

Education as a Catalyst for Innovation and Sustainability in Smart Territories: A Pillar of Morocco's 2030 Energy Transition and Its Implications for Sustainable Development Goals

L'éducation comme catalyseur de l'innovation et de la durabilité dans les territoires intelligents : Un pilier de la transition énergétique du Maroc à l'horizon 2030 et ses implications en matière d'Objectifs de Développement Durable

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Education as a Catalyst for Innovation and Sustainability in Smart Territories: A Pillar of Morocco's 2030 Energy Transition and Its Implications for Sustainable Development Goals:

Abstract:

This study evaluates renewable energy education in Morocco and highlights its pivotal role in the country's 2030 Energy Transition Project and Sustainable Development Goals (SDGs). Qualitative data from 40 expert interviews and quantitative data from a survey of 1,323 university students reveal key gaps in early education, insufficient teacher training, and limited public engagement. Results show that while higher education offers relevant programs, primary and secondary curricula lack integration of renewable energy topics. The study proposes targeted pedagogical reforms, enhanced teacher training, and stronger community engagement to bridge these gaps and accelerate Morocco's energy transition.

Keywords: Renewable energy education, Energy transition, Training, Sustainable Development Goals, Morocco.

Classification JEL: O44

Paper type: Empirical Research

Résumé :

Cette étude évalue l'éducation aux énergies renouvelables au Maroc et souligne son rôle central dans la transition énergétique 2030 et l'atteinte des ODD. L'analyse qualitative de 40 entretiens d'experts et l'enquête quantitative menée auprès de 1323 étudiants révèlent des lacunes au niveau de l'enseignement fondamental, de la formation des enseignants et de l'implication communautaire. Les résultats montrent que l'enseignement supérieur propose des programmes adaptés, mais que le primaire et le secondaire restent insuffisamment intégrés. L'étude recommande des réformes pédagogiques ciblées, un renforcement de la formation des enseignants et une mobilisation accrue des communautés pour soutenir la transition énergétique.

Mots-clés : Éducation aux énergies renouvelables, Transition énergétique, Formation, Objectifs de Développement Durable, Maroc.

Classification JEL : O44

Type du papier : Recherche empirique

1. Introduction

The energy transition has become a strategic priority for countries worldwide seeking to reduce greenhouse gas emissions, combat climate change, and promote sustainable development. In this context, renewable energy has emerged as a fundamental pillar of energy policy, particularly in developing countries that face growing energy demand and environmental pressures. Education plays a central role in this transformation by equipping future generations with the technical skills, environmental awareness, and innovative mindset needed to support and accelerate this transition.

Morocco has demonstrated a strong political commitment to sustainable energy through its ambitious goal of sourcing 52% of its electricity from renewable energies by 2030 (Ministry of Energy, Mines, and Environment, 2023). Since the launch of its national energy strategy in 2009, the country has made significant progress in increasing its renewable energy capacity, particularly in solar and wind power (Alhamwi et al., 2015). However, despite these efforts, the role of education in supporting the energy transition remains underexplored and underutilized. While technical infrastructures and legal frameworks have evolved, the development of human capital through renewable energy education has not kept pace, limiting the long-term sustainability and inclusiveness of the transition (Meir, Opfer, & Hernandez, 2022).

International experiences in countries like Germany, Denmark, and Japan demonstrate that integrating renewable energy topics into educational systems at all levels — from primary schools to vocational training and higher education — is essential for building a skilled workforce and ensuring societal engagement (UN Department of Economic and Social Affairs, 2021; Wiesner, 2014; Alola et al., 2023; Matsumoto & Matsumura, 2022; Masrahi et al., 2021). These models highlight the importance of adopting a comprehensive, lifelong learning approach to renewable energy education that includes formal education, community outreach, and public awareness campaigns.

In Morocco, initial efforts have been made to incorporate renewable energy topics into higher education and vocational training. However, several structural challenges persist: a lack of early integration of energy issues into primary and secondary education, insufficient teacher training, limited access to updated pedagogical resources, and low levels of public engagement (Boulakhbar et al., 2020; Brunet et al., 2022; Ridwan et al., 2022; Kharbach & Chfadi, 2022). These gaps hinder the full mobilization of society and the workforce toward Morocco's energy and environmental goals.

Existing literature has highlighted the importance of educational attainment in supporting clean energy adoption, reducing carbon emissions, and fostering sustainable practices (Fang et al., 2022; Özbey & Duyar, 2022; Zhang et al., 2023). Studies have also pointed to the need for context-specific approaches that align with local socio-economic and institutional realities. Nevertheless, there is limited empirical research examining how renewable energy education is actually implemented in Morocco and how it contributes — or fails to contribute — to the national energy transition and the Sustainable Development Goals (SDGs).

This article aims to address this gap by assessing the current state of renewable energy education in Morocco and analyzing its contribution to the national energy transition strategy and SDGs. Specifically, it explores how educational programs are structured across various levels, the extent of teacher preparedness, the role of community engagement, and the perception of students and experts regarding the effectiveness of such education.

To achieve this, the research adopts a mixed-methods approach combining qualitative data from expert interviews with quantitative data from a large-scale survey conducted among university students. The study is anchored in the theoretical frameworks of the Diffusion of Innovations and the Sustainable Development Goals, which provide conceptual tools for

understanding how new educational practices are adopted and evaluated in terms of their societal impact.

The article is structured as follows: Section 1 presents a review of the relevant literature on renewable energy education and its role in sustainable development. Section 2 outlines the research methodology. Section 3 presents and discusses the key findings. Section 4 offers policy recommendations and outlines future perspectives for strengthening renewable energy education in Morocco. The article concludes by reflecting on the broader implications for energy policy and educational reform in Africa.

2. Theoretical Background

This study draws on two foundational theoretical frameworks: the Diffusion of Innovations Theory and the Sustainable Development Goals (SDGs) Framework. Together, they provide a robust lens for analyzing both the adoption of renewable energy education practices within Morocco's educational system and their alignment with national and global sustainability objectives.

Developed by Everett Rogers (2003) and widely used in education, public policy, and sustainability studies, the Diffusion of Innovations Theory explains how new ideas, technologies, or practices are communicated and adopted across social systems. The model identifies five categories of adopters—innovators, early adopters, early majority, late majority, and laggards—and emphasizes five critical attributes that influence adoption: relative advantage, compatibility, complexity, trialability, and observability.

In the context of this research, renewable energy education is conceptualized as a pedagogical innovation whose diffusion depends on the responsiveness of educational institutions, teacher readiness, curriculum flexibility, and policy support. The theory helps elucidate why certain universities or vocational training centers become frontrunners in adopting these programs (early adopters), while others show resistance or delay (late majority or laggards).

Moreover, this framework provides a powerful explanatory tool for interpreting empirical findings from the 40 expert interviews and the student survey. It helps identify key barriers to diffusion—such as institutional inertia, lack of teacher training, insufficient policy incentives, and social perceptions of renewable energy—and highlights the pathways through which educational innovation can be scaled, especially through community involvement and inter-institutional collaboration (Gandharba & Pant, 2023; Klaperski-van der Wal, 2023).

Thus, the diffusion model is not only descriptive but strategic: it enables policymakers and educators to diagnose institutional readiness, design targeted interventions, and accelerate the integration of renewable energy topics into formal and non-formal education.

The second theoretical foundation of this study is the Sustainable Development Goals (SDGs) Framework, adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure prosperity for all by 2030. In this study, the SDGs serve as a normative and evaluative framework for assessing the broader societal impact of renewable energy education.

The focus is placed on four interrelated goals:

- SDG 4: Quality Education – ensuring inclusive and equitable access to knowledge, with particular attention to environmental and technological literacy.
- SDG 7: Affordable and Clean Energy – expanding access to sustainable energy through public awareness, technical training, and behavioral change.
- SDG 8: Decent Work and Economic Growth – preparing students for green jobs and supporting the development of a renewable energy workforce.
- SDG 13: Climate Action – leveraging education as a tool for climate mitigation, adaptation, and civic mobilization.

The SDGs provide more than aspirational targets; they function as operational benchmarks against which Morocco's education and energy strategies can be evaluated. The framework is especially relevant in highlighting the cross-cutting role of education in promoting innovation, social inclusion, environmental responsibility, and long-term economic resilience (Rachmawati, Loy, & Karolus, 2023).

By situating renewable energy education within the SDGs, this study underscores its transformative potential: not merely as a technical domain, but as a strategic instrument for sustainable development. It also allows the analysis to bridge micro-level insights (from institutions and students) with macro-level policy goals, thereby reinforcing the legitimacy and urgency of educational reform.

3. Literature Review

Renewable energy education has garnered significant attention in recent years, underscoring the global shift towards sustainable energy sources. Researchers have delved deeply into this field, uncovering crucial insights that advance our understanding of renewable energy education.

Studies emphasize the intricate links between urbanization, education levels, and renewable energy adoption in emerging economies. Fang et al. (2022) reveal that urbanization and economic globalization reduce demand for both renewable and non-renewable energy, while higher income levels and education positively influence energy demand. Özbey and Duyar (2022) highlight the pivotal role of a well-educated workforce in lowering CO₂ emissions and promoting renewable energy, contrasting with higher emissions associated with lower educational attainment and per capita GDP. Zhang et al. (2023) underscore the impact of oil reserves and educational levels on renewable energy policies, showing how political globalization supports energy efficiency and renewable energy policies.

Lucas et al. (2018) address the shortage of skilled workers as a barrier to renewable energy market growth. Their analysis of global education and training in renewable energies exposes a pronounced deficit in developing countries, where educational systems struggle to meet industry demands. They note a shift towards online training and increasing female interest in renewable energy education, offering potential solutions to workforce shortages.

Kandpal and Broman (2014) conducted a comprehensive study on global renewable energy education needs. Their research charts the establishment of university programs worldwide over the past three decades, proposing effective strategies to meet the rising demand for renewable energy education.

Acikgoz (2011) emphasizes the significance of renewable energy sources for sustainable development, particularly in countries like Turkey with abundant renewable resources. The study advocates for integrating renewable energy topics into education to inspire environmentally conscious students and enhance educator competencies in Turkey.

This article assesses various dimensions of renewable energy education in Morocco (Fig. 2), exploring its role in the country's energy transition. It examines target groups, pedagogical approaches, training needs, community engagement, and the impact on Sustainable Development Goals (SDGs). Future prospects for renewable energy education are also considered, offering insights to strengthen Morocco's sustainable energy initiatives.

In light of the literature reviewed and the research problem addressed, this study proposes the following research hypotheses:

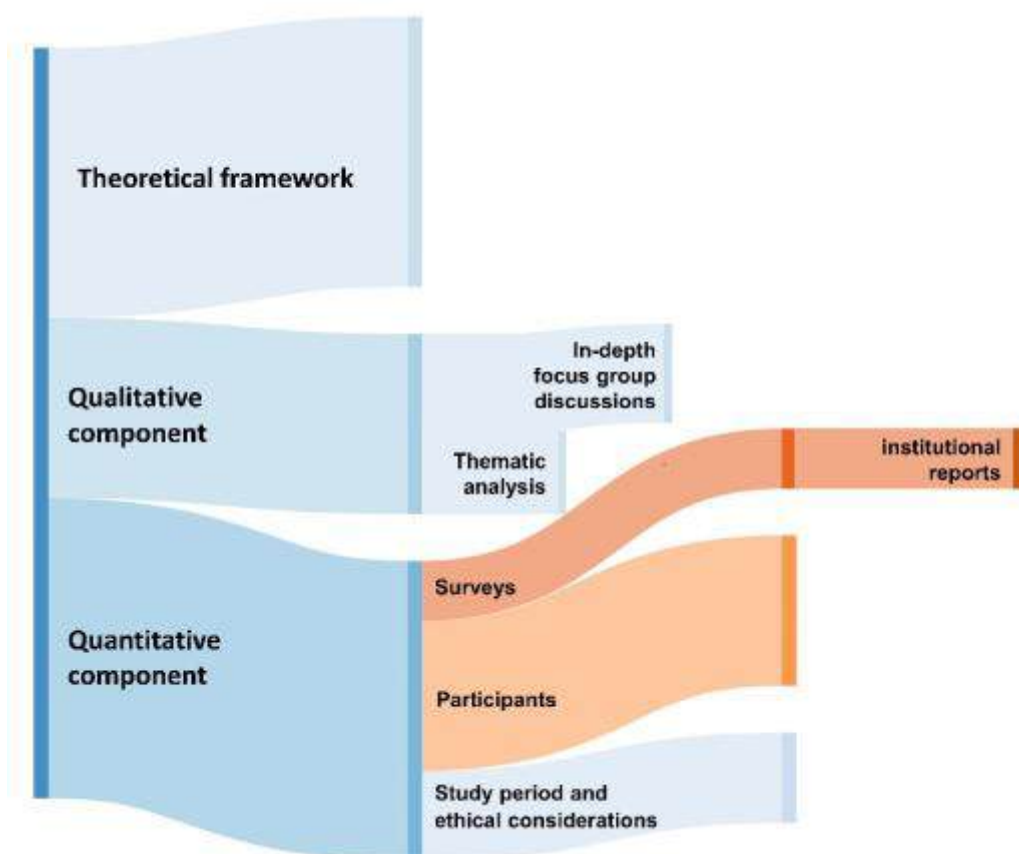
- **H1:** The early integration of renewable energy education improves environmental awareness.
- **H2:** Enhanced teacher training increases the effectiveness of educational programs in supporting the energy transition.

- **H3:** Community engagement fosters greater ownership of sustainable practices.

4. Methodology of Research

Our study is based on two main theories: the Diffusion of Innovations Theory and the Sustainable Development Goals (SDGs) framework (Gandharba & Pant, 2023; Klaperski-van der Wal, 2023; Rachmawati, Loy, & Karolus, 2023). The Diffusion of Innovations Theory helps us understand how new educational practices, like teaching renewable energy, are adopted in education systems. The SDGs framework gives us a global standard to evaluate how well renewable energy education contributes to sustainability.

Fig. 1. Sankey diagram designed to clarify the methodology adopted



Source : Adapted to what is a sankey diagram? — storytelling with data (<https://www.storytellingwithdata.com/blog/what-is-a-sankey-diagram>)

Before detailing the analytical methodology, it is essential to clarify the process through which the research instrument—the survey questionnaire—was developed. Our approach was grounded in a preliminary qualitative study, designed to ensure both contextual relevance and content validity of the subsequent quantitative phase.

Specifically, we conducted a qualitative investigation based on a semi-structured interview guide, composed of five key thematic areas. These themes were carefully formulated to explore distinct analytical dimensions of the renewable energy education landscape in Morocco. The five themes were as follows:

1. General Presentation of Participants

This section served to contextualize the experts interviewed (disciplinary background, institutional affiliation, professional experience). It was not intended to generate analytical insights, but rather to situate responses within a relevant professional and academic framework.

2. **Perceptions of Renewable Energy in Morocco**
 The objective of this theme was to understand how experts perceive Morocco's current national energy strategy, the positioning of renewable energy, and its socio-economic and environmental implications.
3. **Integration of Renewable Energy in the Education System**
 This dimension examined how renewable energy themes are integrated into curricula at various educational levels, the pedagogical approaches adopted, and the extent to which these initiatives respond to national energy goals.
4. **Role of Institutions and Stakeholders**
 This theme aimed to explore the ecosystem of actors—including ministries, universities, NGOs, and private sector entities—who influence the development and implementation of renewable energy education policies and programs.
5. **Challenges and Future Recommendations**
 Finally, this theme sought to identify the major barriers to the advancement of renewable energy education and to collect expert recommendations for improving the system's effectiveness and long-term sustainability.

Each of these thematic areas provided structured yet open-ended space for participants to express their perspectives, and thus enabled a rich thematic analysis of expert viewpoints.

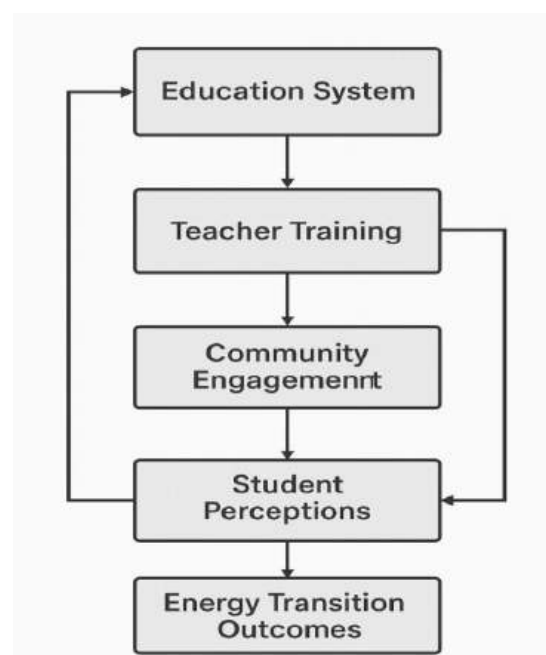
It is important to note that the current study is primarily quantitative in nature. While the qualitative phase played a foundational role, its purpose was not to yield standalone analytical findings but rather to inform the design and refinement of the quantitative survey instrument.

Therefore, instead of presenting detailed qualitative results in this article, we emphasize that the questionnaire and its measurement scales were developed based on two pillars:

- The findings from the qualitative study involving 40 experts, drawn from eight Moroccan universities and energy institutions.
- An extensive review of the academic and institutional literature on renewable energy education, sustainable development, and innovation diffusion.

This methodological sequence ensures a strong alignment between empirical reality and theoretical constructs, reinforcing both the internal validity and applied relevance of the quantitative data collection.

Fig. 2. Research model



Source : Personal research

5. Results

5.1. A Stratified Vision of Renewable Energy Education in Morocco

Renewable energy education in Morocco reveals a vertical and horizontal disparity across different educational levels and community sectors. While higher education institutions and vocational training centers have made significant strides, early-stage education and community outreach remain underdeveloped.

5.1.1. Vertical Educational Integration

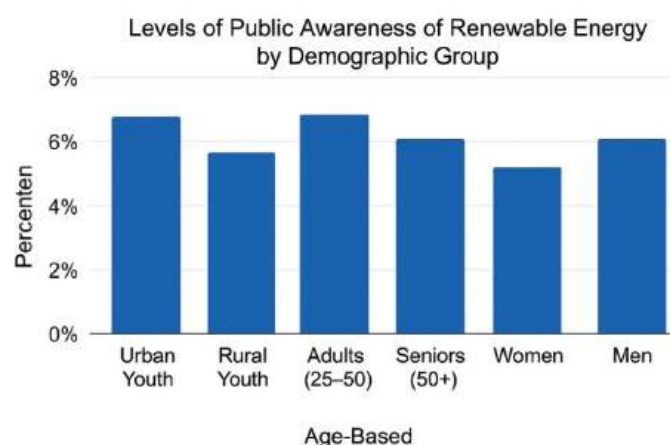
Data analysis indicates strong institutional engagement at the tertiary level. Universities and engineering schools offer bachelor's, master's, and doctoral programs in renewable energy engineering, energy policy, and sustainable development. Additionally, vocational institutions provide targeted training in technical and operational areas such as solar panel installation, energy auditing, and system maintenance.

Despite this vertical development, the absence of renewable energy education at primary and secondary school levels is evident. Interviews with 40 experts emphasized the necessity of early environmental education to instill long-term behavioral change and sustainable thinking. This vertical gap highlights a systemic limitation: the failure to embed sustainability education in the early cognitive development stages. Respondents stressed that comprehensive curriculum reform is crucial for national alignment with Morocco's 2030 energy strategy.

5.1.2. Horizontal Engagement through Public Awareness

At the horizontal level, public education campaigns and grassroots initiatives remain fragmented and underfunded. While some efforts have been made by ministries and local NGOs to raise awareness about the benefits of solar, wind, and hydropower energy, these efforts are sporadic and lack scalability.

Figure 3: Levels of Public Awareness of Renewable Energy by Demographic Group
A bar chart comparing urban vs. rural awareness levels; gender breakdown; age-based perception of renewable energy benefits.



Source: Personal research

Survey and interviews data revealed that public understanding of renewable energy's social and environmental benefits is uneven. Respondents recommended deploying communication strategies through national media, community workshops, and partnerships with local civil society actors. This bottom-up engagement can complement formal education and facilitate behavioral change.

5.2. Capacity Building: Teacher and Trainer Preparation

Teacher and trainer preparation emerged as a pivotal element in operationalizing renewable energy education. Findings suggest that while higher education instructors generally possess subject-specific knowledge, primary and secondary teachers lack both training and resources to integrate sustainability themes into their pedagogy.

Table 1: Capacity Gaps in Teacher Training for Renewable Energy Education in Morocco

Level	Existing Training Programs	Identified Gaps	Recommended Actions
Primary/Secondary	Very limited	No renewable modules; no teacher CPD	National curriculum reform; CPD programs
Vocational	Moderate	Focus on hardware; lacks energy literacy	Update content; industry collaboration
University	Strong	Often siloed; lacks interdisciplinarity	Promote cross-disciplinary courses

Source: Personal research

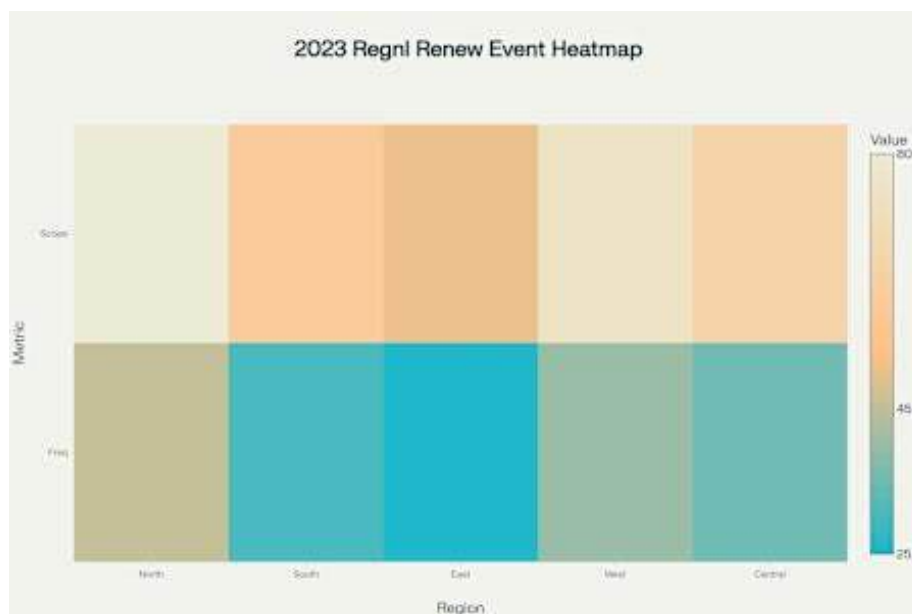
Experts noted that targeted professional development programs and teacher certification in renewable energy topics are urgently needed. Furthermore, collaboration with international institutions can help align training with global best practices.

5.3. Community Participation and Local Capacity Building

Renewable energy education must extend beyond formal classrooms. Community engagement emerged as a core theme in stakeholder interviews, particularly in the context of local ownership and behavioral adoption.

Initiatives like solar training workshops, participatory town hall meetings, and school-community partnerships were cited as effective strategies. However, their reach remains limited due to resource constraints and lack of policy integration.

Figure 4: Community Participation in Renewable Energy Education Activities by Region (2023)



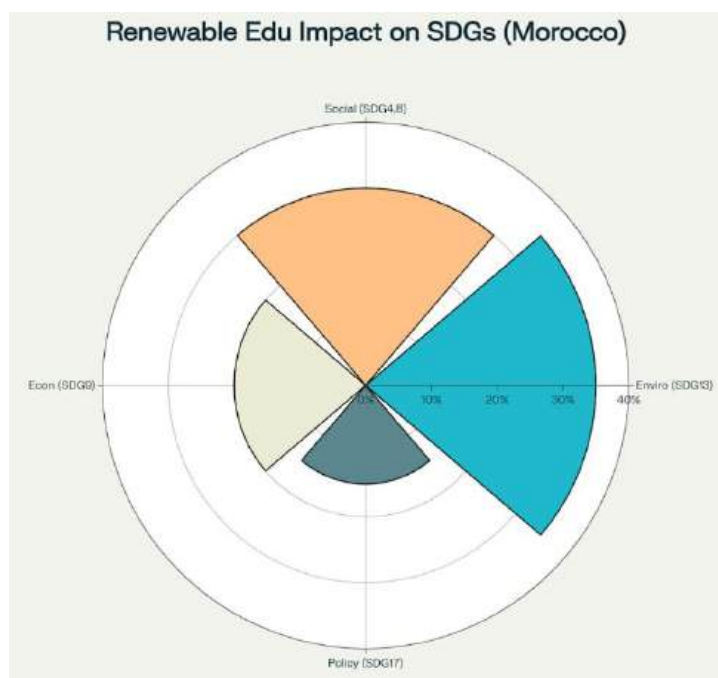
Source: Personal research: A regional heat map displaying frequency and scope of community-based renewable energy training and awareness events.

The interviews indicated that active participation in the energy transition reinforces sustainable behaviors and supports local green job creation. Training programs targeting unemployed youth and women in rural regions were viewed as particularly impactful.

5.4. Contribution to the Sustainable Development Goals (SDGs)

Renewable energy education in Morocco contributes significantly to a variety of SDGs, particularly SDG 4 (Quality Education), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work), and SDG 13 (Climate Action).

Figure 5: Contributions of Renewable Energy Education to the SDGs - A radial diagram mapping educational interventions to specific SDG targets.



Source: Personal research

- Environmental: Reduction in GHG emissions through informed choices and sustainable practices (SDG 13).
- Social: Improved access to education and employment in green sectors (SDG 4, SDG 8).
- Economic: Job creation, innovation, and local industry development (SDG 9).
- Policy: Multistakeholder collaboration supporting national and global sustainability agendas (SDG 17).

Stakeholders viewed education as the most transformative lever in Morocco's energy transition roadmap, highlighting its multiplier effect across environmental, economic, and social domains.

5.5. Summary of Key Results

Table 2: Key takeaways showing the strengths, Weaknesses and opportunities of higher Education, Primary/Secondary schools, community awareness, Teacher Training and SDG contribution in Morocco

Key Area	Strengths	Weaknesses	Opportunities
Higher Education	Strong programs, research output	Limited to few elite institutions	International partnerships, interdisciplinary focus
Primary/Secondary Schools	High potential for behavior change	Absence of curriculum integration	Curriculum reform, early exposure
Community Awareness	Some localized efforts	Lack of national coordination	Grassroots mobilization, inclusive strategies
Teacher Training	Skilled university faculty	No systemic training for school teachers	CPD frameworks, capacity building
SDG Contribution	Wide impact across sectors	Measurement and monitoring still weak	Strategic alignment with national targets

Source: Personal research

6. Future Prospects

The findings of this study highlight several critical gaps and opportunities within Morocco's renewable energy education landscape. To effectively harness these insights, it is essential to transform identified perspectives into actionable strategies that policymakers, educational institutions, and stakeholders can implement. This section elaborates on each perspective, grounding recommendations firmly in the empirical data while linking them to broader educational and energy transition objectives.

A primary concern revealed by the research is the insufficient integration of renewable energy topics in the current education curriculum at both primary and secondary levels. This curricular omission constrains early awareness and engagement with sustainability issues, which are vital for fostering an environmentally conscious generation. Given the urgent need for energy transition aligned with Morocco's national goals, embedding interdisciplinary modules focused on renewable energy within the secondary school curriculum is imperative. These modules should not be isolated content but woven holistically through existing subjects such as science, geography, and civic education. Leveraging the national curriculum reform platform presents a strategic opportunity to institutionalize this integration, ensuring that environmental education becomes a foundational pillar rather than an elective add-on. Such reform would facilitate students' comprehensive understanding of renewable energy principles and their socio-economic implications, thereby cultivating informed future citizens and professionals.

The study further identifies a significant deficit in teacher preparedness regarding renewable energy content. Many educators, particularly in scientific disciplines, currently lack the necessary training to effectively convey this material. This gap undermines the quality and impact of any curriculum reform, as teacher expertise is central to student engagement and learning outcomes. Addressing this challenge requires the establishment of national certification programs dedicated to renewable energy pedagogy, specifically designed for in-service science teachers. These programs would equip educators with both conceptual knowledge and innovative teaching methodologies, enabling them to deliver content confidently and contextually. Moreover, integrating renewable energy modules into teacher training colleges is crucial to build capacity systematically at the pre-service level. By fostering a cadre of well-prepared educators, Morocco can ensure sustainable and scalable improvements in renewable energy education that extend beyond initial reforms.

Community engagement—or the lack thereof—emerged as another critical dimension. The research highlights that awareness and active participation in renewable energy initiatives are particularly limited within rural and marginalized communities. This deficiency impedes the grassroots adoption of sustainable practices and diminishes public support for broader energy transition policies. To counteract this, collaboration between educational institutions, non-governmental organizations (NGOs), and local municipalities is essential. Jointly launched community education projects can serve as platforms for disseminating knowledge, fostering dialogue, and encouraging participatory approaches. Furthermore, incentivizing public-private partnerships could mobilize additional resources and expertise, expanding the reach and impact of awareness campaigns. These community-focused efforts would not only complement formal education but also help bridge socio-economic divides, promoting inclusivity in the transition process.

Institutional coordination, or more precisely the current lack thereof, represents another obstacle identified by the research. The study finds insufficient synergy between the education and energy sectors, leading to fragmented policies and disconnected initiatives. Such institutional silos hinder the development of coherent strategies that address educational needs while aligning with national energy objectives. To overcome this barrier, the creation of an

inter-ministerial renewable energy education task force is recommended. This entity would bring together representatives from the Ministries of Education, Energy, and other relevant stakeholders to foster dialogue, synchronize efforts, and monitor progress. Regular evaluation and strategy updates would ensure that educational reforms remain responsive to technological advancements and policy shifts in the energy sector. Establishing such coordination mechanisms is critical for maximizing the efficacy and sustainability of interventions.

Finally, the research highlights a notable lack of practical exposure for students to renewable energy technologies and real-world applications. Theoretical knowledge, while essential, must be complemented by experiential learning to prepare students effectively for careers in the evolving energy sector. To address this gap, the development of structured internship and mentoring programs that link universities with renewable energy firms is essential. These partnerships would provide students with hands-on experience, industry insights, and professional networking opportunities. Encouraging industry-academia collaborations will not only enhance skill development but also facilitate knowledge transfer, innovation, and responsiveness to labor market demands. Ultimately, expanding practical learning pathways will better equip students to contribute meaningfully to Morocco's energy transition and sustainable development.

In summary, the transformation of these perspectives into strategic actions requires a multi-faceted and coordinated approach involving curriculum innovation, capacity building, community engagement, institutional collaboration, and experiential learning. These recommendations, grounded in empirical evidence, offer a comprehensive framework for strengthening renewable energy education in Morocco and supporting the country's broader sustainability agenda.

7. Conclusion

The transition to renewable energies in Morocco highlights the indispensable role of education as a catalyst for transformative change. Renewable energy education not only disseminates technical knowledge but also nurtures a culture of sustainability by raising awareness of the environmental, economic, and social implications of energy choices. It fosters informed decision-making, equips learners with essential green skills, and cultivates a mindset oriented toward innovation, critical thinking, and long-term sustainability.

This study confirms that education is not a secondary support to the energy transition, but a foundational pillar. It enables the development of a qualified workforce, strengthens institutional capacities, and accelerates community engagement—all of which are vital to the success of Morocco's energy and climate ambitions.

Encouragingly, several efforts—led by government programs, public-private partnerships, and international collaborations—have emerged to support the integration of renewable energy topics across educational systems. However, significant challenges remain, including insufficient resources, the need for context-adapted and interdisciplinary curricula, limited teacher preparedness, and low public awareness in rural areas.

Addressing these challenges requires a more coherent national strategy that embeds renewable energy education across all levels—from primary schools to lifelong learning. This should be accompanied by targeted teacher training, increased access to updated pedagogical materials, and community-based outreach programs to ensure inclusivity.

As this research illustrates, renewable energy education aligns closely with the United Nations Sustainable Development Goals (SDGs), especially SDG 4 (Quality Education), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action). Ensuring equal access to this education, particularly for marginalized and rural populations, is essential for building an inclusive and resilient energy future.

Ultimately, positioning education at the heart of Morocco's energy transition will not only empower its youth but also elevate the country's role as a leader in sustainable development and climate innovation across the African continent.

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