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Review Article

An Analysis of the Techno-Economic, Socio-Technical and Political Perspectives of Kenya's Energy Transition

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Abstract: Efficient energy supply is critical for Kenya's socioeconomic development as it strives to meet national and global development targets. Despite its vast energy resources potential, Kenya faces challenges in providing access to modern energy sources. Achieving sufficient energy for socio-economic development requires transition in energy systems. Using multi-level perspective (MLP) approach, this study explored Kenya's energy transition by analyzing its techno-economic, socio-technical and political dimensions of the transition to understand its energy development trajectory and the potential for economic growth, energy security, and sustainable development. The findings revealed how energy governance and policy structures shape Kenya's transition, with both local and international actors influencing development plans and renewable energy investments. It further showed that Kenya's national energy transition is driven by the abundance of renewable energy sources, leading to a consistent growth in the electricity sector, facilitated by market-based policy instruments such as feed-in tariffs that attracted private sector investment in renewable energy technologies. This study provides valuable insights into Kenya's energy transition by emphasizing the importance of sustainable development and universal energy access. It underscores the significance of aligning technology, societal acceptance, and institutional support and calls for a balanced approach that incorporates local interests in the energy transition.

Keywords: Energy Transition, Techno-Economic, Socio-Technical, Political Perspectives, Multi-Level Perspective, Energy Governance

1. Introduction

Energy plays an important role in the socioeconomic development of a nation including its inhabitants' quality of life [1]. Globally, countries with strong economic growth have shown substantial evidence for the significance of energy in achieving national and global development targets characterized by increased energy demand and consumption [2]. On the contrary, however, many developing countries in Asia and Africa have more than half of their population living in poverty with no access to modern energy.

Sustainable economic development has gained momentum in recent years with countries setting national development targets. In 2008, for example, the Kenyan government formulated an ambitious transformative vision as a blueprint for long-term development that aims to transform the country into an industrialized middle-income nation by 2030 in line with the global sustainable development agenda [3]. Given the importance of energy in achieving Kenya's transformative Vision, access to sufficient supply of electricity remains a key enabler of economic development.

Studies have shown that access to affordable electrical energy is critical in achieving economic growth and smooth transformation towards inclusive sustainable development and poverty reduction. For instance, [2] examined the relationship between energy, health, poverty, and climate change at the household level to understand the social implications of this nexus. They concluded that, ensuring households' energy affordability, access, and adequate production/supply is vital for maintaining individual and population-scale health and well-being, which can lead to poverty reduction and development. Similarly, [1] showed that limited access to

energy affects individual development which further makes it difficult for the residents to implement productive activities and improve their socioeconomic status.

Despite the global acceptance of the link between energy access, development, and poverty reduction, Kenya's total installed electricity generation capacity is only 3,072MW [4], against a growing population of over 53 million people. Like other Sub-Saharan African countries, biomass is the main source of primary energy for most Kenyans [5]. The national energy mix indicates an overwhelming dependency on biomass (68%), particularly in the rural areas while petroleum, electricity, and other forms of energy account for 22%, 9%, and 1% respectively. In the electricity sub-sector, however, renewable sources including geothermal, hydropower, solar, and wind power dominate the electricity mix, which suggests a perfect energy transition model for the rest of the countries in Sub-Sahara Africa.

Achieving sustainable socioeconomic and political development at national or regional levels is rooted heavily in energy transition, which not only focuses on shifting away from fossil-based energy systems to renewable energy technologies, but also on a significant structural change in energy infrastructure and systems linked to energy demand and availability [6-8]. According to [9], an effective transition in national energy systems is shaped by changes in economic development, technological innovation, and policy strategies grounded around the understanding of what they termed as "energy flows and markets, energy technologies, and the existence of energy-related policies".

Recognizing the significance of sufficient energy supply to achieve its transformative 2030 Vision including its commitment to multilateral environmental agreements, the government of Kenya established plans to diversify its energy generation and supply by exploring low-cost geothermal, solar energy, and wind power for on-grid electricity generation [10]. This study, therefore, aims to set light on Kenya's energy transition in the context of its ambitious 2030 Vision by analyzing the techno-economic, socio-technical, and political dimensions of the energy transition processes.

2. Theoretical Framework and Methodological Approach

2.1. The Theoretical Framework

The study of energy transitions is one of the most complex issues facing both policymakers and academia due to the nature of its scope. Cherp [9] and Dong [10] argued that a better understanding of energy transition requires a multi-dimensional perspective involving interdisciplinary approaches centered around issues of economic development, technological innovation, and policy change. In this study, the design approach for investigating Kenya's energy transition was inspired by the application of the multi-level perspective (MLP) framework developed two decades ago by Frank Geels as an empirical tool for explaining or understanding changes in societal system transitions [11]. Since its first publication, MLP has gained enormous popularity in the social science research field, with wide applications in analyzing various theories including transition in national energy systems and policies [12-19].

It is important to acknowledge that investigating energy transition entails dealing with complex systems that have several overlapping layers emanating from the multiple disciplines involved. To strengthen the approach in this study, a meta-theoretical framework described by [9] was also applied. Unlike [11] approach that concentrated on three socio-technical levels including landscapes, regimes, and niches, the Meta-theoretical framework provides additional perspectives to MLP by bringing *Techno-economic and Political perspectives* to the energy transition analysis paradigm. Cherp [9] used the meta-theoretical framework to analyze and differentiate three types of energy transition systems, namely: "energy flows and markets, energy technologies, and energy-related policies". An in-depth examination of the meta-theoretical framework by Cherp and colleagues further revealed three perspectives on national energy transitions including (i) techno-economic which focuses on energy market dynamics involving extraction of energy from the available energy resources and its consumption; (ii) socio-technical, which focus on changes in societal knowledge of technologies used in transforming energy resources into usable forms, and (iii) political perspective-focusing on changes in policies governing energy systems. Figure 1 illustrates the composition and interaction of these three perspectives to highlight the complexity of energy transition analysis.

2.2. The Methodological Approach

This study adopted a secondary method of data collection and analysis by first gathering primary and secondary data from various sources including but not limited to peer-reviewed academic journals, program reports, credible expert opinion articles, national policy documents, training materials, and conference papers. The data was then organized into three categories denoting the three perspectives of national energy transition described by [9] and as presented in Figure 1. For clarity, the term primary data here refers to data derived from government or development partners' reports on energy which contains original data collected in the field and training materials that have not been analyzed for any academic purpose. On this basis, it is, therefore, important to note that, this study is a review of energy transitions in Kenya. The study sought to identify the techno-economic-sociotechnical-political nexus in Kenya's energy transition. Kenya was selected for this analysis because it is one of the leading countries in Sub-Saharan Africa with a high share of renewables in the electricity mix as well as being a global model in exploring low-cost geothermal energy for on-grid electricity supply.

This study is unique because no previous study has comprehensively applied the integration of techno-economic, socio-technical and political perspective with the MLP framework in the analysis of energy transition in Kenya or

elsewhere in East Africa, a region currently battling a catastrophic impact of climate change in which energy extraction from fossil fuels and unsustainable use of wood fuel are considered the main contributors [20]. Although [10, 21] have used the MLP approach in their analysis of energy transition, their focus is exclusively on the role of exogenous actors in energy transition and the sustainability of large-scale renewable energy (solar) in Kenya and Rwanda respectively. This study hypothesized that applying the MLP approach comprehensively can provide a better understanding of Kenya's energy transition toward national economic growth, energy security, and sustainable development.

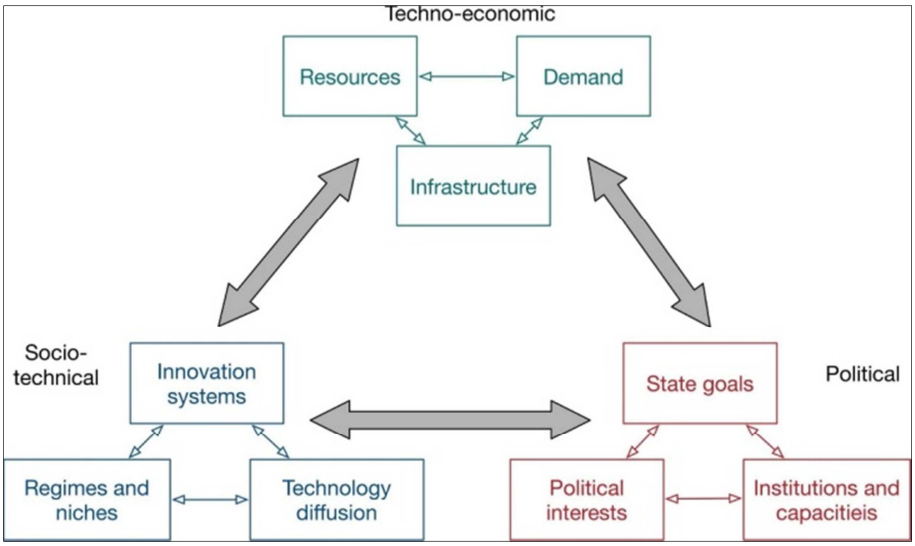

Figure 1. *Three perspectives on national energy transitions [9].*

3. Results and Discussions

3.1. The Techno-Economic Perspective of Kenya's Energy Transition

The Techno-economic perspective of energy transition seeks to understand the interaction between energy technologies and economics linked to energy extraction, conversion, and use as determined by energy markets [9, 22]. This approach has been widely used in analyzing the economic performance of industrial processes at the micro, meso, and macro levels to evaluate the feasibility of upscaling various processes and technologies [22-23]. Edomah [22] highlighted that a techno-economic perspective of a system is a paradigm where technologies and their supporting institutions constitute a key element of research, development, and promotion of technologies to steer innovations in engineering and investment decisions toward the use of specific technologies.

3.1.1. National Renewable Energy Capacity

Kenya is well endured with a huge potential of renewable energy resources, particularly geothermal, wind, solar, and hydropower located at different parts of the country. There are currently 14 known geothermal energy sites in the country capable of generating 7,000 -10,000MW of electricity, of which only 949.13MW has been exploited to date [4, 10]. Wind energy potential in most parts of Kenya is the highest in Africa with 73% of the country experiencing wind speeds ranging from 6-9.5 m/s, which can produce 4,500MW [24]. The Lake Turkana wind project is an example of a single largest wind power generation plant in Africa, which supplies 310MW of electricity to the grid in addition to 25.5MW and 100MW from the Ngong Hills and Kipeto Wind Farms respectively. This brings the total installed capacity of wind energy to 435.5MW [25].

Another renewable energy resource potential of Kenya is hydropower which till recently dominates the total energy mix with a generation capacity of 838MW against a potential of 3,000MW [4, 25]. Additionally, biomass is the largest source of primary energy accounting for 70% of the final energy demand and 90% of rural energy needs. For instance, [25] reported that Kenya's cogeneration power from bagasse in various sugar factories across the country stands at about a third (i.e., 44.5MW) of its potential estimate of 192MW. Solar energy is also another source of renewable energy and one of the cheapest energy options exploited globally to address rural biomass dependence. In 2021, solar power from the Cedate, Selenkei, and Malindi Solar Power Plants added 120MW to Kenya's grid, which raised the total amount of solar in the energy mix to 172MW [4]. Table 1 provides a breakdown of Kenya's renewable energy potential against installed capacity.

3.1.2. Balancing Electricity Demand and Supply

Given the potential of renewable energy in the country, the government of Kenya has been investing in the development of these resources to reduce over-reliance on fossil fuel. The current installed electricity capacity and energy demand in Kenya are 3,074.34MW and 2,056.67MW respectively and 86.98% of this capacity is renewable energy [4]. For the past few years, Kenya has experienced steady growth in its electricity sector. However, [26] warned that climatic events

like persistent drought in most parts of Kenya are expected to affect the hydropower generation capacity. Consequently, [4] indicated in its annual report that the energy generated from hydropower as of June 2022 decreased from 4,142.18 GWh to 3,349 GWh due to poor hydrological events.

Table 1. *Kenya's renewable energy potential against the current installed capacity [4, 27].*

Energy resource type	RE potential (MW)	Installed capacity (MW)
Hydro	3000	837.6
Geothermal	7,000 -10,000	949.13
Solar PV	70000	170
Wind	4600	435.5
Bioenergy (bagasse)	192	44.5

Like other developing countries, a consistent supply of electricity remains critical for Kenya's economic development. To meet its development targets while avoiding continuous electricity supply interruptions, various plans have been made to diversify and enhance energy access in Kenya using renewable energy like geothermal, wind, and solar. As of June 2022, 86.98 percent of Kenya's generated electricity came from renewable sources [4]. This indicates a transitional path towards achieving its 15,000MW projection by 2030 with geothermal taking the lead as the main source of electricity generation.

With the destructive impacts of climate change on national development, sustainable energy transition can revitalize national economic growth, increase employment, improve energy access, and enhance energy security and quality of life. Economic concepts of supply-demand balance also known as *market equilibrium* and the economy of scale are important in observing the dynamics of market mechanisms to ensure stability. While the former presents a critical information where a change in one element of the market must be balanced by a corresponding change in the others, the latter is a critical factor in influencing the success and effectiveness of energy transition through decrease in the average cost of production and increase in return on investments [28-30]. This concept is evident in Kenya's electricity mix. For example, when electricity demand in 2022 increased, generation capacity also increased by 0.65% from renewable sources, meanwhile fossil fuel-based electricity capacity decreased by 102.38MW [4].

The adoption and integration of renewable energy technologies into national energy sector can provide economic incentives by driving down the cost of the technologies to facilitate competitiveness and accessibility. Woollacott [31] quantified the economic impacts of renewable energy investment in Kenya in the context of supply chain and found both direct and indirect local economic benefits in millions of dollars that can be accrued from renewable energy investment in form of jobs and wages which improves societal wellbeing.

Although there has been an increase in generation capacity recently, improving electricity transmission and distribution infrastructure covering 6,295 km with high losses rate of about 22.43% remains Kenya's major challenge in achieving universal energy access and its 2030 Vision [4]. Strengthening the transmission network requires huge financial investment, yet as a developing country, Kenya has limited financial resources to invest in upgrading the transmission network. Consequently, this has created a state of dependency on multilateral foreign aid agencies that tend to incentivize or disincentivize certain energy policies and technology based on their interests.

3.2. The Socio-Technical Perspective of Kenya Energy Transition

The transformation of energy systems is a major societal project that requires technical innovation for social change. The socio-technical perspective of an energy system, which focuses on the alignment of technologies, their social acceptance (*diffusion*), and institutional support, provides a clear picture of the landscape-regime-actors-niche novelties interactions as the underlying determinants of the MLP theory on national energy transition [9]. Understanding the interactions between technological advancement and social, cultural, and political aspects as Kenya transitions to a more sustainable and diverse energy system is important. This viewpoint acknowledges that sociological factors, in addition to technical ones, can play a role in the adoption and integration of new energy technology.

3.2.1. Setting the Ground for National Energy Development in Kenya

Kenya's initial niche novelties exploration dates back to the pre-independence era when the colonial administration established the Kenya Power Company (*now known as Kenya Power and Lighting Company-KPLC*) in 1954 to build the first transmission line, followed by subsequent international technical and financial interventions in Geothermal energy studies [10]. After more than two decades of national and international engagement, the first 30MW Geothermal energy was launched in 1981, which later grew in capacity over the years.

The application of the socio-technical perspective in this study reveals that the abundant of renewable energy resources (niches) in Kenya makes it a unique model for studying energy transition in Sub-Saharan Africa, where most of the population is rural with no access to national electricity grid, and heavily rely on biomass for their energy needs. This reliance on biomass threatens ecological health due to potential incidences of deforestation and carbon emissions that can exacerbate climate change. Since 1981, when the Swedish Beijer Institute recommended the modernization of households' cooking stoves, Kenya established partnerships with donor agencies and jointly implemented several rural biomass-based cooking stoves projects [32].

Despite the penetration of modern biomass-based energy technologies in rural areas of Kenya, electricity remains critical for Kenya's socio-economic development. In 2012, the government of Kenyan, in partnership with the African Development Bank, initiated a rural electrification program to expand the grid connection to rural areas [33]. However, due to the sparse settlement patterns of rural communities coupled

with strong cultural beliefs, the grid extension to most rural areas was considered economically unviable. This gave a chance for the deployment of off-grid solutions that are accustomed to local traditions. Moreover, the emergence of mobile phone technology in Kenya and its integration with financial systems to facilitate transactions via mobile money technology known as M-Pesa, also paved the way for the diffusion of energy technologies such as solar PV and solar home systems (SHS) into both rural and semi-urban areas without access to the grid transmission [34, 35].

The success and sustainability of energy transition from the socio-technical perspective can be increased by identifying and deploying technologies that are compatible with local cultural norms, needs and technological capacity. Such success may be determined by the state willingness to create an enabling policy and governance instruments that draw investments, encourage the use of renewable energy sources, and build an environment that is supportive of innovation and entrepreneurship in renewable energy.

3.2.2. Improving Access to Modern Energy Services

Improving rural access to modern energy services to drive socio-economic growth remains a major development priority for Kenya. This does not only entail the deployment of energy technologies to the society, but also ensuring their social acceptance and utilization to provide the needed energy [36]. Studies by [37-39] have shown that modern biomass-based cooking stoves and biogas are efficient in providing clean energy alternatives for rural households. The deployment of these technologies to the rural areas in Kenya led to the emergence of several women champions in energy-efficient cooking stoves small businesses, which contributed enormously to climate change mitigation efforts through sustainable use of wood fuel and reduction in associated carbon emissions.

Globally, the discourse on energy transition often cast doubts on the possibility of low-income developing countries in timely achieving clean energy targets due to their challenging socio-economic situations compared to their wealthy developed countries [40]. Nevertheless, evidence indicate that the adoption of SHS and solar portable lanterns (SPLs) with mobile phone charging functionalities by many developing countries has increased rapidly. Kenya has been considered one of the most successful private sector-led per capita off-grid solar markets in the developing world [41, 42]. This expansion was facilitated by the introduction of a market-based approach like value added tax (VAT) exemption for solar PV in 2015, coupled with the unbounding of the energy market, as well as IMF's investment in the development of the solar PV market.

Kenya's transitions towards more sustainable energy systems have been shaped by the interactions between people and energy technologies over the past years. This interaction has shaped the country's energy development trajectory directed towards the interest of the people, as demonstrated in the suspension of an 8.8-million-megawatt-hour of coal plant development in Lamu following an overwhelming social objection to the Kenyan government's coal exploration plans [43]. Additionally, the involvement of private sector financing schemes like micro-credit financing also led to a surge in the number of green start-ups in solar home systems and small commercial PV appliances in Kenya that created jobs, brought solar energy technologies close to the people, and improved people's quality of life through affordable renewable energy solutions and increase in youth employment and income levels [42].

3.3. Political Perspective of Kenya Energy Transition

Ensuring sustainable energy development and universal access is critical for Kenya's political transformation vision and for achieving the 2030 global agenda on sustainable development. Yet despite the importance of transitioning to clean and sustainable energy systems, energy development in many developing countries has become a contested geopolitical force with high levels of national, regional, and global power dynamics, involving policies, institutions, and actors across different governance structures and international relations [44].

3.3.1. The Governance of the Energy Sector in Kenya

The political perspective regarding Kenya's energy transition in this study, examined the country's energy governance structures, its policies, regulations, political dynamics and their impacts on energy transitions. Energy being one of the pillars of Kenya's development agenda, this study reveals that Kenya's energy development is shaped by both local dynamics and an international network of institutions that create a competing vision on how to pursue transition through market-based mechanisms. These dynamics are characterized by the role of political elites who use energy development to secure election votes in one part and international institutions and governments who use financial aid and investments as tools for advancing their interest in national energy development agenda. Newell and Phillips [26] observed that determining who sets the terms of transition in Kenya attracts questions about the role of actors, interests, and institutions as they seek to advance competing energy pathways and associated energy technologies. As a developing country, Kenya relies heavily on donor funding for the largest share of its energy generation, transmission, and distribution infrastructure. This reliance over the years gave chance to international agencies and governments to influence national energy policies using tough conditions for concessional financing that benefit their vested interest in the development of Kenya's energy resources [26].

Since early 2000s, the government of Kenya took robust reform measures in its energy sector by establishing institutions and policies that aligned the energy sector with national development goals. This alignment created a conducive policy environment that promoted the expansion of renewable energy technologies at both the utility-scale and micro-grid levels across the country to enhance energy security and promote sustainable development with a low carbon footprint [45]. The current governance structure of the

Kenya's energy sector is composed of several umbrella institutions responsible for three main functions including (i) *policy framework, regulatory and dispute resolution, (ii) power generation, and (iii) power transmission and distribution.* The sector's strategic development plan derived its base from the Policy Paper No. 4 of 2004 and the Energy Act of 2006. While the Policy Paper aimed at ensuring adequate, quality, cost-effective, and affordable energy supply from abundant renewable sources to meet the national development agenda, the Energy Act aimed at establishing a recognized institutional framework to guide the development of the energy sector [46]. This policy landscape set up institutional frameworks including the establishment of the Energy Regulatory Commission (ERC), the Rural Electrification Authority (REA), the Geothermal Development Company (GDC), and the Kenya Electricity Transmission Company (KETRACO) for the power sector after a process of liberalization following the Electricity Act of 1997 that separated the regulatory and commercial functions (i.e., generation, transmission, and Distribution) of the electricity sector in a quest to promote private investment [24]. Figure 2 illustrates the governance structure of the Kenyan energy sector and the involved institutions.

3.3.2. Transitioning Towards a Renewable Trajectory

Kenya's path towards renewable energy transition is well documented in several national strategic development plans including its ambitious national Vision 2030, which aims to generate 23,000MW of electricity by 2030. To achieve its development vision, the government recognized the importance of private sector participation in the energy transition process and developed strategic policies for renewable energy production and an investment framework for Public-Private Partnerships.

Using market-based approaches to attract potential private sector investment in renewable energy development, the government formulated a feed-in tariff (FiT) policy in 2008. This policy instrument guaranteed fair competition among independent power producers (IPPs) in electricity generation from wind, biomass, and small-scale hydropower plants and also established market stability by requiring large power transmission companies like KETRACO and KPLC to purchase electricity at a fixed market price from the IPPs [24, 47]. Given its effectiveness in increasing private investment in clean energy technologies, FiT was further expanded to include solar energy, biogas, and geothermal energy in 2010. Despite the growth in the number of IPPs in the sector, the state-owned parastatal companies (KenGen and the KPLC) still monopolize the energy generation and distribution in the country [26]. This state monopoly demonstrates the role of political elites in the vertical integration of energy development in Kenya. Furthermore, with the introduction of the Financial Act instrument in 2021 which reinstated the exemption of value-added taxes on renewable energy technologies, Kenya has experienced an increase in the generation of clean energy from solar systems, wind power, and clean cooking stove technologies in recent years.

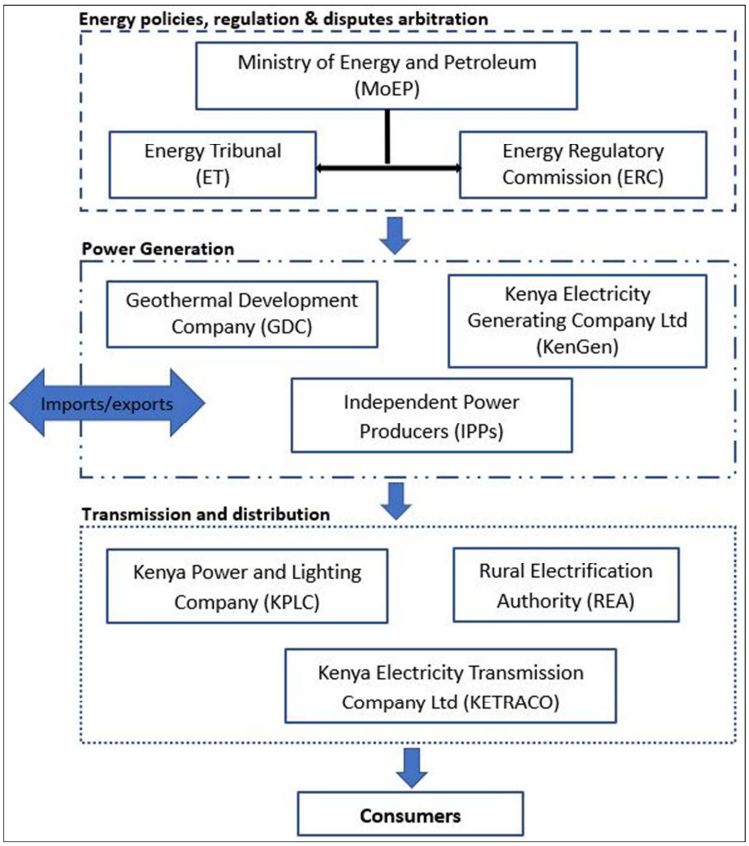

Figure 2. *Overview of Kenya's Energy Sector. A modification of [24].*

Moreover, there is substantial evidence that Kenya's energy supply and economic development are vulnerable to the adverse impact of climate change. While streamlining national development strategies with international obligations related to climate change and greenhouse gases emissions, the Kenyan government showed a strong commitment to low-carbon development as stipulated in its National Climate Change Action Plan and the Nationally Determined Contribution pledges under the Paris Agreement on climate change [45].

Other additional laws which Kenya has formulated and enacted that are currently playing a significant role in its transition to a low-carbon economy include the Climate Change Act and the amended Energy Act [48, 49]. These laws further strengthen the country's energy transition by providing regulatory frameworks for devising a climate resilient and low carbon development direction, while also decentralizing energy services to local governments, hence, simultaneously address national energy and climate change challenges at the grassroots levels [50].

4. Conclusion and Policy Implications

Kenya's energy transition is a multifaceted configuration that intersects with socio-economic development, technological innovation, and policy strategies deployed to achieve national sustainable development, energy security, and environmental sustainability [46, 51, 52]. This study sheds light on the significance of energy access and affordability in achieving poverty reduction, health improvement, and overall human development. Kenya's commitment to diversifying its energy generation through available renewable energy resources, such as geothermal, wind, solar, and hydropower, present a unique opportunity for sustainable energy development and transition in Sub-Saharan Africa [53].

The socio-technical perspective emphasizes the importance of aligning energy technologies with social acceptance and institutional support, which has played a crucial role in shaping Kenya's energy development trajectory. This trajectory prioritized the improvement of access to modern energy sources, particularly in rural areas characterized by the expansion of off-grid electrification solutions using small-scale stand-alone solar PV and solar home systems [54]. Moreover, the adoption of modern biomass-based cooking stoves and biogas technologies has shown promising results in providing clean alternative energy sources for rural households, which contribute to climate change mitigation efforts and improved people's quality of life [55, 56].

Despite the level of progress made, however, Kenya's energy transition also faces several challenges, including the need to strengthen its transmission and distribution infrastructure and reduce dependency on multilateral foreign aid agencies through sustainable financing models and domestic resource investments in electricity transmission and distribution infrastructure networks to minimize losses and ensure efficient power delivery [57]. As the country strives to achieve its ambitious Vision 2030 and international climate change commitments, addressing the energy sector's challenges and supporting the growth of renewable energy technologies remains critical for Kenya's sustainable development.

The political perspective of Kenya's energy transition underscores the complex dynamics of energy governance and policy frameworks, where national and international actors shape the country's energy policy and development agendas [26, 58]. Balancing the interests of various stakeholders involved in energy development is essential for shaping a coherent and inclusive energy transition strategy, which devises policy decisions that prioritize clean energy technologies and create an enabling environment for private sector investment. Hence, the Kenyan government needs to adopt a holistic and inclusive approach, where the government, international development partners, private sector stakeholders, civil society, and local communities jointly collaborate in designing the country's energy transition direction to make significant steps toward achieving universal energy access, sustainable development, reduced poverty, enhanced energy security, and a low-carbon future for all.

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Conflicts of Interest

The author declares no conflicts of interest.

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