Combined Proceedings of the 39th iSTEAMS Bespoke Conference – July, 2025
& iSTEAMS Emerging Technologies onference October, 2025

Society for Multidisciplinary & Advanced Research Techniques (SMART - Scientific Projects & Research Consortium (SPaRC)
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International Institute for Multidisciplinary and Development Research
Harmath Global Educational Services

39th International Science Technology Education Arts Management
& Social Sciences (iSTEAMS) Bespoke Conference - Accra Ghana 2025

Enhancing Decentralised Renewable Energy Trading through Artificial Intelligence and Blockchain Technology

Adelakun Najeem Olawale
Doctoral Programme in Artificial Intelligence
African Centre for Technology Enhanced Learning (ACETEL)
National Open University of Nigeria, Abuja, Nigeria
E-mail: adelakunno@fceiwo.edu.ng
Phone: +2348067655665

ABSTRACT

Renewable energy system decentralisation requires intelligent, transparent and secure energy generation, transmission, distribution, and trading approaches. This study focuses on the role of artificial intelligence and blockchain technology in enhancing the concept of decentralised renewable energy trading through the reduction of inefficiencies, data ignorance, and trust challenges found in conventional power systems. Artificial intelligence predictive algorithms are used to optimise energy consumption and distribution, and the blockchain immutable registry keeps the integrity, transparency and responsibility of transactions. Collectively, these technologies support the creation of a decent and reliable digital energy market. The study reviewed case studies and related studies from African as well as other global environments to investigate the adoption patterns and infrastructural constraints, and regulatory preparedness in influencing the adoption of these technologies. The findings reveal that artificial intelligence and blockchain technology can significantly enhance the energy efficiency and market transparency but the holistic deployment of the technology remains limited with weak digital infrastructure, limited stakeholder awareness, and regulatory uncertainties. The study recommends a well robust harmonised policy and technical solution, which involves focused investments, regional coordination and institutional capacity building to achieve an equitable decarbonisation. This will offer a practical channel on how to improve the power of the decentralised renewable energy trade in the developing nations and at the same time enhance sustainability, fairness and economic stability.

Keywords: Artificial Intelligence, Blockchain Technology, Decentralised Energy, Security, Renewable Energy, Smart Cities.

Proceedings Citation Format
Adelakun Najeem Olawale (2025): Enhancing Decentralised Renewable Energy Trading through Artificial Intelligence and Blockchain Technology. Combined Proceedings of the 39th iSTEAMS Multidisciplinary Bespoke Conference 17th–19th July, 2025 & iSTEAMS Emerging Technologies Conference 30th–31st October, 2025. Ghana-Korean Information Resource Centre, Balme Library, University of Ghana, Accra, Ghana. Pp 25-42. www.isteams.net/ghana2025. dx.doi.org/10.22624/AIMS/ACCRABESPOKE2025P5

1. INTRODUCTION

The energy industry in the world is still vulnerable. Conventional centrally controlled power systems, which have long been the bedrock to industrial development, are now inefficient, unreliable, and not well adapted to satisfy the complicated energy needs of an ever more urbanised and digitalised environment. The urgent need to reduce greenhouse gas emissions, improve grid efficiency, and provide fair energy access requires a massive change and not gradual improvements. The technologies of artificial intelligence and blockchain computing are located at the intersection of this revolution and redefine the energy production, transmission, distribution, and use process. Collectively, it provides cleaner and smarter energy systems, as well as secure and decentralized markets that are based on efficiency, transparency, and sustainability (Rajendran et al., 2025).

Predictive machine learning and analytics are used by artificial intelligence to provide the computational insight needed to forecast demand, optimise energy distribution, and manage energy generated by renewable sources. On the other hand, blockchain gives the energy trading continuum credibility, transparency, and decentralisation, which allows peer-to-peer transactions that cannot be tampered with (Khan et al., 2022). These technologies when combined make up the basic building blocks of a self-regulating and intelligent energy milieu. Mechanisms of smart contracts can independently perform transactions based on real-time data, whereas AI algorithms can adapt to user behaviour to moderate prices, energy flow, and consumption patterns. This synergy creates a decentralised marketplace that minimises manual intervention, minimises the cost of operations, and increases the reliability and trust of the participants (Aakula et al., 2024). The Africa potential of these technologies is high.

The continent is blessed with a lot of renewable resources such as solar, wind and hydroelectric power, but there is lack of fair access and distribution of the resources. Sub-Saharan Africa has a population of about 620 million people who are still without electricity, and even those who have access to it are often faced with unreliable electricity supply and broken billing systems (Onyeanusi, 2025). Decentralised energy trading can help in bridging the gaps identified by allowing small scale producers to sell excess renewable electricity to proximate consumers. Blockchain technology provides a secure and transparent way of transactions, and artificial intelligence increases the stability of the system by predicting changes in supply and demand. Therefore, such converging technologies enable African states to bypass traditional grid systems and create adaptable and community-based microgrids that can work without centralised control (Adelakun et al., 2024; Fantin Irudaya et al., 2025).

On the international level, the fusion of artificial intelligence and blockchain computing is now transforming the working paradigm of energy systems. Power Ledger in the United Kingdom and WePower in Estonia are examples of initiatives in Europe that have shown that blockchain-based trade can save money, enhance transparency and consumer involvement in renewable energy markets (Abdul and Tanveer, 2025; Naveen et al., 2025). Microgrid management solutions based on AI are reducing the impact of power variability caused by fluctuating solar input in Asia (Veerasamy et al., 2025). These global leaders show that blockchain and artificial intelligence are not only theoretical frameworks but practical tools that can be used to guide the process of transforming to a low-carbon, decentralised energy future.

However, there are still many barriers, which prevent the wider adoption. Technical issues also continue to be daunting, including a lack of scalability of the network, high-prohibitive cost of computation, as well as poor data interoperability. There are also policy and regulatory gaps; a number of developing countries do not have clear constitutional regulations on the decentralised energy markets or digital assets. In addition, the lack of knowledge among the legislators and citizens about the principles of operation of these technologies and their possible implementation in the current energy systems still slows down the development. Without a specific investment in digital capabilities, infrastructure, and institutional capacity, artificial intelligence and blockchain can be a technology that is limited to developed economies.

The current research paper assumes that decentralised renewable energy trading, facilitated by the adoption of blockchain computing technology and artificial intelligence, is not only a technological breakthrough but a turning point in the fair and sustainable energy transition. It looks at the history of these technologies, the level of their implementation in Africa and the factors that affect their diffusion in the world. The paper clarifies the adoption behaviour in different socio-economic environments through the application of theoretical models such as the Technology Acceptance Model (TAM) and the Diffusion of Innovation theory.

2. LITERATURE REVIEW

The integration of artificial intelligence and blockchain technology into renewable energy system has become a viable solution to intermittent power supply in most developing nations, which have gained significant attention from the academic and industrial setting. The shift to decentralised, consumer-driven energy systems all over the world has opened the way to more flexible, credible, and independent energy management. The technologies can provide smart, safe, and effective trading platforms, which can improve accountability in energy markets (Hasan et al., 2022). Empirical studies show that the combination of artificial intelligence and blockchain technology enables peer-to-peer energy trading, enhances accuracy in forecasting, build trust between the participants of the renewable energy systems (Mahmoud and Slama, 2023).

Artificial intelligence has become an inevitable part of modern energy management systems with unparalleled analysis capabilities to enhance generation, transmission, distribution, and consumption. Predictive algorithms and machine learning are used to examine complex data, thus improving efficiency, reliability, and sustainability. The fundamental applications include demand forecasting, fault detection and predictive maintenance. Ukoba et al. (2024) conducted a thorough review of the use of artificial intelligence in renewable energy systems, highlighting that it can be used to predict, optimise, and integrate the grid, but noted that there are issues with variability and interpretability of data. Bassey et al. (2024) explored peer-to-peer energy trading that involves blockchain, the Internet of Things (IoT), and AI, noting that it is beneficial in terms of local balancing and renewable integration, regulatory limitations, and adoption limitations.

The analysis of over 200 studies by Safari et al. (2024) shows that AI and machine learning enhance reliability, resilience, and efficiency in smart grids and electric vehicles, and raises the issue of privacy, interoperability, and scalability concerns. Arevalo et al. (2024) have shown that artificial intelligence complements the energy management of electric-vehicles using machine learning, deep learning, and genetic algorithms used to optimise, maintain, and protect cybersecurity. Adelakun (2024) discussed the potential of AI to transform the sustainable and decentralised energy management, promoting the ethical use of AI, investing more in research, and improving international cooperation. The blockchain technology enables transparency, traceability and security in decentralised energy markets because it allows direct trading between the producers and consumers. Its distributed registry guarantees the integrity and auditing of data and transactions are automatically executed by smart contracts thereby improving efficiency and trust.

First-mover projects like Power Ledger in the United Kingdom and SunContract in Slovenia have shown that blockchain can be useful in the community-based energy exchange (Uche-Soria et al., 2025). Saeed et al. (2024) suggested a decentralised peer-to-peer trading platform of microgrids that uses Ethereum smart contracts to automate the process, balance the demand and supply, and decrease grid dependency. Alam et al. (2024) created a multilayer trading system based on blockchain technology to manage virtual power plants and optimise the distributed energy resources to increase grid stability. On the same note, Umar et al. (2025) proposed a decentralised electricity market, which combines blockchain and energy management systems to allow fair and transparent peer-to-peer trading. However, scalability, interoperability and computational requirements are major challenges to large-scale adoption.

Artificial intelligence (AI) and blockchain technology integration forms a groundbreaking foundation of the creation of intelligent, decentralised energy ecosystems, which synthesise the analytical ability with secure, transparent, and immutable data governance (Alzoubi, 2025). Artificial Intelligence assists in adaptive energy management and data-driven decision making, and blockchain helps to verify data and increase the model reliability. Al Shareef et al. (2024) consider such convergence as a driver of automation, security, and efficiency in various industries, and the potential of such convergence is limited due to the lack of implementation frameworks. According to Yang et al. (2024), AI integration with clean energy triggers long-term development; at the same time, the impact of blockchain is the greatest in the extreme circumstances, thus, the need to integrate its adoption to support energy-transition policies and low-carbon investment.

A bibliometric analysis of 23,074 publications (2020 - 2025) on digital innovations, such as AI, blockchain, the Internet of Things, and data analytics, by Jaramillo et al. (2025) demonstrated that AI is the most widely studied area, then IoT and analytics, and blockchain is gaining momentum in the decentralised energy markets. Babaei et al. (2025) examined the use of blockchains in the renewable-energy supply chains through data-driven and fuzzy tri-objective optimisation and found high capital expenditures and deployment complexities to be the main barriers and the need to plan and allocate resources strategically. AI and blockchain are transforming the electricity markets around the world by introducing new projects.

The peer-to-peer renewable-energy sharing is viable in the European Union, with the Horizon 2020 programme, and the Brooklyn Microgrid in the United States (Beckstedde et al., 2023). Japan and South Korea have been the first to pilot blockchain based trading of community solar systems in Asia and AI supports real time forecasting and price optimisation. Jack et al. (2024) concluded that microgrids with blockchain integration improve their efficiency, reliability, and sustainability but still have to face regulatory and interoperability issues.

Fadi et al. (2024) demonstrated that AI-based anomaly detection can be used to improve blockchain cybersecurity, and Qader and Cek (2024) established that AI and blockchain can be used together in financial systems to increase the quality of audits, enhance fraud detection, and investor confidence, which in turn leads to transparency in energy transactions.

The African setting is no exception, as artificial intelligence and blockchain technology are becoming seen as the key to resolving the long-standing issues of energy access and sustainability. Distor et al. (2023) observed that, despite the potential benefits of these emerging technologies several issues such as poor infrastructure, weak governance, and limited capacity still hindered its wide adoption. Abbas et al. (2024) noted that these technologies promote more job opportunities, electricity to more remote areas but its adoption process still presents legal and data governance issues. Bawa (2025) showed that AI-based supply chains can hasten the implementation of renewable energy, and mobile broadband and high-quality regulations contribute to it.

All these studies, combined, highlight the importance of policy alignment, the development of infrastructures, and strategic investment to be effective in implementation. Even though research and pilot projects have been proliferated, there are still major gaps in the integration of AI and blockchain in renewable energy systems. The major issues include standardisation of data, interoperability, scalability and high costs of deployment. The ethical and regulatory frameworks are not well developed especially in the developing areas. Furthermore, there is a lack of empirical research in the African contexts, which underscores the need to have context-specific models, enabling policies, and capacity-building programmes to enable sustainable technological adoption.

3. EVOLUTION AND ADOPTION OF AI AND BLOCKCHAIN TECHNOLOGY

The introduction of artificial intelligence (AI) and blockchain technologies (BCT) into the renewable energy systems have completely altered the way energy is generated, distributed, and traded across the world. Technological innovation, market demand and environmental concerns have driven their development. With the growing energy-transition and decarbonisation ambitions of nations, the incorporation of these technologies into decentralised renewable energy trading systems has been made more of a strategic move. The diffusion and adoption path is different in different regions depending on the infrastructural preparedness, regulatory frameworks and socio-economic factors.

- ❖ Development of AI and Blockchain within Energy Systems: Artificial Intelligence was initially popular in the energy industry in the late twentieth century, especially during grid optimisation and predictive maintenance (Ejiyi et al., 2025; Hamdan et al., 2024). Initial use of neural networks and fuzzy logic was used to predict demand (Repetto et al., 2025). With the rise in the complexity of the energy systems and the rise in the renewable penetration in the twenty first century, the necessity of intelligent decision support tools became clear. AI then grew to be more sophisticated rule-based algorithms into machine learning and deep learning systems that can analyse real-time data. In the energy trade, artificial intelligence has become useful in demand forecasting, price optimization, and dynamic resource allocation (Ejiyi et al., 2025). The blockchain technology, which was launched in 2008 as a digital registry linked to the cryptocurrency, has quickly entered different industries, such as energy (Alt and Graser, 2025). It was initially used in energy trading in 2016 with the Brooklyn Microgrid project in the United States, which allowed residents to trade solar power using smart contracts with blockchain technology (Boumaiza & Sanfilippo, 2024). Blockchain has since emerged as a major tool to achieve transparency and trust in decentralised markets. Its combination with AI is a new epoch when automated and data-driven processes are consistent with immutability and distributed consensus.

- Global Spread of Technologies: Policy incentives, technological maturity, and cross-sector cooperation have been the key factors in the global spread of AI and blockchain technologies in the renewable energy markets. Governments and non-governmental organisations in Europe have initiated programmes to embrace digitalisation in the energy systems. The Energy Digitalisation Action Plan of the European Union facilitates the implementation of AI and blockchain to make smart grids more flexible, secure, and transparent (Campana et al., 2024). Japan and South Korea are among the countries in Asia that are deploying AI-based microgrid management systems and blockchain-based peer-to-peer trading platforms to ensure their urban energy networks are more resilient (Al Shareef et al., 2024). They have advanced due to strong digital infrastructure, good governance, and policies that support innovation which are supported by the government. In North America, energy efficiency and emission reduction pilot projects have been focused on, with the United States and Canada considering AI-based analytics to modernise smart grids and track carbon, and blockchain to ensure data exchange and verification (Mahmood et al., 2024). Equally, Power Ledger and other blockchain-based tools in Australia show how decentralised trading can empower consumers and enable them to be less dependent on central utilities. Its adoption globally shows that that the widespread of the technologies is heavily reliant on effective institutions and stable regulatory frameworks.
- Progress and Integration across Africa: The development and adoption of artificial intelligence and blockchain technologies in Africa have been developed gradually but with low adoption. The unique energy environment of the continent, which is characterised by low electrification rates, ineffective central grids, and high renewable potential, provides a promising ground to decentralized energy solutions (Foster et al., 2021). The first efforts focused on the creation of solar mini-grids and microgrids to solve the rural electrification problem, and the latest trends show the growing interest in digital technologies to improve the transparency, accountability, and sustainability of energy trading. These adoption efforts are being led by Kenya, Nigeria, South Africa and Ghana. Carbon-credit transactions and community-level energy trading are also achieved via blockchain-based platforms in Kenya (Levi-Oguike et al., 2019). The pilot projects in Nigeria utilize blockchain to finance solar-energy and AI to optimise consumption. Artificial intelligence is also making metering smarter across the continent, and aiding in the prediction and maintenance of grid performance, and Ghana is considering the use of distributed ledger technology to track renewable energy certificates. Although these improvements have been made, the adoption rates are still below those of the developed economies, which could be explained by a lack of internet connectivity, a lack of investment in digital infrastructure, and the lack of effective policy frameworks. However, the understanding of AI and blockchain as the means to alleviate energy poverty and promote energy justice by means of community-driven microgrids is growing.
- Adoption and Socio-Economic Impact: Trust, perceived usefulness, and institutional legitimacy are identified as important factors of adoption in the analysis of the socio-economic effects of AI and blockchain in renewable energy systems. Areas with low digital literacy are those where the issue of data security and automation are raised, and these may hinder acceptance. Research shows that individuals are

more ready to participate in decentralized energy trading in case the systems are open, reliable, and offer a clear financial advantage (Bassey et al., 2024). The acceptance of users in Africa is increasing because people are enjoying the fruits of reduced costs, community ownership, and increased energy independence. Nevertheless, the lack of awareness among decision-makers, the fear of job loss, and uncertainty about the policy remain the obstacles to wider adoption (Rane et al., 2024).

- Cross-Regional Global Perspective: The AI and blockchain penetration of energy systems is an uneven situation across the globe. Research and commercial applications are dominated by Europe and Asia, and Africa and some parts of Latin America are still at their early experimentation phase. This difference is an indication of differences in funding, uniformity in regulations, and technological infrastructure. However, Africa has the chance to bypass conventional systems by using agile innovation models that bypass centralised architectures. The growth of mobile connectivity, digital payment platforms, and youth-led innovation platforms will put the continent in a position to enjoy significant gains of AI- and blockchain-enabled energy solutions.

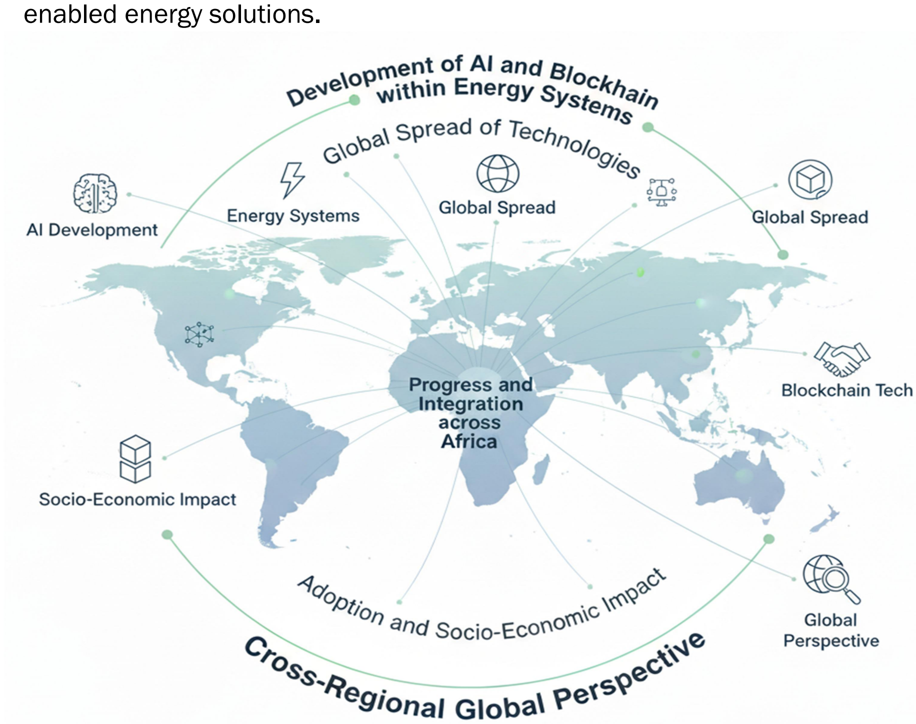

Fig. 1: Global Technological Evolution Map

Fig. 1 illustrates the international development and interactions between artificial intelligence (AI) and blockchain technologies in energy systems. The centre is placed on Africa to highlight its new position in technological innovation. The arcs and icons show the way these technologies spread and connect all over the world, connecting development, integration, and socio-economic influence. All the labeled items, including AI and Blockchain Development in Energy Systems, Global Technology Diffusion, and Progress Across Africa, are separate stages in this technological development. In general, the figure summarises the transregional infiltration of AI and blockchain, which promotes international cooperation and sustainable progress.

The development, spread, and implementation of AI and blockchain technologies in the renewable energy trading are changing at uneven speeds around the world. Advanced economies are focused on efficiency and sustainability, and developing areas, especially in Africa, consider such technologies as the way to improve energy availability and facilitate social inclusion. An emerging trend of the digital decentralisation of energy systems can be observed. Nevertheless, to reach mass adoption, it will be necessary to have supportive policies, invest more in digital infrastructure, and have substantial capacity-building initiatives to break institutional and economic barriers. Future studies should focus on integrative models that match the technological innovation with the local socio-economic conditions.

4. THEORETICAL FRAMEWORKS FOR THE EVOLUTION AND ADOPTION OF TECHNOLOGY

The development, spread, and implementation of Artificial Intelligence (AI) and Blockchain Technology (BCT) in decentralised renewable energy trading require a theoretical framework. The models offer systematic methods of examining technological change, user behaviour and institutional adjustment. The most relevant theories are the Diffusion of Innovation Theory (DOI), Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), and the Socio-Technical Systems (STS) Theory. Collectively, these frameworks provide in-depth information on the way new technologies are developed, diffused, and adopted in socio-economic and regulatory environments, especially in Africa and other regions.

Diffusion of Innovation Theory (DOI) has been one of the focal points in explaining the permeation of innovations within the social systems. It implies that the process of adoption occurs in phases, where innovators and early adopters are the first, then the early majority, late majority, and slow adopters, and the process is affected by relative advantage, compatibility, complexity, trialability, and observability (Mbatha, 2024; Wiweko and Anggara, 2025). In the framework of decentralised renewable energy, DOI explains how artificial intelligence and blockchain technologies can be introduced into traditional energy markets. The relative benefits of early adopters, such as Kenya, Germany, and Australia, are increased transparency, lower transaction costs, and energy efficiency (Fernando et al., 2021). The compatibility is observed when digital energy platforms are compatible with renewable infrastructures and market needs; on the contrary, complexity and lack of technical expertise hinder the adoption in developing areas. The success of the initiatives that have already been launched, like the Power Ledger in Australia and WePower in Europe, facilitates the diffusion in the emerging markets by offering concrete evidence of the effectiveness (Abdul and Tanveer, 2025; Naveen et al., 2025).

The Technology Acceptance Model (TAM) emphasises the importance of the perceived usefulness and ease of use as the key factors of technology adoption. The model holds that technologies that are seen to be useful and easy to use are easily accepted. TAM is applied in the area of renewable energy trading to describe the adoption of consumers, traders and policymakers. The adoption in African settings largely relies on the perceptions of users about the technologies as the possible solutions to the energy access problems and their applicability to the low-literacy setting (Bassey et al., 2024). An example of this dynamic is mobile-based blockchain-based solar credit trading in Kenya, which provides straightforward and transparent systems and is customised to local requirements. On the other hand, the perceived complexity and poor infrastructure hinder participation.

The successive versions of TAM include other variables like trust, cost efficiency, and social influence- variables that are very important in low-trust contexts. This lack of trust can be addressed by the transparency and immutability of the blockchain technology, which in turn enhances the willingness to adopt.

Unified Theory of Acceptance and Use of Technology (UTAUT) is a synthesis of multiple antecedent models, such as TAM and DOI, into a holistic theory. It determines four main constructs that influence the use of technology, namely, performance expectancy, effort expectancy, social influence, and facilitating conditions (Ursavas, 2022). Performance expectancy in energy systems is the enhancement of efficiency, reliability, and cost-effectiveness of energy systems that artificial intelligence and blockchain technologies can achieve. Effort expectancy deals with the ease of use; social influence deals with support by governmental agencies, peers and communities; and facilitating conditions deals with supportive infrastructure and regulations. UTAUT is specifically relevant in Africa where adoption is highly influenced by community involvement and decision-making. Empirical evidence indicates that government incentives, innovation programmes that are funded by donors, and peer influence are all beneficial in promoting acceptance (Njenga & Mogaka, 2025). Nevertheless, weak policies and low digital literacy rates remain the barriers to the large-scale adoption.

Socio-Technical Systems (STS) theory offers a holistic view because it anticipates the interaction of social and technical subsystems. It claims that sustainable technological change becomes a reality when the technological design is congruent to the social realities and institutional situations (Eason, 2014; Yu et al., 2023). The decentralized energy situation in Africa requires local involvement, effective governance and social trust to be adopted successfully. Blockchain systems which do not consider social norms can be easily resisted in spite of their technical soundness, and artificial-intelligence systems trained on external data might not optimally work without localisation. In turn, STS emphasizes the need to engage in design, develop capacity, and match innovations with local governance systems (Bereziartua-Gonzalez et al., 2025).

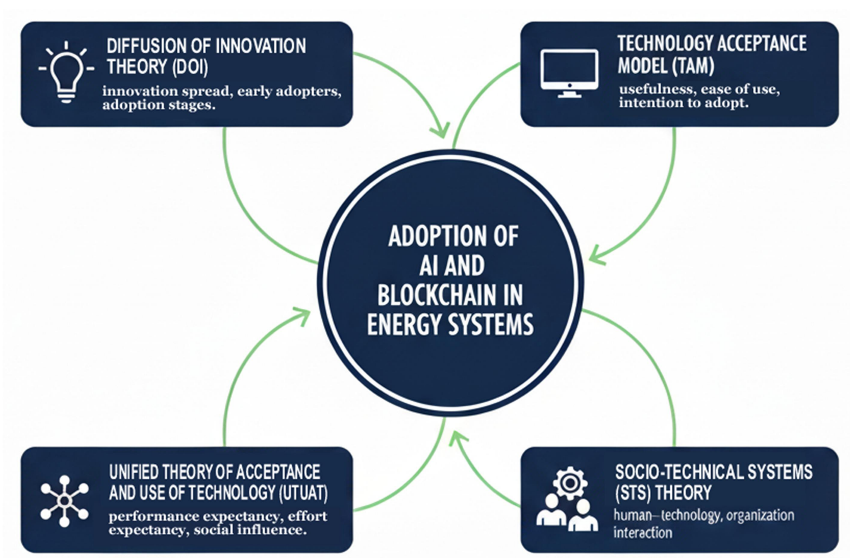

Fig. 2: Hierarchical Frameworks for AI and Blockchain Adoption in Energy Systems

Fig. 2 illustrates the hierarchical connections between the main theoretical frameworks that support the implementation of artificial-intelligence (AI) and blockchain technologies into the energy systems. The diagram starts with the background views of the Diffusion of Innovation (DOI) and the Technology Acceptance Model (TAM), progresses to the integrative Unified Theory of Acceptance and Use of Technology (UTAUT), and ends with the situational Socio-Technical Systems (STS) theory. Conversely, these frameworks describe the technological evolution, acceptance and system-wide integration processes. Both frameworks, taken separately, provide a different set of insights into how technological change occurs; collectively, they provide an analytic perspective in totality.

The DOI and UTAUT models show how artificial intelligence and blockchain technologies are distributed within socio-economic systems, while the TAM model interprets why individuals or organisations adopt the usage of these technologies. However, the Socio-Technical Systems theory interpret this adoption through cultural, institutional, and social environment. The combination of these theoretical insights in Africa shows that effective implementation of decentralised renewable-energy trading systems does not only depend on the level of technology but also on the compatibility with the local culture, institutional capabilities, and social credibility. Combined, these frameworks provide a solid base on the analysis of the development, spread, and uptake of emerging technologies in both developed and developing areas.

5. FINDINGS ON THE USEFULNESS OF TECHNOLOGY AND EXISTING GAPS

The concept of artificial-intelligence (AI) and blockchain technology (BCT) integration into renewable-energy systems is recognised as a major step in the world towards sustainable, efficient, and transparent energy markets. Such technologies change the process of energy production, distribution, and consumption, allowing the decentralisation, data-driven, and trust-based processes. However, despite the fact that their benefits have been widely reported in developed economies, there are still significant gaps in the implementation of the same in the African environment.

- ❖ AI and Blockchain Applications in Renewable Energy Systems: The fact that artificial intelligence (AI) and blockchain technologies can help reduce the inefficiencies and complexities that characterise the traditional centralised power systems has been confirmed in a variety of studies. AI algorithms help to make real-time predictions, predict demand, and optimise the system, which leads to less energy waste and enhances the balance between generation and consumption (Ukoba et al., 2024). Specifically, AI-based analytics has the potential to forecast solar irradiance, wind speed, and energy load patterns, which will improve the utilisation of storage and trading operations. Europe and Asian empirical studies have shown that machine learning models achieve forecasting accuracies of more than ninety per cent, which has fostered better grid stability and cost efficiency (Singh et al., 2024). At the same time, blockchain provides a decentralised system of transparent and safe peer-to-peer energy transactions. Its unchangeable registry makes the energy flows and financial transactions accountable and traceable, and its smart contracts automatize the trading process, reduce transaction expenses and remove intermediaries. Empirical studies on the use of blockchain to facilitate energy democratisation and financial inclusion have been piloted by Power Ledger (Australia), WePower (Lithuania) and SunContract (Slovenia). In African settings, the innovations provide opportunities to deal with untrustworthy grid systems, funding shortages and a lack of transparency. The predictive maintenance based on AI can minimize the equipment failures in off-grid solar networks, and the blockchain-based microgrids can enable rural communities to sell the excess energy with the help of digital tokens or mobile payment systems, which is aligned with the United Nations Sustainable Development Goal 7.

- Technology Deficits and Barriers in Africa: Despite their potential, the implementation of AI and blockchain in the African energy systems is faced with a myriad of technical, infrastructural and socio-economic challenges. One of the main weaknesses is the lack of digital infrastructure: many areas are characterised by unreliable internet connectivity, unreliable power supplies and the lack of data centres to facilitate AI computations and blockchain node operation (Khan et al., 2023). The quality and availability of data are still sub-optimal because the majority of institutions do not have standardised data collection and sharing systems, which eventually reduces the accuracy of AI (Ukoba et al., 2024). Blockchain systems require trusted data entry and authentication, neither of which is available in low-resource settings. Even though more recent verification systems, such as Proof of Stake, consume less energy, these systems remain expensive to implement and maintain. Furthermore, lack of qualified personnel is a hindrance in the development, implementation and control of these technologies. The lack of regulatory and policy frameworks contributes to the problem since most African nations do not have explicit frameworks to regulate decentralised energy trading, digital assets, and smart contracts. This lack of legal regulation therefore restricts the investment in the private sector and the flexibility of the new technologies.
- Socio-Economic and Institutional Barriers: The major barriers are also due to lack of financial resources, limited digital literacy and cultural change resistance. Sulek and Borowski (2024) noted that a significant number of consumers still use traditional energy buying techniques and do not realise the advantages that digital trading offers. The initial capital needed to run decentralised networks is often prohibitively expensive to independent producers, especially in areas where sources of finance are limited. The development is hampered by institutional resistance by the centralised utility companies, as well as bureaucratic indifference. Lack of strong governmental backing and poor stakeholder cooperation results in disjointed pilot projects that can hardly be sustained in the long run.
- Comparative Insights Beyond Africa: Outside African comparative experiences indicate that the industrialised nations have addressed these issues through the development of robust digital infrastructure, massive investments in research, and the development of adaptable regulatory frameworks. According to Jorgensen et al. (2025), the regulatory sandbox of the European Union and the AI-enabled smart grid programs of the United States Department of Energy can be viewed as examples of the policy environments that promote innovation. Similarly, Japan, Singapore, and South Korea have implemented artificial intelligence to forecast and optimise their grids, and at the same time, develop blockchain-based energy markets, which focus on transparency and efficiency. The following foreign case studies can offer valuable lessons to Africa when it comes to creating adaptable regulatory frameworks and developing innovation ecosystems.

The related literature and emerging empirical data affirmed that artificial intelligence and blockchain technologies are transformative and cannot be ignored in the development of renewable energy systems. They have their main contributions in decentralising control, increasing trust, and automation of energy trading processes. However, their influence differs depending on the geographical location, which is preconditioned by the presence of infrastructure, the power of institutional support, and the existing socioeconomic abilities.

The adoption of such technologies in Africa is still low, and this can be explained by the lack of infrastructure, critical skills shortages, and frozen policy frameworks. The solution to these shortcomings must be a comprehensive approach that will include technological innovation, human capacity building, regulatory reform, and specific investment. Without such coordinated efforts, the potential of the decentralised renewable energy trading may not be realised.

6. RECOMMENDATIONS FOR POLICY, RESEARCH, AND PRACTICE

The integration of artificial intelligence and blockchain technology into decentralised renewable energy systems has significant potential to provide access to energy in the long term, in a transparent and equitable way. To realise these benefits, there is a need to take proactive and coordinated efforts that cut across policy formulation, technological development and ground implementation.

1. Policy Recommendations: The governments should develop an enabling legislative framework that will encourage peer-to-peer energy exchange and smart contract implementation. These policies should be designed in such a way that energy innovation is in line with environmental sustainability and digital transformation goals to prevent disjointed governance. The incentive mechanisms such as tax incentives, research grants, and subsidies should be implemented to encourage the involvement and investment in AI- and blockchain-based energy solutions by the private sector. Moreover, there is a need to focus on the fair access to digital infrastructure and renewable resources to reduce the energy gap between urban and rural populations.
2. Research Recommendations: Future research should prioritise the creation of a model that will align with the economic, infrastructural, and socio-cultural environments of the developing regions. Research is needed on the interoperability of the systems, the cybersecurity risks, and the effectiveness of blockchain consensus mechanisms in the energy trading environment. The collaboration of experts in energy engineering, computer science and public policy is the most important aspect of producing holistic insights. Developing more effective research collaborations and open-access data sources will contribute to evidence-based innovation and simplify the process of sharing knowledge between various regions.
3. Practice Recommendations: Practically, the implementation of decentralised renewable energy trading means that it needs user-friendly and flexible platforms that would accommodate the low connectivity regions. End users, technicians, as well as policy makers should be the focus of the training and capacity building to ensure digital literacy and competence in operations. Pilot projects and community-based microgrids may be used as a demonstration, revealing the socio-economic and environmental usefulness of the technologies. The collaboration between government agencies and commercial funding sources and start-ups should be promoted to ensure that the deployment and scale-up programs are expedited.
4. Collaboration and Ethical Considerations: The successful adoption of AI and blockchain technologies should rely on the multistakeholder partnership and strong ethical governance. Strict policies should be prepared to guarantee equity, transparency, accountability, and data safety in the AI-driven energy systems. The regional collaboration, especially in Africa, will have to align the technical standards, facilitate the cross-border energy flow, and build the ecosystems of innovation to facilitate inclusive and responsible development. The alignment of supporting regulation, comprehensive research, and inclusive behaviours will eventually define the successful implementation of the artificial intelligence and

blockchain-based decentralised energy systems. The countries can collaborate in these areas to establish a more transparent, productive, and fairer system of renewable energy.

The smooth adoption and implementation of artificial intelligence and blockchain-based decentralised energy systems depend on well aligned regulations, solid research, and inclusive practices. Transnational cooperation between nations will ensure a fair, credible, transparent and efficient renewable energy framework.

7. CONCLUSION

The adoption of artificial intelligence and the blockchain technology in decentralising the renewable energy markets will be an important move towards equity in sustainable energy. Integration of predictive intelligence with transparent digital ledgers will not only enhance energy trade, but will also help in transforming credible, transparent and accountable emerging energy ecosystems. The outcome of the study shows that the predictive analytics of artificial intelligence and an immutable structure of blockchain technologies will be a viable solution to challenges such as inefficiency, privacy, and marginalisation associated with conventional centralised power systems. Moreover, unlocking the full potential goes beyond mere technological acceptance; it involves the creation of a robust regulatory framework, investment in long-term digital infrastructure as well as the creation of skilled human resources.

To Africa and other developing nations, its integration will provide an avenue to replace the conventional centralised system with an emerging energy solution for sustainable development and inclusive economic growth. It is evident that a collaboration between government agencies, academic institutions and industry stakeholders to enhance energy governance and promote innovation is a necessity. Consequently, decentralised renewable energy trading with artificial intelligence and the blockchain technology is a viable and scalable way to a cleaner, smarter, and more equitable worldwide energy future, whereby technology empowers, sustainability remains, and access is made available to all.

8. FUTURE DIRECTIONS

The future of AI-powered blockchain-based decentralised renewable energy trade is set to change the global energy systems. With the ever-growing technological advancement, various strategic measures may have an impact on the emergence, propagation, and permanent effects of these emerging technologies.

- Integration with Advanced Energy Storage Systems: The unification of AI and blockchain with the next generation energy storage systems is a major future trend. Artificial intelligence models are used to optimise the performance of energy storage by forecasting demand, controlling variations in loads and automating the process of charging and discharging. The integration will result in stability of the grids, reduce energy wastage, and improve the stability of the decentralised power systems.
- Interoperability and Scalability Enhancement: Interoperability between various trading platforms will be required to realise the full potential behind decentralised energy markets. Future directions will be on making of international technical standards and communication protocols on safe exchange of data. In the future blockchain architectures will also become more energy efficient and scalable moving to more efficient and less harmful forms of consensus and operations.

- **Emergence of the Internet of Energy (IoE):** The integration of the artificial intelligence, blockchain, and the Internet of Energy will create self-governing, smart energy systems. The IoE will make smart energy through the connection of smart metres, sensors, and distributed energy resources, which will allow managing energy in real-time, preemptive maintenance, and responsive grids to dynamic conditions.
- **AI-Driven Policy and Market Simulation:** Future research should focus more on the use of AI-related models in policy making, investment planning and regulatory decision-making. Predictive analytics will also help the policymakers by forecasting market behaviour, assessing the impacts of incentives or tariffs and developing flexible frameworks that encourage efficiency and sustainability in the decentralised energy systems.
- **Capacity Building and Inclusive Innovation:** Long term growth requires the growth of human capital and active inclusion. The governments, higher education and industry partners are encouraged to invest on digital literacy programmes, local production of smart devices and joint innovation hubs. The regional cooperation especially in Africa should be aimed at the exchange of technical skills and standardisation of the energy laws to facilitate cross border energy trade.

Hence, smart, safe, and decentralised renewable energy trading in the future is intertwined with technologies and human progress. With collaboration and synchronization between AI and blockchain development with policy transformation and capacity development, countries will be able to establish a sustainable, transparent, and fair energy future.

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