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Towards the Expansion of Energy Transition in Mali: Issues, Challenges, and Perspectives

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Abstract- This study analyzes the dynamics and challenges of the energy transition in Mali, a country endowed with significant potential in renewable energy (solar, hydro, biomass). Access to reliable and sustainable energy remains a major issue for a large part of the population. The methodology relies on an economic and descriptive statistical analysis of data collected between 2010 and 2023. Sources include reports from the World Bank, the IEA, the Malian Ministry of Energy, as well as a critical review of energy policies. The study focuses on investments, installed capacities, electrification rates, and regional interconnection projects. The results reveal a significant expansion of renewable energy infrastructures between 2010 and 2023. The installed capacity of photovoltaic solar energy increased by 1,900%, while hydro capacity progressed by 180%, notably due to the Gouina dam. Energy storage capacities and hybrid power plants also experienced notable growth, with respective increases of 300% and 400%. This diversification of the energy mix has led to a 400% reduction in CO₂ emissions

related to electricity over the same period. However, major challenges persist. The national electrification rate, which rose from 32.5% to 50.6%, masks marked territorial inequalities (78% in urban areas compared to 18% in rural areas). Financial constraints, a lack of transportation and storage infrastructure remain significant barriers, as well as the need for increased geostrategic cooperation. To overcome these obstacles, we propose several solutions: strengthening research and public policies to attract private investments; developing new renewable energy power plants and hybrid systems; modernizing transportation networks using innovative technologies; and consolidating regional cooperation through the interconnection of electrical networks. This research underscores that the energy transition in Mali is both an opportunity for sustainable development and a challenge that requires an integrated approach to ensure socio-economic prosperity and climate resilience.

Keywords: energy transition, renewable energy, access, climate resilience, energy policies.

Introduction

The energy transition, defined as the structural transformation of energy systems aimed at gradually replacing fossil fuels with renewable and sustainable sources (IPCC, 2022), is now a global imperative in the face of the climate emergency and the depletion of non-renewable resources (IEA, 2021). In developing countries, this transition is of strategic importance, as it conditions both energy security, socio-economic development, and the mitigation of the effects of climate change (UNDP, 2020). Mali, a landlocked Sahelian country, perfectly illustrates this issue, with specific challenges related to its energy dependence, low electrification rate, and underexploited potential in renewable resources.

The energy transition is a critical issue for Mali. Although the country has abundant solar (57 kWh/m²/day) and hydroelectric (1,000 MW) potential, its rural electrification rate (18%) remains alarming (World Bank, 2022), and a significant availability of biomass (PERC, 2023) is underexploited, hindering its socio-economic development. The country has abundant energy potential, particularly in optimal renewable and hybrid energies, but its optimal exploitation requires strategic investments and partnerships to ensure reliable access to energy, strengthen climate resilience, stimulate economic growth, and improve the well-being of the population.

Period from 2010 to 2023, 2010 marks a turning point with the adoption of more ambitious energy policies in West Africa.

Mali has a national electrification rate of only 50.6% (World Bank, 2022), with stark disparities between urban (78%) and rural (18%) areas. This energy insecurity hinders industrial development, limits access to basic services, and perpetuates poverty (UNDP, 2021). An inclusive energy transition could thus be a major lever for achieving the Sustainable Development Goals (SDGs), particularly SDG 7 (clean energy), SDG 13 (climate action), and SDG 10 (reduced inequalities). The government of Mali is now considering increasing the hybridization of its mini-grids by adding photovoltaic capacity to diesel power plants. However, this energy transition faces multidimensional obstacles. On the structural front, infrastructural gaps, insufficient investments (less than 15% of climate financing allocated to sub-Saharan Africa; AFD, 2023), and regulatory weaknesses hinder its deployment. On the socio-economic front, technological barriers, cultural resistance, and political instability exacerbated by security crises in the northern and central regions complicate the implementation of sustainable projects (OECD, 2023).

This study aims to analyze the structural and socio-economic obstacles to this energy transition, drawing on data collected between 2010 and 2023. Our theoretical framework intersects the concepts of energy justice (Sovacool & Dworkin, 2015) and resilience (IRENA, 2022), offering an innovative approach for the Sahelian context.

The originality of this study lies in its holistic approach, integrating a critical analysis of the technical, economic, and geopolitical challenges specific to the Malian context. Through a systematic review of national energy policies from the Mali 2030 Energy and Water Sector Master Plan (PDSEEM 2030), sectoral data, and international best practices, this research aims to assess the current state of energy transition in Mali by analyzing current dynamics, implemented policies, and achieved results between 2010 and 2023. What are the progress and limitations of Malian energy policies in terms of transitioning to renewable energy between 2010 and 2023?

Increased investments in renewable energies (solar, hydro, hybrid) could increase electricity production by 30 to 50% and reduce carbon emissions by 10 to 20% by 2030. This analysis is based on a theoretical framework that combines the concepts of energy justice (Sovacool and Dworkin, 2015) and energy system resilience (IRENA, 2022), thus offering an innovative contribution to the debates on the energy future of sub-Saharan Africa.

Methodological

The data comes from reports by the World Bank, the IEA, and the Malian Ministry of Energy (2010-2023), analyzed through descriptive statistics and a critical review of policies. The study is exploratory/descriptive. Electrification rates and CO₂ emissions were selected to measure the socio-environmental impact.

The following section presents the theoretical framework and the literature review.

I. Theoretical framework and literature review

1. Theoretical framework

The energy transition, defined as a structural transformation of energy systems aimed at replacing fossil fuels with renewable and sustainable sources (IPCC, 2022), falls within a multidisciplinary theoretical framework integrating economic, environmental, and social concepts. This section articulates the theoretical foundations of the energy transition, focusing on approaches to energy justice (Sovacool &

Dworkin, 2015) and the resilience of energy systems (IRENA, 2022), while examining the specific dynamics of the Malian context.

1.1. Theoretical foundations of the energy transition

1.1.1. Theory of energy justice

" Energy justice, according to Sovacool and Dworkin (2015), includes three dimensions: distributive (equitable access to energy resources), procedural (inclusion of populations in decision-making processes), and recognized (respect for local rights and cultures).

In Mali, urban-rural disparities (electrification rate of 78% in cities versus 18% in rural areas, World Bank, 2022) illustrate the challenges of distributive justice. Energy policies must therefore integrate these inequalities for an inclusive transition (UNDP, 2020).

1.1.2. Resilience of energy systems

Energy resilience, as defined by IRENA (2022), involves the ability of a system to absorb shocks (climatic, economic) and maintain a stable supply. Mali, faced with climate challenges (droughts) and geopolitical challenges (Sahelian instability), must strengthen its infrastructure and diversify its energy sources (solar, hydroelectric, hybrid) to ensure its resilience (OECD, 2023).

1.1.3. Development economics and energy transition

Development theories (World Bank, 2022) highlight the key role of energy in economic growth. A successful transition could increase the energy sector's contribution to GDP (from 5% in 2010 to 8% in 2023, INSTAT Mali) and create jobs (5,000 jobs in renewable energy sectors in 2023, ILO).

2. Literature review on the challenges and issues of energy transition in Mali

This literature review examines the main issues and challenges of the energy transition in Mali based on recent data and analyses.

2.1. Energy potential and recent advances

Mali has significant energy potential, but it is still largely underexploited. The country enjoys high sunshine, with an estimated potential of between 5 and 7 kWh/m²/day (PERC, 2023). The national hydroelectric potential is estimated at around 1,000 MW. The installed capacity has seen a notable increase, particularly with the Gouina dam (140 MW in 2023).

Biomass is available, but its utilization remains limited and underused in the national energy mix. Recent advancements demonstrate a dynamic of transition. Solar capacity has significantly advanced, increasing from 5 MW in 2010 to 100 MW in 2023 (IRENA, 2023). Moreover, energy dependence on oil has decreased, dropping from 85% to 70% between 2010 and 2023 (IEA, 2023).

2.2. Major obstacles to the transition

Academic literature and institutional reports identify several structural obstacles that hinder the energy transition. The electricity transmission and distribution networks are often outdated. The lack of storage capacity is also a challenge, with only 200 MWh recorded in 2023 (African Development Bank, 2023). Mali, like many sub-Saharan African countries, faces a funding deficit. Less than 15% of global climate financing is allocated to this region (AFD, 2023). The weaknesses of regulatory frameworks and governance issues are risk factors for investments (UNDP, 2021).

2.3. Solutions and perspectives

Existing studies offer avenues to overcome these challenges. Regional partnerships to strengthen energy interconnections, particularly through the West African Power Pool (WAPP), are a promising solution. The number of interconnection projects increased from 2 in 2010 to 5 in 2023 (WAPP, 2023). The implementation of incentive-based fiscal and regulatory policies is essential to attract private investors (World Bank, 2023).

2.4. Conceptual framework and contribution of the study

This research is based on a conceptual framework that integrates several dimensions: energy justice to assess equitable access, resilience to analyze the sustainability of the system, and development economics to measure socio-economic impacts.

The energy transition in Mali is both a development opportunity and a multidimensional challenge. Previous studies highlight the importance of an integrated approach. This study contributes to this discussion by updating the data for the period 2010-2023 and proposing new avenues to accelerate the transition.

II. Presentation of Results

According to the study results, Malian energy policies have progressed between 2010 and 2023, but challenges persist in terms of energy transition.

1. Access to energy in Mali

Access to energy in Mali has seen notable progress between 2010 and 2023, although disparities persist, particularly in terms of electrification and access to energy sources for cooking. The national electrification rate has significantly improved, rising from 32.5% in 2010 to 50.6% in 2023. However, this national average masks deep territorial inequalities. In 2023, the electrification rate in urban areas stood at 78%, while it was only 18% in rural areas. This gap highlights a major challenge in equitable access to energy. Access to clean and reliable energy sources for cooking remains a critical issue. The proportion of the population using these sources has only slightly increased, from 3% in 2010 to 5% in 2023. This low percentage highlights gaps in public policies aimed at ensuring universal access to cooking energy, and suggests a persistent reliance on traditional energies such as firewood.

Mali's dependence on oil has been reduced during the period. It decreased from 85% to 70% between 2010 and 2023. This decrease, although positive, reflects an ongoing energy diversification. However, it remains insufficient to achieve a sustainable energy transition and resilience against fluctuations in international hydrocarbon markets. The following table presents energy access in Mali over the period 2010-2023.

Table 1: Access to energy

Indicators	Unité	Année 2010		Année 2023	
		Level	Sources*	Level	Sources**
National electrification rate	%	32,5	World Bank , AIE	50,6	World Bank , AIE
Urban electrification rate	%	55	EDMSa, AMADER	78	DMSa AMADER
Rural electrification rate	%	12	AMADER, PNUD	18	AMADER, PNUD
Share of the population with access to reliable energy sources for cooking	%	3	OMS, IEA	5% en 2020	OMS, IEA
Energy dependence (oil)	%	85	Ministry of Energy of Mali , AIE	70 (2023)	Ministry of Energy of Mali , AIE

Note: *(2011); ** (2023)

Source: Developed by the authors

2. Evolution of installed energy capacity

From 2010 to 2023, Mali experienced a notable growth in its energy production capacities, with a diversification of the energy mix. The installed capacity of photovoltaic solar energy has progressed exponentially, increasing from 5 MW to 100 MW. This represents an increase of 1900% over this period. The capacity of hydroelectric energy has also increased significantly, from 50 MW to 140 MW, an increase of 180%. This increase is mainly due to the commissioning of major infrastructures, such as the Gouina dam.

The storage capacity has quadrupled, increasing from 50 MWh to 200 MWh. This represents a 300% increase. The capacity of hybrid systems has seen a significant expansion, increasing from 10 MW to 50 MW, a 400% increase. Unlike other sources, thermal capacity experienced a more moderate growth of 33.33% over the same period. The number of completed energy infrastructure projects has tripled, going from 5 to 15. Although this progress is positive, the number of projects remains insufficient to meet the country's growing energy needs. The following table presents the capacity of the energy systems.

Table 2: Capacity of energy systems

Indicators	Unity	2010		2023	
		Level	Sources*	Level	Sources**
Installed capacity of photovoltaic solar	MW	5	IRENA, Ministry of Energy of Mali	100	IRENA, Ministry of Energy of Mali
Installed thermal capacity	MW	300	EDMSa, AMADER	400	EDMSa, AMADER
Installed hydraulic capacity	MW	50	OMVS, African Development Bank, Regional Projects	140 (Gouina , 2023)	OMVS, African Development Bank
Hybrid installed capacity	MW	10	AMADER, PNUD	50	AMADER, PNUD
Energy storage capacity	MWh	50	African Development Bank, Regional Projects	200	African Development Bank, Regional Projects
Infrastructure projects completed	Number	5	Ministry of Energy , PNUD	15	Ministry of Energy PNUD
Ongoing infrastructure projects	Number	3	Ministry of Energy CEDEAO	10	Ministry of Energy , CEDEAO

Note: *(2011); ** (2023)

Source: Developed by the authors

3. Economic and environmental impact

The reduction of CO2 emissions related to electricity increased from 100,000 tons in 2010 to 500,000 tons in 2023. Over the period 2010-2023, the reduction of CO2 emissions related to electricity has overall increased by 400%. The average cost of kWh for households has decreased from 250 FCFA to 150 FCFA, while for businesses, it has decreased from 350 FCFA to 200 FCFA. The energy sector saw its contribution to GDP increase from 5% in 2010 to 8% in 2023. The number of jobs created in the renewable energy sectors has quintupled, going from 1,000 in 2010 to 5,000 in 2023. The following table shows the economic and environmental impact.

Table 3: Economic and environmental impact

Indicators	Unity	Year 2010		Year 2023	
		Level	Sources*	Level	Sources**
Evolution of the amount of CO2 emissions avoided related to electricity	Tonnes	100 000	Ministry of the Environment, AIE	500000	Ministry of the Environment, AIE
Average cost of KWh for households	F CFA	250	EDM-SA, GIZ	150	EDM-SA, GIZ
Average cost of KWh for businesses	FCFA	350	EDM-SA, GIZ	200	EDM-SA, GIZ
Contribution of the energy sector to GDP	%	5	INSTAT Mali, World Bank	8	INSTAT Mali, World Bank
Jobs created in the renewable sectors	Number	1 000	OIT, Ministry of Energy	5 000	OIT, Ministry of Energy

Note: *(2011); ** (2023)

Source: Developed by the authors

4. Regional Cooperation and Integration

The number of regional interconnection projects with ECOWAS has increased from 2 to 5. Mali has increased its integration rate in the regional electricity market, rising from 10% to 25%. The funds mobilized for the energy transition have increased, rising from 50 million US dollars in 2010 to 300 million in 2023.

Table 4: Regional Cooperation and Integration

Indicators	Unity	Year 2010		Year 2023	
		Level	Sources*	Level	Sources**
Regional interconnection projects with CEDEAO	Number	2	WAPP, CEDEAO	5	WAPP (2023), CEDEAO (2023)
Regional interconnection projects with OMVS	Number	1	WAPP, OMVS	3	WAPP, OMVS
Regional interconnection projects with WAPP	Number	1	WAPP, CEDEAO	4	WAPP, CEDEAO (2023)
Rate of Mali's integration into the regional electricity market	%	10	ECREEE, UEMOA	25	ECREEE, UEMOA
Financing mobilized for the energy transition	Millions of USD	50	BAD, UE, World Bank	300	BAD, UE, World Bank

Note: *(2011); ** (2023)

Source: Developed by the authors

III. Discussions

However, disparities persist between urban (78%) and rural (18%) areas, highlighting a major issue of energy justice (Sovacool & Dworkin, 2015). Mali has increased its installed capacities, notably in photovoltaic solar (5 MW to 100 MW) and hydroelectric (50 MW to 140 MW with the Gouina dam). However, the storage capacity (200 MWh in 2023) remains limited, hindering the integration of intermittent energies. The increase in infrastructure projects (from 5 to 15 completed) demonstrates efforts, but their number remains low compared to the needs.

The energy transition has generated economic and environmental benefits.

The contribution of the energy sector to GDP increased from 5% to 8%, creating 5,000 jobs in renewable energy sectors and reducing CO₂ emissions (from 100,000 to 500,000 tons), although marginal on a global scale. However, the cost of kWh remains high for households at 150 FCFA and for businesses at 200 FCFA, reflecting financial accessibility challenges.

Mali has strengthened its integration through interconnection projects (2 to 5 with ECOWAS) and an increase in mobilized financing (50 to 300 million USD). The rate of integration into the regional market (25%) remains modest but shows a positive dynamic for energy security.

Our results align with those of IRENA (2022) on the key role of hybrid mini-grids in rural areas. The results call for more ambitious policies to achieve SDGs 7 and 13, in alignment with the theoretical frameworks of energy justice and resilience (IRENA, 2022).

The reduction of CO₂ emissions (500,000 tons in 2023) partially validates H1, but remains insufficient to meet the targets of the Paris Agreement (IPCC, 2022).

Conclusion

This study analyzed the trajectory of the energy transition in Mali over the period 2010-2023, evaluating its progress, challenges, and contribution to the Sustainable Development Goals (SDGs). The results reveal a positive dynamic, particularly in terms of developing renewable energy production capacities, while highlighting the persistence of significant gaps.

The analyzed data shows significant progress in the development of renewable energies and access to electricity. Between 2010 and 2023, Mali achieved a remarkable expansion of its renewable energy infrastructure. The installed capacity of photovoltaic solar power has increased by 19 times (an increase of 1,900%), and that of hydropower has increased by 180%, notably thanks to projects such as the Gouina Dam. Energy storage capacities and hybrid power plants have also experienced notable growth, increasing by 300% and 400% respectively.

This diversification of the energy mix has led to a decrease in CO₂ emissions related to electricity production, which have been reduced by 400% over the same period. The national electrification rate increased from 32.5% in 2010 to 50.6% in 2023, which represents a notable improvement in energy access for the Malian population.

Despite these advancements, major structural challenges persist and compromise the full achievement of SDG 7. Disparities between urban and rural areas remain a central obstacle. In 2023, the electrification rate reached 78% in urban areas, compared to only 18% in rural areas. This inequality highlights an inequitable access to energy infrastructure. Challenges such as insufficient network infrastructure, financial constraints, and vulnerability to external shocks hinder a faster and more equitable expansion of the energy transition.

To overcome these obstacles and accelerate a more inclusive and sustainable energy transition, the study proposes several solutions:

- Innovate the model: the hybridization of mini-grids, combining for example solar and thermal, is a solution to electrify isolated areas.
- Strengthen research and innovation: prioritize support for research centers specializing in microgrids and off-grid energy solutions. These technologies are essential to meet the specific needs of rural and isolated areas.
- Modernize infrastructure: public policies must direct investments towards hybrid power plants integrating energy storage capabilities. At the same time, modernizing existing distribution networks is imperative to improve reliability and efficiency.
 - Implement territorial equity policies: Targeted subsidy and financial incentive policies must be implemented for rural communities to reduce the energy gap and ensure equitable access to electricity.
- Amplify international and regional cooperation: It is crucial to strengthen partnerships with neighboring countries and regional organizations. The mutualization of infrastructure project costs and the exchange of best practices can optimize investments and accelerate the deployment of technologies. By combining an integrated geo-political approach that combines social justice, technological innovation, and international cooperation, Mali will not only be able to capitalize on its progress but also address persistent challenges and fully align with global sustainable energy goals.

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