Renewable Energy Future for Sierra Leone: Systems Modeling for Energy Security and Sustainability

Renewable Energy Future for Sierra Leone: Systems Modeling for Energy Security and Sustainability

Musa Bah

[1]Department of Mechanical and Maintenance Engineering, Fourah Bay College, University of Sierra Leone

https://orcid.org/0000-0001-7234-5145

Abstract

Purpose: Sierra Leone faces persistent energy security challenges, including dependence on imported petroleum products, limited electricity access, and vulnerability to global fuel price fluctuations. This study investigates renewable energy futures as a pathway to enhance energy security, reduce fossil fuel imports, and support sustainable socio-economic development.

Methodology: The Modelling User Interface for OSeMOSYS is applied to simulate alternative energy pathways.

Findings: Scenarios emphasize the renewable transition, which includes solar, hydropower, and biomass expansion, with comparative assessment against energy-imported fossil-based trajectories. Renewable energy pathways provide a cost-effective substitute for fossil fuels, with the potential to reduce import dependence by up to 60% by 2040. Beyond lowering greenhouse gas emissions, renewable deployment advances rural electrification, job creation, and technology transfer. The Renewable Transition (RT) pathway emerges as the most viable option, aligning with Sierra Leone's development priorities and international climate commitments under the Paris Agreement.

Unique Contribution to Theory, Policy and Practice: The study advances theoretical understanding by applying systems modeling to a low-access, fossil-reliant context, showing the viability of renewable-dominant transitions. The findings highlight the importance of scaling solar PV, hydropower, and mini-grids, upgrading transmission and distribution networks, and establishing robust regulatory frameworks to attract private investment. The study recommends restricting new fossil-based generation to backup roles, expanding engagement in the West African Power Pool (WAPP), and investing in human capital to strengthen system planning and operation. Collectively, the findings demonstrate the transformative potential of renewable energy futures to reinforce Sierra Leone's energy security and sustainable growth.

Keywords: *Renewable Energy, Energy Security, Energy Modeling*, *OSeMOSYS, Sierra Leone*
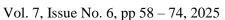
1.0.   Introduction

The shift towards decarbonization and sustainable energy systems is anticipated to significantly contribute to alleviating the impacts of global warming, while also promoting human well-being, security, and sustainable development [1]. To quantify the effects of this transition and to devise potential pathways, energy system models and mathematical representations of energy systems are frequently required [2,3]. Given their growing complexity, a variety of energy system modeling tools are accessible, offering energy modeling practitioners and planners an extensive array of options to depict energy systems based on diverse technical and methodological factors, which can aid policy and decision-makers in their energy planning and policy formulation processes [4,5]. These tools are continuously refined in response to the emerging challenges associated with the energy transition and recent technological advancements [3,5].

The global transition towards renewable energy, encouraged by events such as the Conference of the Parties (COP21), represents a collective effort to combat climate change. At COP 21, nations adopted the Paris Agreement and committed to reducing emissions through Nationally Determined Contributions (NDCs). NDCs outline specific plans tailored to each country's unique circumstances, aiming to limit global warming below 2 degrees Celsius above pre-industrial levels [6,7].

 Energy system modeling is fundamental to guiding such transitions. The Open Source Energy Modelling System (OSeMOSYS) has emerged as a powerful and accessible framework for long-term energy planning, particularly in contexts with limited data and resources [12]. Its open-source nature, modular architecture, and growing global community make it particularly attractive for developing countries like Sierra Leone, where institutional capacities and datasets may be constrained but ambitions for sustainable energy transitions remain high. Between 2008 and 2017, greenhouse gas emissions in African nations increased at a slower rate compared to other developing economies; however, the overall energy-related emissions rose by almost 20 percent (albeit starting from a very low baseline) [8,9]. Despite the implementation of efficiency measures, energy demand in African economies is projected to nearly double by 2040 due to population growth and improvements in living standards [10]. Therefore, making the vision of zero-emission African power sectors a reality by 2050 primarily involves preventing the growth of emissions as demand increases. The importance of enabling developing economies to leapfrog fossil fuels and instead benefit from low-carbon energy sources, particularly renewables [10,11].

Sierra Leone, located in West Africa and bordered by Guinea, Liberia, and the Atlantic Ocean, is a low-income country with an economy largely dependent on agriculture. According to the African Development Bank's 2020 assessment, the nation ranked 46th out of 54 sub-Saharan African countries on the Africa Infrastructure Development Index and 44th on the Electricity Index [13]. That same year, the United Nations Human Development Index ranked Sierra Leone 181st out of 191 countries, underscoring the country's significant development challenges [14]. As one of the most energy-deficient countries in the region, Sierra Leone continues to face major gaps in meeting
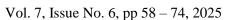
its energy demands [8]. The national electricity supply is widely recognized for its instability and unreliability, with frequent blackouts. As of 2019, nearly 5 million citizens were still living without access to electricity [15]. The sector also suffers from a wide gap between energy demand and supply, compounded by distribution losses estimated at up to 50% [8]. Data from the 2018 household survey further reveal that poverty remains pervasive, particularly in rural areas, with 10.8% of the population classified as living in extreme poverty and 57% considered poor [16]. This study aims to provide a comprehensive systems analysis of renewable energy pathways, to enhance energy sustainability to improve energy security in Sierra Leone using the Modelling User Interface for OSeMOSYS (MUIO 5.3).

This study will introduce a novel approach to renewable energy research and development, providing a comprehensive analysis that is specifically tailored to the unique characteristics of the country. It underscores the importance of temporal resolution for capturing resource variability and devises targeted strategies for the complete deployment of renewable energy. By combining assessments of technical potential, system optimization, and scenario analysis, this study seeks to identify viable strategies for decarbonizing the power sector in Sierra Leone, while ensuring energy security, economic efficiency, and environmental sustainability. The research centers on renewable energy sources and aims to: a) analyze the challenges and opportunities linked to renewable energy sources in Sierra Leone, which involves investigating the unique socio-economic factors, geographical conditions, and policy frameworks that shape the renewable energy transition in the nation. b) To underscore the critical role of temporal resolution in capturing the variability of renewable resources, particularly hydro and solar, and to consider factors such as seasonal demands. c) To devise targeted strategies for achieving 100% renewable energy deployment in Sierra Leone, guided by both national and international perspectives. In doing so, it not only contributes to the broader discourse on sustainable energy planning but also establishes a transparent framework to guide policy formulation, investment decisions, and long-term energy security in the country.

1.1. Energy Situation in Sierra Leone

Despite the diverse energy potential in Sierra Leone, which includes biomass derived from agricultural waste, hydroelectricity, and solar energy, these resources remain largely untapped. The predominant source of energy consumption is fuelwood biomass, which constitutes approximately 80 percent of the total energy utilized [17,18,19].

The second most significant energy source is imported petroleum products, primarily used for power generation, accounting for 13 percent of energy consumption [17]. As of 2021, only about 27.5 percent of the overall population and roughly 4.9 percent of the rural population have access to electricity [18]. The power sector is relatively small, with less than 150 MW of energy capacity serving over 270,000 customers, and the cost of electricity is heavily subsidized [19,20]. The nation suffers from an unreliable and unstable public power supply, resulting in domestic demand being largely unmet. The current electricity supply faces challenges related to generation capacity

and seasonal fluctuations, and it is distributed through outdated and insufficient transmission and distribution networks [18,17,20]. The delivery of electricity incurs very high costs, with Sierra Leone experiencing some of the highest electricity tariffs in the sub-region [21,22].

Sierra Leone possesses substantial renewable energy resources, spanning hydropower, solar, biomass, and wind. Hydropower represents the largest potential, with estimates of about 50–60 MW from existing small-scale rivers and up to 4,000 MW of untapped medium- to large-scale hydro potential across major rivers such as the Rokel, Seli, and Moa [23,22]. The primary hydropower facility, Bumbuna Dam, has a peak capacity of 50 MW during the rainy season, but this output diminishes to 8 MW in the dry season [24,18]. Solar irradiance is high, with an average daily global horizontal irradiance of 4–5 kWh/m²/day, making solar PV highly viable for rural electrification and urban supply expansion [25,21]. Solar energy opportunities are estimated to be above 240 MW [22,17].

Biomass resources, primarily from agricultural residues and wood, could theoretically supply over 3,000 GWh/year, though sustainable harvesting and conversion technologies remain limited [26]. Wind energy potential is relatively modest, averaging 4–5 m/s at 50 m height along coastal areas, yet could complement hybrid renewable systems in off-grid communities [22]. Despite these resources, grid-connected renewable penetration remains below 5%, with electricity largely dependent on diesel generators and imported fossil fuels [10].

2. Literature Review

Energy system modeling tools play a crucial role in supporting energy policy formulation and evaluating various energy pathways [27]. The variety of energy modeling tools available is extensive and is consistently growing. Numerous studies have explored the advancements in this area, concentrating on various facets of these models and highlighting the distinct challenges encountered in energy systems analysis. For example, Connolly et al. [2] provide a comprehensive overview of computational modeling tools that can assess the integration of renewable energy sources (RES) within energy systems broadly, based on survey feedback from model developers. In the work of Foley et al. [28], a comprehensive literature review is provided, concentrating exclusively on system models within the electricity sector. In a similar vein, Després et al. [29] review modeling tools that emphasize the integration of variable renewable energy (VRE), primarily within the power sector. More recently, a study conducted by Ringkjøb et al. [5] offers an extensive review of 75 energy and electricity system modeling tools, evaluating their modeling scopes, characteristics, and limitations, while also validating the majority of inputs in collaboration with tool developers. Energy models have been utilized to guide and support the processes of policymaking by analyzing potential energy futures, diverse socio-technical pathways, and various scenarios [3,4,30]. Numerous researchers have examined decarbonization pathways to guide clean energy policy within the context of developing nations. For example, Plazas-Niño et al. [31] employed the OSeMOSYS model to evaluate feasible methods for decarbonizing Colombia's energy sector. The results of the study indicated that the carbon intensity of the energy sector could

potentially decrease by approximately 93%, accompanied by significant reductions in energy intensity, fuel imports, and socio-economic advantages, provided that appropriate energy policies are established.

In Ethiopia, Gabremeskel et al. [32] performed long-term modeling of electricity supply utilizing OSeMOSYS. Their findings indicated that renewable energy (RE) technologies are more competitive and advantageous within the Ethiopian context due to their low costs and plentiful availability. Hydropower is identified as a vital component in the future energy landscape of Ethiopia, alongside solar photovoltaic (PV), concentrated solar power (CSP), wind energy, geothermal energy, and natural gas. Saad et al. [33] utilized the OSeMOSYS tool to enhance energy security and facilitate long-term energy system modeling in Botswana. Their findings highlighted the necessity for significant financial investment to promote renewable energy (RE) deployment. It has been determined that effective RE policies are essential, which encompass the implementation of strategies for the expansion of solar photovoltaic (PV) systems and energy storage, as well as the revision of regulatory frameworks, to support decarbonization and guarantee universal energy access. Furthermore, Vazdanie [34] employed an optimization model to perform an analysis of resilient energy systems in Ghana and China. The author has carried out various analyses to illustrate the incorporation of resilient energy systems in developing areas and the related advantages. Nevertheless, the study points out several limitations and recommends additional analysis to enhance the findings.

Moreover, Akpahou et al. [35] have formulated strategies for sustainable energy planning in the Benin Republic. By integrating natural gas with solar photovoltaic (PV), concentrated solar power (CSP), wind energy, and hydropower, the authors have devised various scenarios that are vital for the country to incorporate a greater share of renewables into the national grid to fulfill its Nationally Determined Contributions (NDC) as stipulated in the Paris Agreement.

The aforementioned studies have illustrated that OSeMOSYS and energy modeling play a crucial role in supporting policy development and analyzing decarbonization pathways in developing nations. Furthermore, to the best of the author's knowledge, this research represents the first instance of utilizing OSeMOSYS (MUIO 5.3), an open-source optimization model, for long-term energy systems in Sierra Leone, incorporating various clean energy resources. This research aims to support researchers, policymakers, and stakeholders in the energy sector by highlighting the potential advantages that may be realized through a shift from conventional energy sources to clean energy technologies, thereby advocating for increased investment in the sector.

3.0 Materials and Methods

The OSeMOSYS software, along with its Model User Interface (MUIO 5.3) version 5.3, has been utilized for this study. This model provides a distinctive benefit of evolving without any financial expenditure within an open-source setting, offering various scenarios essential for decision-makers and policymakers in the energy sector [9]. The model illustrates Sierra Leone's renewable energy

framework, incorporating a range of technologies that convert primary and secondary commodities to meet total electricity demand. OSeMOSYS is an energy modeling system that employs a bottom-up optimization approach, utilizing a comprehensive representation of technologies and flows within the energy system. It takes into account performance, costs, resource utilization, and environmental effects [30]. OSeMOSYS, like other long-term optimization models, operates under the assumption of perfect foresight and ideal competition within energy markets [3]. This implies that it presumes a comprehensive understanding of future circumstances and that energy markets operate in a perfectly competitive fashion. From a mathematical perspective, OSeMOSYS is characterized as a deterministic and linear optimization framework [27]. It has been extensively employed as a long-term optimization framework across many nations [12]. This model determines the most cost-effective method of energy production to satisfy a specified demand, utilizing a range of power generation technologies.

3.2 Model Input Data

A comprehensive summary of the information regarding renewable energy sources in Sierra Leone, as presented in this model and the subsequent sources from which it was obtained, is detailed in IRENA (2023) and ECREEE (2022) [17,36]. The supplementary data incorporated into the model were obtained from publicly accessible sources and through official requests submitted to the relevant energy institutions in Sierra Leone.

Table 1: Annual Electricity Demand (GWh)

Year	2018	2019	2020	2021	2022
Electricity Demand(GWh)	182.08	284.19	250.42	324.91	328.59
Electricity Demand (PJ)	0.66	1.02	0.91	1.169	1.18

The Compound Average Growth Rate for 2019 was assessed, revealing a value of 7.21% under the Business-as-Usual Scenario, while the Renewable Energy Scenario indicated a value of 9.59%. A comprehensive overview of historical and anticipated Gross Domestic Product (GDP) metrics from 2018 to 2028, encompassing total GDP.

Table 2: Historical and Projected Gross Domestic Product (GDP) between 2018 and 2028

GDP (US$ Billion)	2018	2019	2020	2021	2022	2023	2024	2025	2028
GDP Growth Rate % US$ Million	4.09	5.25	-2.0	4.1	3.98	2.75	4.74	5.19	4.6

A summary of historical and anticipated demographic parameters from 2018 to 2030 indicates that the population of Sierra Leone in 2018 was 7.86 million people.

Table 3: Historical and projected demographic parameters between 2019 and 2030

	2019	2020	2021	2022	2023	2024	2025	2030
Population Growth Rate %	2.13	2.09	2.06	2.06	2.06	2.06	2.06	2.07

Table 4: Household Electrification Rate (%)

Country	2018	2019	2020	2021	2022	2023	2025	2030	2040
Urban %	53.2	51.4	55	57	57	57	61.82	73.87	98
Rural %	6.4	4.7	4.7	4.9	4.9	4.9	10.9	26	56

Scenarios

Business As Usual

In a business-as-usual scenario, it is anticipated that Sierra Leone's primary energy consumption will largely rely on imported fuels and hydropower plants nationwide, while the ongoing challenges within the energy sector remain unchanged. Emission regulations are not implemented, and energy sources are forecasted based on past trends, maintaining the same technological ratios and conditions seen in prior years. This scenario serves as a valuable comparative benchmark for evaluating alternative pathways.

Renewable Target Scenario

The Renewable Energy (RE) integration scenario is based on Sierra Leone's ambitious objective of achieving substantial RE penetration by 2040. This scenario examines the required supply mix for Sierra Leone to meet this target at the national level, as well as the contribution of biomass energy to the future energy matrix of Sierra Leone.

3.1. Reference Energy System

The Reference Energy System (RES) serves as a simplified graphical depiction of the renewable energy sources being evaluated in Sierra Leone. It illustrates all current and prospective supply chains that connect primary energy resources to the ultimate energy demand [12]. This model integrates a range of renewable energy sources for electricity generation alongside wind. It encompasses various technologies to illustrate both existing and prospective future energy conversion alternatives [30]. The reference energy system for energy sources in Sierra Leone is shown in Figure 1.
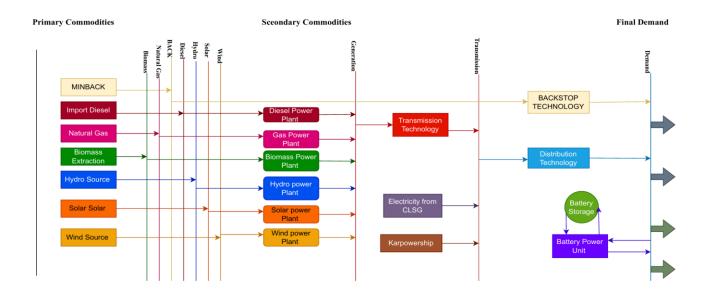
Figure 1: Reference Energy System for Sierra Leone

4.0 Result and Discussion

The modeling outcomes for Sierra Leone reveal contrasting trajectories between the business-as-usual (BAU) and renewable transition (RT) scenarios, with significant implications for energy security, sustainability, and economic resilience.
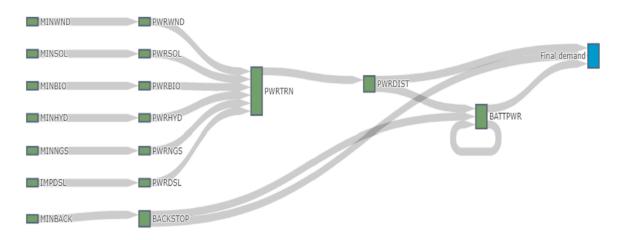

Figure 2: Modelled Diagram of the Energy System in Sierra Leone

In the BAU scenario, as shown in Figure 3, diesel (DSL) and thermal-based generation dominate the mix, accounting for more than 60% of total production throughout most of the projection period. Hydropower (HYD) contributes moderately, while solar (SOL) and wind (WND) remain marginal. Transmission and system losses also remain significant, reducing efficiency. This

structure underscores the continuation of fossil fuel dependence, exposing Sierra Leone to global petroleum market volatility, foreign exchange burdens, and environmental externalities. The lack of substantial diversification reflects the systemic inertia associated with fossil reliance and limited renewable integration, as also observed in regional analyses of Sub-Saharan energy systems [8]. By contrast, the Renewable Target scenario presents a gradual but transformative rebalancing of the energy mix. The share of diesel steadily declines, offset by increased contributions from solar, wind, and expanded hydropower. By 2039, renewables collectively account for over 50% of total generation, compared to less than 35% in the BAU trajectory. Notably, solar's role expands consistently, reflecting both falling global technology costs and Sierra Leone's high solar irradiation potential. Wind penetration also appears modest but progressive, while natural gas (NGS) plays a stabilizing role. Importantly, transmission and generation efficiency improve relative to the BAU scenario, highlighting system-level gains from diversification and decentralization. This transition aligns with Sierra Leone's national energy policies and regional ECOWAS Renewable Energy Strategy, while also contributing toward Sustainable Development Goal 7 [17,36].
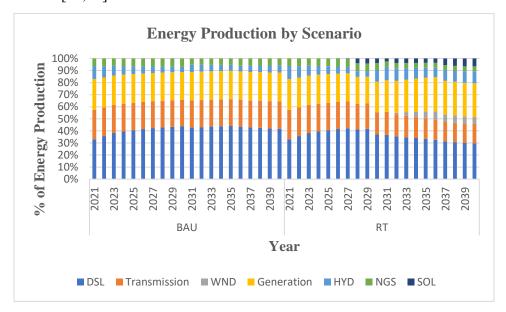

Figure 3: Energy Production by Scenario

Overall, the comparative scenarios demonstrate that while BAU perpetuates fossil fuel dependence and macroeconomic vulnerability, the RT pathway provides a credible route to resilience, sustainability, reduced import dependence, and improved energy security. The discussion reinforces that achieving such gains, however, depends on overcoming barriers such as financing, policy uncertainty, and infrastructure deficits.

The analysis of energy production by technology between 2021 and 2040, as shown in Figure 4, reveals two distinct trajectories under the energy import–dependent pathway and the renewable-based pathway.

In the import-dependent pathway, overall energy production increases steadily from approximately 120 GWh in 2021 to over 450 GWh by 2039. This growth, however, is largely driven by fossil-based generation, particularly diesel (DSL) and natural gas (NGS). Diesel maintains a substantial share throughout the period, with backup and thermal generation also contributing significantly. Hydropower (HYD) shows only modest growth, while contributions from solar (SOL) and wind (WND) remain negligible. This configuration underscores a structural reliance on fossil imports, exposing Sierra Leone to international fuel price volatility, foreign exchange risks, and supply insecurity. The trajectory is consistent with the "business-as-usual" (BAU) scenario identified in other Sub-Saharan African studies, where fossil fuels dominate energy mixes despite rising environmental and fiscal costs [8].

By contrast, the renewable-based pathway demonstrates a markedly different composition of the energy mix by 2039. Total generation rises in parallel with the import-dependent case, reaching close to 480 GWh, but with a diversified portfolio. Hydropower, solar, and wind increase progressively, with solar and hydro making particularly strong contributions from the late 2020s onward. Diesel and backup generation decline proportionally, while natural gas stabilizes at a marginal role. The visible expansion of renewables not only reduces dependency on imported fuels but also improves the sustainability of the system by lowering greenhouse gas emissions and diversifying supply sources. This aligns with Sierra Leone's commitments under its Nationally Determined Contributions (NDCs) and the regional ECOWAS Renewable Energy Policy [36].
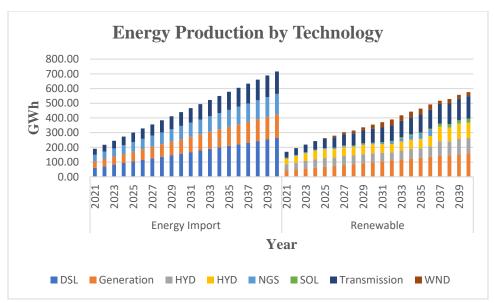

Figure 4: Energy Production by Technology

By 2039, the divergence between the two scenarios is particularly evident. In the import-dependent pathway, fossil fuels (diesel and natural gas combined) account for roughly 65–70% of total energy production, while renewables (hydro, solar, and wind) make up less than 30–35%**.** In contrast, under the renewable-based pathway, the balance shifts significantly: renewables contribute nearly
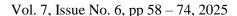
55–60% of generation, led by hydropower and solar, while fossil fuels are reduced to around 40–45%**.** This structural shift demonstrates the extent to which renewable integration can alter Sierra Leone's energy security profile, transforming the system from one reliant on imported petroleum products to one anchored in indigenous, low-carbon resources.

The comparative analysis highlights several implications. First, while both scenarios deliver higher total energy output, the composition matters greatly for long-term security and sustainability. An import-driven model risks perpetuating macroeconomic vulnerability and carbon lock-in, whereas a renewable-led model fosters resilience, local job creation, and alignment with Sustainable Development Goal 7 [17]. Second, the renewable trajectory enhances grid reliability by integrating variable sources, though it requires complementary investment in storage, transmission, and regulatory frameworks to mitigate intermittency risks. Finally, the progressive increase in renewables signals a window of opportunity for Sierra Leone to leverage its abundant natural resources to reduce fossil import dependence while achieving a just and inclusive energy transition.

 The analysis of energy production trends in Sierra Leone from 2021 to 2039 reveals distinct patterns across the Business-as-Usual (BAU) and Renewable Transition (RT) pathways. Across both trends, renewable energy sources, primarily solar (SOL), hydropower (HYD), and wind (WND), demonstrate consistent growth over the study horizon. Under the energy import trend, renewable generation grows moderately, with solar emerging as the dominant renewable contributor, followed by hydropower. Wind energy increases more slowly but still registers a steady upward trajectory. In the Renewable trend, however, renewable growth is significantly accelerated, particularly after 2027. Solar experiences rapid expansion, surpassing 500GWh by 2039, while hydropower and wind also grow substantially.

The RT pathway underscores the transformative potential of renewable energy as the backbone of Sierra Leone's energy future, with renewables contributing the vast majority of projected generation capacity. In contrast, under the Energy Import trend, Diesel (DSL) and natural gas (NGS) fuels that are primarily imported into Sierra Leone show contrasting trends compared to renewables. In the energy Import Trend, diesel generation increases only modestly, maintaining a marginal share of the mix, while natural gas grows slightly but remains secondary. In the Renewable Trend, reliance on fossil fuels is further minimized: diesel remains relatively flat, and natural gas contributes only a limited role in total generation. This trend illustrates a deliberate reduction in fossil fuel dependency, which in practice translates to lower energy import requirements. By 2039, fossil fuels will represent only a small fraction of overall generation under RT, compared with the more visible role they retain under Energy Import.
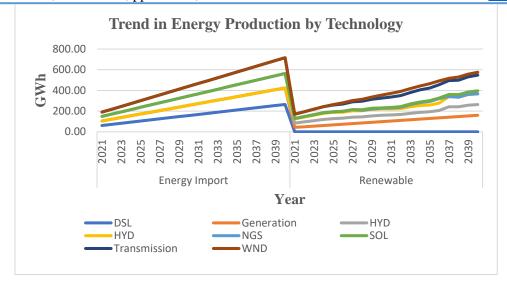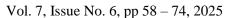
Figure 5: Trend in Energy Production by Technology

The divergence between Energy Import and Renewable trends highlights a critical strategic choice. Under Energy Import, fossil fuels continue to play a significant role in electricity production, perpetuating a high degree of dependency and vulnerability to international fuel price fluctuations. In contrast, the Renewable pathway projects a decisive shift toward energy self-reliance, with renewables contributing the bulk of the electricity supply.

This confirms that Saad et al. [33] applied the OSeMOSYS model to enhance energy security and support long-term energy planning in Botswana. Their findings underscore the need for significant financial investment to promote renewable energy deployment. The study highlights that comprehensive policies, including the expansion of solar photovoltaic systems, integration of energy storage, and updates to regulatory frameworks, are essential to advance decarbonization and achieve universal energy access. This aligns with Sierra Leone's energy policy goals to reduce fuel imports, strengthen energy security, and promote sustainable growth.

5.0 Conclusion and Recommendations

The modeling results underscore the centrality of renewable energy in advancing Sierra Leone's energy security and sustainability agenda. Scenarios integrating solar, hydro, and biomass resources demonstrate substantial potential to reduce dependence on imported petroleum products, thereby enhancing resilience against international fuel price volatility. In addition to lowering greenhouse gas emissions, renewable pathways support broader socio-economic objectives by expanding electricity access, particularly in underserved rural regions, while contributing to job creation and technology transfer. The analysis confirms that a diversified renewable portfolio, supported by grid modernization and storage systems, offers a cost-effective and environmentally sustainable alternative to fossil fuel dependence. Under the business-as-usual scenario, import dependence is projected to rise in tandem with demand, reinforcing fiscal pressures and widening

the trade deficit. Conversely, renewable energy pathways show that scaling up solar, hydro, and biomass resources could reduce energy import requirements by up to 60% by 2040, with the most significant reductions occurring in scenarios that prioritize decentralized renewable deployment and grid expansion.

This reduction in import dependence carries broader implications for energy security, macroeconomic stability, and sustainable development. Lower reliance on energy imports not only insulates Sierra Leone from global market shocks but also improves the balance of payments, freeing fiscal space for social and infrastructural investments. Moreover, the shift toward indigenous renewable resources enhances supply reliability, especially in rural areas where imported diesel is often prohibitively expensive and logistically challenging to deliver. However, achieving these gains requires addressing systemic challenges such as financing constraints, grid bottlenecks, and the need for effective regulatory frameworks. The analysis clearly indicates that the Renewable Transition (RT) pathway is not only more aligned with Sierra Leone's national sustainable development goals but also consistent with international climate commitments such as the Paris Agreement. By harnessing its abundant renewable potential, Sierra Leone can achieve universal electricity access, reduce vulnerability to external fuel price shocks, and lay the foundation for green economic growth.

Recommendations

To operationalize the Renewable Transition (RT) pathway, a set of strategic interventions is required. Central to this transition is the large-scale deployment of renewable energy technologies, particularly through expanded investments in utility-scale solar photovoltaic (PV) projects, hydropower, and decentralized mini-grids to accelerate rural electrification. Complementing this expansion, robust policy and regulatory frameworks must be established to provide stable investment incentives, enforce renewable energy standards, and promote transparent power purchase agreements, thereby reducing investor risk and fostering market confidence. Equally important is the modernization and extension of transmission and distribution infrastructure to enable the effective integration of intermittent renewable sources and minimize technical losses across the grid. In parallel, measures should be taken to avoid carbon lock-in by restricting new fossil fuel-based generation, especially diesel and natural gas, to roles in system balancing and backup supply only. Regional integration also offers substantial benefits, with deeper participation in the West African Power Pool (WAPP) providing opportunities for cross-border electricity trade, cost reduction, and enhanced system resilience. Finally, sustained investment in human capital through training programs and institutional capacity building is vital to ensure the effective planning, operation, and long-term maintenance of renewable energy systems. Collectively, these strategies form a comprehensive approach to advancing decarbonization while securing universal and sustainable energy access.

Future Work

While this study provides valuable insights into potential energy futures, further research is needed to refine the understanding of Sierra Leone's transition pathways. First, future modeling efforts should address climate and resource variability, particularly hydrological fluctuations and the intermittency of solar and wind resources under different climate change scenarios. Second, beyond technical feasibility, more attention should be given to the economic and social implications of renewable energy expansion, including its potential for job creation, affordability, and poverty reduction. Finally, the role of emerging technologies such as battery storage and digital grid management should be explored, as these innovations could significantly influence long-term pathways toward a resilient and sustainable energy system.

Acknowledgement

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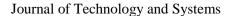
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