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RESEARCH PAPER

Institutional Framework for Scaling Renewable Energy and Green Finance in India: A Special Focus on Tamil Nadu

Swetha P [1*], Dr. G Karunamoorthi [2]

1 PhD Research Scholar, PG & Research Department of Economics Pachaiyappa's College, Chennai, Tamil Nadu, India

2 Associate Professor, Supervisor and Guide PG & Research Department of Economics Pachaiyappa's College, Chennai, Tamil Nadu, India

Corresponding Author: *Swetha P

ABSTRACT

This paper explores the critical role of institutions and green finance in advancing renewable energy in Tamil Nadu, a leading state with around 20 GW installed capacity—10 GW from wind and 6 GW from solar. Despite its progress, Tamil Nadu faces structural, financial, and regulatory challenges including financing gaps, grid integration issues, and policy inconsistencies. The study assesses the contribution of institutions like MNRE, SECI, IREDA, RBI, NIIF, and TEDA in promoting clean energy and evaluates state-specific policies such as the Tamil Nadu Solar Policy 2019. It examines innovative financial instruments—green bonds, carbon credits, and climate funds—and their potential to attract private and foreign investments, especially for SMEs and IPPs. The paper highlights a research gap in understanding state-level institutional frameworks and financing barriers, proposing solutions like enhanced public-private partnerships, international cooperation, and the adoption of emerging technologies such as AI and blockchain for transparency and efficiency. Findings suggest the need for improved policy coordination, better infrastructure for grid integration, and increased access to green finance.

The study offers practical recommendations for stakeholders to strengthen institutional collaboration, promote investment, and support Tamil Nadu's transition into a resilient, sustainable energy hub aligned with national and global climate goals.

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1. INTRODUCTION

Transitioning to clean energy is vital for eco-friendly economic progress, reducing carbon footprints, and ensuring long-term energy security. India has emerged as a global frontrunner in renewable energy growth, with Tamil Nadu contributing significantly due to its vast wind and solar potential. The state's proactive policy environment, coupled with national-level institutional support, has contributed to significant capacity additions in renewable energy. However, despite these advancements, multiple challenges persist, including financing constraints, policy inconsistencies, grid integration issues, and infrastructure bottlenecks.

The institutional framework and availability of green finance are two crucial elements that determine the pace of RE adoption. Institutions such as the NIIF, MNRE, IRDEA, RBI,

TNEDA and SECI. Serve as a key player in shaping policies, attracting investments, and implementing projects. Additionally, financial instruments like green bonds, carbon credits, and climate funds play a important role in closing investment gaps facilitating the widespread deployment of sustainable power solutions. Despite Tamil Nadu's leadership in renewable energy, a research gap exists in understanding how institutional frameworks and green finance impact the state's energy transition. While national-level policies have been widely studied, there is limited research on state-specific institutional effectiveness, financing challenges, and sectoral constraints. Furthermore, emerging financial technologies such as blockchain and AI in energy trading, as well as the role of international collaborations in clean energy investment, remain underexplored.

This research paper aims to assess the role of national and state-level institutions in promoting renewable energy expansion and examine the contribution of green finance instruments in accelerating renewable energy development in Tamil Nadu. By analyzing policy interventions, financial mechanisms, and institutional effectiveness, this study aims to offer strategic guidance on overcoming challenges and building a resilient, sustainable renewable energy ecosystem.

2. OBJECTIVES OF THE STUDY

2.1 Assess the role of national and state-level institutions (MNRE, SECI, IREDA, RBI, NIIF, TEDA) in promoting renewable energy expansion in Tamil Nadu.

2.2 Analyze the impact of green finance tools in scaling renewable energy projects.

3. Research Question

3.1 How do institutional frameworks and green finance contribute to scaling renewable energy in Tamil Nadu?

3.2 What are the key institutional and financial drivers ensuring the sustainability of Tamil Nadu's renewable energy sector?

4. Research Gap

4.1 The role of institutional frameworks in facilitating or hindering large-scale renewable energy adoption remains underexplored.

4.2 Limited research on how technological innovations in finance (blockchain, AI) and international collaborations can support Tamil Nadu's renewable energy transition.

5. REVIEW OF LITERATURE

Several studies highlight the crucial role of institutional frameworks and green finance in scaling renewable energy adoption. Sharma and Ghosh (2020) emphasize the contributions of MNRE, SECI, and TEDA in policy formulation and investment facilitation. Keerthi (2013) identifies key challenges in green finance, including financial accessibility and regulatory barriers, while Gupta and Banerjee (2018) examine the effectiveness of green bonds and climate funds in attracting private sector participation. Kumar et al. (2019) discuss infrastructure constraints, particularly grid integration issues that hinder renewable energy scalability. Additionally, IRENA (2021) explores innovative financial mechanisms like blockchain and AI in energy trading, enhancing transparency and efficiency. Despite extensive research on India's renewable energy policies, limited studies focus on Tamil Nadu's institutional effectiveness and state-specific financial barriers. This paper addresses these gaps by analyzing the role of institutional frameworks and financial mechanisms in Tamil Nadu's renewable energy transition.

6. METHODOLOGY

This study adopts quantitative approach using secondary data. Data is collected from policy documents, government reports (MNRE, TEDA, SECI, IREDA), academic literature on renewable energy and green finance, and financial reports from institutions like RBI and NIIF. Additionally, case studies of Tamil Nadu's wind and solar projects provide insights into sectoral developments. The analysis includes descriptive assessment of renewable energy growth trends, comparative evaluation of policy initiatives, and financial performance analysis to examine green finance instruments and investment patterns.

7. Limitations of the Study

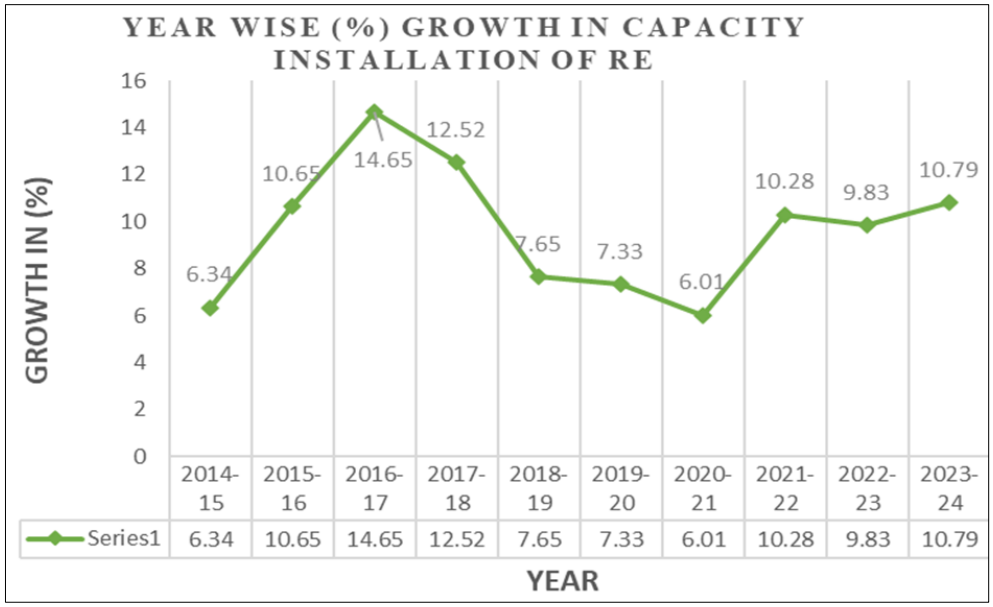
7.1 Reliance on secondary data may not capture real-time challenges and stakeholder perspectives.

7.2 Findings may not be fully generalizable beyond Tamil Nadu.

7.3 Does not analyze emerging technologies like blockchain or AI in green finance.

7.4 May not reflect the latest regulatory updates or policy effectiveness.

8. Yearly Progress in India's Renewable Energy Sector (%)



Source: MNRE

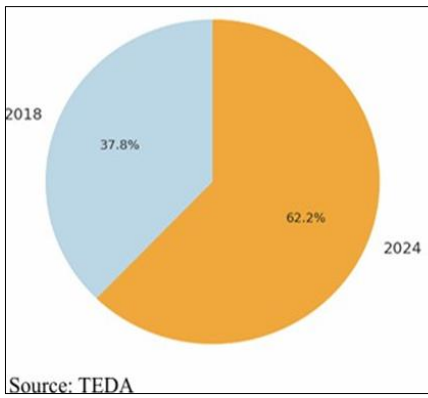
The RE industry has shown impressive annual growth, outpacing the non-renewable energy sector, which includes traditional thermal and nuclear sources. The graph indicates that since 201617, the expansion rate of renewable energy has steadily exceeded 6%, while the non- renewable sector has struggled to exceed 3.01%.

9. Renewable Energy Overview – Tamil Nadu (As Of 31st March 2024)

Category	Details	Rank/Share
Total Renewable Energy (RE) Installed Capacity	22.16 GW	3rd in India (11.63% of national total)
Growth in Installed Capacity (2017-2024)	RE: 1.65 times increase Non-RE: 1.06 times increase	-
Share of RE in Tamil Nadu's Installed Capacity	55.49% (2023-24) 44.70% (2017-18)	-
Major RE Sources in Tamil Nadu	Wind Power: 47.85% Solar Power: 37.05%	-
Total RE Generation (2023- 24)	33.17 BU	9.22% of total clean energy (5th in India)
Generation from RE(2023-24)	29.60 BU	4th in India (13.11% of total)
Share of RE in Tamil Nadu's Total Power Generation (2023-24)	26.90%	-
Breakup of RE Generation in Tamil Nadu (2023-24)	Wind Power: 50.98% Solar Power: 35.39%	-

***Source*:** MNRE & TEDA

10. Share in RE Installed Capacity in Tamil Nadu

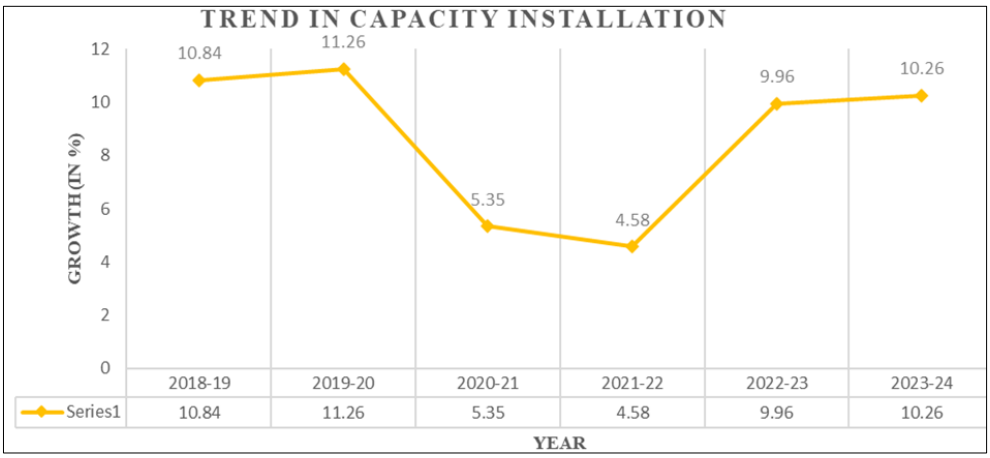


Source: TEDA

YEAR	INSTALLED CAPACITY (%)	KEY OBSERVATION
2018	37.8%	Lower share of total installed capacity
2024	62.2%	Significant increase in installed capacity.

The pie chart illustrates the percentage distribution of installed capacity in Tamil Nadu for the years 2018 and 2024. In 2018, the installed capacity accounted for 37.77% of the total, represented in light blue. By 2024, there was a significant increase, with the installed capacity rising to 62.23%, depicted in orange. This growth highlights the substantial expansion of renewable energy infrastructure over the six-year period. This indicates a substantial growth in installed capacity over the years.

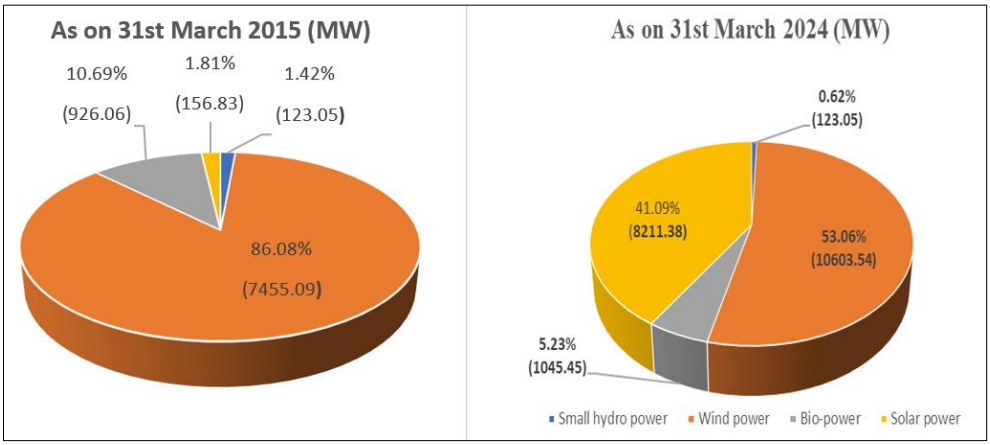
11. Annual Expansion Rate Of (Re) Installed Capacity in Tamil Nadu



Source: MNRE

The pattern highlights an initial period of steady growth (2018-20), followed by a sharp decline (2020-22), and a strong recovery (2022-24). The fluctuations suggest the influence of external factors like economic slowdowns and policy impacts, while the recent recovery signifies renewed efforts in capacity expansion, particularly in the RE industry. This trend underscores the value of consistent policy support, investment stability, and technological advancements in sustaining long-term capacity growth.

12. Contribution (%) to Cumulative Installed Capacity



Source: MNRE

The two pie charts compare the installed capacity of renewable energy sources in India between March 31, 2015, and March 31, 2024. Wind power, which dominated in 2015 with 86.08%, reduced to 53.06% in 2024, despite an increase in absolute capacity. The most significant growth was seen in solar power, which surged from a minimal share in 2015 to 41.09% by 2024. Small hydro power also increased moderately to 5.23%, while bio-power slightly declined to 0.62%. This shift highlights India's increasing focus on solar energy expansion, reducing wind power's relative dominance in the renewable energy mix.

13. Institutional Framework for RE (Tamil Nadu)

A thorough analysis of the institutional framework for renewable energy in Tamil Nadu requires an in-depth examination of the key national and state-level institutions involved in policy development, project execution, and financial assistance. These institutions are instrumental in

expanding renewable energy capacity by attracting investments, enforcing regulatory standards, and advancing technology. The following table outlines the core functions of these institutions in supporting the growth of clean energy.

Institution	Role
MNRE	Formulates policies for development of RE at the national level, providing strategic direction and financial incentives.
SECI	Facilitates solar energy projects and auctions, supporting large-scale deployment and ensuring the achievement of national solar capacity targets.
IREDA	Operates as a non-banking financial entity that projects through loans and credit facilities.
TEDA	Leads state-level RE initiatives, implementing policies, supporting project development, and promoting clean energy adoption in Tamil Nadu.
RBI	Regulates and facilitates green financing by setting policies for priority sector lending, issuing guidelines for sustainable finance, and promoting financial instruments like green bonds to support renewable energy investments.
NIIF	Acts as a sovereign wealth fund, mobilizing domestic and international investments for large-scale infrastructure projects, including renewable energy initiatives, through long-term equity financing.

Tamil Nadu has been at the forefront of India's transition to RE, achieving significant progress in both wind and solar power. The following case studies provide key insights into the state's advancements and expansion in the sector.

13.1 Muppandal Wind Farm – India's Largest Land-Based Wind Energy Project Location: Kanyakumari district
Capacity: Over 1,500 MW

Muppandal Wind Farm was established to harness Tamil Nadu's strong monsoon-driven wind potential. Supported by both public and private investments, the project has significantly reduced dependency on conventional fuels. However, challenges like seasonal fluctuations.

13.2 Kayathar Solar Park – Advancing Renewable Energy Solutions Location: Tuticorin district
Capacity: Around 100 MW

Kayathar Solar Park, developed under Tamil Nadu's Solar Energy Policy and backed by TANGEDCO, plays a vital role in expanding solar power generation in the state. The project highlights the significance of land availability and solar irradiation for feasibility. However, challenges such as grid integration and the financial sustainability of DISCOMs remain key hurdles for long-term growth.

13.3 Kamuthi Solar Power Project – A Massive Solar Energy Hub Location: Ramanathapuram district
Capacity: MW- 648

Developed by Adani Green Energy, the Kamuthi Solar Power Project, a large-scale renewable energy facility, was commissioned in 2016, initiative covering 2,500 acres and featuring over 2.5 million solar panels. However, challenges such as dust accumulation can reduce efficiency, emphasizing the importance of regular maintenance and advanced cleaning solutions to sustain optimal performance.

13.4 Wind-Solar Hybrid Projects – Balancing Clean Energy Generation Location: Various regions, including Coimbatore and Tirunelveli
Tamil Nadu is implementing hybrid renewable energy systems to maximize power generation and maintain a stable electricity supply. By combining wind and solar energy, the state seeks to reduce intermittency challenges and strengthen grid reliability for long-term sustainability.

14. Financial Performance Analysis: Green Finance Instruments and Investment Patterns in Renewable Energy
Tamil Nadu has attracted significant private sector investments due to favorable policies and economic incentives. The state has approved the establishment of biomass gasification-based energy facilities with a combined capacity of 41.2 MW, including various waste-to-energy biogas projects, have been backed by MNRE.

14.1 Green Finance Initiatives
Green Finance in India report highlights Tamil Nadu's efforts in integrating renewables like wind and solar with cleaner natural gas, aiming for a diversified energy mix. The state collaborates with organizations like the United Nations to support renewable energy manufacturing, backed by progressive policies. Green finance instruments play important role in scaling RE projects by providing sustainable financial solutions that support clean energy transition. These instruments help bridge the investment gap, mitigate financial risks.

14.2 Green Finance Initiatives Driving Renewable Energy Growth in Tamil Nadu

Instrument	Description	DATA
Tamil Nadu Green Climate Fund (TNGCF)	Established with a corpus of ₹1,000 crore, the TNGCF is managed by the Tamil Nadu Infrastructure Fund Management Corporation (TNIFMC). It aims to invest in projects related to renewable energy, energy transition, electric mobility, circular economy, and sustainable agriculture.	**Fund Size**: ₹1,000 crore • **Initial Government Commitment**: ₹100 crore • **Fund Tenure**: 10 years, extendable by up to 2 years
	The Tamil Nadu government is considering issuing green bonds to finance sustainable	**Status**: Under consideration
Green Bonds	urban infrastructure projects, including district cooling systems and renewable energy initiatives.	• **Potential Projects:** District cooling systems, renewable energy
CARBON MARKETS	The state is exploring carbon markets to finance green projects, Facilitating the acquisition of carbon credits through carbon emission reductions. These credits can be traded, providing financial incentives for emission reduction projects.	• **Projects Identified:** 7 to 8 potential projects for green credits • **Focus Areas:** Renewable energy, community-based climate initiatives

15. Case Studies on Green Finance Driving Renewable Energy Growth in Tamil Nadu

15.1 Case Study 1: IREDA's Green Energy Fund for Solar Projects

Project: The Indian Renewable Energy Development Agency (IREDA) provided concessional loans under its Green Energy Fund to solar power developers in Tamil Nadu.

Impact: Green finance has been instrumental in supporting the development of the Kamuthi Solar Power Plant, a 648 MW facility. By giving long-term, low-interest loans to developers, green finance made the project financially viable, encouraging large-scale renewable energy investments. Additionally, the plant has significantly reduced reliance on coal-based energy, leading to a reduction of approximately 1.2 million tons of CO_2 emissions annually.

15.2 Case Study 2: TANGEDCO's Green Bonds for Renewable Energy Integration

Project: Tamil Nadu Generation and Distribution Corporation (TANGEDCO) issued Green Bonds to fund RE infrastructure.

Impact: Green finance plays a key role in strengthening Tamil Nadu's transmission network for renewable energy, helping to reduce the curtailment of wind power and ensuring efficient energy distribution. It has also facilitated investments in battery storage solutions, enhancing the reliability of renewable energy by addressing intermittency challenges. Furthermore, these financial initiatives have enabled Tamil Nadu to meet its Renewable Purchase Obligations (RPOs), reinforcing the state's commitment to sustainable energy growth and environmental responsibility.

15.3 Case Study 3: World Bank and ADB Financing for Wind Energy Projects

Project: The World Bank and Asian Development Bank gives monetary support for wind energy projects in Tamil Nadu.

Impact: Green finance has significantly contributed to the expansion of Tamil Nadu's wind energy capacity beyond 10 GW, reinforcing the state's leadership in renewable energy. It has provided both technical and financial assistance for upgrading wind farms and repowering old turbines, enhancing their efficiency and output. Additionally, investments in improved grid integration technology have helped reduce energy losses.

16. Key Roles of Green Finance Instruments

16.1 Facilitating Large-Scale Investments: Green investment bonds, and climate funds provide long-term financing for large-scale renewable energy projects, ensuring their financial viability. They help mobilize institutional and private capital towards sustainable energy infrastructure.

16.2 Reducing Cost of Capital: Concessional financing and subsidies lower borrowing costs, making renewable projects more competitive compared to fossil fuel-based alternatives. Risk mitigation tools, such as credit guarantees, enhance investor confidence and reduce financing risks.

16.3 Encouraging Innovation and Technological Advancement: Green finance supports R&D in new energy technologies like energy storage, smart grids, and hydrogen energy, enabling scalability of renewable energy.

16.4 Enhancing Grid Integration and Infrastructure Development: Investment in hybrid energy systems (wind-solar) and grid modernization ensures better integration of renewable sources, addressing intermittency issues.

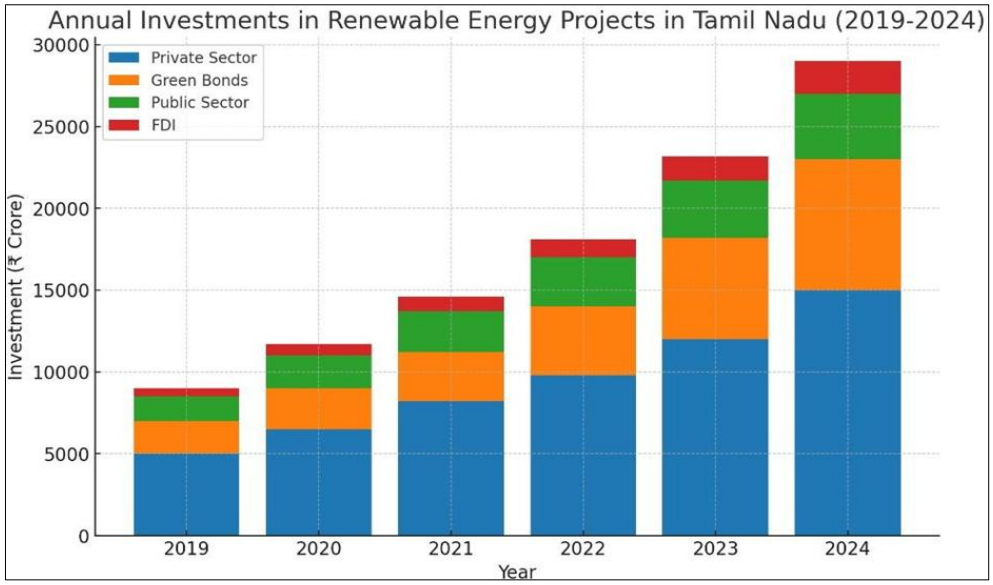
16.5 Meeting Global Climate Commitments: Green finance helps countries achieve their Net Zero and Paris Agreement goals by channeling funds toward clean energy projects and reducing carbon footprints.

16.6 Strengthening Policy Implementation: Governments and financial institutions use green finance instruments to align renewable energy expansion with policy frameworks, ensuring a stable regulatory environment for investors. Green finance instruments serve as a catalyst for scaling renewable energy by ensuring affordable, sustainable, and long-term funding.

17. Annual Investments In Tamil Nadu's Renewable Energy (In ₹ Crore)

Year	Private Sector (Tata, Adani, etc.)	Green Bonds (Govt. of India)	Public Sector (Tangedco, SECI)	Foreign Direct Investment (FDI)	Total Investment
2019	5,000	2,000	1,500	500	9,000
2020	6,500	2,500	2,000	700	11,700
2021	8,200	3,000	2,500	900	14,600
2022	9,800	4,200	3,000	1,100	18,100
2023	12,000	6,186	3,500	1,500	23,186
2024	15,000	8,000	4,000	2,000	29,000

Source: Tamil Nadu Government Energy Reports



Source: Hindu business line

The graph visually represents the contributions from private sector investments, green bonds, public sector investments, and foreign direct investment (FDI) over the years. The graph illustrates how green finance mechanisms and institutional interventions have collectively increased renewable energy investments in Tamil Nadu. By assessing the trends, policymakers can optimize funding strategies to further accelerate sustainable energy development.

18. CONCLUSION

Tamil Nadu has established itself as an important contribution in India's RE landscape, driven by substantial advancements solar-wind power. This study emphasizes the relevance of institutional frameworks and green finance in expanding renewable energy initiatives. Institutions such as MNRE, SECI, IREDA, RBI, TEDA, and NIIF have contributed in policy formulation, financing, and capacity building, facilitating the state's energy transition. The analysis of investment trends demonstrates a consistent increase in renewable energy financing, with private sector participation, green bonds, and foreign direct investments playing crucial roles. The case studies of major wind and solar projects, including Muppandal Wind Farm, Kayathar Solar Park, and Kamuthi Solar Power Project, underline Tamil Nadu's ability to attract large-scale investments. However, challenges persist, such as intermittency issues, grid integration bottlenecks, financial sustainability of DISCOMs, and the need for consistent policy support.

The contribution of green finance instruments, including and concessional loans and green bonds, has been instrumental in reducing the cost of capital, driving large-scale investments, and encouraging technological advancements. However, further strengthening of financing mechanisms and regulatory frameworks is essential to ensure long- term sustainability and investor confidence in the sector.

19. Suggestion

A stable and predictable policy environment is essential for attracting private investments in Tamil Nadu's renewable energy sector. Ensuring consistency and transparency in policies will help minimize investor risks and foster long-term confidence. Strengthening green finance mechanisms is also critical, with the expansion of options such as sovereign green bonds, sustainability-linked loans, and carbon credit markets accelerating renewable energy deployment. Moreover, the integration of smart grid techs and investments in energy storage solutions can help mitigate intermittency issues. Public-private partnerships (PPPs) should be further encouraged, encouraging partnerships among the government, private investors, and international stakeholders to secure additional funding and distribute risks linked to large-scale renewable energy projects. Tamil Nadu must also leverage technological innovations, exploring blockchain for energy

trading, Leveraging AI-driven predictive analytics and smart financing tools can enhance investment strategies and improve efficiency in the renewable energy sector. Additionally, expanding R&D in energy storage, particularly in battery technology and hybrid wind-solar projects, can strengthen energy security while reducing reliance on conventional fuels. Developing inclusive financial models—such as low-interest loans, microfinance initiatives, and targeted subsidies—will empower SMEs and rural communities to actively involve in RE adoption. Scaling up wind-solar hybrid projects will further optimize Tamil Nadu's energy generation, establishing a firm and efficient power flow.

To streamline project approvals, enhance policy implementation, and ensure efficient financial disbursements, institutional coordination among key entities like TEDA, MNRE, RBI, and SECI must be reinforced. Addressing the monetary viability of distribution companies through policy reforms, strategic financial restructuring is also crucial to ensuring prompt payments to RE developers, thereby strengthening investor assurance and long-term project sustainability. By overcoming these challenges and implementing the recommended strategies, Tamil Nadu can reinforce its leadership in India's renewable energy transition and serve as a benchmark for other states aiming to expand their clean energy capacity.

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