

The Role of Renewable Energy in Achieving Net-Zero Emissions, Case Study: Rwanda

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Abstract: The global transition to a low-carbon economy is crucial to mitigate the devastating impacts of climate change. Rwanda, a landlocked country in East Africa, has set an ambitious target of achieving net-zero emissions by 2050. This case study examines the role of renewable energy in Rwanda's efforts to reach this goal. Through an analysis of Rwanda's energy mix, policy framework, and renewable energy projects, this paper demonstrates the country's progress and challenges in scaling up renewable energy sources. The findings indicate that Rwanda has made significant strides in diversifying its energy portfolio, with a growing share of renewable energy, particularly solar and hydropower. However, barriers such as grid infrastructure limitations and access to finance remain obstacles to further renewable energy deployment. The paper concludes with policy recommendations to accelerate Rwanda's transition to a renewable-powered, net-zero emissions economy, including strengthening grid integration, fostering private sector investment, and enhancing regional cooperation. The lessons learned from Rwanda's experience can provide valuable insights for other developing countries seeking to harness the potential of renewable energy to achieve their climate goals.

Key words: Renewable energy, emissions, environmental impact assessment.

1. Introduction

Rwanda, a small, landlocked country in East Africa, has emerged as a leader in renewable energy development and climate action. In 2020, the Rwandan government announced an ambitious target of achieving net-zero emissions by 2050 [1]. This commitment is particularly noteworthy given Rwanda's relatively low historical contribution to global GHG emissions, underscoring the country's proactive approach to addressing climate change. Rwanda's climate is generally tropical, with two rainy seasons and two dry seasons. However, like many other parts of the world, Rwanda has been experiencing the effects of climate change in recent years. Climate change is one of the greatest threats facing humanity in the 21st century. To limit global temperature, rise to 1.5 °C above pre-industrial levels, as per the Paris Agreement, the world must achieve net-zero GHG (greenhouse gas) emissions by mid-century [2]. This transition to a low-

carbon economy requires a fundamental shift in the way we produce and consume energy, with a significant increase in the deployment of renewable energy technologies.

The climate change situation in Rwanda in 2024 based on the temperatures has continued to rise, with average temperatures across the country now around 1-2 °C higher compared to the 1990s, Rainfall patterns have become more erratic, with some regions experiencing increased rainfall and flooding, while others face more prolonged droughts. The rainy seasons have become less predictable, causing challenges for agricultural activities and food security, extreme weather events like heavy storms, landslides, and droughts have become more frequent and intense. Climate change has exacerbated environmental degradation, including deforestation, soil erosion, and biodiversity loss. However, the impacts of climate change have posed significant socioeconomic

challenges for Rwanda, affecting sectors like agriculture, water resources, and public health. This case study examines the role of renewable energy in Rwanda's efforts to reach its net-zero emissions goal. By analyzing the country's energy mix, policy framework, and ongoing renewable energy projects, the paper aims to assess Rwanda's progress in scaling up renewable energy deployment, identify the key drivers and barriers to renewable energy development in the country, and provide policy recommendations to accelerate Rwanda's transition to a renewable-powered, net-zero emissions economy.

2. Methodology Used

This study employs a mixed-methods approach, combining quantitative and qualitative analysis. The data used in this paper were gathered from various sources, including energy sector reports and statistics from the Rwandan government and international organizations, policy documents such as national energy and climate strategies, laws, and regulations, academic literature, and grey literature on renewable energy development in Rwanda. Interviews were conducted with key stakeholders, including government officials, renewable energy developers, and civil society representatives. The quantitative analysis focuses on the evolution of Rwanda's energy mix, renewable energy capacity, and related socioeconomic and environmental indicators. Meanwhile, the qualitative analysis explores the policy and regulatory environment, as well as the opportunities and challenges encountered by renewable energy projects in the country.

3. Data Collection and Analysis Methods

To assess the role of renewable energy in achieving net-zero emissions in Rwanda, a comprehensive data collection strategy is crucial. This strategy combines both quantitative and qualitative methods to thoroughly evaluate renewable energy's impact on emissions reduction and overall sustainability. Quantitative data

collection involves analyzing energy production and consumption metrics from sources like the REG (Rwanda Energy Group), the RDB (Rwanda Development Board), and the IEA (International Energy Agency). Key variables include the amount of electricity generated from renewable sources such as solar, wind, and hydroelectric power, as well as overall energy consumption and fossil fuel use. Additionally, emission data from the REMA (Rwanda Environmental Management Authority) and the UNFCCC (United Nations Framework Convention on Climate Change) are used to assess CO₂ (carbon dioxide) and greenhouse gas reductions. Economic and employment data from the NISR (National Institute of Statistics of Rwanda) and industry surveys provide insights into investment levels, job creation, and economic growth associated with renewable energy projects. Qualitative data collection complements this by analyzing policy and regulatory frameworks through government publications and strategic plans from entities like the Rwanda Green Fund (FONERWA). Semi-structured interviews with key stakeholders, including government officials, project managers, and local communities, offer valuable perspectives on the challenges and opportunities of renewable energy adoption. Finally, case studies of specific projects, such as solar mini-grids or hydroelectric plants, provide a detailed examination of their impact on emissions reduction and community benefits. This integrated approach ensures a comprehensive understanding of how renewable energy contributes to Rwanda's net-zero emissions goals [3].

To effectively analyze the data on renewable energy's role in achieving net-zero emissions, several key methods are employed. Statistical analysis uses tools and software such as SPSS and R to process quantitative data related to energy production, consumption, emissions, and economic indicators. This approach aims to identify trends, correlations, and the impact of renewable energy on emissions and

economic factors. Comparative analysis involves examining data across different periods, regions, and projects to evaluate the effectiveness of various renewable energy initiatives. This method helps assess the relative success of different technologies and policies in meeting emissions reduction targets. Finally, thematic analysis is used to analyze qualitative data from interviews and case studies, focusing on identifying common themes and insights. This approach provides a deeper understanding of stakeholder perspectives, the impacts of policies, and the successes and challenges of renewable energy projects. Together, these methods offer a comprehensive view of renewable energy’s contributions to achieving net-zero emissions. Rwanda (refer to Fig. 1), warmly known as “the land of a

thousand hills” is situated in East-Central Africa. It lies 121 km South (75 miles) of the equator in the Tropic of Capricorn, 1,416 kilometers (880 miles) west of the Indian Ocean, and 1,250 km (777 miles) east of the Atlantic Ocean literally the heart of Africa [4].

4. Rwanda Renewable Energy Ongoing Projects and Challenges

Rwanda’s renewable energy sector in 2024 is marked by significant progress with ongoing projects (Table 1) across hydropower, solar, methane gas, and geothermal energy. However, challenges such as financing, grid integration, capacity building, regulatory frameworks, and environmental considerations remain critical areas for attention and improvement.



Fig. 1 Map of Rwanda’s provinces and districts a case study.

Table 1 Renewable's ongoing projects with their challenges.

S/N	Ongoing projects	Description	Common challenges
1	Hydropower expansion	Rwanda is expanding its hydropower capacity with ongoing projects such as the Rusumo Falls Hydroelectric Project. This project involves collaboration with Burundi and Tanzania and aims to increase electricity generation from shared water resources.	Securing adequate financing for renewable energy projects remains a challenge. While Rwanda has attracted investment through international partnerships and initiatives like the Green Climate Fund, accessing sufficient funding for large-scale projects can be complex. Integrating intermittent renewable energy sources like solar and wind into the national grid poses technical challenges. Balancing supply and demand while maintaining grid stability requires advanced grid management systems and infrastructure upgrades. Developing renewable energy projects must consider potential environmental and social impacts. Mitigating these impacts through rigorous environmental assessments and community engagement is vital to ensure sustainable development.
2	Solar energy initiatives	The country is promoting solar energy through various initiatives. Ongoing projects include the Scaling Solar initiative, which facilitates the development of grid-connected solar power projects. This initiative streamlines the process of private sector involvement in solar energy development.	
3	Methane gas Utilization	Rwanda continues to harness methane gas from Lake Kivu through ongoing projects like the KivuWatt project. This involves extracting methane from the lake bed and using it for electricity generation, contributing to energy security and environmental sustainability.	
4	Geothermal exploration	Geothermal energy exploration is ongoing, with efforts focused on identifying potential sites for geothermal power generation. This includes geological surveys and feasibility studies to assess the viability of geothermal resources.	
5	Mini-grid expansion	Rwanda is expanding mini-grid systems powered by renewable energy sources, including solar and hydro. These mini-grids improve electricity access in remote and off-grid areas, supporting rural development and economic growth.	

5. The Role of Renewable Energy in Decarbonization

Decarbonization refers to the process of reducing or eliminating CO₂ (carbon dioxide) emissions and other greenhouse gases across various sectors of the economy, including energy production, transportation, industry, and buildings. The primary goal of decarbonization is to mitigate climate change by decreasing the concentration of greenhouse gases in the atmosphere, thereby limiting global warming and its adverse effects. Decarbonization efforts are typically integral to broader climate action plans aimed at achieving net-zero emissions, where any remaining emissions are offset through activities such as reforestation, carbon sequestration, or investments in renewable energy projects (refer to Fig. 2). Key strategies for decarbonization include transitioning from fossil fuel-based energy sources to renewable alternatives such as solar, wind, hydroelectric, geothermal, and tidal power. This transition involves phasing out coal, oil, and natural gas in favor of cleaner options that do not release CO₂ during combustion. Decarbonization also encompasses improving energy efficiency in buildings, transportation, and industrial

processes to reduce overall energy consumption and associated emissions. Addressing climate change through decarbonization entails promoting sustainable practices, reducing reliance on fossil fuels, and encouraging behavioral changes to minimize energy waste. These measures are essential for achieving a more sustainable future and mitigating the impacts of climate change on a global scale.

6. Results and Discussions

6.1 Summary Results

Rwanda's energy sector has been undergoing a significant transformation in recent years, driven by the country's commitment to diversifying its energy sources and increasing the share of renewable energy in the mix. In the first quarter of 2024, Rwanda generated electricity from diverse sources. Hydroelectric power constituted the largest portion at 55.24%, followed by methane gas at 34.03%, solar energy at 1.20%, peat at 2.36%, thermal sources at 0.72%, and 6.46% were imported. This mix highlights Rwanda's commitment to diversifying its energy portfolio and increasing reliance on renewable

resources to sustain economic growth while mitigating environmental impacts. As shown in Fig. 3, Rwanda’s energy mix has historically been dominated by biomass, which accounted for over 80% of the total primary energy supply in 2018 [5]. However, the share of renewable energy, particularly solar and hydropower, has been steadily increasing, reaching around 55.24% of the total energy supply in 2024.

As of 2024, Rwanda has made substantial strides in expanding its installed electricity capacity through the deployment of renewable energy technologies. The country has capitalized on its abundant water resources by developing hydropower plants, which now contribute the largest share to Rwanda’s electricity generation capacity. The installation of various hydropower facilities across the country has not only increased installed capacity but also provided reliable and relatively low-cost

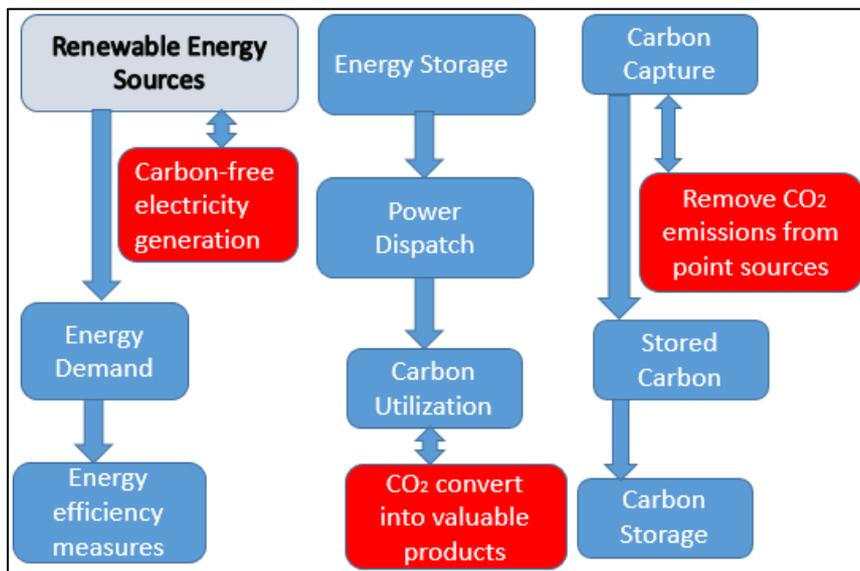


Fig. 2 Components of a net-zero emissions system.

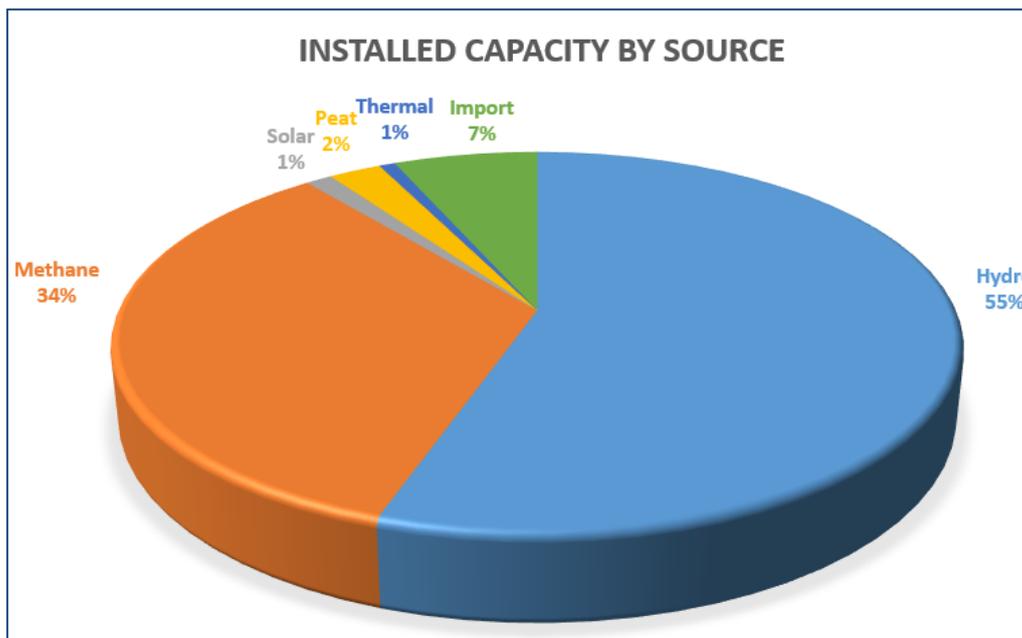


Fig. 3 Installed capacity contribution by source (2024).

electricity. Additionally, Rwanda has prioritized the harnessing of solar energy, installing solar PV (photovoltaic) systems in diverse locations, including rooftops of buildings and rural areas. These systems play a crucial role in decentralizing electricity generation, particularly in remote areas with limited grid connectivity [6].

Rwanda has also tapped into methane gas resources, notably from Lake Kivu, using specialized extraction and power generation facilities. Methane gas now significantly contributes to the electricity mix, offering a stable source of power. Although not renewable in the strictest sense, peat has been utilized as an energy source through the development of peat-fired power plants, which diversify Rwanda's energy sources and bolster energy security by meeting electricity demand. Furthermore, Rwanda has explored its geothermal potential by assessing geological formations for viable geothermal energy production. Developing geothermal resources has the potential to further enhance Rwanda's renewable energy portfolio in the future. Rwanda's commitment to renewable energy deployment in 2024 underscores its efforts to promote sustainable development, mitigate climate change impacts, and enhance energy security through diversified sources of electricity generation. Rwanda has also set ambitious targets for further renewable energy deployment. The country's NDC (Nationally Determined Contribution) under the Paris Agreement aims to increase the share of renewable energy in the electricity mix to 68% by 2030 [1].

6.2 Discussions

Rwanda's efforts to harness the potential of renewable energy are commendable and offer valuable lessons for other developing countries. The country has made significant strides in diversifying its energy mix, with a growing share of renewable energy sources, particularly solar and hydropower. The role of renewable energy in achieving net-zero emissions is pivotal in the global effort to combat climate change

and transition to a sustainable future. Renewable energy sources such as solar, wind, hydroelectric, geothermal, and tidal power generate electricity with minimal greenhouse gas emissions, contrasting sharply with fossil fuels like coal, oil, and natural gas, which emit CO₂ and other pollutants when burned. Transitioning to renewable energy is essential for decarbonization. By replacing coal-fired power plants, oil refineries, and gas turbines with renewable infrastructure, countries can significantly lower their carbon footprints and advance towards net-zero emissions. Diversifying the energy mix with renewables also enhances system resilience and security, as resources like sunlight and wind are abundant and widespread, reducing reliance on finite fossil fuels and mitigating geopolitical risks. Furthermore, the renewable energy sector stimulates economic growth by creating jobs in manufacturing, installation, and maintenance, and by fostering investment and innovation. Technological advancements have reduced costs, making renewables more competitive with fossil fuels, and improving the efficiency and scalability of energy systems. Additionally, renewable energy sources avoid emitting harmful pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, leading to better public health and reduced healthcare costs. Finally, deploying renewable energy supports sustainable development goals by providing clean and affordable energy, enhancing climate resilience, conserving biodiversity, and promoting poverty alleviation, while also enabling rural electrification and empowering communities towards energy self-sufficiency.

7. Conclusion and Further Research

Rwanda's experience exemplifies the transformative potential of renewable energy in achieving net-zero emissions. Through robust policy support, institutional frameworks, and strategic investments, Rwanda has made considerable progress towards a sustainable energy future. This paper emphasizes the critical need

for ongoing efforts to scale up renewable energy deployment and tackle challenges to ensure long-term sustainability and resilience. By addressing these challenges and implementing the recommended strategies, Rwanda can further solidify its leadership in renewable energy and climate action. It can serve as a model for other developing countries striving to achieve their net-zero emissions goals. Renewable energy generation plays a crucial role in achieving net-zero emissions by reducing reliance on fossil fuels and lowering the amount of GHGs (greenhouse gases) released into the atmosphere. Unlike coal, oil, and natural gas, renewable sources generate electricity without producing CO₂ (carbon dioxide) or other harmful emissions. Shifting the energy mix towards renewables significantly cuts GHG emissions. In Rwanda, adopting renewable energy targets for electricity generation is helping to reduce emissions in sectors reliant on grid power. Moreover, investing in renewable energy technologies promotes the development of sustainable industries and green jobs, supporting economic growth while meeting environmental goals. Decarbonizing the energy sector through renewables fosters innovation, accelerates the transition to cleaner technologies, and strengthens resilience against future energy shocks. Ultimately, renewable energy is a vital component in the transition to a net-zero emissions future. By replacing fossil fuels, electrifying key sectors, improving energy efficiency, and integrating carbon capture solutions, renewable energy mitigates climate change while ensuring sustainable, long-term growth. Future research should focus on assessing the long-term environmental and socio-economic impacts of renewable energy adoption in Rwanda, exploring innovative technological solutions to enhance energy storage and grid reliability, and evaluating policy effectiveness in promoting renewable energy investments in developing country contexts.

- Promote energy efficiency measures in buildings, transportation, and industrial sectors to reduce energy consumption and emissions.

- Encourage retrofitting of existing infrastructure to improve energy performance and reduce carbon footprint.

Declarations

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Authors' Contributions

Eustache Hakizimana: Made substantial contributions to conception and he was also involved in data interpretation and contributed to writing and revising the manuscript.

Honorine Umuhoza: She provided editorial support and helped with manuscript preparation.

Kayibanda Venant: Led the data analysis, and drafted the manuscript and he contributed to the interpretation of results and reviewed the manuscript for important intellectual content.

Availability of Data and Materials

The original contributions presented in the study are included in the article and Supplementary Material. Further inquiries can be directed to the corresponding author. All data and information used in this paper were properly cited, with additional data collected from REG, RDB and IEA.

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