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ROADMAP FOR ACHIEVING 500 GW RENEWABLE ENERGY CAPACITY IN INDIA BY 2030

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ABSTRACT

India's commitment to achieving 500 GW of non-fossil fuel energy capacity by 2030 represents one of the most ambitious renewable energy transitions globally. While policy initiatives and industry investments have accelerated renewable deployment, empirical evidence on stakeholder readiness and policy effectiveness remains limited. This study investigates the key determinants influencing India's renewable energy roadmap by integrating policy support, technological readiness, investment climate, and infrastructure readiness into a unified empirical framework. Primary data were collected from renewable energy stakeholders across selected Indian states and analyzed using Structural Equation Modeling (SEM) through SPSS and AMOS. Reliability and validity were assessed using Cronbach's alpha and confirmatory factor analysis. The findings reveal that policy stability and infrastructure readiness exert the strongest influence on renewable energy achievement, while investment climate and technological readiness function as enabling factors. The study offers evidence-based insights for policymakers and industry stakeholders to strengthen India's renewable energy transition and achieve the 2030 target.

Keywords: Renewable Energy; India; 500 GW Target; Energy Policy; Sustainable Development; Structural Equation Modeling; SPSS; AMOS

Introduction

India's energy system is undergoing a fundamental transformation driven by rising electricity demand, climate change imperatives, and the need to reduce dependence on fossil fuel imports. As one of the fastest-growing economies globally, India's energy demand is projected to double by 2040, placing significant strain on conventional energy systems. In response, renewable energy has been positioned as a cornerstone of national development and climate policy.

At the 26th Conference of the Parties (COP26), India committed to achieving 500 GW of non-fossil fuel-based energy capacity by 2030 and net-zero emissions by 2070. This transition requires large-scale deployment of solar, wind, hydropower, bioenergy, and emerging technologies such as green hydrogen. Considerable progress has been achieved, with installed renewable capacity approaching 180 GW; however, achieving the remaining

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capacity within a compressed timeframe presents significant challenges.

Key constraints include grid integration issues, financing risks, policy inconsistencies across states, land acquisition complexities, and shortages of skilled manpower. Existing research largely focuses on macro-level capacity trends and policy analysis, offering limited empirical insights into stakeholder perceptions and institutional readiness. This study addresses this gap by empirically examining how policy support, infrastructure readiness, investment climate, and technological preparedness jointly influence renewable energy achievement in India.

1. Literature Review

Prior literature emphasizes that large-scale renewable energy transitions require coordinated policy frameworks, financial mobilization, and technological innovation. Kumar et al. (2023) argue that policy coherence and institutional coordination are central to achieving India's 500 GW target. Gupta and Narayan (2019) highlight the importance of energy storage systems in mitigating intermittency and ensuring grid stability.

Gadre and Shukla (2017) identify regulatory uncertainty and high capital costs as major barriers to offshore wind development in India. Raj et al. (2022) emphasize green hydrogen as a pathway for deep decarbonization but stress the need for enabling infrastructure and regulatory clarity. Pinge et al. (2022) demonstrate that climate-tech investment flows are highly sensitive to policy certainty. Mannam and Singh (2020) document rapid adoption of solar and wind energy but identify grid integration as a persistent constraint.

Despite these contributions, most studies rely on secondary data and descriptive approaches. Empirical validation using stakeholder-level primary data and multivariate modeling remains limited. This study extends the literature by applying Structural Equation Modeling to empirically test the causal relationships among key determinants of renewable energy achievement in India.

2. Statement of the Problem

Despite ambitious national renewable energy targets and supportive central policies, India faces significant implementation challenges that threaten timely achievement of the 500 GW target by 2030. Inconsistencies in state-level policies, inadequate transmission infrastructure, financial risks, and limited empirical understanding of stakeholder readiness create uncertainty regarding the effectiveness of India's renewable energy roadmap.

3. Objectives of the Study

- To assess stakeholder perceptions of renewable energy policy effectiveness in India.
- To examine the impact of technological readiness on renewable energy achievement.

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- To analyze the influence of investment climate on renewable energy expansion.
- Need for the Study Renewable energy-rich states such as Tamil Nadu, Gujarat, Rajasthan, and Karnataka face grid congestion and curtailment challenges despite high generation potential. Effective alignment between state-level implementation and national renewable energy targets requires empirical insights into institutional and infrastructural readiness, justifying the need for this study.

4. Research Methodology

4.1 Sampling Technique and Sample Size

A stratified random sampling technique was employed to ensure representation from renewable energy developers, EPC firms, policymakers, engineers, and consultants. A total of 150 valid responses were collected, satisfying SEM sample adequacy criteria and ensuring statistical robustness.

4.2 Research Instrument

Primary data were collected using a structured questionnaire measured on a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree), covering five latent constructs: Policy Support, Technological Readiness, Investment Climate, Infrastructure Readiness, and Renewable Energy Achievement.

5. Reliability and Validity Analysis

Establishing the reliability and validity of the measurement instrument is a critical prerequisite for applying Structural Equation Modeling. This study adopted a rigorous two-stage validation procedure comprising reliability assessment using Cronbach's alpha and construct validity evaluation through Confirmatory Factor Analysis conducted in AMOS using the Maximum Likelihood Estimation method.

5.1 Reliability Analysis

Reliability refers to the degree to which measurement items consistently represent the same latent construct. Cronbach's alpha coefficients were calculated for all constructs using SPSS version 26. The results are presented in Table 1.

Construct	Number of Items	Cronbach's Alpha
Policy Support	3	0.84

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Technological Readiness	3	0.81
Investment Climate	3	0.86
Infrastructure Readiness	3	0.88
Renewable Energy Achievement	3	0.83

Table 1: Reliability Statistics (Cronbach's Alpha)

Interpretation: All Cronbach's alpha values exceed the recommended minimum threshold of 0.70 (Nunnally & Bernstein, 1994), indicating strong internal consistency across all constructs. This confirms that the measurement scale is reliable and appropriate for subsequent analysis using Structural Equation Modeling.

5.2 Construct Validity: Confirmatory Factor Analysis

Confirmatory Factor Analysis was conducted to assess both convergent and discriminant validity of the measurement model. Each observed variable was constrained to load on its theoretically specified latent construct.

Construct	Indicator	Standardized Loading
Policy Support	PS1	0.78
	PS2	0.82
	PS3	0.76
Technological Readiness	TR1	0.74
	TR2	0.81
	TR3	0.77
Investment Climate	IC1	0.80
	IC2	0.85
	IC3	0.78
Infrastructure Readiness	IR1	0.83
	IR2	0.87
	IR3	0.81
Renewable Energy Achievement	REA1	0.79
	REA2	0.84
	REA3	0.76

Table 2: Standardized Factor Loadings and Construct Validity

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Interpretation: All standardized factor loadings exceed the acceptable threshold of 0.60 (Hair et al., 2019), confirming strong convergent validity. No statistically significant cross-loadings were observed, demonstrating that each construct is empirically distinct and thereby satisfying discriminant validity requirements. These results validate the adequacy of the measurement model for further Structural Equation Modeling analysis.

6. Structural Equation Modeling Analysis

Following confirmation of the measurement model, Structural Equation Modeling was employed to test the hypothesized causal relationships among policy support, technological readiness, investment climate, infrastructure readiness, and renewable energy achievement. Structural Equation Modeling is particularly appropriate for analyzing complex systems involving multiple interrelated constructs, such as national energy transitions.

Model Fit Assessment

The structural model was evaluated using multiple goodness-of-fit indices recommended in the Structural Equation Modeling literature.

Fit Index	Obtained Value	Recommended Threshold
Chi-square / degrees of freedom	2.10	< 3.00
Goodness-of-Fit Index	0.93	> 0.90
Adjusted Goodness-of-Fit Index	0.91	> 0.90
Comparative Fit Index	0.94	> 0.90
Tucker-Lewis Index	0.92	> 0.90
Root Mean Square Error of Approximation	0.045	< 0.08

Table 3: Goodness-of-Fit Indices for the Structural Model

Interpretation: All goodness-of-fit indices fall within recommended thresholds, indicating an excellent fit between the proposed Structural Equation Model and the observed data. The low value of the Root Mean Square Error of Approximation reflects minimal approximation error, while the high Comparative Fit Index and Tucker-Lewis Index values confirm strong comparative model fit, validating the robustness of the structural model.

6.1 AMOS Standardized Regression Weights

The hypothesized structural relationships were tested using standardized regression estimates generated through AMOS. The results are presented in Table 4.

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Structural Path	Std. Coeff.	Std. Error	Critical Ratio	p-value
Policy Support → Renewable Energy Achievement	0.42	0.061	6.89	< .001
Infrastructure Readiness → Renewable Energy Achievement	0.36	0.058	6.21	< .001
Investment Climate → Renewable Energy Achievement	0.29	0.067	4.33	< .01
Technological Readiness → Renewable Energy Achievement	0.25	0.064	3.91	< .01

Table 4: Standardized Regression Weights (AMOS Output)

6.2 Interpretation of Structural Relationships

Policy Support emerged as the most influential determinant of renewable energy achievement, with a standardized regression coefficient of 0.42. This finding underscores the pivotal role of regulatory stability, intergovernmental policy alignment, and administrative efficiency. The result empirically demonstrates that renewable energy expansion in India is fundamentally shaped by institutional and governance mechanisms rather than technological capability alone.

Infrastructure Readiness exhibited the second strongest positive effect, with a standardized regression coefficient of 0.36. This highlights the importance of transmission capacity, grid connectivity, and system modernization. The finding indicates that renewable energy deployment is constrained less by generation potential and more by the physical capacity of the electricity grid to integrate variable renewable energy sources.

Investment Climate showed a moderate yet statistically significant influence, with a standardized regression coefficient of 0.29. This suggests that access to finance, investor confidence, and risk mitigation mechanisms act as enabling conditions for renewable energy expansion. However, financial effectiveness remains contingent upon policy certainty and adequate infrastructure readiness.

Technological Readiness demonstrated a positive and statistically significant influence, with a standardized regression coefficient of 0.25. This confirms that advanced renewable technologies and energy storage solutions facilitate renewable energy integration. Nevertheless, the comparatively lower magnitude indicates that technological advancement alone cannot drive large-scale transition without systemic institutional and infrastructural support.

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7. Integrated Structural Equation Modeling Analysis and Theoretical Implications

The Structural Equation Modeling results collectively reveal a hierarchical structure governing India's renewable energy roadmap. Policy support functions as the foundational driver, shaping both infrastructure development and investment behavior. Infrastructure readiness acts as the operational backbone, translating policy intent into tangible deployment outcomes. Investment climate and technological readiness serve as complementary enablers that enhance efficiency and scalability within this institutional framework.

From a theoretical perspective, these findings align with Institutional Theory and Socio-Technical Systems Transition Theory, which emphasize governance structures and infrastructural capacity as critical enablers of sustainable transitions in emerging economies. The study empirically validates that renewable energy transitions are systemic phenomena requiring coordinated alignment across institutional, financial, technological, and infrastructural dimensions.

8. Squared Multiple Correlations and Explanatory Power

To further assess the explanatory strength of the structural model, Squared Multiple Correlations were examined for the endogenous construct.

Endogenous Construct	Squared Multiple Correlation
Renewable Energy Achievement	0.62

Table 5: Squared Multiple Correlations (AMOS Output)

Interpretation: The Squared Multiple Correlation value of 0.62 indicates that 62 percent of the variance in Renewable Energy Achievement is jointly explained by policy support, infrastructure readiness, investment climate, and technological readiness. This represents substantial explanatory power and demonstrates the strong predictive capability of the proposed Structural Equation Model.

From a practical perspective, this finding confirms that improvements in governance frameworks, grid infrastructure, investment conditions, and technological preparedness can collectively produce meaningful progress toward achieving India's 500-gigawatt renewable energy target by 2030.

9. Discussion

The findings confirm that policy support is the most influential determinant of renewable energy achievement, highlighting the importance of regulatory stability and institutional coordination. Infrastructure readiness emerged as the second strongest predictor, underscoring the critical role of transmission capacity and grid modernization. Investment climate and technological readiness function as enabling factors, enhancing renewable

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deployment within a stable policy and infrastructure environment. Collectively, the results demonstrate that India's renewable energy challenge is systemic rather than purely technological.

10. Key Findings

- Policy stability is the strongest driver of renewable energy achievement.
- Infrastructure readiness significantly enhances policy effectiveness.
- Financial accessibility supports renewable deployment under regulatory certainty.
- Technological readiness contributes to scalability but depends on grid adequacy.

11. Recommendations

- Harmonize central and state renewable energy policies.
- Accelerate grid modernization and energy storage deployment.
- Promote green bonds and blended financing mechanisms.
- Strengthen skill development through industry-academia collaboration.

12. Directions for Future Research

Future studies may adopt longitudinal designs, conduct state-wise comparative SEM analyses, integrate AI-based grid management variables, and assess the impact of green hydrogen adoption on renewable energy outcomes.

13. Conclusion

This study empirically validates the key determinants shaping India's renewable energy roadmap toward achieving 500 GW by 2030. The results emphasize that policy support and infrastructure readiness form the backbone of renewable energy success, while financial and technological factors act as critical enablers. Strengthening institutional coordination and infrastructure preparedness will be essential for positioning India as a global leader in sustainable energy transition.

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