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# Energy Transition, Territorial Dynamics, and Economic Growth in the Atsinanana Region: Towards an Integrated Sustainable Development Model

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***Abstract* - The Atsinanana Region, located on the east coast of Madagascar, faces a dual structural challenge : a persistent electricity access deficit that hinders its industrialization, and growing environmental pressure threatening its forest heritage and climate resilience. This article provides an analytical synthesis combining official regional socio-economic, trade, and environmental data (Prefecture of Toamasina, INSTAT, Regional Directorate of Fisheries and Blue Economy) with scientific literature on the energy transition. The study systematically examines the territorial and economic divide in Atsinanana, Madagascar's renewable energy potential, the expected economic impacts of productive electrification, adapted decentralized models, and institutional viability conditions. The empirical diagnosis highlights extreme spatial polarization around Toamasina I, a hyper-tertiarized economy heavily reliant on food imports, and alarming deforestation rates. Furthermore, econometric insights indicate that deploying renewable energy and strengthening local human capital can generate substantial sustainable economic growth. The conclusion advocates for an integrated strategy linking decentralized renewable energy, productive uses (agriculture, fisheries, local processing), blended finance, and participatory governance, rather than a mere linear extension of the national grid.**

***Keywords* -** *Energy Transition, Economic Growth, Atsinanana Region, Mini-Grids, Productive Uses, Energy–Water–Agriculture Nexus.*

## I. INTRODUCTION

Madagascar possesses an exceptional natural heritage, characterized by rich primary forests and mangroves that give the island a major role as a global carbon sink. However, this ecological function is currently threatened by intensifying deforestation, heavy household reliance on wood energy, slash-and-burn agriculture (tavy), and urban sprawl. These anthropogenic pressures reduce the country's carbon sequestration capacity while exacerbating greenhouse gas emissions. Paradoxically, although its contribution to global emissions remains marginal, Madagascar ranks among the countries most vulnerable to climate change : the intensification of cyclones, floods, droughts, and sea-level rise generates significant human, economic, and environmental losses.

Faced with this dual constraint, the Malagasy State aims to reconcile economic development with ecosystem preservation through green, low-carbon, and resilient industrialization. At the heart of this national strategy, the Atsinanana Region emblematically illustrates the tensions between strong geoeconomic potential and persistent energy isolation [1, p. 1098]. Recent scientific literature demonstrates that the energy transition only truly catalyzes economic growth when reliable electricity access is closely linked to productive uses and solid financial institutions [2], [3, p. 101269]. Conversely, electrification limited solely to residential needs yields marginal economic returns when disconnected from agriculture, industry, and household solvency [4, p. 52], [5, p. 34].

This paper evaluates the operational conditions required to transform the energy transition into a genuine lever for territorial development in the Atsinanana Region around five guiding questions: (1) what demographic, economic, and environmental characteristics structure the Atsinanana territory; (2) what macroeconomic and institutional determinants condition the valorization of renewable energies in Madagascar; (3) what indicative and sectoral economic effects can be expected from this energy transition; (4) which electrification models are best suited to the geographical realities of Atsinanana's districts; and (5) what governance and financing levers guarantee the sustainability of these infrastructures?

## II. MATERIALS AND METHODS

This research adopts a mixed methodological approach combining the empirical analysis of official regional statistical data with a systematic review of scientific literature.

### *A. Statistical and Documentary Corpus*

The territorial analysis relies on recent data from decentralized administrations and national statistical agencies: demographic and spatial data from the Prefecture of Toamasina and the National Institute of Statistics (INSTAT / RGPH-2018 and demographic projections up to 2025) [6], [7]; economic and trade data from the Interregional Directorate of INSTAT Toamasina and the Regional Service of INSTAT Atsinanana (Directory of Formal Establishments and Trade and Services Statistics Service, 2021–2025) [8]; and environmental indicators from the Regional Directorate of Fisheries and Blue Economy of Atsinanana (2023–2025)
[9].



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In addition, a systematic review of 36 scientific and institutional references (World Bank, IEA, IRENA, and journals indexed in Scopus and Web of Science published primarily between 2015 and 2026) was conducted using the keywords : "renewable energy", "economic growth", "minigrid", "rural electrification", "productive use of energy", and "Madagascar".

### *B. Selection Criteria and Analytical Approach*

Only studies demonstrating direct thematic relevance, rigorous empirical or econometric grounding, and publication in peer-reviewed journals or recognized international organization reports were retained. The analysis is structured around five axes : (1) structural diagnosis of Atsinanana, (2) determinants of renewables, (3) orders of magnitude of expected economic impacts, (4) decentralized electrification models, and (5) governance and financing conditions.

## III. RESULTS : TERRITORIAL DIAGNOSIS AND TRANSITION LEVERS

### *A. Structural Context of the Atsinanana Region*

Cross-referencing regional indicators highlights three major structural imbalances that condition any energy strategy:

**1) Extreme Spatial and Demographic Divide:** The Atsinanana Region is experiencing sustained demographic growth, with its total population rising from 1.52 million in 2019 to over 1.86 million in 2025 [7]. However, this growth occurs within a deeply polarized territory: the District of Toamasina I concentrates 417,451 inhabitants in 2025 within a cramped area of 28 km² (138 Fokontany), whereas the six peripheral districts (ranging from Mahanoro, the second demographic hub, to Antanambao Manampontsy, the least populated) share 99.8% of the regional territory [6], [7]. Furthermore, regional electricity supply remains heavily concentrated around the Toamasina agglomeration via JIRAMA's interconnected grid, leaving most landlocked rural communes without reliable access despite the hydroelectric potential of the Ivondro basin (notably the structuring Volobe project). This spatial configuration makes conventional extension of the national grid technically complex and financially prohibitive in the hinterland [10, p. 5], [11, p. 110].

**2) Hyper-Tertiarized Economy and Trade Dependence:** The formal economic fabric of Atsinanana totals 25,857 registered establishments, over 80% of which (20,843 structures) are centralized in Toamasina I [8]. The tertiary sector massively dominates with over 18,300 establishments in trade and services, and 4,019 structures in transport and auxiliaries linked to the port hub of Toamasina, absorbing over 87% of formal business creations [8]. Conversely, the secondary sector (food processing, wood, textiles, metals) remains embryonic, and registrations in the primary sector plummeted from 131 units in 2021 to 25 in 2025 [8]. Simultaneously, imports through Toamasina increased by 22% between 2023 and 2025 (from 10,024 to 12,258 billion Ariary), dominated by food products (3,971 billion Ariary for 1.33 million tons in 2025) [8].

**3) Concerning Environmental Vulnerability:** The evolution of regional environmental indicators (Table I) confirms the urgency of substituting wood energy. Although restored land area increased slightly (from 3,850.4 ha in 2023 to 4,141.5 ha in 2025), the annual planting rate declined (2.80 million seedlings in 2025 compared to 3.65 million in 2023), while burned areas surged to 9,104.7 ha in 2024 [9].

**TABLE I. ENVIRONMENTAL INDICATORS OF THE ATSINANANA REGION (2023–2025) [9]**

| Environmental Indicators | 2023 | 2024 | 2025 |
|---|---|---|---|
| Waste treatment centers | 1 | — | — |
| Number of reforested seedlings | 3,654,753 | 3,326,224 | 2,806,924 |
| Restored surface area (ha) | 3,850.4 | 4,058.7 | 4,141.5 |
| Burned surface area (ha) | 6,236.6 | 9,104.7 | — |

### *B. Malagasy Renewable Potential and Deployment Determinants*

Madagascar possesses considerable yet largely underexploited renewable energy potential, characterized by approximately 2,800 hours of sunshine per year and a hydroelectric potential of 7,800 MW [6]. According to economic literature [12, p. 118175], valorizing this potential in Atsinanana depends on four hierarchical determinants: (1) local economic dynamism creating solvent demand; (2) intensity of productive energy use; (3) incentive public policies (feed-in tariffs, targeted subsidies, tax exemptions) correcting market failures [12, p. 118201]; and (4) grid pooling to smooth intermittency.

Conversely, rural habitat dispersion combined with a subsistence economy limits infrastructure absorption capacity. At the macroeconomic level, renewable energy consumption is positively linked to GDP growth [13, p. 3882], green finance, foreign direct investment (FDI) [14, p. 121759], and trade openness [15, p. 383].

### *C. Expected Economic Effects in the Atsinanana Region*

International econometric studies highlight four impact channels (equipment investment, local installation and maintenance jobs, energy security reducing operating losses, and productivity gains) synthesized in Table II. Applied as indicative orders of magnitude to the Atsinanana context, these findings anticipate the following dynamics: • **Direct Impact of Renewable Energies (+3.2% order of magnitude):** Comparative econometric models indicate that a substantial increase in installed renewable capacity generates an average estimated gain of +3.2% on sustainable economic growth through lower marginal costs and substitution of imported hydrocarbons [16]. • **Multiplier Effect of Human Capital (+4.4% order of magnitude):** According to the same empirical literature, joint investments in R&D and local technical training induce an indicative +4.4% increase in sustainable economic performance, underscoring the importance of upskilling in the districts [16].



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- **Effective Adoption (Uptake) Constraints:** In gridcovered areas of Sub-Saharan Africa, effective connection rates often remain below 50% due to upfront costs and low household solvency, while service interruptions penalize businesses [17, p. 25].
- **Leverage Effect of Green Finance and FDI:** Integrating climate finance and FDI significantly increases the share of renewables in the energy mix [18].

**TABLE II. SYNTHESIS OF ECONOMIC CHANNELS AND IMPLICATIONS FOR ATSINANANA**

| Dimension | Empirical Result | Implication for Atsinanana | Ref. |
|---|---|---|---|
| Electricity access | Adoption < 50% without solvency | Couple access and income generation | [17, p. 33] |
| RE Investment | Positive correlation with GDP | Target productive uses | [12, p. 118164] |
| RE Deployment | +3.2% sustainable growth | Valorize solar and hydro potential | [16] |
| R&D / Human Capital | +4.4% sustainable performance | Train local technicians | [16] |
| Green Finance / FDI | Increase in RE share | Mobilize blended finance | [18] |

### *D. Electrification Models and the Energy–Water–Agriculture Nexus*

Given the geographical dispersion of Atsinanana's six rural districts (99.8% of the territory), decentralized solutions (mini-grids and solar-hydroelectric hybrid systems) outperform centralized grid extension [19, p. 17], [20, p. 1631]. While individual solar kits meet basic domestic needs, only mini-grids support community and productive uses. Their viability rests on three institutional factors that outweigh technical equipment quality [5, p. 32], [21], [22, p. 111572]: a tariff model covering operation and renewal, local technical maintenance skills, and transparent governance involving local authorities, operators, and users.

At the sectoral level, productive electrification (motorized irrigation, cold chains for fisheries, agri-food processing) generates a far greater impact than residential use [23], [24, p. 13014]. In Madagascar, where 80% of rural agricultural production relies on smallholders [25], [26, p. 1043], adopting an Energy–Water–Agriculture Nexus approach [27, p. 6], [28] creates a virtuous circle: energy powers irrigation and product preservation, increasing rural incomes, reducing food import dependence, and ensuring solvent electricity demand that makes mini-grids profitable.

## IV. DISCUSSION: TERRITORIAL STRATEGY, FINANCING, AND GOVERNANCE

### *A. A Spatially Differentiated Electrification Strategy*

To address Atsinanana's spatial heterogeneity, three models must be coordinated:

- **Urban and Peri-Urban Zone of Toamasina I:** Strengthening the existing grid, integrating medium-scale renewable power plants (and connecting to major regional hydroelectric projects), and supporting green industrialization in processing activities (agri-food, wood, materials). • **Dense Rural Areas and District Capitals (e.g., Mahanoro, Brickaville, Vatomandry):** Priority deployment of hybrid solar mini-grids coupled with cold storage units (fisheries and agriculture) and small-scale processing.
- **Landlocked, Very Low-Density Areas (e.g., Antanambao Manampontsy, Marolambo):** Dissemination of off-grid solar systems accompanied by entrepreneurial support for local micro-activities.

### *B. Financial Engineering and Human Capital Strengthening*

Financing this transition requires a blended financial architecture combining official development assistance, climate funds (green finance) valorizing Madagascar's role as a carbon sink [29], public-private partnerships (PPPs) absorbing initial risk, and FDI directed toward green industrialization [30], [31, p. 109001]. Concurrently, establishing skills transfer partnerships and technical training in the districts is essential to prevent premature infrastructure obsolescence [32, p. 121], [33, p. 77].

### *C. Governance Conditionality and Territorial Roadmap*

The effectiveness of energy policies depends directly on governance quality [34, p. 101409], [35]. In Atsinanana, this entails transparent tendering and concession procedures, citizen oversight of operators, intersectoral coordination (energy, agriculture, fisheries, environment), and strengthening local administrative capacities [36, p. 9]. Developing a prioritized energy roadmap with measurable indicators will align investments with the actual needs of rural populations.

## V. CONCLUSION

The energy transition represents a major lever for structural transformation in the Atsinanana Region. By harnessing Madagascar's solar (2,800 hours/year) and hydroelectric (7,800 MW) potential through adapted decentralized systems, the region can simultaneously curb wood-energy deforestation, modernize its agriculture and fisheries, and reduce its dependence on food imports.

Three priority operational recommendations emerge: (1) systematically integrate energy infrastructures with productive uses following an Energy–Water–Agriculture Nexus approach; (2) deploy a regional blended finance mechanism mobilizing public capital, green funds, and the private sector; and (3) institutionalize local technical training and transparent governance to ensure infrastructure sustainability.

## DECLARATION STATEMENT

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**Data Availability:** The statistical data supporting the findings of this study are available from INSTAT Madagascar, the Prefecture of Toamasina, and the Regional Directorate of Fisheries and Blue Economy of Atsinanana upon reasonable request.

**Author Contributions:** All authors contributed equally to the conceptualization, methodology, data analysis, and writing of the manuscript.

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