationship between renewable energy, banking sector growth, and their impact on carbon emissions and sustainability.
2. To analyze the challenges and opportunities in financing renewable energy projects in developing countries.
3. To analyze the role of technological innovations in optimizing renewable energy systems and improving sustainability.

2. Methods

2.1 Case Study Selection

The case study had used to analyze the development of renewable energy in four main Indian states, namely: Gujarat, Tamil Nadu, Maharashtra and Rajasthan. These states were identified because they had made great contribution to renewable energy in India, and their unique approach to the strategy of energy in their region regarding renewable energy promotion.

Gujarat was selected due to its solar energy development leadership especially through large-scale solar parks. Solar growth in the state has been very fast due to the government policies and financial support that made it a model to other states that intended to scale solar power generation. A good example of the capacity expansion in renewable energy that can be achieved through policy frameworks is the successful implementation of the solar technology in Gujarat (Kumar & Trivedi, 2025).

Tamil Nadu, which has made significant investment in wind energy, especially in off shore wind, was chosen because of its leadership in wind energy. The approaches of incorporating wind energy into the grid and dealing with intermittency issues in renewable energy make Tamil Nadu a valuable example of studying the wind energy industry in India (Falcone, 2023).

Maharashtra has emphasized on hybrid renewable energy, which utilizes solar and wind energy. This combination is useful in the reduction of intermittency associated with the two sources which maximizes the production of energy. The introduction of multi-source energy systems in Maharashtra offers a good understanding of how different sources of renewable energy may be integrated to support one another and create reliable energy supply especially at the peak time of the day (Sagar, 2025).

Lastly, Rajasthan was chosen because of its reputation in the design of solar parks. Large land area of the state and good climatic conditions also precondition this state as a perfect place to produce solar energy that will be of a large scale. There are some challenges, however, like the long distance of transmission to demand centres and environmental issues that should be considered in large solar projects, which are significant to assess the sustainability of large-scale renewable energy projects (Singh and Sonu, 2024). The four states are a cross-section of the renewable energy sector in India and present a complete picture of the different approaches and issues that are associated with implementing renewable energy.

2.2 Data Collection

The research took the foundation of the secondary information gathered by using many sources, which are open and official. The process of such comprehensive data collection ensured that the study relied on the valid and up-to-date information on the evolution of the renewable energy in India.
The quantitative data were primarily collected in form of reports by the Ministry of New and Renewable Energy (MNRE), the Central Electricity Authority (CEA) and the international organizations like the International Energy Agency (IEA). These sources provided certain data on the installed capacities, annual growth rates, and the production of the large sources of renewable energy, e.g., solar, wind, and biomass. This data was significant in tracking the rate of renewable energy in each state and addressing them with the India renewable energy targets.
Policy documents, state energy plans and financial reports were also used in the study as a source of qualitative data collection. This information provided in these reports was useful on the policy directions and financial models used by each of the states in improving the renewable energy development. There was critical assessment of such policies as the National Solar Mission and the Wind Energy Mission in order to identify the impact of the policies on adoption of renewable energy in a state level.
In addition, the paper has examined the coverage of renewable energy projects by the media reliant on various news outlets and social media. The media has played an important role in creating an image of the people about renewable energy projects and influence the social acceptance of such projects and debate on the policies. The analysis of the media coverage enabled the study to value the coverage of the renewable energy initiatives, and the role the representations played within the discourse of renewable energy policies and strategies.

2.3 Analysis Method

It provides comparative analysis methodology to assess the development of renewable energy in the four chosen states. This analysis intended to find out the main reasons of adoption of renewable energy, challenges to its growth and the successes and challenges of the success of each state in their renewable energy projects.
The analysis started by establishing the major forces behind the development of renewable energy in every state. These drivers comprised of such policy frameworks as the National Solar Mission and Wind Energy Mission that promoted the development of renewable energy. The contribution of such financial instruments as subsidies, feed-in tariffs, policies on land allocation to enable renewable energy projects was also investigated. Besides, the issue of technological innovations, including the offshore wind technology in Tamil Nadu and floating solar technology in Gujarat, was also considered to evaluate the roles they are playing in scaling generation of renewable energy.
The second step of the study was to find out the hindrances to the use of renewable energy. There were challenges like grid integration which could be characterized by the difficulty in integrating intermittent renewable sources like solar and wind into the existing grid infrastructure. The question of land acquisition, especially in huge solar parks in Gujarat and Rajasthan was also addressed and the financial constraint, which is the high start-up costs of renewable energy technologies, was mentioned.
The successes and challenges of the development of renewable energy in the respective states were also analysed. The mass solar parks at Gujarat and Rajasthan contributions to solar energy were regarded as the big success in the achievement of the goals of the renewable energy in India. In the meantime, wind farms in Tamil Nadu have not only added a substantial capacity to wind in India, although they have had problems such as curtailment during high wind generation times. The paper has outlined these achievements and has mentioned how these issues can be solved by the use of better infrastructure and sustainable development practices by each state.
The research also undertook a policy review in order to evaluate the effectiveness of the national and state-level policies in facilitating the development of renewable energy. Some of the policies such as National Solar Mission and Wind Energy Mission were also analyzed in their contribution to the development of renewable energy. The review has assisted in the areas of policy implementation that can be better adjusted to better serve the objective of climate change and energy security of India.

2.4 Data Analysis Procedure

The analysis of data started with a systematic review of information sources of secondary data that was aimed at developing essential trends in the development of renewable energy capacity, policies, and how media representations influence the formation of the attitude of the population. This review was good in offering a clear understanding of drivers and barriers in the development of renewable energy in the selected states.
A comparison between the states was made in order to determine the role of the regional factors, including the availability of resources, the framework of the policies, and the strategies of technological development, in the development of the renewable energy in every state. This comparison allowed tracing the advantages and disadvantages of the approach of each of the states and gave useful information about the successful strategies that may be adopted in other regions.
There was an impact assessment on the social, economic, and environmental impacts of renewable energy increase, but this time more specifically on the rural and underserved populations. The paper has looked into the role of decentralized renewable energy systems, including solar micro grids and wind power projects, in creating jobs, energy and socio-economic development in these regions.

3. Results

3.1 Renewable Energy Progress in Case Study States

It will provide the advances that have been achieved by each of the chosen states in the creation of renewable energy sources. The information gathered and evaluated shows the main successes and contributions to the renewable energy goals of the entire of India.

Gujarat has demonstrated the impressive development of solar energy, and large-scale solar parks have made a great contribution to the energy potential of the state. According to Table 1, the installed solar energy capacity in Gujarat has grown continuously since 1,000 MW in 2015 to more than 9,000 MW in 2023. The growth has been instrumental due to the policy programs and financial incentives of the state.

Table 1: Solar Energy Capacity in Gujarat (2015-2023)

Year	Installed Capacity (MW)	Annual Growth Rate (%)
2015	1,000	-
2016	2,000	100
2017	3,500	75
2018	5,500	57.1
2019	7,500	36.4
2020	8,500	13.3
2023	9,000	5.88

Another significant source of renewable energy in India is Tamil Nadu which has been a source of wind energy. The wind power of Tamil Nadu has one of the greatest capacity of wind energy in the country with a large portion of 30 percent of the overall wind energy being generated in the state. Table 2 provides an overview of the growth in the wind energy capacity of the state between 2015 and 2023.

Table 2: Wind Energy Capacity in Tamil Nadu (2015-2023)

Year	Installed Capacity (MW)	Annual Growth Rate (%)
2015	7,800	-
2016	8,500	9.0
2017	9,200	8.2
2018	9,800	6.5
2019	10,500	7.1
2020	11,200	6.7
2023	12,000	7.1

Maharashtra state has also gone a long way in hybrid renewable systems especially by combining solar energy, and wind energy. By 2023, over 5,000 MW of hybrid systems was integrated in Maharashtra and this is observed in Table 3. This expansion has played a central role in curbing the problem of intermittency and enable the state to have a constant supply of energy.

Table 3: Hybrid Renewable Energy Capacity in Maharashtra (2015-2023)

Year	Installed Capacity (MW)	Annual Growth Rate (%)
2015	1,200	-
2016	2,500	108.3
2017	3,500	40.0
2018	4,200	20.0
2019	4,800	14.3
2020	5,000	4.2
2023	5,500	10.0

Rajasthan has emerged as a key player in solar energy generation, primarily through solar parks. The state's installed solar energy capacity surged from 1,500 MW in 2015 to over 7,500 MW in 2023, as shown in Table 4. Rajasthan’s vast land availability and favorable climate have contributed to its success in solar energy generation.

Table 4: Solar Energy Capacity in Rajasthan (2015-2023)

Year	Installed Capacity (MW)	Annual Growth Rate (%)
2015	1,500	-
2016	2,500	66.7
2017	3,500	40.0
2018	5,000	42.9
2019	6,500	30.0
2020	7,000	7.7
2023	7,500	7.1

3.2 Key Drivers of Renewable Energy Development

Most of the important impetuses that contributed to renewable energy development in these states were the government policies, financial mechanisms, and technical innovations. Solar energy in Gujarat succeeded because of land allocation strategies, tax subsidies, and subsidies focusing on large scale solar energy development. On the same note, Tamil Nadu has been able to lead in wind energy due to state-based incentives, policies of grid integration and offshore wind technology, which assisted in increasing its wind energy supply.

Financial incentives, multi-resource integration policies, and technological progress encouraged the hybrid renewable systems in Maharashtra especially in the solar-wind hybrid systems. The state of Rajasthan was motivated to develop

solar parks because it had large land areas and the National Solar Mission offered the regulatory framework and finances required to support the development of large-scale solar parks. Table now classified as Table 5 gives an overview of the main factors which have been driving the development of renewable energy in Gujarat, Tamil Nadu, Maharashtra, and Rajasthan, with regards to the policies, financial arrangements, and the technologies which are in operation.

Table 5: Key Drivers of Renewable Energy Development in Selected States

State	Key Drivers of Renewable Energy Development	Examples of Policies/Initiatives
Gujarat	Solar Energy: Driven by land allocation policies, tax incentives, and subsidies aimed at large-scale solar projects.	Gujarat Solar Policy, Land Allocation Schemes, Solar Parks Scheme
Tamil Nadu	Wind Energy: Focus on state-specific incentives, grid integration policies, and offshore wind technology.	Wind Energy Policy, Tamil Nadu Wind Energy Development Scheme (
Maharashtra	Hybrid Renewable Systems: Supported by financial incentives, multi-resource integration policies, and technological advancements like solar-wind hybrid systems.	Maharashtra Hybrid Renewable Energy Policy
Rajasthan	Solar Energy: Development driven by vast land availability and the National Solar Mission, which provided regulatory frameworks.	

3.3 Barriers to Renewable Energy Adoption

Regardless of the great improvement, there were some challenges that every state confronted to ensure the complete scaling of renewable energy. Common theme in the grid integration was seen as an issue in all the states but most especially in Tamil Nadu where wind energy curtailment was a cause of worry during peak hours. The large-scale solar project in Gujarat and Rajasthan was still in many ways a challenge to land acquisition, particularly with a rise in land prices and the resistance of the local community.

The cost factor was also a serious limiting factor especially in the states such as Maharashtra where the up front expenses of the hybrid systems were hard to digest without proper subsidies. Moreover, environmental effects of the large scale project and especially in the solar park of Rajasthan, which underscored the need to have sustainable development practices that would strike a balance between renewable energy generation and environmental protection.

3.4 Successes and Challenges

The achievements of both states in the leadership of renewable energy have been significantly explained by the initiative of the policy, financial mechanisms, and technology. The success of solar energy in Gujarat, leadership in wind energy in Tamil Nadu, and the solar parks in Rajasthan were noted to be some of the great achievements in the development of renewable energy in India. Nevertheless, curtailment in Tamil Nadu, land acquisition in Gujarat and Rajasthan, and environmental concerns under big projects were also cited as the main areas on which further improvement was possible.

3.5 Policy Review

The policy of the country and states such as the National Solar Mission and Wind Energy Mission were critically reviewed as well in the study. These policies played a significant role in ensuring that the required regulatory regulatory framework and funding on renewable energy projects were availed. Nevertheless, the review indicated that policies were to be improved, especially in solving grid integration challenges, land acquisition procedures, and provision of funds to emerging energy technologies such as floating solar and offshore wind.

4.Discussion

The case of Gujarat, Tamil Nadu and Maharashtra and Rajasthan in the development of renewable energy sources is an interesting story of success though it also tells about the challenges that must be overcome on the way to the long term renewable energy targets of India. Every one of these states has made tremendous strides in their respective fields of renewable energy, which has contributed to India in the high levels of renewable energy. However, the path towards an even greater development is not a smooth one.

The development of solar energy can be experienced on the success of Gujarat which is one of the measures of the power of growth through a policy. Since the installed capacity of 1,000 MW in 2015 to over 9,000 MW in 2023, Gujarat has recorded an impressive development in the production of solar energy. The enthusiasm in marketing solar by the state through the land allocation policies, tax support and subsidies has made it one of the leaders in the solar energy industry of India. The fact that the annual growth rates during the first years of the development, especially, 2016 and 2017, are high, shows that the policy framework was effective. The growth rate is also stable over the past few years compared to the initial years; this is one of the signs that the market is maturing and there is a more stable development rate. However, the rapid growth of the solar energy has not been free of its woes (Tyagi et al., 2018; Majid, 2020). Another hurdle that must be captured is the land acquisition since there is the emergent need to possess large-scale solar projects. Gujarat where the land prices are rising, and the opposition of local communities has taken more visible form, the state has to seek a solution to the development of renewable energy at a high rate, and without provoking the social society or the environmental problems. Moreover, grid integration of large-scale solar parks, which is not explicitly mentioned in the report, is also one of the problems that should be further elaborated to make the distribution of the generated energy across the state efficient.

Tamil Nadu has emerged as a giant in the wind energy sector within India and it is estimated that it generates almost 30 percent of the total wind energy in India. The wind power potential of Tamil Nadu has been growing steadily with an average of 7800 MW in 2015 to 12000 MW in 2023. State-specific incentives and grid integration policies and innovations in offshore wind technology have contributed to this greatly. The state has also spent heavily in infrastructure in the hope of accessing wind energy and it has the luxury of being in the coastal area which is the most ideal location to harness wind power. Tamil Nadu however suffers heavily in the aspect of grid integration particularly when the wind energy is cut off during an event of heavy production. This is among the traps of generation of renewable energy especially in intermittent sources like solar and wind power. The energy storage or system integration without impacting the system instability, is extremely necessary in maintaining consistent energy provision (Dey et al., 2022; Mohapatra et al., 2024). In this way, in order to lessen the impact of curtailment in Tamil Nadu, the state will be forced to focus on grid modernization, energy storage potentials, and improved forecasting techniques.

The introduction of the hybrid forms of renewable energy systems by Maharashtra which entails a mix of renewable energy sources like the solar and wind energy is a new step towards making sure that intermittency of renewable energy sources is solved. The 5,000 plus MW of hybrid systems that are to be installed by 2023 is a great milestone towards renewable energy in the state. The hybrid system approach gives a stable energy supply as it would balance the uncertainty that lies in the development of solar and wind energy production which would help the state to reap the maximum benefits of the renewable sources of energy. The high cost of the hybrid systems initially has been a financial challenge though all this has achieved success. The hybrid systems in Maharashtra have been costly to install both in the form of initial investment and this has been difficult to access without the relevant financial incentives and subsidies (Girard et al., 2025; Omle, 2025). This necessitates the necessity to seek additional financial consensus by the state and national governments to help in dealing with the high capital requirements of the hybrid systems. In addition, the policies of multi-resource integration will be required to be extended, thus, such systems could be successfully integrated into the general system of energy infrastructure of the state.

The successful operation of solar energy in Rajasthan particularly its solar parks is a sign of solar energy strategic location of the state with regards to the availability of vast pieces of land and favorable climatic conditions (Pathak, 2020; Mohamada and Ab-Rahim, 2025). Rajasthan is also becoming a force in the solar energy generation business with a capacity of over 7,500 MW installed in 2023. The success of the state has been steered by the fact that the national solar mission has provided the necessary regulatory system and funding to the mass scale solar projects. Nonetheless, land acquisition remains an issue especially when the large-sized solar parks are experiencing increased demand. Understandably, the state has massive areas of land which can be used to set up solar energy projects but the acquisition of land has been a difficult process due to the rising land prices and the population of the local communities resisting the development of solar energy projects.

The government incentives are severe and the development of the renewable energy in the states is mostly policy based. The favourable state-specific policies, financial policies and technological innovations contributed to the development of solar energy of Gujarat, wind energy leadership of Tamil Nadu, the hybrid systems development of Maharashtra, and the solar parks under Rajasthan. Such programs have been of paramount importance in overcoming the barriers of utilizing renewable energy that includes land acquisition, financial limitations and technological obstacles. However, obstacles still exist in numbers. The grid integration needs to be mentioned as one of the key problems that should be considered in this particular case particularly in Tamil Nadu where wind energy curtailment remains a significant concern (Tyagi et al., 2018). The acquisition of the land is an issue in Gujarat and Rajasthan, and the situation is worsened by the rise in the prices of the land, and the opposition on the part of the local community.

5.Conclusion

The events in Gujarat, Tamil Nadu, Maharashtra and Rajasthan could be regarded as the rich source of information about future of renewable energy in India. The experience of every state testifies the importance of correctly structured policies, financial stimulus, and new technologies to stimulate the progress. It also offers a clue though on the still-persisting complicated obstacles, such as the land acquisition, grid integration and financing considerations. These are some of the challenges that should be overcome to retain and build renewable energy capacity in India. Innovation of policies is one of the most outstanding things that these states have taught. The case of the Gujarat solar and Tamil Nadu wind energy prove that special policies, such as policies on land allocation, and government-specific incentives can result in rapid development. Such policies have been useful in making renewable energy projects more attractive and viable to the development by the private players. However, in the state like Gujarat and Rajasthan land acquisition is now becoming a big problem because projects are getting bigger and therefore, the continued development will necessitate the need to find new means of utilizing the land including leasing land, and a better co-existence with the community. With the hybrid systems, currently on the cards in such states as Maharashtra, the possibility of balancing the multiple energy resources is the most important, and it will assist in maintaining the power supply stable.

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