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Blockchain Technology, Regulatory Environment and Competitive Edge in Renewable Energy Sector in Kenya: A Systematic Literature Review

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Abstract: This systematic review of literature bears the objective of exploring the potential of transformative novel blockchain technology, its regulation, and the substantive impact it bears on renewable energy firms' competitive advantage. The study provides a minutiae of the current trends in research, their implications, and blockchain implementation and innovation between 2019 to 2024. The methodology comprised a comprehensive search of scholarly databases, selection, and analysis of the relevant research studies. The findings revealed that Blockchain is essential based on its transparency, traceability, data privacy, and decentralization features which enhance trust, transparency, and traceability across the supply chain. Furthermore, blockchain technology is relevant in the renewable energy sector in Kenya ranging from p2p trading platforms, digitization by IoT, E-mobility, and decentralized trading platforms. The distributed ledger technology is a promising disruption for a wide area of service and product management in the energy sector ranging from the producers, transmitters, regulators, and distributors involved. The review concludes with future research recommendations and the practical implications for the industry players and the regulators.

Keywords: Blockchain technology, smart meter, smart property, energy microgrids, regulatory framework, competitive advantage

I. Introduction

Globally, renewable energy has been recognized as a mainstream source of electricity generation for several years as the estimated share of renewables in the global generation of electricity was more than 26% by the end of 2018 according to Motyka, (2019). Kenya has a significant amount of renewable energy resources such as wind, solar, geothermal, and biomass. If well exploited these resources can have a significant impact on the country's energy supply mix. In Africa, Kenya leads in the exploitation of renewable energy sources to provide the energy required to complement realization of the Vision 2030 with technology such as wind, geothermal, small-scale hydro, and biofuels (USAID Kenya, 2016).

Sustainable competitive advantage allows a company to outperform its competitors consistently over an extended period. It is a long-term advantage that is difficult for competitors to replicate or surpass, providing a company with a strong market position and higher profitability Ruta et al., (2017). Competitive advantage is a pool of competencies that empower a company to exhibit superior performance compared to opponents according to Bobillo et al., (2010). Companies have to fulfill customer needs to attain competitive advantage. Indicators of sustainable competitive advantage in the energy sector entail provenance, auto-billing, traceability, and cost efficiency. Cost efficiency is the ability of a company or organization to minimize its costs while maximizing the value it generates. Traceability is the ability to track and trace the history, location, and journey of a product or ingredient throughout its entire supply chain, from its origin to the end consumer. Auto billing, also known as automatic billing or recurring billing, is a process by which a company automatically charges its customers regularly for products or services rendered. Provenance is the origin, history, and documentation of the ownership, custody, and location of an object, product, or asset throughout its lifecycle.

Blockchain technology was originally introduced as the underlying technology for cryptocurrencies like Bitcoin but has since found applications in various industries beyond finance. Blockchain technology provides a sustainable competitive advantage by ensuring secure and transparent recording of transactions, reducing the risk of fraud, and enhancing trust (Hyvärinen et al., 2017). By leveraging blockchain for decentralized and efficient data management, organizations can enhance their reputation, attract customers, and gain a competitive edge in the market (Francisco & Swanson, 2018).

The constitution of Kenya 2010 guarantees the right to privacy and protection of personal data under Article 31 which forms a significant framework for legislation on data protection and regulations in Kenya (Makulilo, & Boshe, 2016). Moreover, the Data Protection Act of 2019 provides a comprehensive framework for personal data protection as the act establishes the Office of Data Protection Commissioner and provides a framework principle for the collection, processing, transfer as well as storage of personal data. The Office of the Data Protection Commissioner (ODPC) has an oversight responsibility and enforces compliance with the Data Protection Act as the office can investigate breaches and enforce penalties for non-compliance (Laibuta, 2023). Furthermore, the Communications Authority of Kenya (CAK) also regulates the licensing and regulation of telecommunication services in Kenya and plays a significant role in ensuring compliance with ICT laws in the country such as the Computer Misuse and Cyber Crimes Act of 2018 that addresses cybercrimes and online fraud.

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Problem statement

As Kenya embraces renewable energy potential the government has come up with a range of incentives to encourage the adoption of renewable energy across the country (Lindman, Tuunainen & Rossi, 2017). In July 2021 the Finance Act was signed into law effectively reinstating the VAT exemptions on renewable energy products to support the government's efforts to ensure 100% of Kenyans have access to electricity (Chanyisa, 2021). With a present increase in demand for renewable energy, the government identified renewable energy such as wind, solar, and geothermal energy to ramp up the energy supply to the national grid. With the demand increase for renewable energy, there is however little or no significant development and incorporation of the use of blockchain technology in facilitating the use of renewable energy in the wider supply chain industry, especially the energy sector where the industry seems to have stagnated on the already established conventional standards of operation (Wang & Su, 2020).

Blockchain technology holds a promise for enhancing the competitive position of energy firms, however, the influence of regulatory factors on its effectiveness is still not certain. Ambiguities around regulatory compliance, the privacy of data as well as interoperability may work against the realization of blockchains' full potential within the critical energy sector. Understanding how the regulatory dynamics moderate the relationship between blockchain technology adoption and sustainable competitive advantage in energy firms is essential for informing strategic decision-making and policy formulation in the energy industry. Researchers have proposed the application of blockchain technologies as they bear possible solutions to the logistical operation challenges. However, there is a lack of adequate research that is focused on the adoption and use of blockchain technology in supply chain activities in the renewable energy industry. In addition, the technology is also relatively new as Nakamoto introduced it in 2008 (Andoni, 2019). Furthermore, more emphasis has been given to cryptocurrency applications, and this overshadowed other possible applications of the technology in logistics. There is a knowledge gap in the application of blockchain technologies in the energy industry.

Objectives

The significant objective is to undertake a systematic review of the literature to determine the adoption of blockchain technology, its regulatory framework, and sustainable competitive advantage in renewable energy firms between 2019 to 2024. The rationale for 2019 to 2024 is;

Concentrating on the recent studies, literature, and publications the review captures the up-to-date development and trends in the industry.

Relevance is guaranteed as the focus on the recent publications in the review keeps the discussion relevant to the contemporary landscape as the findings as well as recommendations align with the current trends and needs of the industry.

The development of new challenges and solutions that emerge that are associated with the use of the novel technology such as ethical considerations are captured as the recent studies discuss these challenges and put forward solutions.

The diverse application of novel technologies such as the Internet of Things, blockchain technology, and big data analytics across various domains in recent research offers a diversity of insights into how these technologies are used across different disciplines.

i. To analyze and explore the consequences of adopting blockchain technology, its regulations, and sustainable competitive advantage in the renewable energy sector

ii. To examine the role of the regulations and their impact on sustainable competitive advantage in the renewable energy sector

II. Literature review

The review of literature synthesizes the existing literature on blockchain technology, regulatory environment, and sustainable competitive advantage in the renewable energy sector. It provides for both the positive and negative effects of the adoption of the technology as well as their theoretical framework. Key topics include digital product memory, smart grid, smart property, smart energy microgrids, Regulatory framework, sustainable competitive advantage, and comparative insights.

Digital product memory

Blockchain technology is a distributed ledger system of information recording that makes it impossible for the information to be changed, hacked, or manipulated. Digital product memory indicators in energy firms use digital systems and technologies to track, monitor, and manage the operational history and performance data of energy products or assets (Vitoi, Junqueira, & Miyagi, 2022). These indicators provide a digital memory or record of important information related to energy products throughout their lifecycle.

Digital product memory is essential in data collection and logging as they bear memory capabilities that collect data continuously and log data about user's interactions, preferences as well as usage patterns. These data may also include sensor readings, transaction history, and user inputs. The data collected is often stored in digital memory systems such as databases and cloud storage which retain huge amounts of data allowing historical analysis and identification of trends. Digital product memory

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enables predictive analytics and machine learning algorithms that help in forecasting future behaviors based on trends in historical data (Wu et al., 2022).

By leveraging digital product memory, energy firms can create personalized experiences for their users as their products can remember user preferences, past interactions, and settings to streamline workflow, reduce friction, and enhance customer satisfaction (Wahlster, 2013).

Smart grid

Smart grids in energy firms refer to the key metrics or measures used to assess the performance, efficiency, and effectiveness of a smart grid implementation. It is an advanced electrical grid infrastructure that incorporates a variety of digital technologies, automation, and communication systems to improve efficiency, sustainability, and reliability in the production of electricity, consumption, and distribution(Chen, Chen, & Lan, 2016).

Smart grids are composed of smart meters which are fundamental components that provide real-time monitoring of the usage of electricity and enable two-way communication between the consumers and the utility company. These smart meters help utility companies to better understand consumers' energy consumption patterns, and detect energy outages fast (Saxena, Kumar, & Nangia, 2021).

Smart grids often incorporate distributed energy sources such as solar panels and wind turbines as well as energy storage systems along with demand response technologies into the electricity network allowing a decentralized generation and storage of electricity. This reduces dependence on centralized power plants improving grid resilience. Furthermore, smart grids leverage on analysis of data, machine learning, and predictive modeling techniques to undertake analysis of vast amounts of data obtained from energy sensors, and meters. The data is used to forecast electricity demand, optimize grid performance, implement proactive maintenance strategies, and anticipate failure in equipment (Prabhu, 2012).

Smart grids rely on communication networks that are robust to facilitate the exchange of information between several grid components including meters, control centers, sensors, and energy management systems. The communication networks enable seamless coordination and integration of grid assets that support real-time control and monitoring of grid operations (Salkuti, 2020).

Smart Property

Smart property refers to the integration of smart technologies and automation systems within buildings and properties to enhance energy efficiency, optimize resource management, and improve occupant comfort. The physical assets are embedded with sensors and connectivity features that enable them to collect, transmit, receive data, and respond to commands or changes in the environment. In the energy sector smart property is essential in transforming the traditional infrastructure into interconnected intelligent systems that optimize production of energy, consumption, and distribution (Chen, Chen, & Lan, 2016).

Smart meters are essential in smart properties as they monitor electricity consumption in real-time and provide communication to utility firms as well the consumers enabling accurate billing, remote meter reading, and institution of demand-guided management strategies. Smart grid infrastructures are also essential as they integrate communication monitoring and control systems into the grid infrastructure. These technologies include the use of sensors and automation systems that enable real-time monitoring of grid conditions (Nowicka, 2020). Smart property facilitates blockchain-enabled trading platforms as the technology facilitates peer-to-peer trading platforms which allow the users to buy, sell, and exchange energy directly with each other in a decentralized manner. Smart contracts enable meters that are blockchain-enabled to secure transactions in a transparent manner fostering efficiency and sustainability (Morelli, et al., 2022). Smart property technologies foster resilience and reliability of energy infrastructure through data-driven insights and decision-making as the vast amounts of data on energy consumption, patterns in demand, and system performance are generated from the sensors, automation systems, and smart meters that monitor and analyze the information. Utility companies leverage this data by harnessing advanced analytics, predictive modeling techniques, and machine learning to extract valuable insights from the data to optimize their operations and make strategic decisions (Lee, Chen, & Chen, 2015).

Smart meters

These are advanced energy meters that monitor and record the consumption of electricity in real time as they are equipped with communication capabilities that allow two-way communication between the utility company and the meter (Barai, Krishnan, & Venkatesh, 2015). Smart meters are not part of blockchain technology but can be integrated with features of blockchain technology to create innovative solutions in the energy industry.

Smart meters often generate a large amount of information related to the consumption of electricity that blockchain technology can secure and store in a decentralized ledger ensuring data integrity and eliminating unauthorized access. By leveraging blockchain technology, smart meters allow for transparent and automated billing and settlement processes. This is because smart meters enable smart contracts that are self-executing with the terms of the agreement directly inputted into the code used to automate billing based on the energy consumption recorded by the smart meters (Zheng, Gao & Lin, 2013). This goes a long way in reduction of disputes in billing improving transparency for the consumer and the utility company.

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Smart meters that are blockchain-enabled can facilitate peer-to-peer trading among consumers within a microgrid. The smart meters record energy consumption and production data that is stored securely and verified on the blockchain. Further, consumers can buy and sell excess energy directly with their neighbours bypassing traditional utility companies potentially reducing costs of energy (Morello et al., 2017).

Blockchain technology can enable tracking and tracing of sources of energy from renewable sources such as solar and wind. This is because the smart meters equipped with blockchain technology can certify the renewable energy generated and consumed providing transparency and accountability in the energy chain (Chen et al., 2023). Moreover, the smart meters that are blockchain-enabled support the development of decentralized energy markets where the producers of energy sell directly to consumers. This goes a long way in encouraging the adoption of renewable energy sources enabling the transition to a sustainable energy system (Avancini et al., 2019).

Kenya's metering system is largely prepaid and post-paid conventional meters. In 2003, Kenya Power and Lighting Company called for bidders in the supply of smart meters to curb illegal connections and reduce losses. The utility firm invited public suppliers for single-phase and three-phase meters projecting over 200,000 meters to have been acquired by January 2024. The country has already received the initial 700,000 smart meters and it has liaised with a local telecommunication firm to transmit the smart meter readings according to Otuko et al., (2024).

Energy microgrids

Energy microgrids are small-scale localized energy systems that integrate multiple energy sources, such as renewable energy generation, storage technologies, and demand management. They offer increased resilience, reliability, and efficiency to energy firms. These systems can operate in conjunction with the main grid or independently as they integrate various distributed energy resources such as conventional generators, wind turbines, and solar photovoltaic panels (Wang et al., 2018). Microgrids bear the ability to generate, store, and manage electricity within a specific geographic area providing reliability, resilience, and cost savings compared to conventional centralized grid systems.

Microgrids are equipped with advanced control systems and management software that monitor, coordinate, and optimize the operations of distributed energy sources as the systems enable dynamic load management, forecasting energy requirements in real-time, and grid balancing to ensure reliable energy delivery (Zia, Elbouchikhi, & Benbouzid, 2018). Furthermore, the microgrids bear the ability to undertake islanded operations where they can disconnect from the main grid during disturbances or outages and continue providing electricity to locals independently as a result reducing vulnerability during disruptions in the national grid (Shi et al., 2015).

Microgrids are easily integrated with smart grid technologies such as the advanced metering infrastructure (AMI), distribution automation, and grid analytics to foster control, and visibility by optimizing grid operations (Rahbar, Chai, & Zhang, 2016). Moreover, in remote areas where grid infrastructure is limited or unreliable energy microgrids provide backup power and resilience to critical facilities such as military bases and data centers as well as hospitals to ensure continuous operation during emergencies.

Energy microgrids help in demand response programs as well as energy management strategies to optimize energy usage, reduce peak demand, and lower the costs of electricity. Consumers can adjust their consumption of electricity based on grid conditions or price signals as a result of improving the efficiency of the overall system (Fathima, & Palanisamy, 2015). Energy storage systems such as the use of batteries to store excess energy generated during periods of low demand help in balancing supply and demand, enhance grid stability, and provide power during outages. Renewable energy sources such as solar are used in energy microgrids to generate electricity. This localized generation eliminates dependence on distant power plants enhancing energy resilience among the users (Wang et al., 2018).

Regulatory environment

The regulatory environment is governed by regulatory bodies, laws, and regulations which provide a framework for industry players to align with. For instance, the Energy Act of 2019 gives a legal framework for the development, promotion, and regulation of the energy sector in Kenya as it gives an outline of the responsibilities of the various stakeholders such as the Ministry of Energy and the Energy Regulatory Commission (Ogeya et al., 2021). The Energy Regulatory Commission is the primary regulator responsible for licensing, regulation, and tariff setting in the energy sector in the country. The commission oversees the generation of electricity, transmission, distribution, and retail supply activities to ensure compliance with technical and legal standards (Janho, 2020).

Kenya has seen significant electricity sector reforms that have liberalized and diversified the energy market. These reforms entailed the participation of the private sector and the promotion of renewable energy to enhance affordability and access to energy resources. The government implemented the feed-in tariff program to promote investment in renewable energy, especially in wind, hydropower, and solar projects (Takase, Kipkoech, & Essandoh, 2021). Furthermore, the country adopted the renewable energy policy framework that is aimed at increasing the share of renewable energy in the national grid by offering incentives such as tax breaks and regulatory support to attract investment.

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The Kenya Rural Electrification Authority bears the mandate to facilitate the extension of electricity infrastructure to the underserved remote areas of the country (Keshavadasu, 2023). The authority implements electrification projects by promoting off-grid solutions and supporting community-based solutions. Regulations and guidelines supporting off-grid and mini-grid electrification projects have been developed to provide frameworks for licensing, consumer protection, and maintaining technical standards in off-grid systems.

Kenya established initiatives that demonstrated its interest in blockchain technology like the creation of the blockchain and artificial intelligence taskforce formed in 2018. This was a step in the right direction, however, the country has severe regulatory gaps that stall the adoption of block chin across the wider spaces of the energy industry. For instance, the country does not have comprehensive legislation bearing specific laws that govern the novel technology as the legal framework that is in operation does to address the unique attributes of blockchain. This discourages innovation in the sector and also makes it difficult for dispute resolution for instance in smart contracts and decentralized grid systems. Moreover, the Kenyan law does not recognize blockchain transactions such as smart contracts that bear no legal recognition which makes it difficult to enforce blockchain-based agreements bringing to the core problems with asset ownership and right validation for tokenized resources like energy credits. The Kenyan regulatory framework is based on the centralized utilities and energy systems and does not give legal status to blockchain-enabled decentralized trading platforms, this significantly limits the P2P energy trading platforms and also limits the ability of small energy producers to sell their surplus to consumers directly.

Kenya is limited by the Energy Act of 2019 which limits its support for decentralized systems as the related policies focus on grid-based solutions and offer limited provisions for decentralized systems of energy. This greatly discourages innovation in off-grid projects that are based on rural electrification and draws back opportunities for blockchain to optimize the management of decentralized energy systems. Moreover, Kenya lacks standards essential for blockchain integration with the existing energy infrastructure such as the smart meter systems and the national grid. This increases the cost of integrating blockchain solutions and hinders interoperability between the existing infrastructure and the blockchain systems.

In addition, there exists a significant drawback concerning a fragmented regulation authority as there exist several bodies that bear overlapping authority in blockchain-related activities. This prevents confusion among the stakeholders on compliance requirements. Weak enforcement from the regulator EPRA as a result of its lack of expertise and tools to enforce compliance on blockchain-based projects has resulted in an increase in non-compliant projects and difficulty in monitoring and evaluating the projects.

To solve the regulation gaps the country needs to come up with comprehensive policy frameworks which address the adoption of blockchain in peer-to-peer trading, renewable energy certificates, and the management of decentralized energy systems. In addition, the Energy Act of 2019 needs amendments to accommodate peer-to-peer blockchain-enabled energy trading and management of microgrids. There is a need to introduce new legislative frameworks that recognize smart contracts and blockchain transactions. Furthermore, the Energy Regulatory Commission among other regulators needs to be enhanced to understand the idea of blockchain technology and its adoption in the energy sector. For instance, the development of a regulatory sandbox, a controlled environment where blockchain solutions in the renewable energy sector are tested to refine policies and enhance their practical application.

The Data Protection Act along with the regulator and the Office of Data Protection Commission need to update the Data Protection Act to provide guidelines for data handling in blockchain systems. The state is to prioritize training and capacity building for the regulator to enhance its oversight of blockchain projects and improve enforcement. It is also recommended for the state to come up with a unified taskforce that will have the responsibility of overseeing the adoption of blockchain technology resolving the jurisdictional conflicts among the various regulatory bodies.

Comparative insights

South Africa is among the developing countries that have a significant renewable energy potential just like Kenya, and is exploring blockchain technology to address inefficiencies in its energy systems. For instance, firms like the Sun Exchange have pioneered blockchain-based peer-to-peer trading systems that allow businesses and individuals to trade surplus energy directly reducing national grid dependence and promoting access to energy in rural areas (Maine, Leke, & Longe, 2024). In addition, blockchain technology has been adopted in the rural off-grid areas to better manage microgrids in an effective manner that has in turn supported renewable energy adoption in the rural areas. In addition, blockchain has enabled transparent trading of renewable energy certificates and carbon credits enabling transparent tracking and compliance with environmental goals (Chime, 2023). The adoption of blockchain technology has brought on board immutable records as there is a transparency guarantee in the energy transactions, reduced national grid reliance that is the major cause of inefficiencies, and brought about efficiency in billing processes.

India has actively explored blockchain technology and its adoption in renewable energy by recognizing the potential to enhance sustainability and efficiency. The country has adopted energy microgrids in its rural electrification in areas such as Uttar Pradesh, where blockchain is used in the management of microgrids enabling the local trade in excess energy (Gupta, et al., 2023). This has reduced dependence on the national grid's centralized utilities. In addition, the integration of the Internet of Things into blockchain technology along with smart meters has gone a long way to automate grid management, energy billing, and energy

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allocation. This is evident, especially in urban areas like Bangalore where blockchain is used to balance the grid and efficient demand response management. The technology has also been used to enhance transparency and traceability of renewable energy certificates and carbon credits as companies like the power ledger collaborate with Indian utility firms to implement blockchain-based solutions that reduce fraud and simplify compliance with renewable energy purchase obligations (Waseem et al., 2024). In addition, blockchain is used in peer-to-peer energy trading where the collaboration between Tata Power and INEAI has enabled households and businesses to trade surplus solar energy on blockchain platforms

III. Methodology

The systematic literature review methodology is majorly qualitative based on the collection, analysis, and synthesis of the available existing qualitative and quantitative research studies along with their findings. The focus is on gathering, textual information interpretation, identification of patterns, trends, and themes and comprehensively summarizing the available knowledge. The methodology for the systematic review is designed to give a comprehensive examination of the adoption of blockchain technology, regulatory framework, and competitive advantage in the renewable energy industry from 2019 to 2024 because of their relevance in current trends, government policies, and implementation of the novel technology. The synthesis approach ensured a rigorous and comprehensive search of the relevant publications that enabled the selection and subsequent analysis of the studies that addressed the objectives.

Büyüközkan and Göçer (2018) undertook a study on digital supply chain where they reviewed and proposed a framework for future research where suppliers, partners, and dealers share information across the supply chain to create a digital supply chain that is value-driven and efficient as it creates value for organizations leveraging on innovative technologies such as internet of things and cloud computing.

Dobrovnik et al., (2018) study on blockchain for and in logistics identifies the limited literature concerning frameworks that categorize blockchain application potentials and implications especially academic literature in transport and logistics. Kamble et al., (2017), looked at different aspects of supply chain and logistics operations and how they could be boosted by integration of the BCT framework in its operation. The findings of the studies are based on analytical models that are context-specific. This presents a contextual gap as it’s impossible to determine whether similar conclusions are arrived at in different contexts.

A study undertaken by Wang, Han, and Beynon-Davies, (2019) on understanding blockchain technology for future supply chains ascertained that technology is in its infancy stage but rapidly gaining momentum within supply chains driven by the trust deficit as its usefulness lies in traceability, visibility, smart contracts, data security and digitalization of the supply chain. A study by Kshetri, (2021) on the blockchain and sustainable supply chain management in developing countries demonstrated that the technology is essential in promoting sustainability in the supply chain although as a result of limited resources the benefits to vulnerable populations such as the smallholder farmer are not guaranteed as a result of their lack of relevant skills and unfavorable technological conditions, infrastructure as well as market development.

A study by Mwangakala et al., (2023) on leveraging blockchain technology to revitalize the agricultural supply chain in East Africa based on the lessons from Tanzania and Uganda revealed that several emerging technologies such as blockchain technology and the Internet of things bear significant potential in the agricultural supply chains. Blockchain is essential based on its transparency, traceability, data privacy, and decentralization features which enhance trust, transparency, and traceability across the supply chain.

A study undertaken by Samuel (2020) on leveraging blockchain technology for secure energy trading and least cost evaluation for decentralized contributions to electrification in sub-Saharan Africa identifies the smart grid as an emerging technology in sub-Saharan Africa that provides two-way communication between energy producers and customers. The technology is faced with difficulties such as energy theft as a result block chain blockchain-based decentralized energy system is proposed to accelerate rural-urban electrification.

Research undertaken by Atinda, (2022) on the effect of blockchain technology on the operational efficiency in Kenya’s power sector established that blockchain technology is relevant in the renewable energy sector in Kenya ranging from p2p trading platforms, digitization by IoT, E-mobility, and decentralized trading platforms. Distributed ledger technology is a promising disruption for a wide area of service and product management in the energy sector ranging from the producers, transmitters, regulators, and distributors involved. A study undertaken by Robu and Merlinda (2019) on the effect of blockchain technology shows the need for the technology to prove its scalability, security, and speed before it is fully adopted in the energy sector.

Obi and Ngila, (2020) in their assessment of blockchain technology to boost power access in rural areas noted that in a blockchain-based power market, all plants that generate energy will bear a digital identity that will link the entire power production unlike in the current situation where the regulator EPRA centrally manages energy regulation that should be decentralized minimizing corruption, price fluctuations, and mismanagement. Blockchain technology is useful as it can aggregate and generate electricity consumption patterns that inform decisions. Smart grid technology backed by blockchain technology in microgrids helps in keeping all the data on power distribution and purchase.

A study by Musyoki, Shitanda, and Nganu, (2020) on determining the adoption of blockchain in the insurance industry in Kenya ascertained that the technology is still in the innovation trigger phase as the spectrum of possible applications has not been fully

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explored to ascertain whether to adopt the technology in the industry or not. A study by Wangui, Ombati, and Oboko, (2022) on the use of blockchain in the informal distributed manufacturing industry in Kenya ascertained that the use of immutability and tamper-proof origin features of the technology greatly enhances traceability within the supply chain especially when working with a diverse range of producers dealing in similar products.

IV. Discussion

Blockchain technology bears a significant potential in the energy sector, however, its adoption is faced with several challenges emanating from the country's limited infrastructure, prohibitive cost for its countrywide rollout, and resistance from the society. Blockchain technology heavily relies on a robust digital infrastructure with reliable electricity that is not available in several regions resulting in a slowdown in its deployment and disruption of its operations based on unreliable electricity. In addition, public blockchains such as Bitcoin have scalability limitations as they cannot handle large transaction volumes as a result of slow processing time (Waseem et al., 2024). The integration of blockchain with existing traditional databases and legacy systems is impossible as a result of their incompatibility resulting in delays in its adoption based on technical challenges and extra cost to upgrade the existing systems.

Furthermore, the initial cost for the development and deployment of blockchain infrastructure requires significant capital investment in skilled personnel, software, and hardware development (Tang et al., 2024). This slows its adoption, especially in developing countries, and makes its adoption among small and medium enterprises unaffordable. Furthermore, maintaining the blockchain networks incurs additional costs such as transaction and electricity bills which proves to be a challenge for projects that heavily rely on public participation funding and limit the scalability of the projects.

Society also is key in the adoption and implementation of blockchain technology, however, resistance as a result of limited knowledge about the technology by the stakeholders, businesses, and policymakers makes it hard to operationalize based on misconceptions of the technology being complex or unnecessary. In addition, the conventional energy systems and practices are often deeply rooted in the stakeholders that may stall the transition to a decentralized model as a result of hesitation to adopt blockchain solutions. The public is also skeptical about their data and its security in blockchain technology and is reluctant to participate at the same time, this has heightened scrutiny from privacy advocators and the regulators (Ondiek, & Onyango, 2024). Finally, the risks associated with decentralization and automation brought about by blockchain technology may directly threaten traditional job roles such as supply chains and may cause resistance from labor organizations and the affected persons as a result of their potential job displacement.

The Kenyan energy sector can address the technology implementation challenges by enhancing the energy infrastructure through significantly investing in reliable internet and energy infrastructure in the underdeveloped parts of the country as well as supporting the development of energy-efficient blockchain protocols like the proof of stake protocol. In addition, cost reduction is a prudent measure through the provision of subsidies and blockchain tax incentives to enable its adoption and encourage private blockchains which require fewer resources compared to public blockchains. It is also essential for the state and private actors to undertake public awareness campaigns to demystify blockchain through offering programs to policymakers, business persons, and IT personnel. This goes a long way in developing collaborative efforts with trusted institutions to validate solutions provided by blockchain technology and pilot blockchain projects that bring to light the technology benefits such as cost saving according to Sadiku, Chukwu, and Sadiku, (2024). There is a need to develop supportive policies and regulations that encourage innovation with a keen eye on the privacy and security of data. This can be encouraged through the development of sandboxes to test the application of blockchain technology in a controlled environment. This is important as it involves diverse stakeholders in blockchain initiatives. Addresses job displacement fears through an emphasis on the creation of new job roles and ensures equitable benefits. The Kenyan government has adopted several policies and regulations such as feed-in tariffs, exemption on VAT, and importation duties on renewable energy infrastructure.

A vibrant solar market has emerged in Kenya over the years providing electricity to institutions and homes remote from the national grid. Solar utilization is mainly for photovoltaic systems (PV), drying, water heating, water pumping, and lighting. The renewable energy sector has experienced changes following the government's intervention to promote its usage. With a present increase in demand, the government identified renewable energy such as wind, solar, and geothermal energy to ramp up the country's supply (Lindman, Tuunainen & Rossi, 2017).

Several firms have entered into the sector aimed at taking advantage of the government's policy to increase production. These companies' products range from solar pumps, security lighting, solar street lighting, solar panels, and solar water heating systems. The country's national energy policy bears a framework to facilitate the provision of clean, affordable, sustainable, secure, and reliable energy services at the least cost while conserving the environment. With the present increase in demand for renewable energy, the government identified renewable energy such as wind, solar, and geothermal energy to ramp up the energy supply to the national grid (Wang & Su, 2020).

Scalability and long-term feasibility of blockchain in the energy sector

Kenya faces significant challenges in its blockchain scalability for instance the country's growing energy demand requires systems that can handle high transaction volumes efficiently. The current blockchain systems especially those that use proof of

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work bear a limited transaction throughput that hinders large-scale applications. In addition, the cost of deploying blockchain infrastructure nationally is prohibitive as a result the energy pricing mechanisms inputted by the adoption of blockchain technology may benefit the well-connected regions bringing about inequality. Furthermore, the Kenyan energy infrastructure is not designed for blockchain integration which brings about interoperability challenges (Atinda, 2022).

The Kenyan renewable energy sector aligns well with blockchain energy demand especially when energy-efficient consensus mechanisms such as proof of stake are adopted. As a result, proactive regulatory frameworks are essential to enable blockchains' long-term viability in the country. The technology can empower communities through the decentralized energy markets increasing affordability and access (Rawhouser et al., 2022). Blockchain technology advancement for instance the adoption of layer 2 solutions and sharing can address concerns of scalability that make it feasible for deployment on a large scale in Kenya.

It is therefore recommended that Kenya leverage and draw lessons from microgrid use from countries like India and Bangladesh solar trading networks to develop localized energy solutions.it is essential to invest in capacity building and education to develop technical expertise that supports the maintenance, deployment, and innovation of blockchain systems. Furthermore, there is a need to incorporate and make use of energy-efficient blockchain protocols such as the transition to hybrid consensus mechanisms to reduce the cost of energy and improve scalability (Mutuku, 2023). It is also important to come up with a national blockchain strategy that aligns the adoption of the technology to the country's Vision 2030 goals that enable access to energy, economic growth, and sustainability. Public-private partnership is encouraged as collaboration between the state, private actors, and international organizations to fund and pilot blockchain initiatives goes a long way in enabling its advancement and adoption of best practices.

V. Limitations of the review

Existence of publication bias despite the use of search strategies that are adopted to include far and wide studies that are published and unpublished.

The existence of temporal bias based on the focus on publications from 2019 to 2024 excludes the earlier studies and also misses out on the ongoing research that bears long-term impacts.

The presence of heterogeneity based on the diverse nature of the studies in the various disciplines in terms of their designs, study participant characteristics, and outcomes makes it hard to come up with definite conclusions.

The existence of researcher bias is based on the systematic process in review that is subjective in nature at several stages such as data synthesis that introduces researcher bias.

VI. Conclusion and recommendation

Blockchain technology, regulatory environment, and sustainable competitive advantage in the renewable energy sector in Kenya are essential in harnessing and leveraging novel technology to better the company’s efficiency, effectiveness, and bottom line. This paper has discussed the importance of the adoption of smart meters, smart property, energy microgrids, digital product memory, and the subsequent regulatory frameworks that affect the competitive edge of the renewable energy sector. It has also brought to light areas that innovation and novel technology can improve and enhance significantly. The practical case studies illustrate the successful application of blockchain constructs and the significant role of the regulator and data protection to realize a competitive edge in the renewable energy industry.

The study therefore recommends that to be able to realize a competitive edge in the renewable energy sector there is a need to make use of novel transformative and disruptive technologies and innovations to enhance efficiency, and effectiveness and enhance the company's bottom line. Regulations have to be enforced by the regulator with precision and should be proactive and not reactive. There needs to be a clear definition of the roles each regulator in the field regulates based on disruptive novel technologies that emerge in the contemporary world to eliminate ambiguities and role duplication and encourage collaboration between the various government regulation agencies.

Data availability statement

The review of literature made use of literature and data that is publicly available from peer-reviewed sources such as articles and journals. All the references cited are included to foster transparency. The research searched databases that are scholarly following a defined criteria explained in the methodology section. There was no primary data collection instead the study synthesized and analyzed existing works to give an overview. The specific sources used for the review can be accessed through their respective digital libraries, publishers or directly contacting the authors.

Declaration of interest

The author declares no competing interests.

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