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Renewable Energy Development and Its Key Determinants in Leading Indian States

Khushboo Singh[1]; Sebak Kumar Jana[2]

[1] Research Scholar, Department of Economics, Vidyasagar University, Rangamati, Midnapore, West Bengal, India
[2] Professor, Department of Economics, Vidyasagar University, Rangamati, Midnapore, West Bengal, India

Correspondence should be addressed to Khushboo Singh; khushboosinghkhushi006@gmail.com

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ABSTRACT- Human civilisation became increasingly reliant on non-renewable energy resources to fulfil its need for energy, so that CO_2 emissions increased and global warming and environmental degradation occurred simultaneously in all sectors over the time. In reaction, India has taken ambitious steps towards increasing their renewable energy capacity. The picture of renewable energy deployment in the country is, however, highly uneven, with almost half of the capacity being concentrated in a few states. This paper also attempts to analyze the status of the renewable energy sector in the top five states contributing to renewable production, as well as it analyzes the major determinants of renewable generation. Based on the panel data between 2009 and 2023, the research aims to empirically explore what drives renewable energy development success in the frontrunner states. The findings of the analysis reveal that renewable energy potential, GSDP and education level (proxied with degree college) positively influence capacity expansion in renewable power. The results indicate that economies with better economic development, more human capital formation and more access to renewable resources can perform a large-scale expansion of their renewable energy generation. The analysis provides operational policy-specific insights for states to further their renewable energy development and plan focused mechanisms to speed up the energy transition process of India.

KEYWORDS: Renewable Energy, Panchamrit Goals, Solar Power, Renewable Energy Determinants

I. INTRODUCTION

Centuries ago, humans were dependent upon renewable energy resources like wood, animal sources, plants etc. Later, they adopted hydro power and wind power to perform their task e.g., water pumping and grinding grains etc. After technological improvement human start to extract fossil fuels for different metals and use them in manufacturing, industrial products and transportation, etc. It is very true that modern civilization is stand on the cost of extraction of fossil fuels. As time passed, we got to know the result of fossil fuel combustion is climate change due to CO_2 emissions. Due to the combustion or burning of fossil fuels greenhouse gases increase in the environment. It also creates the situation of energy import, which day by day increases the burden on the nation [1]. The country should emphasize energy efficiency and energy security by giving importance to renewable energy development [2]. In the process of economic development, there is a need of adequate amount of energy or we can say, energy works as the backbone of economic development. Economic improvement of India is recognised by the world as well as the energy transition. Due to population growth and economic expansions, different sectors like agricultural sector, the manufacturing sector and the service sectors of India continuously increase their energy demand. The energy demand from different sectors needs a suitable and stable energy supply. In India, there is a major part of energy demand fulfilled by non-renewable energy resources but nowadays the contribution of renewable energy resources increased across all Indian states over the year. Although coal contributes the maximum for energy consumption, India moves forward day by day, decreasing the cost of solar power and wind power [3]. Year-wise renewable energy capacity increases from 9061.26 MW to 10786 .22 MW, from 2019-20 to 2021-22 [4]. Renewable energy development is necessary to achieve the target of the Sustainable Development Goals. Due to a huge gap existing between renewable energy potential and renewable energy installed capacity, here is a huge opportunity in renewable energy production in India [5]. In 2025, the top five renewable energy-producing Indian states are Rajasthan, Gujarat, Tamil Nadu, Karnataka, and Maharashtra. These states have been making a significant contribution in renewable energy production in India from a very early period. There are 17 sustainable development goals, among them six sustainable development goals are affected by renewable energy consumption. These sustainable development goals are SDG7, SDG13, SDG8. SDG9, SDG11 and SDG3 [6].

II. OBJECTIVES OF THE STUDY

There are two objectives of this study-

- To evaluate the situation of the currently top five Indian states in renewable energy production.
- To find the determinants of renewable energy production in the currently top five states in renewable energy production of India.

III. DATA AND METHODOLOGY

Secondary data have used in this study from the Handbook of Statistics on Indian States (RBI) [8], Energy Statistics of India (MoSPI) [9], Annual Report (Central Electricity Authority [10]), different energy data from the dashboard of NITI Aayog (NITI Aayog) and different power data from the Ministry of power etc.

We have used graphical and tabular methods for presenting the situation of different currently top five renewable energy-producing states in India. Exponential growth rate has used to show the growth of different green energy sources for major performing states. We have used Panel Data Analysis to find the determinants of renewable energy production among the currently top five states of India with the help of STATA. There are two model fixed effect model and the random effect model. After regression of these two regression models, we have tested the Hausman test, that indicate to prefer fixed effect model.

IV. RESULTS AND DISCUSSION

To achieve environmental sustainability and sustainable development goals, India targeted the Panchamrit goals under which India committed for five climate commitments in cop 26 (2021). 1. To achieve 500 GW of installed capacity from non-fossil fuel energy resources by 2030. 2. 50% of energy need fulfil by renewable energy resources by 2030. 3. Reduction of carbon emissions by 1 billion tonnes by 2030. 4. Lowering the carbon intensity of economy by 45% by 2030. 5. To achieve net zero emissions by 2070 (UNFCCC [7]). On the path of achieving target, the India's condition can be seen from Table 1.

Table 1: Total installed capacity of India and share of renewable energy resources in it (From 31.03.2009- 31.03.2024)

Data as on	Total Installed capacity of power sectors from all sources (MW)	Total Installed Capacity from RE sources (Including LH) (MW)	India share of RE in total installed capacity (%)
31.03.2010	151160.83	52981.02	35.05
31.03.2012	188658.23	63148.87	33.47
30.03.2014	231135.07	71317.68	30.86
30.03.2016	285327.64	84516.42	29.62
31.10.2018	332285.51	117490.71	35.36
31.03.2020	350897.54	131546.95	37.49
31.03.2022	379670.49	155395.95	40.93
31.03.2024	435247.7	190470.83	43.76

Source: Various years of Energy Statistics of India (MoSPI)

From Table 1, we can see in the period of announcement of Panchamrit goal commitment (2021), the renewable energy contribution was 38.69%, and it has increased to 43 .76 % as on 31st March 2024. The 50% achievement from renewable energy resources by 2030 is still far because growth in installed capacity of renewable energy is very slow.

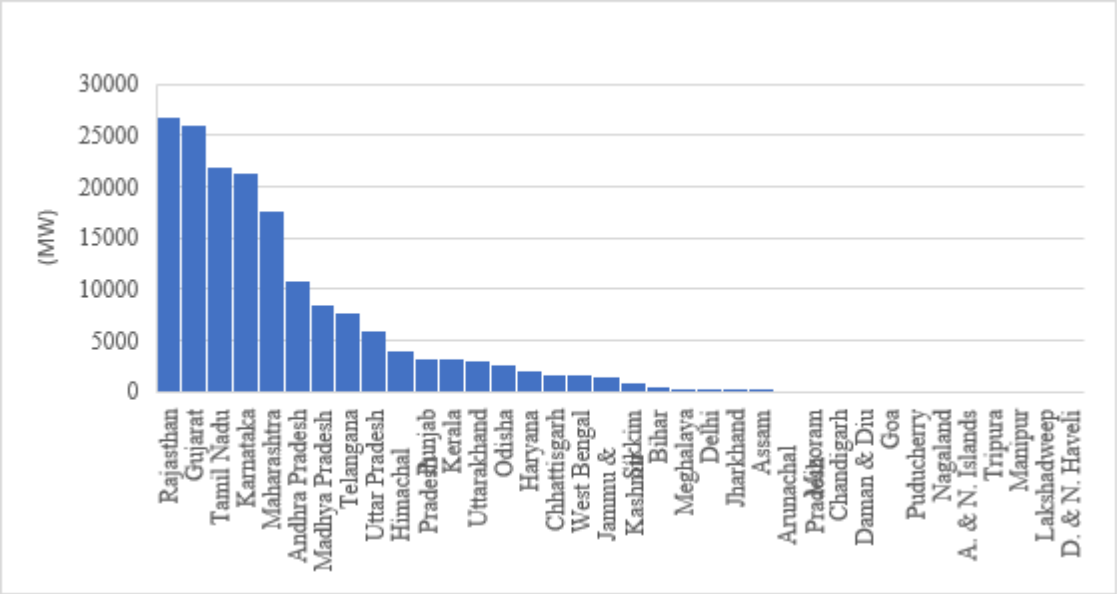
The other chasing target shown in Table 2, which is 500 Gigawatt installed capacity from non-fossil fuel resources. When we discuss for non-fossil fuel resources then we have to add nuclear power with renewable energy.

Table 2: Trend of installed capacity of India from non-fossil fuel resources

Data as on	Installed capacity (GW) from non-fossil fuel resources
31.03.2010	57.04
31.03.2012	67.42
30.03.2014	75.59
30.03.2016	89.64
31.10.2018	123.36
31.03.2020	137.41
31.03.2022	161.26
31.03.2024	198.65

Source: Various years of Energy Statistics of India (MoSPI)

From Table 2, we can see the installed capacity from non-fossil fuel resources was 57.04 GW in 31st March 2010 and it has increased to 198.65 GW in 31st March 2024. It is much far from the target. This installed capacity mostly produced by some major states of India.



Source: Energy Statistics of India (2025)

Figure 1: Installed capacity (MW) from renewable energy resources by different states of India as on 31.03.2024

The highest renewable energy producing state is Rajasthan as on 31st march 2024 followed by Gujarat, Tamil Nadu, Karnataka, Maharashtra and so on. The Figure 1 shows that these are top 5 Indian states for renewable energy production in 2025. The top five states contribute for 61.08% in installed capacity from renewable energy resources in India among all 28 states and 8 union territories as on 31st march 2024. This contribution trend shows it is increasing over the year.

Table 3: Increasing contribution trend by major (currently top 5) states in India in installed capacity of renewable energy in India (From 2009 to 2024)

As on date	Total Installed Capacity from RE sources (Including LH) in India (MW)	Total installed capacity from RE resources of top 5 Indian states (MW)	% Share in RE capacity in India
31.03.2010	52981.02	24688.85	46.60
31.03.2012	63148.87	31886.57	50.49
30.03.2014	71317.68	37265.39	52.25
30.03.2016	84516.42	43398.23	51.35
31.10.2018	117490.7	60581.23	51.56
31.03.2020	131547	71381.93	54.26
31.03.2022	155396	88145	56.72
31.03.2024	190470.8	116342.2	61.08

Source: Various years of Energy Statistics of India (MoSPI) and Annual Report (CEA)

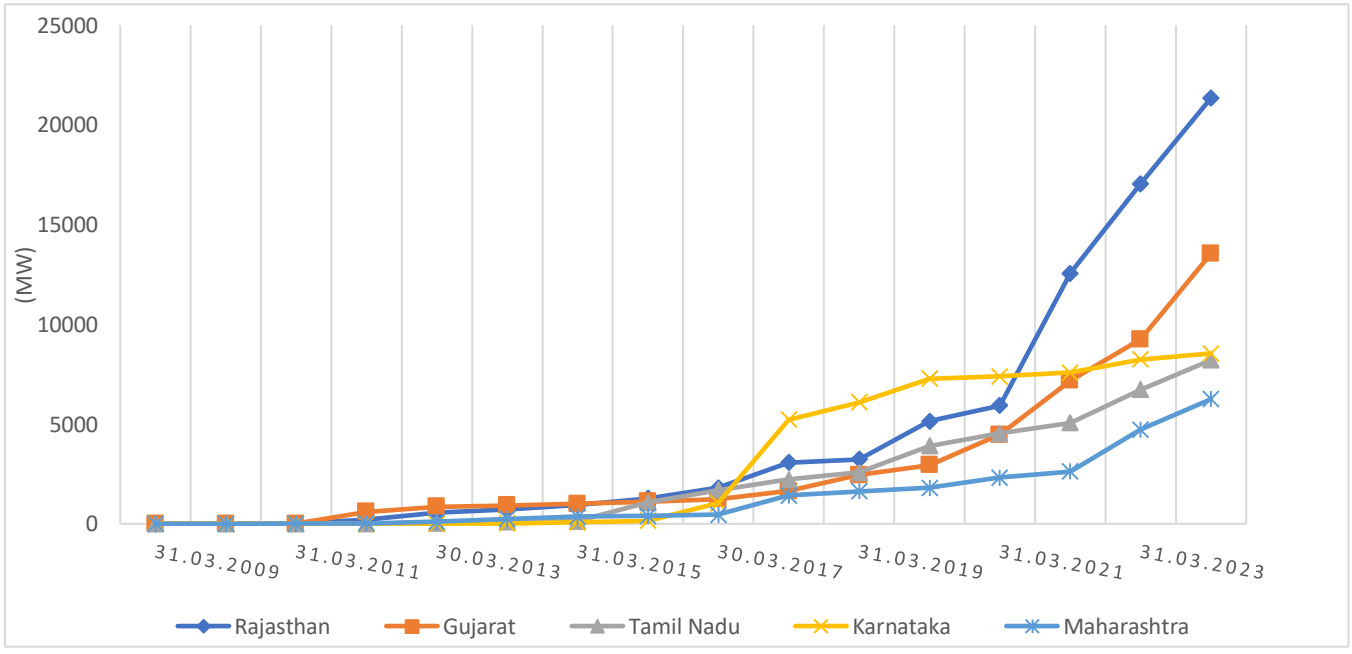
Table 3 shows the increasing sharing trend of the top 5 states in installed capacity from renewable energy resources. The share was 45.11% in 31st March 2009 and it increased to 61 .08% in 31st March 2024. The table shows year by year the contribution of these top 5 states is increasing cumulatively. This scenario clearly shows the fact that the remaining states are performing below the benchmark.

Table 4: Trend growth of different renewable energy resources in currently top 5-States in RE production in India from 2009 to 2024

Energy Resources	Rajasthan	Gujarat	Tamil Nadu	Karnataka	Maharastra
Biomass Energy	7.36%	32.21%	7.53%	14.68%	17.83%
Waste to Energy			12.05%		19.86%
Wind Energy	10.93%	12.94%	5.09%	10.43%	6.58%
Small Hydro Power	0%	17.27%	1.69%	5.33%	3.47%
Large Hydro Power	2.42%	0.03%	0.25%	0.09%	0%
Solar Power	74.59%	37.58%	77.08%	64.87%	47.10%
Total Renewable Energy (Except LH)	20.39%	15.14%	7.39%	10.36%	7.57%
Nuclear Power	0.18%	0.50%	8.81%	10.20%	0.50%

Source: Author's estimation

In Table 4 We have calculated the growth rate of different renewable energy resources for currently top five Indian states for renewable energy production. From Table 4, we can see that among these five states, only Tamil Nadu and Maharashtra perform for waste-to-energy production with growth rates of 12.05% and 19.86%, respectively. Growth rate for small hydropower and large hydro power is significantly lower compared to other energy resources. A huge and significant growth has been seen in solar power generation for top performing states of India. Table 4 shows the state Tamil Nadu growth rate for solar power is 77.08%, which is the highest among them followed by Rajasthan (74.59%) and Karnataka (64.87%). Nowadays, India performing in terms of Solar energy production very well, top most states performed better in solar power than other resources. India's solar installed capacity is 81760 .79 MW as on 31st March 2024 in which 57898.19 MW contributed by top 5 states.



Source: Various years of Energy Statistics of India (MoSPI)

Figure 2: Installed capacity from solar power (MW) by currently top five renewable energy producing Indian States (as on 2009-2024)

Among the top performing states, Rajasthan's installed capacity from solar power is highest i.e., 21347.58 MW. The top five states contribute 70.81% of the installed capacity from solar resources, which is significantly high. As of 31st March 2024, only Rajasthan contributes 26.11%, which is also high among the 28 states and 8 union territories. In Rajasthan, the contribution of renewable energy resources is very high in compare to non-renewable energy resources which is increasing day by day.

Table 5: Share of renewable energy resources (%) in the installed capacity of that state (From 2009-2024)

As on	Rajasthan (%)	Gujarat (%)	Tamil Nadu (%)	Karnataka(%)	Maharastra(%)
31.03.2010	32.54	18.75	50.23	57.09	27.36
31.03.2012	38.13	19.83	54.59	50.95	26.67
30.03.2014	36.83	18.82	48.39	53.15	25.70
30.03.2016	39.72	20.09	45.92	50.25	24.50
31.10.2018	43.42	26.93	46.03	60.80	27.99
31.03.2020	45.49	32.42	50.33	63.10	30.05
31.03.2022	56.59	41.13	52.09	63.89	32.20
31.03.2024	68.52	51.43	58.63	66.09	37.27

Source: Various years of Energy Statistics of India (MoSPI) and Annual Report (CEA)

When we see the trend of the share of renewable energy resources in installed capacity of that state, then we find from Table 5 that it is increased over time for almost all top performing states for renewable energy capacity installation. In 31st march 2010 the share of renewable energy was 32.54%, 18.75%, 50.23%, 57.09% and 27.36% for Rajasthan, Gujarat, Tamil Nadu, Karnataka and, Maharashtra respectively. Except Karnataka, all values are not so high in 2009 but in 31st march 2024 these values are increased to 68.52%, 51.43%, 58.63%, 66.09% and 37.27% respectively. These values are significantly high and we can say this is the major reason why they are in top position. Now, we are finding the reasons behind the high contribution of these states. We can see this from the result of the panel data analysis.

Table 6: Panel Data Regression Result

Fixed-effects (within) regression	Number of obs = 75
Group variable: subject	Number of groups = 5
R-sq:	Obs per group:
within = 0.9141	min = 15
between = 0.0721	avg = 15.0
overall = 0.5231	max = 15
	F(3,67) = 237.67
corr(u_i, Xb) = -0.6267	Prob > F = 0.0000
lntrel	Coef.
lnrep	.1007657
lngsdp	1.614315
lncol	.3756964
_cons	-17.43394

Source: Author's Estimation

Table 6 shows the Fixed effect model result of panel data regression. Here, we have taken data for the currently top five renewable energy producing state in India from 2009 to 2023. We have taken installed capacity from renewable energy resources except large hydro (trel) as the dependent variable. From the result of Table 6, we see there is a positive and significant impact of the renewable energy potential of the state on total installed capacity from renewable energy resources. This indicates that the state having high renewable energy potential have high renewable energy production. We can see that the GSDP of the state is positive and significant impact on the installed capacity of renewable energy, which means that the state having high growth have high installed capacity from renewable energy resources. Here we have taken several degree colleges as the proxy of education in the states, and we find that it has significant and positive impact on renewable energy production. The states having high education have high renewable energy installed capacity. Annexture 1 shows the result of the Hausman test for the panel data regression analysis, and the results indicate that fixed effect model is preferable for the model of our panel data.

There is different policy implementations found in different state level of India regarding renewable energy production. At present, Rajasthan's implemented renewable energy policies are:

- Rajasthan Renewable Energy Policy, 2023
- Rajasthan Biomass and Waste to Energy Policy, 2023
- Rajasthan Green Hydrogen policy,2023

- Integrated clean energy policy,2023
- Rajasthan Investment Promotion Scheme, 2024
- Household solar programme PM- Surya Ghar Muft Bijli Yojana, 2024

The implemented renewable energy policies for Gujarat are

- Gujarat Renewable Energy Policy, 2023
- Gujarat Small Hydel Policy, 2016
- Gujarat Waste to Energy Policy, 2022
- Gujarat Electricity Regulatory Commission Regulation, 2025

The state of Tamil Nadu also has some implemented programmes regarding renewable energy, and these are

- Tamil Nadu Solar Energy Policy, 2019
- Tamil Nadu Electricity Vehicle Policy, 2023
- Tamil Nadu Pumped Storage Project policy, 2024
- Policy Note 2024-25 (Energy development, government of Tamil Nadu)
- Tamil Nadu policy for small hydel project, 2024
- Tamil Nadu repowering, refurbishment and life extension policy for wind power projects,2024

The above states are the top three states in installed capacity from renewable energy resources. Other states of India can follow these state as the role model for renewable energy production.

V. CONCLUSION

The results suggest that although India has made some significant advancements toward its Panchamrit pledges since COP26, the rate and spatial distribution of energy transition are uneven and will not suffice to achieve the 2030 targets without more robust policy action. Its share of total installed capacity in renewable energy jumped from around 39% in 2021 to near 44% in 2024, and its non-fossil capacity was about 199GW – but both were well off the goals of getting to about 50% renewable energy and 500 GW non-fossil capacity by a decade later, by 2030. Growth has been lopsided among states -- Rajasthan, Gujarat, Tamil Nadu, Karnataka and Maharashtra now together account for more than 60 per cent of India's renewable capacity -- indicating a widening disparity between the states. Solar power is the frontrunner in renewable capacity addition, followed by small hydro, large hydro, as well as bio-energy/waste-to-energy, suggesting an inadequate diversification. Panel data findings also show the vitality of renewable potential, higher state income (GSDP), and superior educational infrastructure in promoting renewable capacity creation. These results suggest that India's energy transition policy should go beyond nationwide aggregate targets, and further emphasis on regionally diversified policies is needed. Stronger fiscal and regulatory incentives to lagging states, investments in grid infrastructure and storage capacity that can accommodate variable renewable energy sources, and diversification into undeveloped renewable sources should be the priority. Additionally, the alignment of growing renewables with state-level economic development and human capital formation in terms of skill development, higher education and technical training can further accelerate capacity addition. A joint federal–state policy framework to harmonise investment, technology transfer and institution building is therefore critical for India's ability to reach its Panchamrit goals as it moves towards net-zero by 2070.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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See the Annexure 1: On the Next Page

ANNEXTURE 1: HAUSMAN TEST RESULT

Coefficient				
	(b)	(B)	(b-B)	sqrt (dia(V_b-V_B))
	fe	re	Difference	S.E
lnrep	0.1007657	0.2399516	(-.1391859)	0.0357382
lngsdp	1.614315	0.9488958	0.6654197	0.2034567
lncol	0.3756964	0.2980799	0.0776166	0.0998459
b = consistent under Ho and Ha; obtained from xtreg				
B = inconsistent under Ha, efficient under Ho; obtained from xtreg				
Test: Ho: difference in coefficients not systematic				
chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)				
= 31.52				
Prob>chi2 = 0.0000				