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The Role of Electricity Transmission and a Stable Grid in Kenya's Energy Transition

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ABSTRACT

The transition to renewable energy sources is crucial for Kenya's sustainable development, yet the effectiveness of this transition hinges on the robustness of the nation's electricity transmission and grid stability. This paper explores the critical role that a reliable electricity transmission infrastructure plays in facilitating Kenya's energy transition, emphasizing the need for a stable grid to support the integration of renewable energy technologies. The paper examines current transmission networks, identifying key challenges such as grid reliability, transmission losses, and infrastructural bottlenecks. It evaluates the potential of renewable energy resources like solar, wind, and geothermal, and their integration into the national grid. Furthermore, the paper assesses existing initiatives aimed at upgrading transmission infrastructure and enhancing grid stability, including smart grid technologies and cross-border interconnections. Technological innovations, such as energy storage systems and advanced grid management software, are analyzed for their potential to mitigate intermittency issues associated with renewable energy sources. The study also explores the socio-economic impacts of a stable grid, focusing on improved energy access, economic growth, and job creation in urban and rural areas. Case studies from successful implementations within Kenya and other comparable regions provide insights into best practices and effective strategies for strengthening grid infrastructure. The paper discusses the policy frameworks and regulatory measures necessary to support these advancements, offering strategic recommendations to policymakers and stakeholders. In conclusion, this paper presents a comprehensive roadmap for enhancing electricity transmission and grid stability in Kenya, aligning with the country's Vision 2030 and global climate commitments. By addressing the infrastructural and technological challenges, Kenya can achieve a more resilient and efficient energy system, crucial for its sustainable energy transition.

Keywords: Energy transition, electricity transmission, stable grid, Kenya, renewable energy, grid infrastructure, technological innovations, energy access, sustainable development, policy frameworks.

INTRODUCTION

The global energy sector is undergoing a profound transformation in the face of escalating climate change and the urgent need for sustainable development. Countries worldwide are transitioning from fossil fuel-based energy systems to cleaner, renewable energy sources. This transition aims to reduce greenhouse gas emissions, enhance energy security, and create sustainable economic growth. As part of this global movement, Kenya is making significant strides in reshaping its energy landscape, aligning with its Vision 2030 development blueprint.

CONTEXT AND BACKGROUND

The global energy transition is characterized by a shift from traditional, carbon-intensive energy sources to renewable and sustainable alternatives. According to the International Renewable Energy Agency (IRENA), renewable energy capacity has increased significantly over the past decade, driven by falling costs and supportive policies (IRENA, 2021). Key trends include the rapid growth of wind, solar, and hydropower projects, advancements in energy storage technologies, and the digitalization of energy systems. The International Energy Agency (IEA) reports that renewable energy accounted for nearly 90% of the global power capacity increase in 2020 (IEA, 2021).

These trends are not only driven by technological advancements but also by international commitments to climate goals. The United Nations Environment Programme (UNEP) highlights the role of the Paris Agreement in accelerating the adoption of renewable energy, as countries commit to reducing their greenhouse gas emissions (UNEP, 2020). Moreover, the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), underscore the importance of transitioning to sustainable energy systems to combat climate change and ensure universal access to clean energy.

Electricity transmission plays a crucial role in the global energy transition, ensuring that renewable energy generated in remote areas can be delivered to consumers efficiently and reliably. According to the IEA, a robust and resilient transmission network is essential for integrating variable renewable energy sources like wind and solar, which are often located far from population centres (IEA, 2021). Innovations in grid technology, such as advanced grid management systems, high-voltage direct current (HVDC) lines, and smart grids, are enhancing the stability and resilience of electricity transmission systems worldwide.

Objectives of the Paper

Broad Objective

To assess the role of reliable electricity transmission infrastructure in supporting Kenya’s energy transition, with a focus on their impact on renewable energy integration, grid stability, and the broader challenges and opportunities associated with their development.

Specific Objectives

i. To explore the critical role of electricity transmission in Kenya's energy transition
ii. To analyse the impact of grid stability on renewable energy integration
iii. To explore the challenges and opportunities associated with transmission systems in Kenya's energy transition

Scope of the paper

This paper examines the essential role of electricity transmission and grid stability in Kenya's shift towards renewable energy. It starts with a global overview of current energy transition trends and places Kenya's efforts within the larger context of Africa's Agenda 2063 and the African Renewable Energy Initiative. The focus then shifts to Kenya’s energy transition goals under Vision 2030 and the progress made towards incorporating renewable energy sources.

The analysis identifies key challenges facing Kenya's electricity transmission infrastructure, including technical, economic, regulatory, and operational barriers that impede the effective integration and distribution of renewable energy. Case studies of projects like the Lake Turkana Wind Power (LTWP) and the Garissa Solar Power Plant are used to highlight these challenges.

The paper also explores innovative technologies and solutions being implemented to enhance electricity transmission and grid stability in Kenya, such as High Voltage Direct Current (HVDC) systems and smart grids. It assesses how these innovations contribute to the resilience of Kenya's energy grid and support the country’s renewable energy objectives.

Further, the paper aligns Kenya’s energy transition efforts with international climate commitments, particularly the Paris Agreement and the Sustainable Development Goals (SDGs), focusing on SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

Finally, the paper reviews Kenya’s policy and regulatory framework supporting renewable energy and grid stability and provides policy recommendations to improve the integration and distribution of renewable energy. This comprehensive analysis aims to highlight the role of electricity transmission and grid stability in achieving Kenya's sustainable energy future.

METHODOLOGY

This study employed a comprehensive methodology to assess the role of transmission infrastructure in enhancing energy security, promoting economic growth, and ensuring social inclusivity. The approach adhered to conventional research ethics and standards, incorporating a multi-faceted analysis that included a literature review, technical document analysis, case study examination, and policy and legislative review.

LITERATURE REVIEW

The literature review aimed to assess the existing body of knowledge regarding the impact of transmission infrastructure. Peer-reviewed journals, academic books, reports from reputable organizations, and relevant case studies were meticulously examined. Comprehensive searches were conducted in academic databases and digital libraries to identify relevant studies. These studies were selected based on their relevance to the research questions, and key findings were extracted and synthesized. This process ensured proper citation and adherence to ethical standards, including accurate attribution and avoidance of plagiarism.

Review of Technical Documents

This phase focused on understanding the current status and impact of transmission infrastructure through an analysis of official documents from the Ministry of Energy and Petroleum (MoEP) and its associated utilities. Technical reports, strategic plans, project evaluations, policy papers, and legislative tools were reviewed to gather insights into the technical and social aspects of transmission infrastructure. Documents were collected through formal channels, and a systematic analysis was performed to extract relevant details. The data was handled ethically, with confidentiality respected where applicable, and findings were analyzed for their implications on energy security and social inclusivity.

Case Study Analysis

To illustrate the practical impact of transmission projects, the study included a detailed analysis of case studies, specifically focusing on the Kenya-Tanzania power line project. Case studies were identified and reviewed to provide real-world examples of how transmission systems affect energy security and social inclusivity. Project documentation, stakeholder reports, and impact assessments were analyzed to ensure that the data was represented accurately and transparently, maintaining high ethical standards throughout the analysis.

Policy and Legislative Review

The policy and legislative review aimed to evaluate the influence of policy papers and legislative tools on the development and implementation of transmission infrastructure. Relevant policy papers and legislative documents related to energy and infrastructure were reviewed to understand their impact on transmission system development and social inclusivity. The analysis focused on how these policies and tools shaped the planning and execution of transmission projects, ensuring that the handling of information adhered to ethical guidelines.

This methodology provided a thorough, transparent, and ethically sound examination of the role of transmission systems in achieving energy security, economic growth, and social inclusivity.

Energy Transition Policy and Legal Framework

Guiding Principles

The guiding principles of Kenya's energy transition provide a framework for achieving a sustainable and equitable energy system. These principles address environmental sustainability, economic impacts, energy costs, employment (job creation), energy security, and social inclusivity to ensure a comprehensive approach to transitioning towards a low-carbon future.

Table 0.-1: Energy Transition Guiding Principles

Guiding Principle	Goal	Objective
Environmental Sustainability	Reduce carbon emissions to achieve Net Zero and minimize Kenya's overall carbon budget.	Align with international investor expectations for sustainable development.
Energy System Costs	Minimize energy costs for the Kenyan population and energy-dependent domestic sectors.	Ensure affordability and economic viability of the energy system.
Economic Impact	Optimize macroeconomic benefits by supporting economic activity in the energy sector and the broader economy.	Foster economic growth through sustainable energy investments.
Employment Impact	Retain existing jobs and create new job opportunities through the decarbonization of Kenya's economy.	Enhance employment prospects in the evolving energy sector.
Energy Security and Trade Balance	Ensure energy system security through self-sufficiency, stability, and low-risk access to suppliers.	Strengthen energy security and improve trade balance by reducing dependence on energy imports.
Social Inclusivity and Just Transitions	Ensure the energy transition is fair and inclusive for all segments of society.	Address energy poverty, provide affordable energy solutions, and involve local communities in decision-making processes.

Policy and Legal Framework

Kenya is at the forefront of the energy transition in Africa, with ambitious goals outlined in its Vision 2030 strategy. Vision 2030 outlines Kenya's long-term development agenda, focusing on transforming the country into a newly industrializing, middle-income nation. A crucial component of this vision is the transition to a sustainable energy system.

Kenya is one of the leading nations in Africa Africa's quest towards a 100% energy transition. Kenya aims to attain 100% transition by 2030, with a sustainable energy system with a focus on renewables, reducing fossil fuel dependence, and achieving universal electricity access. Key investments include geothermal, wind, and solar projects. KETRACO has been expanding the grid to integrate renewable sources and ensure stability. However, without additional action, energy-related emissions could rise from 20 Mt CO2e in 2021 to 130 Mt CO2e by 2050, mainly from transport and industry. Achieving Net Zero by 2050 will require significant investments, estimated at USD 600 billion, and the implementation of low-carbon technologies such as renewables and clean cookstoves (GoK, 2023).

Other key policy and legal documents are provided in the table below: -

Table 0-2: Pertinent Policy and Legal Framework Documents

Policy/Act/ Policy document	Description
Energy Act (2019)	Consolidates laws related to energy in Kenya; establishes institutions for the regulation and promotion of renewable energy; aims to facilitate the use and ensure the sustainable production and consumption of renewable energy sources.

Climate Change Act (2016 & 2023 amendments)	Provides a regulatory framework for enhanced response to climate change; establishes the National Climate Change Council to coordinate climate actions and guide the transition to a low-carbon economy.
Vision 2030	National development blueprint aiming to transform Kenya into a newly industrializing, middle-income country by 2030; emphasizes the development of renewable energy and expansion of electricity transmission infrastructure.
National Energy Policy (2018)	Ensures affordable, sustainable, and reliable energy supply to meet national and county development needs; focuses on promoting renewable energy sources and modernizing the transmission network to improve grid stability and reliability.
National Climate Change Action Plan (NCCAP) 2018-2022	Outlines strategies to reduce greenhouse gas emissions and enhance climate resilience; includes measures for scaling up renewable energy and improving energy efficiency, aligning with international commitments under the Paris Agreement.
Kenya's Nationally Determined Contributions (NDCs)	Commitment under the Paris Agreement to reduce greenhouse gas emissions by 32% by 2030 relative to the Business-As-Usual (BAU) scenario; emphasizes the importance of renewable energy and efficient energy systems in achieving national and global climate goals.
Renewable Energy Regulations (2021)	Provides guidelines for the development, management, and use of renewable energy resources; aims to encourage investment in renewable energy projects and ensure sustainable exploitation of these resources.
Kenya Electricity Transmission Company (KETRACO) Strategic Plan/ Transmission Master Plan	Outlines the expansion of the national grid to connect renewable energy projects to the main transmission network; aims to improve grid reliability and support the integration of renewable energy into the national grid.

Alignment with Global Statutes

Kenya's energy transition aligns with global commitments to climate action and sustainable development, notably the Paris Agreement (2015), which aims to limit global warming to well below 2°C with efforts to keep it to 1.5°C by transitioning to low-carbon energy systems (UNFCCC, 2015). This transition also supports Africa's Agenda 2063, which emphasizes renewable energy for economic transformation and sustainable development (African Union Commission, 2015). Furthermore, Kenya's efforts contribute to the African Renewable Energy Initiative's goal of achieving 300 GW of renewable energy capacity by 2030, demonstrating a commitment to both continental and global sustainability goals (AREI, 2015).

Additionally, international frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Climate Action Agenda emphasize the importance of energy transition in achieving a low-carbon future. Kenya's proactive approach in expanding its renewable energy capacity and enhancing its transmission network reflects its commitment to these international laws and agreements.

Alignment with the SDGs

Kenya's energy transition strategy is closely aligned with several SDGs. The country's commitment to increasing the share of renewable energy in its energy mix directly supports SDG 7 (Affordable and Clean Energy), aiming to ensure access to affordable, reliable, sustainable, and modern energy for all. By focusing on renewable energy sources such as geothermal, wind, and solar power, Kenya also contributes to SDG 13 (Climate Action), which emphasizes urgent actions to combat climate change and its impacts (United Nations, 2015). The expansion of electricity transmission infrastructure, facilitated by the KETRACO, supports SDG 9 (Industry, Innovation, and Infrastructure), promoting resilient infrastructure and fostering innovation for sustainability.

RESULTS AND DISCUSSION

Electricity Transmission Baseline

Kenya's national electricity transmission network plays a crucial role in the country's energy transition, facilitating the delivery of power from generation sites to distribution networks and end-users. The transmission network operates at three primary voltage levels: 132kV, 220kV, and 400kV, ensuring efficient and reliable power delivery across the nation.

As outlined in the Transmission Master Plan (Kenya Electricity Transmission Company, 2023), the total length of Kenya's transmission network is approximately 9,105 km. Of this, the Kenya Electricity Transmission Company Limited (KETRACO) owns and operates about 61.92%, equating to 5,638 km. This network includes 1,206 km of 132kV lines, 718.8 km of 220kV lines, 2,431 km of 400kV lines, and 1,282 km of 500kV lines. These extensive transmission lines are pivotal in linking various power generation sources, such as hydroelectric, geothermal, wind, and solar, to the national grid, thereby supporting the country's diverse energy mix.

KETRACO has made significant advancements in enhancing the transmission infrastructure. The company has completed and commissioned 42 new substations with a total capacity of 6,396 MVA (Mega Volt Amperes), along with 31 bay extensions as of 2023. These substations are critical for stepping up or stepping down voltage levels to match the requirements of different regions and for maintaining grid stability.

The integration of renewable energy (RE) sources into the grid is a central component of Kenya's energy transition strategy. The transmission network facilitates the incorporation of RE sources by connecting large-scale projects like the Lake Turkana Wind Power project and the Garissa Solar Power Plant to the national grid. Currently, Kenya's grid has an installed capacity of approximately 2,819 MW from renewable sources, which includes geothermal, wind, hydro, and solar power (Government of Kenya, 2023). This integration is essential for reducing reliance on fossil fuels and achieving sustainable energy goals.

The completed transmission lines have successfully achieved multiple objectives. These include facilitating power evacuation, supplying new load centres, connecting regions previously not connected to the grid, reinforcing the existing transmission network, and enhancing power trade through regional interconnectors to enhance system reliability and efficiency. Furthermore, KETRACO is actively developing additional transmission projects.

These projects focus on power evacuation, grid strengthening, and establishing regional interconnectors, thereby supporting the continuous improvement and expansion of Kenya's electricity transmission infrastructure. Key to these developments is the facilitation of the decommissioning of thermal power generators, especially in Kenya's northern and coastal areas, hence hastening the national progress towards 100% renewable energy integration by 2030.

Prevailing Challenges and Issues

Grid Reliability and Frequent Outages

Globally, grid reliability remains a critical issue as ageing infrastructure and rising electricity demand lead to frequent outages and instability. In the United States, outdated infrastructure combined with natural disasters contributes to numerous power outages annually (U.S. Department of Energy, 2021). South Korea and South Africa also face similar challenges, with frequent outages impacting economic activities and quality of life.

In Kenya, grid reliability issues are prominent, with frequent outages and voltage instability complicating system stability during operations (Odhiambo, 2020). These instabilities often manifest as over-voltages, under-voltages, over-frequency, and under-frequency, leading to inefficiencies, potential infrastructure damage, and high maintenance costs, especially around protection engineering. These reliability issues impede the energy transition by undermining the stability needed to integrate renewable energy sources, which require a dependable grid to function effectively.

Infrastructural Bottlenecks and Capacity Constraints

Infrastructural bottlenecks and capacity constraints further exacerbate grid reliability issues. Beyond aging infrastructure, challenges such as inadequate financing, insufficient infrastructure, bureaucratic hurdles, and regulatory barriers impede the development and modernization of power grids. Europe, for instance, contends with aging power grids requiring significant investment for upgrades and modernization (European Commission, 2020).

In Kenya, these bottlenecks lead to increased maintenance costs, frequent downtimes, higher failure risks, reduced efficiency, and poor power quality. Insufficient investment in modernizing the grid, coupled with the slow pace of infrastructure development, makes it challenging to meet growing electricity demands and integrate new renewable energy sources effectively (Mwangi et al., 2019). These infrastructural challenges hinder the energy transition by limiting the grid's capacity to accommodate renewable energy, thus delaying the shift to a more sustainable energy system. Addressing these issues is essential for improving grid reliability, reducing outages, and facilitating a smoother transition to renewable energy sources.

Transmission Losses and Inefficiencies

Transmission losses significantly impede the energy transition, particularly in developing nations such as Kenya. High transmission and distribution losses, estimated globally at around 8% by the International Energy Agency (IEA, 2020), reduce the overall efficiency of power systems, necessitating increased generation to meet demand. This inefficiency leads to higher operational costs and increased electricity prices, diverting funds away from renewable energy investments (Kiplagat et al., 2020).

Overloading of transmission lines, particularly evident in Kenya's western region, exacerbates reliability issues, causing blackouts and equipment failures, which undermine grid stability and deter renewable energy projects. Furthermore, compensating for transmission losses often involves fossil fuel-based generation, increasing greenhouse gas emissions and counteracting carbon reduction efforts. Consequently, addressing transmission losses through infrastructure upgrades and advanced technologies is essential for enhancing grid efficiency, reliability, and the integration of renewable energy, thereby facilitating a smoother energy transition (Kiplagat et al., 2020; IEA, 2020).

Grid Connectivity

Grid connectivity remains a significant issue, particularly in rural and remote areas. Globally, approximately 770 million people still lack access to electricity, with Sub-Saharan Africa accounting for about 75% of this population (IRENA, 2021). In Kenya, despite efforts to expand the grid, many regions remain unconnected or underserved, hindering economic development and equitable energy distribution. Currently, Kenya's electrification rate is about 75%, leaving a substantial portion of the population without reliable electricity access (Republic of Kenya, 2020). The northern regions of Kenya remain largely off-grid despite indications of growing demand (KETRACO, 2023). This lack of connectivity poses a significant barrier to the energy transition, as it prevents the widespread adoption of renewable energy solutions and limits the benefits of electrification for economic growth and development.

Climate Resilient Infrastructure

The resilience of power grids to environmental factors is increasingly important as climate change and extreme weather events cause significant damage to infrastructure worldwide. Countries like the United States, Japan, and Australia have experienced severe impacts from hurricanes, floods, and heat waves (UNEP, 2021). In Kenya, extreme weather events such as heavy rains, floods, storms, and rising temperatures cause significant damage to transmission infrastructure. If left unchecked, these factors can lead to prolonged outages and costly repairs. Additionally, the intermittent nature of renewable energy sources like solar and wind adds complexity to maintaining grid stability (Cheruiyot et al., 2021). Enhancing the climate resilience of power infrastructure is crucial for ensuring reliable energy supply and facilitating the integration of renewable energy sources, thereby supporting the overall energy transition.

Financing Challenges

Limited Funding and Investment in Transmission Infrastructure

Developing Kenya's electricity transmission infrastructure faces significant challenges due to limited funding and investment. Upgrading and expanding the grid is capital-intensive, requiring substantial financial resources that are often constrained by competing national priorities and limited budget allocations (World Bank, 2019). Attracting private sector investment is difficult due to perceived risks and regulatory uncertainties. There is a global need to triple investment in the transmission sector to implement 50 miles of transmission lines by 2040, with an estimated requirement of $600 million by 2030 (Clifford, 2023).

Forecasts project electricity demand in Kenya to grow from 2,036 MW to 5,757 MW by 2041 under the reference scenario, with an interconnected installed capacity rising from 2,919.2 MW in 2021 to 8,204.8 MW by 2041. To meet this demand, the transmission network needs to expand by approximately 7,018 km in route length and 18,474 MVA in transformation capacity by 2041. The total investment requirement for the Transmission Master Plan (TMP) is estimated at USD 4,599.21 million, with only USD 1,280.85 million secured, creating a financing gap of approximately USD 3,318.35 million (TMP, 2024).

Dependency on External Funding

Kenya's reliance on external funding from international donors and financial institutions adds another layer of complexity. While these sources provide critical support, they often come with conditions that may not always align with national priorities or timelines, leading to delays and inconsistencies in project implementation (African Development Bank, 2020).

Intermittency of Renewable Energy Sources

Variability in Power Supply

In Kenya, the integration of renewable energy sources such as solar and wind presents challenges like those experienced globally. The intermittent nature of these sources, which are highly dependent on weather conditions, complicates efforts to ensure a stable and reliable power supply. The variability in renewable energy generation can lead to fluctuations in grid stability and reliability. To address these challenges, Kenya requires advanced grid management technologies and strategies to effectively balance supply and demand. The Ministry of Energy and Petroleum (MoEP) is working on enhancing grid infrastructure and integrating renewable sources, but managing this variability remains a critical issue (TMP, 2024).

Need for Energy Storage Solutions

To address the challenges of renewable energy variability, the development and deployment of energy storage solutions are crucial. However, the high cost and limited availability of advanced storage technologies, such as batteries, pose significant barriers. Energy storage is essential for smoothing out fluctuations in power supply and enhancing the reliability of renewable energy integration. In Kenya, while there have been efforts to explore energy storage solutions, the required scale of investment and technological advancement remains substantial. The lack of adequate storage infrastructure could impede the transition by preventing efficient utilization of renewable energy resources and undermining grid stability (IRENA, 2021; IEA, 2020).

Project Acceptability and Community Perception

The development of electricity transmission infrastructure in Kenya faces challenges related to project acceptability and community perception. Transmission lines and associated infrastructure are often situated in areas that are remote from major urban centres, leading to feelings of neglect among local communities. These communities may perceive such projects as benefiting distant urban areas while they bear the environmental and social impacts. This perception can lead to resistance and hinder project development, thus impeding the energy transition. Addressing these concerns through effective community engagement and benefit-sharing strategies is essential for improving project acceptability. Ensuring that local populations see tangible benefits from energy projects and actively involving them in the planning process can help overcome resistance and facilitate the successful implementation of energy infrastructure projects (Mwangi et al., 2019).

Environmental and Social Challenges

Impact on Avifauna and Habitat Fragmentation

The construction and operation of transmission lines in Kenya pose significant environmental challenges, particularly concerning avifauna and habitat fragmentation. Birds are at risk of collision with power lines, leading to fatalities that impact avian populations. Additionally, the installation of transmission lines in critical habitats, such as forests and wildlife sanctuaries, can fragment ecosystems and disrupt wildlife populations. This disruption can result in the loss of biodiversity and adverse effects on ecological balance. To mitigate these impacts, comprehensive environmental impact assessments (EIAs) and effective mitigation measures are essential. Ensuring that environmental considerations are integrated into planning and operational phases is crucial to minimize ecological damage (Kiplagat et al., 2020; UNEP, 2021).

Nature of Compensation and Easements

In Kenya, the compensation process for land affected by transmission lines often involves establishing easements rather than full land acquisition. This approach can lead to dissatisfaction among landowners, as compensation typically reflects the impact on land use rather than its full market value. As a result, landowners may perceive the compensation as inadequate, leading to resistance against transmission projects. Addressing these concerns requires ensuring fair and transparent compensation processes that comprehensively address the impact on landowners' rights and interests. Effective engagement with affected communities and equitable compensation is critical for overcoming resistance and facilitating the development of transmission infrastructure (Republic of Kenya, 2020).

Slow Development of Research and Development (R&D)

The slow pace of research and development (R&D) in Kenya's energy sector hampers the advancement of innovative technologies necessary for improving transmission infrastructure. Investment in R&D is often insufficient, limiting the exploration and implementation of new technologies that could enhance grid stability and efficiency. Additionally, the lack of coordinated collaboration and knowledge sharing between research institutions, industry stakeholders, and government agencies further impedes progress. Increasing investment in R&D and fostering collaboration can drive innovation and ensure that the latest technological advancements are effectively utilized to address transmission challenges (Karekezi & Kithyoma, 2021; Odongo et al., 2019).

Regulatory and Policy Barriers

Regulatory and policy barriers in Kenya pose significant challenges to the development and modernization of the electricity transmission network. Inconsistent regulations, bureaucratic delays, and unclear policies create an uncertain environment for investors and developers. Streamlining regulatory frameworks and implementing clear, supportive policies are essential for facilitating infrastructure development and attracting investment. Addressing these regulatory challenges is crucial for advancing Kenya's energy transition and ensuring the successful implementation of transmission projects (Kiplagat et al., 2020).

Technical Skills and Workforce Development

The development and maintenance of transmission infrastructure in Kenya also faces challenges related to technical skills and workforce development. There is a need for adequately trained personnel to manage and operate advanced technologies. Building capacity through targeted training programs and educational initiatives is vital for ensuring that the workforce can effectively support the evolving needs of the transmission sector. Enhancing technical skills and workforce development is crucial for the successful implementation and management of advanced transmission systems (Republic of Kenya, 2020).

Table 0-1: Transmission Sector Challenges Matrix

S. No	Challenges	Causes	Mitigation
1.	Over - voltages at receiving ends Over voltages during low loads Technical losses	Long transmission lines to load centres from generation locations. Low loads during off peak periods	Reactive power compensation study was carried, and the below recommendations are being implemented: - Installation of Reactors Installation of Fast acting reactive power compensation devices i.e. Statcoms/Static Var Generators (SVGs) in Suswa and Rabai.
2.	High loading of transmission infrastructure and curtailment of generation	Insufficient transmission capacities	Fast track completion of ongoing projects: - Ndhiwa- Sondu, Turkwel-Ortum-Kitale 220kV Upgrading and expansion of identified transmission infrastructure. Installation of transmission devices i.e phase shifting transformers on Suswa-Nairobi North line to direct power flows and improve utilization of the existing infrastructure. Synchronize the protection settings and design transfer capacities for optimal performance in the operation of the transmission line network.
3.	The renewable generation is intermittent, and this will be a challenge to the weak system. The renewables are now significantly penetrating the power system and if not properly managed might lead to system instability.	Renewable Energy Plants	Management of entry of the renewables More flexible plants i.e., gas turbines Spinning reserves FITs projects should also contribute to the reactive requirements. Continuous training on dispatch of renewables for NSCC officers More accurate forecasting methods for wind and solar plants Installation of battery storage systems for frequency regulation.
4.	Limited generation at the Coast Region. This affects the voltage profiles and system response in the event of system disturbances. Increase interruption to customers	Low Generation at the coast region	Increase generation at coast. Fast acting reactive compensation devices i.e., Statcoms/Static Var Generators (SVGs)

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	connected to 132kV lines on faults occurring on distribution lines		
5.	Insufficient transformation capacity Inadequate transmission lines Lack of required transmission infrastructure High cost of infrastructure Weak electricity infrastructure in West and Coast regions	New load centres Need to meet Electricity access target of 100% by 2030. Minimum investments in transmission sector	Transmission and substation reinforcements Construction of new transmission lines Completion of Malaa 220/66 kV substation and its 66kV feeders. at Kimuka and Malaa
6.	Inadequate system security and reliability	Lack of alternative supply paths for generation and key load centres.	A link between Olkaria IV /V to Olkaria I is suggested to be done by KenGen Future proposed circuit to be done as double circuit. Ongoing 220kV Nairobi Ring (Malaa 220kV Substation) and planned greater 400kV ring. Narok- Bomet, Kabarnet –Rumuruti Kitui-Wote Lessos -Loosuk Operation of the 500kV HVDC link in bipole mode.
7.	Vandalism of transmission lines and also high voltage cables.	Vandalism and terrorism	Co-ordinate with regional and county commissioners Engage critical infrastructure police unit (CIPU) and the Energy Police Unit Sensitise local communities on protecting/policing power infrastructure. Toll number to report vandalism cases for immediate action.

Impact of Grid Stability on Energy Transition from a Sustainability Front

Advancing Environmental Sustainability

Transmission grids are crucial for achieving environmental sustainability by integrating renewable energy

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sources like wind, solar, and hydro into the national energy mix. Renewable energy is often geographically dispersed and intermittent, which challenges its integration into existing power systems (Hodge & Milligan, 2018). A well-designed transmission grid enables efficient delivery of power from diverse renewable sites to load centres, reducing reliance on fossil fuels and lowering carbon emissions (IEA, 2020).

The capacity and flexibility of transmission grids, supported by high-voltage lines and advanced grid management technologies, facilitate the transfer of electricity over long distances and varying voltage levels, minimizing the curtailment of renewable energy (Lund et al., 2021). Upgrading and expanding grid infrastructure, including smart grid technologies and energy storage systems, enhances the grid's ability to manage intermittent renewable sources and supports a sustainable energy system (Baker & Reilly, 2022). Strategic expansion of transmission networks helps reduce environmental impacts by connecting renewable projects and decreasing emissions from fossil fuel-based power plants (IEA, 2020).

Marsabit County, with a 4 MW load demand, currently relies on three diesel generators with an average consumption rate of 0.51 L/kWh. This results in an annual diesel consumption of approximately 17.87 million liters and associated CO_2 emissions of about 47.92 million kg/year. Plans are at an advanced stage to transitioning to grid-connected renewable from the 310MW Lake Turkana Wind Power Project and the Seven Forks Dam Project. This will result in facing out of the thermal generators to low carbon pathways facilitated through transmission projects. The table below shows the CO_2 coefficient for wind, HEP and thermal generators (EIA, 2021)

Energy Source	CO2 Emission Coefficient (kg CO2/kWh)	Notes
Wind Energy	0.01–0.02	Low direct CO_2 emissions; emissions from manufacturing and installation.
Hydropower (HEP)	0.01–0.03	Low direct CO_2 emissions; emissions from reservoir creation and maintenance.
Diesel Power Generation	0.25–0.30	Higher CO_2 emissions due to fossil fuel combustion.

In addition, Kenya's Transmission Master Plan emphasizes the importance of grid infrastructure in enabling the country's transition to a low-carbon energy system. By investing in high-voltage transmission lines and regional interconnectors, Kenya is enhancing its ability to deliver renewable energy across the nation, thus minimizing reliance on fossil fuels and promoting environmental sustainability (TMP, 2024).

Minimizing Energy System Costs

Transmission grids are crucial for delivering electricity from generation sources to consumers, but transmission and distribution losses—typically ranging from 10% to 15% in Kenya—can significantly affect energy costs (KETRACO, 2023). These losses, which increase the cost of energy for consumers, are mitigated through investments in modernizing transmission infrastructure, including high-voltage direct current (HVDC) systems, which enhance grid efficiency and reduce losses over long distances (IEA, 2022).

Expanding transmission networks involves substantial costs related to land and wayleave acquisition, which can impact overall energy affordability. To address these challenges, Kenya has focused on strategic planning and community engagement, as well as innovative solutions like co-locating infrastructure (Kenya Tanzania, Isinya Namanga Lines) with existing utility corridors, and adoption of smart technologies.

Additionally, decommissioning costly thermal power plants in favour of more sustainable and cost-effective sources such as wind and solar energy reduces operational costs and enhances energy system viability (EPRA, 2023). Financing models, such as public-private partnerships and green bonds, can ease the burden of these costs by attracting investment and spreading financial risk, thereby helping to lower energy bills for consumers.

Biomass energy, though renewable, must be managed alongside conservation efforts to avoid negative impacts on land use and deforestation. Integrating biomass with sustainable land management and promoting energy efficiency can support conservation goals while meeting energy needs (IRENA, 2023).

Energy as a Key Enabler of Sustainable Socio-Economic Development

Transmission lines are crucial for efficient electricity delivery and integrating diverse energy sources, including renewables such as wind, solar, and hydro. IEA 2020 indicates that robust transmission networks are vital for accommodating variable renewable energy sources and stimulating investment in sustainable technologies. The development of transmission infrastructure not only supports investment but also creates jobs in design, construction, maintenance, and operation, contributing to local economic growth (European Commission, 2021). Reliable grids alleviate economic losses from power outages and inefficiencies, further bolstering economic stability.

Transmission networks also facilitate cross-border electricity trade, enhancing resource use and balancing supply and demand more effectively. The World Bank (2022) highlights that regional power markets supported by strong transmission infrastructure can improve energy security, reduce costs, and promote economic cooperation. In Africa, initiatives like the African Power Pool (APP) aim to optimize energy resources and reduce reliance on costly fossil fuels through improved transmission networks (ADB, 2021). 440kV Kenya - Tanzania, the 132kV Jinja- Naivasha, and the Eastern Electricity Highway Project (EEHP) are among the projects that have been implemented to foster cross-border trade.

A study by the International Renewable Energy Agency (IRENA, 2019) found that improving electricity access in rural areas boosts living standards and economic development. In Kenya, KETRACO has expanded the transmission network to connect renewable energy projects, benefiting local economies by providing reliable electricity and supporting renewable energy investments (TMP, 2024).

Role of a Transmission Grid in Enhancing Employment Impact

A robust transmission grid significantly impacts employment by generating direct and indirect job opportunities through several mechanisms. The construction and maintenance of transmission infrastructure create diverse roles, including engineers, construction workers, and technicians, essential for building and operating the grid (IEA, 2020). Additionally, local economies benefit from increased economic activity associated with transmission projects, which can stimulate job creation in supporting sectors such as hospitality and retail (World Bank, 2019).

Efficient grids facilitate the integration of renewable energy sources, fostering growth in labour-intensive green energy sectors and generating new employment opportunities (IRENA, 2021). Regional power trade and integration also promote job creation in both the energy sector and related services, enhancing economic stability (AfDB, 2020). Moreover, advancements in transmission technologies drive innovation and require specialized skills, leading to job growth in emerging fields (UNDP, 2021).

Provision of Energy Security and Trade Balance

Transmission infrastructure is vital for energy security and trade balance. It enhances energy system security by integrating diverse energy sources and ensuring stable power supply (IEA, 2022). In Kenya, expanding transmission networks like those by KETRACO reduces reliance on imported fossil fuels, promoting self-sufficiency TMP, 2024). Investment in transmission infrastructure also stimulates local employment and economic growth (World Bank, 2021), as seen globally in projects in the U.S. and India (U.S. Department of Energy, 2020; India Energy Forum, 2022).

Additionally, robust transmission grids support regional power trade and integration, optimizing resource use and strengthening energy security through initiatives like the Southern African Power Pool (AfDB, 2021). Overall, effective transmission infrastructure is crucial for a stable, reliable, and efficient energy system, supporting both national and regional energy goals.

The European Supergrid and Kenya's integration of diverse energy sources underscore the importance of transmission systems in ensuring energy security and trade balance. The European Supergrid, with its high-capacity network, effectively balances supply and demand, integrates renewable sources, reduces fossil fuel reliance, and supports regional economic growth and power trade (European Commission, 2021). Similarly, Kenya's use of projects like Lake Turkana Wind Power, Olkaria Geothermal, Hydroelectric Power Stations, and Garissa Solar Power enhances energy security by combining intermittent and reliable energy sources, improving grid reliability, and bolstering regional energy stability. Both examples illustrate how robust transmission infrastructure is crucial for maintaining stable and efficient energy systems.

Technological and Operational Improvements

The integration of advanced transmission technologies and the expansion of the grid are essential for addressing the increasing demand for electricity in Kenya. A stable and robust grid ensures minimal power losses, improved reliability, and the capacity to integrate more renewable energy sources. As Kenya continues to pursue its ambitious energy transition goals, the development and modernization of the electricity transmission network remain foundational elements in achieving a sustainable and resilient energy future

RECOMMENDATIONS

The transition to a sustainable energy future necessitates a multifaceted approach encompassing the modernization of transmission infrastructure, integration of advanced technologies, and promotion of social inclusivity. These recommendations aim to enhance Kenya's energy transition by leveraging existing frameworks, advancing technological innovation, and fostering community engagement.

Enhance Financing Mechanisms

Leverage Climate Financing

Kenya should tap into international climate finance mechanisms such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF) to support the development and expansion of transmission infrastructure. These funds can provide necessary capital for implementing grid-scale energy storage solutions and modernizing the grid (Chadwick & Choudhury, 2023; MoE&P, 2023).

Promote Public-Private Partnerships (PPPs)

Engaging in PPPs will attract private sector investment and expertise, ensuring cost-effective and efficient development of transmission networks. Aligning public and private interests will enhance transmission infrastructure while managing financial risks effectively (Jones et al., 2021).

Advance Grid Modernization

Adopt Smart Grid Technologies

Investing in smart grid technologies, including Advanced Metering Infrastructure (AMI), Substation Automation, and Flexible AC Transmission Systems (FACTs), will enhance grid efficiency, reliability, and integration of renewable energy sources. Smart grids facilitate real-time monitoring, issue resolution, and operational efficiency, contributing to a more resilient energy system (Kabeyi & Olanrewaju, 2023; Kimani et al., 2019).

Integrate Energy Storage Solutions

Incorporating grid-scale energy storage systems such as Battery Energy Storage Systems (BESS), Pumped Hydro Storage (PHS), and green hydrogen technologies will improve grid stability and flexibility. These solutions support the integration of intermittent renewable energy sources and optimize overall grid

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performance, aligning with Kenya's Least Cost Power Development Plan (LCPDP) 2022-2041 (MoE&P, 2023; Statista, 2023).

Facilitate a Just Transition

Promote Social Inclusivity

Extending transmission infrastructure to underserved areas is crucial for reducing energy poverty and ensuring equitable access. Involving local communities in the planning processes helps address their needs and ensures fair compensation, fostering a just transition (Agarwal et al., 2012; Kemp & Parto, 2005).

Implement Supportive Policies

Developing and enforcing policies that promote social inclusivity, offer fair compensation, and incentivize renewable energy integration will enhance the transition. Regulatory frameworks should facilitate private investment and streamline project development (Baker & Hargreaves, 2018).

Utilize the Energy Act

Capitalizing on provisions in the Energy Act that empower counties to develop local energy plans will be pivotal in alleviating energy poverty and ensuring just transitions. By leveraging this legal framework, counties can address region-specific energy needs and promote local energy solutions, enhancing resilience and inclusivity.

Strengthen Community Involvement

Involving local stakeholders in the planning and execution of transmission projects ensures that community concerns are addressed and the benefits are equitably distributed. Supporting local economic development through job creation and business opportunities related to transmission projects will contribute to broader societal benefits (World Bank, 2021).

Foster Research and Development (R&D)

Collaborate with Local Universities

Partnering with local universities can advance R&D in critical areas such as infrastructure and community resilience, community engagement, and energy storage technologies. These collaborations will drive innovation and address emerging challenges in the energy sector (Stenclik et al., 2017).

Support Technological Innovation

Investing in research initiatives that explore new technologies and methods for enhancing transmission infrastructure is essential. Encouraging innovation will improve efficiency, reliability, and sustainability within the energy system (Karue et al., 2019).

Acronyms and Abbreviations

AfDB	African Development Bank
AMI	Advanced Metering Infrastructure
BESS	Battery Energy Storage Systems
CO_2	Carbon Dioxide
EEHP	Eastern Electricity Highway Project

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FACTs	Flexible AC Transmission Systems
FIT	Feed-in Tariff
GCF	Green Climate Fund
GEF	Global Environment Facility
GoK	Government of Kenya
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KETRACO	Kenya Electricity and Transmission Company Limited
kV	Kilovolts
kWh	Kilowatt-hour
LCPDP	Least Cost Power Development Plan
LTWP	Lake Turkana Wind Power
MoEP	Ministry of Energy and Petroleum
Mt CO2e	Metric Tons of Carbon Dioxide Equivalent
MVA	Mega Volt Amperes
MW	Megawatts
PHS	Pumped-Hydro Storage
PPP	Public-Private Partnership
RE	Renewable Energy
R&D	Research and Development
SDGs	Sustainable Development Goals
TMP	Transmission Master Plan
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

REFERENCES

1. African Development Bank. (2020). "Financing Africa’s Energy Transition."
2. African Development Bank. (2020). “African Renewable Energy Initiative (AREI): A Framework for Achieving Universal Access to Modern Energy Services.” Retrieved from African Development Bank.
3. African Development Bank. (2021). Power Pools and Regional Integration. Retrieved from

https://www.afdb.org/en/documents/document/power-pools-and-regional-integration-41182

4. African Renewable Energy Initiative. (2015). Framework and Guiding Principles. Abidjan, Côte d'Ivoire: AREI.
5. African Union Commission. (2015). Agenda 2063: The Africa We Want. Addis Ababa, Ethiopia: African Union.
6. African Union. (2015). “Agenda 2063: The Africa We Want.” Retrieved from African Union.
7. Agarwal, A., Narain, S., & Sharma, R. (2012). Energy and equity: A comprehensive framework for energy transitions. Environment and Development Economics, 17(3), 327-348.
8. Baker, S., & Hargreaves, T. (2018). Renewable energy and electricity price formation: Understanding the impact of wind and solar on electricity markets. Energy Policy, 123, 457-468.
9. Baker, S., & Reilly, M. (2022). Smart Grid Technologies: Advancements and Impact on Renewable Integration. Journal of Clean Energy Technologies, 10(2), 123-135.
10. Barasa Kabeyi, M. J., & Olanrewaju, O. A. (2023). Smart grid technologies and application in the sustainable energy transition: A review. International Journal of Sustainable Energy, 42(1), 685-758. https://doi.org/10.1080/14786451.2023.2222298
11. Cheruiyot, C. K., Ochieng, R. M., & Ogola, J. P. (2021). "Assessing the Resilience of Kenya’s Energy Infrastructure to Climate Change." Journal of Energy Research and Reviews, 10(2), 25-36. doi:10.9734/jerr/2021/v10i230226.
12. Cheruiyot, K., Kamau, R., & Kiprono, B. (2021). Climate Change and Energy Systems in Kenya: Impacts, Vulnerabilities, and Adaptations. Journal of Energy Research
13. Clifford, C. (2023, October 17). The world has to add or replace 50 million miles of transmission lines by 2040, IEA says. CNBC. https://www.cnbc.com/2023/10/17/world-must-add-or-replace-50-million-miles-of-transmission-lines-iea.html
14. KETRACO Draft Transmission Master Plan (2024-2043)
15. European Commission. (2020). "EU Energy System: Challenges and Opportunities." Retrieved from European Commission.
16. European Commission. (2021). Clean Energy for All Europeans. Retrieved from https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en
17. Government of Kenya (GoK). (2023). Kenya energy transition & investment plan 2023 - 2050. Ministry of Energy and Petroleum.
18. Government of Kenya. (2007). Vision 2030: A globally competitive and prosperous Kenya. Nairobi, Kenya: Ministry of Planning and National Development.
19. Government of Kenya. (2016). Climate Change Act. Nairobi, Kenya: Government Printer.
20. Government of Kenya. (2018). National Energy Policy. Nairobi, Kenya: Ministry of Energy.
21. Government of Kenya. (2021). “Kenya’s Nationally Determined Contributions (NDCs).” Retrieved from Government of Kenya.
22. Government of Kenya. (2023). Kenya's Renewable Energy Strategy. Nairobi, Kenya: Ministry of Energy.
23. Hodge, B.-M., & Milligan, M. (2018). The Impacts of Transmission on Renewable Energy Integration. IEEE Transactions on Power Systems, 33(4), 4395-4402.
24. IEA. (2020). World Energy Investment 2020. International Energy Agency. https://www.iea.org/reports/world-energy-investment-2020
25. India Energy Forum. (2022). Transmission and Distribution in India. Retrieved from https://www.indiaenergyforum.org/transmission-and-distribution-in-india
26. International Energy Agency (IEA). (2020). "Renewables 2020: Analysis and Forecast to 2025." Retrieved from IEA.
27. International Energy Agency (IEA). (2021). “Renewables 2021: Analysis and Forecast to 2026.” Retrieved from IEA.
28. International Energy Agency. (2022). Technology Roadmap: High-Voltage Direct Current (HVDC) for Power Transmission. Retrieved from https://www.iea.org/reports/technology-roadmap-hvdc-for-power-transmission
29. International Energy Agency. (2022). World Energy Outlook 2022. Retrieved from https://www.iea.org/reports/world-energy-outlook-2022
30. International Renewable Energy Agency (IRENA). (2019). Off-grid renewable energy solutions:

Innovation and scaling up. Retrieved from https://www.irena.org

31. International Renewable Energy Agency (IRENA). (2021). "World Energy Transitions Outlook: 1.5°C Pathway." Retrieved from IRENA.
32. International Renewable Energy Agency (IRENA). (2021). “Renewable Capacity Statistics 2021.” Retrieved from IRENA.
33. International Renewable Energy Agency. (2023). Renewable Energy and Land Use: Opportunities and Challenges. Retrieved from https://www.irena.org/publications/2023/Jan/Renewable-Energy-and-Land-Use
34. IRENA. (2021). Renewable Energy Statistics 2021. International Renewable Energy Agency. Retrieved from https://www.irena.org/Publications/2021/Aug/Renewable-Energy-Statistics-2021
35. Karekezi, S., Lata, K., & Coelho, S. T. (2021). "Traditional Biomass Energy: Improving Its Use and Moving to Modern Energy Use." Renewable Energy and Development, 5(2), 4-19. doi:10.1016/S1364-0321(00)00042-1.
36. Karue, C. N., Murage, D. K., & Muriithi, C. M. (2019). Smart grid technology and distributed generation. Proceedings of the Sustainable Research and Innovation Conference, JKUAT Main Campus, Kenya.
37. Kemp, R., & Parto, S. (2005). Governance for sustainable development: Moving from theory to practice. International Journal of Sustainable Development, 8(1), 26-36.
38. Kenya Electricity Generating Company (KenGen). (2023). “Kenya’s Energy Generation Mix.” Retrieved from KenGen.
39. Kenya Electricity Transmission Company. (2023). Strategic Plan 2023-2030. Nairobi, Kenya: KETRACO.
40. Kenya Electricity Transmission Company. (2023). Transmission Master Plan 2023-2030. Nairobi, Kenya: KETRACO.
41. Kenya Energy and Petroleum Regulatory Authority (EPRA). (2023). Annual Report 2023. Retrieved from EPRA website
42. Kenya Energy and Petroleum Regulatory Authority. (2023). Annual Report 2023. Retrieved from https://www.epra.go.ke/annual-reports/
43. KETRACO. (2023). Feasibility Study for 220kV Loiyangalani Marsabit Isiolo Transmission Line. Kenya Electricity Transmission Company Limited.
44. Kimani, K., Oduol, V., & Langat, K. (2019). Cyber Security Challenges for IoT-based Smart Grid Networks. International Journal of Critical Infrastructure Protection.
45. Kiplagat, J. K., Wang, R. Z., & Li, T. X. (2020). "Renewable Energy in Kenya: Resource Potential and Status of Exploitation." Renewable and Sustainable Energy Reviews, 15(6), 2960-2973. doi:10.1016/j.rser.2011.03.023.
46. Lund, H., Lindgren, J., Möller, B., & Söder, L. (2021). Integration of Renewable Energy into the Grid: The Role of Transmission Systems. Energy Policy, 144, 111609.
47. Mwangi, J. K., Oluoch, N. K., & Otieno, J. A. (2019). "Challenges Facing Kenya’s Energy Sector." Energy Policy Research Journal, 7(3), 123-132. doi:10.1016/j.enpol.2018.01.042.
48. Mwangi, J., Kamau, M., & Njeri, J. (2019). Community Perceptions and Acceptance of Energy Infrastructure Projects in Kenya. Journal of Energy Policy and Management.
49. Odhiambo, N. M. (2020). "Electricity Consumption and Economic Growth in Kenya: A Trivariate Causality Test." Energy Economics, 32(5), 887-892. doi:10.1016/j.eneco.2010.03.011.
50. Republic of Kenya. (2020). "Kenya National Electrification Strategy." Retrieved from Kenya National Electrification Strategy.
51. U.S. Department of Energy. (2020). Electric Grid Modernization. Retrieved from https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid
52. U.S. Department of Energy. (2021). "Grid Modernization: Building a Resilient and Reliable Electricity System." Retrieved from U.S. DOE.
53. U.S. Energy Information Administration (EIA). (2021). International Energy Outlook 2021. Retrieved from EIA.
54. UNEP. (2021). Adaptation Gap Report 2021: The Gathering Storm. United Nations Environment Programme. Retrieved from https://www.unep.org/resources/adaptation-gap-report-2021
55. United Nations Environment Programme (UNEP). (2020). Emissions Gap Report 2020. Retrieved from

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue XI November 2024

UNEP.
56. United Nations Environment Programme (UNEP). (2021). "Adaptation Gap Report 2021." Retrieved from UNEP.
57. United Nations Framework Convention on Climate Change (UNFCCC). (2015). The Paris Agreement. Paris, France: UNFCCC.
58. United Nations. (2015). "Sustainable Development Goals." Retrieved from UN SDGs.
59. United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/post2015/transformingourworld
60. World Bank. (2019). "Financing Renewable Energy Projects in Developing Countries."
61. World Bank. (2021). Infrastructure for Development: Land Acquisition and Wayleave Management. Retrieved from https://www.worldbank.org/en/topic/infrastructure
62. World Bank. (2022). Regional power markets and cross-border electricity trade. Retrieved from https://www.worldbank.org