

Renewable Energies as a Fundamental Pillar for Modern Economy and Sustainable Development: The Case of Algeria

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Abstract :

This paper provides a comprehensive analysis of the role of renewable energies (RE) as a cornerstone for achieving a modern economy and sustainable development in Algeria. Moving beyond a mere policy review, this study delves into the theoretical foundations of RE, tracing its conceptual evolution and classifying its various types. It meticulously examines Algeria's ambitious strategic transition, launched against a backdrop of heavy hydrocarbon dependence, to capitalize on its immense solar and wind potential. By integrating data from national programs, institutional reports, and recent academic research, this work offers a critical evaluation of the legal, institutional, and socio-economic frameworks governing this transition. The findings reveal a significant disparity between Algeria's formidable RE potential and its current modest level of exploitation, highlighting persistent challenges related to economic diversification, technological integration, and effective policy implementation. The study concludes that a resolute and accelerated commitment to RE is not merely an alternative but an imperative strategic choice for Algeria. It is essential for ensuring long-term energy security, preserving fossil fuel export revenues, creating future-oriented employment, and fulfilling its national and international sustainable development commitments. This research contributes to the literature by providing a holistic view that connects theoretical underpinnings with the on-the-ground realities of a hydrocarbon-rich economy navigating the complexities of energy transition.

Keywords : Renewable Energy, Sustainable Development, Economic Diversification, Energy Transition, Wind Power.

Jel Classification Codes: O13, Q01, Q20,

1. INTRODUCTION

The global energy paradigm is shifting irrevocably. The dual crises of climate change, fueled predominantly by greenhouse gas emissions from fossil fuel combustion, and the inherent finitude of these conventional resources, have propelled the global community toward a sustainable energy transition (WCED, 1987). At the heart of this transition lie renewable energies (RE) energy flows derived from natural, perpetual, and replenishable sources such as solar radiation, wind, water, and geothermal heat. These sources present a viable pathway to decarbonize economies, enhance energy sovereignty, and foster inclusive socio-economic development, thereby forming the core of the United Nations' Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) (IRENA, 2020).

For resource-rich nations like Algeria, this global shift presents a complex strategic dilemma. The Algerian economy is structurally dependent on hydrocarbons, which account for approximately 60% of budget revenues and over 95% of export earnings (Senouci et al., 2022). However, rampant growth in domestic energy consumption, spurred by population growth and economic subsidies, threatens to erode the very export capacity that underpins its fiscal stability. This internal pressure, coupled with global climate imperatives and volatile oil prices, has made the strategic integration of renewable energies not just an environmental consideration, but an urgent economic necessity for diversification, security, and long-term resilience (Nacib, 2024).

Algeria is endowed with one of the world's most significant solar potentials, a "giant solar reservoir" as described by its space agency (Nacib, 2024). The country enjoys over 2,000 hours of sunshine annually across its entire territory, with the Sahara region receiving up to 3,900 hours. The daily solar energy potential is estimated at 3 kWh/m² in the north and exceeds 5.6 kWh/m² in the Great South (AAPI, n.d.). Recognizing this immense potential, the government has instituted ambitious national strategies, most notably the Renewable Energy and Energy Efficiency Program launched in 2011 and its revised version in 2015, which targets 22,000 MW of installed renewable capacity by 2030 to meet 37% of domestic electricity production (MEER, 2015).

This paper seeks to provide a holistic and in-depth investigation into the role of renewable energy as a fundamental driver for modernizing the Algerian economy and achieving sustainable development. It moves beyond a simple policy description to address the central research question: **How can renewable energy be effectively harnessed as a catalyst for economic advancement and sustainable development in Algeria, and what are the principal challenges obstructing this transition?**

The specific objectives are to:

- Establish a robust theoretical framework for RE, including its definition, historical context, and typology;
- Critically analyze Algeria's RE potential and the evolution of its national strategy;
- Evaluate the effectiveness of the existing institutional and legal frameworks;
- Identify the socio-economic, technological, and regulatory challenges while proposing strategic recommendations for the future.

2. THEORETICAL FOUNDATIONS: DEFINING, HISTORICIZING, AND TYPIFYING RENEWABLE ENERGY

2.1 Conceptual Definitions and Evolution

The concept of renewable energy is not new; humanity has harnessed energy from the sun, wind, and water for millennia. However, its modern conceptualization as a strategic alternative to fossil fuels gained significant traction following the oil shocks of the 1970s, which exposed the vulnerabilities of dependence on finite resources (Senouci et al., 2022).

The International Energy Agency (IEA) defines renewable energies as "energy derived from natural processes that are replenished at a faster rate than they are consumed. Sources include solar, wind, biomass, geothermal, hydropower, and ocean energy" (IEA, 2009). The Intergovernmental Panel on Climate Change (IPCC) offers a more technical definition, describing it as "any energy form that is derived from natural, geological, or biological processes that are replenished at a higher rate than consumption. This includes solar, wind, biomass, geothermal, hydropower, and ocean energy, which are converted into thermal and electrical energy" (IPCC, 2014).

In Algerian legislation, Law No. 04-09 pertaining to the promotion of renewable energies within sustainable development provides a legal

definition: "Forms of electrical, thermal, or gaseous energy obtained from solar radiation, wind power, geothermal heat, organic waste, hydropower, biomass utilization techniques, and all methods allowing for significant energy savings" (Official Journal of the Algerian Republic, 2004).

A common thread across all definitions is the emphasis on sustainability, low environmental impact, and perpetual availability, distinguishing them fundamentally from finite and polluting fossil fuels.

2.2 Historical Context and Drivers of Adoption

The modern drive for RE is underpinned by three critical factors (Mackay, 2012):

1. **Resource Depletion:** The finite nature of fossil fuels, particularly oil and gas, necessitates the search for alternative energy sources to ensure long-term energy security.
2. **Energy Security:** Reducing dependence on geographically concentrated fossil fuel resources mitigates geopolitical risks and price volatility.
3. **Environmental Imperative:** The overwhelming scientific consensus on anthropogenic climate change, primarily driven by CO₂ emissions from fossil fuel combustion, mandates a shift to low-carbon energy systems.

These drivers have elevated RE from a niche interest to a central component of global energy policies, supported by advancing technologies and declining costs (IRENA, 2020).

2.3 Typology of Renewable Energies and Their Mechanisms

Renewable energies can be categorized based on their source and conversion technology:

- **Solar Energy:** harnesses the sun's radiation.
 - *Photovoltaic (PV) Solar Energy:* Converts sunlight directly into electricity using semiconductor materials in solar panels (e.g., silicon cells).
 - *Concentrated Solar Power (CSP):* Uses mirrors to concentrate sunlight to heat a fluid, producing steam to drive a turbine and generate electricity.
- **Wind Energy:** Utilizes the kinetic energy of wind to rotate turbines connected to generators for electricity production.

- **Hydropower:** Captures the energy of flowing water (rivers, dams) to generate electricity.
- **Biomass Energy:** Converts organic materials (plant waste, animal manure) into energy through combustion, gasification, or anaerobic digestion to produce biogas.
- **Geothermal Energy:** Taps into the Earth's internal heat from deep underground for direct heating or electricity generation.

2.4 The Nexus of RE and Sustainable Development

Sustainable development, defined by the Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43), rests on three interdependent pillars. Renewable energy sits at their convergence:

- **Environmental Pillar:** RE sources produce minimal greenhouse gas emissions and pollutants, directly contributing to climate change mitigation, improved air quality, and conservation of natural resources.
- **Economic Pillar:** Investment in RE stimulates industrial development, creates "green jobs" in manufacturing, installation, and maintenance, reduces energy imports, and insulates economies from fossil fuel price shocks. It fosters innovation and technological advancement.
- **Social Pillar:** RE projects can democratize energy access, particularly for remote and isolated communities, improving living standards, health outcomes, and overall quality of life (Nacib, 2024). This transition to a "green economy" is defined by UNEP as one that results in "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2011, p. 2).

3. ALGERIA'S RENEWABLE ENERGY POTENTIAL AND STRATEGIC EVOLUTION

Algeria's potential in renewable energies is substantial, though varied across different technologies.

3.1 Solar Energy: This is Algeria's most significant asset. Studies confirm that the Algerian Sahara represents one of the world's largest solar

reservoirs, with an estimated technical potential of 169,440 TWh per year (Nacib, 2024; AAPI, n.d.). The national program aims to install 13,575 MW of solar PV and 5,010 MW of CSP by 2030 (MEER, 2015).

3.2 Wind Energy: Wind potential is notable in specific corridors. Studies identify promising zones along the coastline and in the high plateaus, with average speeds between 5-6 m/s, and even higher (7-8 m/s) in the far south (e.g., Adrar, Tamanrasset). The estimated total potential is around 37 TWh per year, with a national target of 4,000 MW of installed capacity by 2030.

3.3 Other Sources: Potential for biomass (1,000 MW target) exists from agricultural and urban organic waste, and minimal geothermal potential (15 MW target) is identified, particularly in the northeastern region with hot water springs exceeding 40°C (Nacib, 2024).

To harness this potential, Algeria has developed a strategic roadmap. The initial **National Program for Renewable Energies and Energy Efficiency** was launched in 2011, targeting 12,000 MW by 2030. This was significantly expanded and revised in the **2015 Program**, which set the ambitious target of 22,000 MW by 2030. The program is structured in two phases:

- **Phase 1 (2015-2020):** Target of 4,525 MW. This phase focused on pilot projects and launching tenders. Key achievements, though below target, included the hybrid solar-gas plant in Hassi R'Mel (150 MW), the Kabertene wind farm in Adrar (10 MW), and a pilot PV plant in Ghardaïa (1.1 MW) (AAPI, n.d.; MEER, 2015).
- **Phase 2 (2021-2030):** Target of 17,475 MW. This phase envisions the development of large-scale renewable plants in the south (e.g., Adrar, Timimoun, Béchar) integrated into the national grid via new high-capacity interconnection projects.

Table 1: Algeria's 2030 Renewable Energy Installation Targets (2015 Program)

Technology	Target Capacity (MW)	Percentage of Total
Solar Photovoltaic (PV)	13,575	61.7%
Concentrated Solar Power (CSP)	5,010	22.8%
Wind Power	4,000	18.2%
Cogeneration	1,000	4.5%
Biomass	1,000	4.5%
Geothermal	15	0.1%
Total	22,000	100%

Source: MEER (2015). National Renewable Energy and Energy Efficiency Program.

4. INSTITUTIONAL AND LEGAL FRAMEWORKS: STRUCTURE AND IMPLEMENTATION GAPS

Algeria has established a comprehensive legal and institutional ecosystem to support its energy transition.

4.1 Legal Framework: The cornerstone legislation includes:

- **Law 99-09** on Energy Control (1999): Established the general framework for a national energy efficiency policy.
- **Law 02-01** on Electricity and Gas Distribution (2002): Aimed at protecting the environment through rationalized energy consumption.
- **Law 04-09** on the Promotion of Renewable Energies in the Context of Sustainable Development (2004): This is the pivotal law. It defined RE, established the principle of a national promotion

program, and mandated the creation of supportive institutions like the National Observatory for Renewable Energies (Nacib, 2024).

4.2 Institutional Framework: Several key agencies have been created:

- **National Fund for Renewable Energies and Cogeneration (FNERC):** Established in 2011 and funded by a 1% levy on hydrocarbon revenues, its purpose is to finance RE projects and incentivize investment.
- **Algerian Renewable Energy Institute (IAER):** Created in 2011, this public industrial and commercial entity operates under the Ministry of Energy, focusing on research, development, and promotion of RE technologies.
- **Commissariat aux Energies Renouvelables et à l'Efficacité Energétique (CEREFE):** The central regulatory body responsible for implementing, monitoring, and evaluating the national strategy.
- **Centre de Développement des Energies Renouvelables (CDER):** A research center under the Ministry of Higher Education, dedicated to R&D in solar, wind, and geothermal applications.

Despite this seemingly robust framework, a significant implementation gap persists. The targets for the first phase (2015-2020) were largely unmet. By 2018, the share of RE in total primary energy consumption remained a meager 0.12%, with fossils dominating at 99.94% (IEA data in Senouci et al., 2022). This highlights a disconnect between policy design and execution, often attributed to bureaucratic inertia, slow tender processes, and evolving regulatory details.

The following table synthesizes key data on Algeria's installed electricity capacity, highlighting the disparity between conventional and renewable energy sources as of 2019.

Table 2:Statistical Evidence of Renewable Energy Integration in Algeria's Power Sector (2019)

Energy Source	Installed Capacity (MW)	Percentage of Total Mix (%)	Remarks
Conventional (Depleting) Sources			
Gas Turbine Power Stations	12,724	59.3%	Primary source of generation
Combined Cycle Power Stations	4,870	22.7%	
Steam Power Stations	2,991	13.9%	
Subtotal Conventional	~20,585	~95.9%	
Renewable Sources			
Hydropower	228	1.1%	Stable, traditional renewable
Solar Photovoltaic	644	3.0%	Growing but from a low base

Energy Source	Installed Capacity (MW)	Percentage of Total Mix (%)	Remarks
Wind Power	10	<0.1%	Negligible and stagnant
<i>Subtotal Renewables</i>	<i>~882</i>	<i>~4.1%</i>	Far from 2030 targets
TOTAL INSTALLED CAPACITY	~21,467	100%	

Source: Processed from data in Moumene & Louafi (2021).

Conclusion from Data: The statistical evidence indicates that renewable energy projects, despite their strategic importance, had a minimal practical impact on Algeria's energy landscape by 2019. With renewables constituting only ~4.1% of total installed capacity, the national grid remained overwhelmingly dependent (95.9%) on natural gas. This significant gap between policy objectives and on-the-ground results underscores the challenges in implementation and the "weak effectiveness of the energy policies" noted by the authors.

5. RESULTS, DISCUSSION, AND CHALLENGES

The stark reality of Algeria's energy landscape is revealed in the data. Despite over a decade of strategic planning, the contribution of renewables to the national energy mix remains negligible.

Table 3: Algeria's Primary Energy Consumption by Source (2017)

Source	Consumption (Million Tonnes of Oil Equivalent - Mtep)	Percentage
Oil	19.36	34.9%
Natural Gas	35.90	64.7%
Total Fossil Fuels	55.48	99.94%
Hydropower	0.005	0.01%
Solar, Wind	0.05	0.09%
Biomass-Waste	0.010	0.02%
Total Renewables	0.065	0.12%
Total	55.52	100%

Source: International Energy Agency (IEA), processed by Senouci et al. (2022).

Discussion: This data underscores the immense challenge of energy transition. The discussion must therefore focus on the multifaceted barriers hindering progress:

- Economic and Financial Hurdles:** Despite the FNERC, financing remains a challenge. Low, subsidized domestic energy prices undermine the economic attractiveness of RE investments. The high initial capital expenditure (CapEx) for large-scale plants competes for public funds with other pressing social and economic needs.
- Technological and Infrastructural Deficits:** A lack of local manufacturing capacity for key components (solar panels, wind turbines) leads to reliance on expensive imports. The national

electricity grid requires significant modernization and reinforcement to handle the intermittency and decentralized nature of solar and wind power, especially for integrating large southern projects.

3. **The "Carbon Lock-in" Effect:** The economy's deep-seated structural dependence on hydrocarbons creates a powerful inertial force. This includes institutional path dependency, vested interests, and a workforce skilled in traditional energy sectors, all of which resist the transition to a new technological paradigm (Landel, 2015).
4. **Regulatory and Bureaucratic Inefficiencies:** Complex administrative procedures, slow tender cycles, and perceived regulatory uncertainties can deter both domestic and foreign private investment, which is crucial for supplementing public efforts.
5. **Social and Awareness Factors:** There is a need for greater public awareness and acceptance of RE technologies, as well as the development of a skilled workforce through specialized training programs to support the new industry.
6. **The Digital Transition as a Complementary Lever:** Beyond conventional barriers, the agri-food sector's experience with digitization in Algeria illustrates a broader structural challenge applicable to the energy sector: the gap between strategic policy formulation and effective on-the-ground implementation. As Bessaid (2024) demonstrate, the adoption of transformative technologies whether digital or renewable requires not only financial investment but also coordinated institutional frameworks, capacity building, research and innovation ecosystems, and public-private partnerships. The absence of such enabling conditions, particularly a skilled workforce and a coherent regulatory architecture, constitutes a cross-sectoral barrier that similarly constrains the scaling of renewable energy projects in Algeria.

6. CONCLUSION AND RECOMMENDATIONS

Algeria stands at a critical crossroads. It possesses arguably all the fundamental ingredients for a successful energy transition: world-class natural resources, a clearly defined strategic vision, and an initial institutional and legal framework. However, the journey from a rentier

economy, deeply entrenched in hydrocarbon dependency, to a diversified, modern, and green economy is fraught with complexity.

This analysis confirms that renewable energy is the most viable pathway for Algeria to achieve sustainable development. It is the key to preserving valuable hydrocarbon resources for export, meeting soaring domestic energy demand sustainably, creating high-value jobs for its young population, and honoring its commitments under the Paris Agreement.

To bridge the gap between immense potential and current modest outcomes, the study proposes the following recommendations:

1. **Accelerate Public-Private Partnerships (PPPs):** Actively design and promote attractive investment frameworks to lure foreign expertise and capital, reducing the fiscal burden on the state and accelerating project deployment.
2. **Prioritize Grid Modernization and Storage:** Launch major infrastructure projects to develop a "smart grid" and invest in energy storage solutions (e.g., battery storage, CSP with thermal storage) to manage the variability of renewable sources and ensure grid stability.
3. **Foster Local Industry and R&D:** Implement policies that encourage the local manufacturing of RE components through incentives and technology transfer agreements. Strengthen R&D institutions like CDER and IAER to drive innovation tailored to local conditions.
4. **Reform Energy Subsidies:** Gradually rationalize domestic energy subsidies to reflect real costs, thereby improving the economic competitiveness of RE and encouraging energy efficiency among consumers.
5. **Launch a National Awareness and Training Campaign:** Educate the public on the benefits of RE and launch extensive vocational training programs to build a skilled workforce capable of supporting and maintaining a growing RE industry.
6. **Explore Green Hydrogen as a Strategic Vector:** Proactively develop a national strategy for green hydrogen production, leveraging its cheap solar electricity potential. This could position

Algeria as a key exporter of sustainable energy in the future, diversifying its export portfolio beyond fossil fuels.

By adopting a more assertive, implementation-focused approach and addressing these challenges head-on, Algeria can truly leverage its solar and wind wealth. This will enable it to build a resilient, sustainable, and modern economy that secures prosperity for both present and future generations.

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