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A Survey on the Influence of Blockchain and Neural Network Technologies on Smart Grid Systems

Rashed M. Ahmed Marimi [1*]

[1] University of Zawia, Department of Electric and Electronic Engineering, *Libya*.

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***Corresponding Author:**
Rashed M. Ahmed Marimi
E-mail:
r.mariami@zu.edu.ly

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ABSTRACT

Energy transactions benefit from blockchain technology because it creates an independent system that provides secure data protocols and protects against unauthorised alterations of information while strengthening protection. Multipurpose blockchain tools let traders conduct secure peer-to-peer energy exchanges, and they can run automated networks while diminishing dependence on central control systems. Small and distributed energy control methods decrease infrastructure vulnerability by shielding it from cyber threats while creating a tamperproof network, which builds modern energy security and visibility. Organisations use advanced machine learning algorithms to study historical and real-time data to optimise energy distribution, identify consumption patterns, and detect anomalies. The predictive models enable better decision-making through preventive maintenance plans, reduced energy losses, and optimised distribution of electricity loads in the grid system. The research investigates detailed implementations of predictive models that unite neural networks and blockchain technology into a system that builds up smart grid functions. These technologies form a synergistic relationship that enables smart automation systems along with continuous real-time monitoring and boosted operational efficiency. The study investigates actual blockchain-based energy market examples alongside case studies on predictive maintenance carried out through AI and decentralised power trading platforms. The research results show that integrating blockchain with neural networks can enhance smart grid security and reliability while also supporting the development of a sustainable and adaptable energy system. Through their resolution of scalability problems and regulatory requirements as well as computational limits, these technologies establish future frameworks for smart power networks of the next generation. The survey findings create a basis for researchers to use for advancing energy informatics and smart grid innovation in the future.

Keywords: Blockchain; Neural Network Technologies; Smart Grids; Security and Reliability; Applications of Blockchain and Neural Network Technologies.

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1. Introduction

Smart grids emerge as an upgraded energy system through the combination of smart communication systems, automatic systems, data analytical mechanisms to optimize power source management, distribution networks and consumption operations (Khan & et al, 2023). Smart grids transform traditional power grids by implementing bidirectional communication, real-time monitoring systems, and adaptive control mechanisms to enhance operational efficiency and system resilience (Gonen, 2014). Javaid et al. (2018) and Li et al. (2023) explain that smart grids improve energy reliability, support renewable energy connections, and manage power demands—thereby lowering the costs of operations and minimizing environmental effects (Li & et al, 2023). The rising adoption of solar and wind energy enables smart grids to carry out essential tasks such as balancing power supply and demand, preventing grid instabilities, and promoting ecological stability. Advanced computational security solutions must develop for decentralized energy platforms to ensure the secure and efficient management of vast amounts of data and transaction flows (Javaid & et al, 2018).

Smarter energy grids face several significant challenges, including critical security threats to their systems, faulty marketplace trading systems, and complex predictive servicing requirements. Leading-edge technologies, which include neural networks and blockchain solutions, need to be implemented, as they will boost security parameters, decision-making capabilities, and overall operational efficiency (Hua & et al, 2022).

Blockchains represent an independent ledger technology that secures energy deals by being tamper-proof, making details transparent, and stopping cyber theft attacks. The research by Wu et al. (2018) demonstrates that blockchain Peer-to-Peer (P2P) trading enables secure, direct transactions between energy producers and consumers by creating trust and reducing fees (Wu & et al, Towards collective energy Community: Potential roles of microgrid and blockchain to go beyond P2P energy trading, 2022).

Artificial Intelligence (AI) enables neural networks to provide predictive analytics, detect failures, and forecast energy demand, as they are a subset of AI. The work of Almasoudi et al. (2023) demonstrates how deep learning algorithms enhance live power forecasting, alongside improved electric grid reliability and enhanced power grid energy transmission performance. Traditional and current data analysis using neural networks helps forecast power outages and required maintenance, while simultaneously improving system reliability (Almasoudi, 2023).

Figure 1 relates the linkages between blockchain and other applications (Prakash & et al, 2022). The fusion of neural network technology with blockchain presents a powerful approach to enhancing the operation of smart grids. Blockchain ensures the secure and decentralized exchange of information, while neural networks facilitate real-time decisions with enhanced intelligence, making the grid more responsive and efficient.

The purpose of the study is to investigate the relationship that exists between blockchain and neural networks and their influence on smart grids with regard to energy management optimization, boosting cyber security measures, and enabling predictive maintenance. In simpler terms, the main goals of the research are:

- To understand the role played by blockchain in the security and transparency of smart grid transactions.
- To assess the capability of neural networks in predicting energy demand and identifying faults within the system.
- To assess the synergy of blockchain and neural networks on the smart grid technology performance.
- To find applicable examples of incorporating such technologies into energy systems.

This research is significant due to the anticipated outcome of building a more sustainable, secure, and intelligent energy infrastructure. Smart grids using blockchain technology and neural networks can attain greater efficiency and resilience, which would accelerate the adoption of decentralized renewable energy sources.

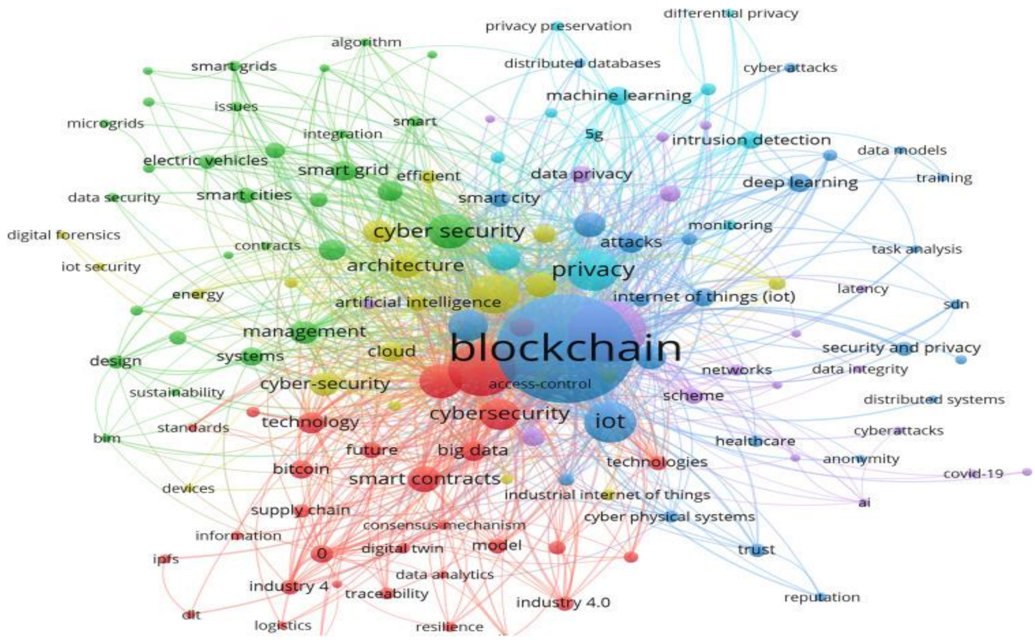

Figure 1. The correlation between Blockchain and different sections (Prakash et al, 2022) and (Marimi, 2025).

2. Fundamentals of Smart Grids

Smart grids comprise various components and subcomponents that integrate to enhance the efficiency, resiliency, and sustainability of today's energy systems. Alotaibi et. Al (2020) states that the primary components of smart circuits include (Alotaibi & et al, 2020):

- Energy is consumed optimally and in real time by monitoring and controlling its consumption in a way that reduces waste. Furthermore, controlled energy consumption is non-harmful.
- Utility to end-user and end-user to utility multi-channel communication that improves demand forecasting and nominal tariff rate execution for additional units sold service.
- Processes of the grid are observed and managed to guarantee stability on the grid as well as to eliminate failures.
- Alternative energy sources (solar panels, wind rotors) and energy storage systems, together with mobile devices that contribute to the grid decentralization, are included.
- Renewable energy technologies, especially solar photovoltaics, figure prominently in the economies of South Asian countries and correlate with increasing energy storage and facilitating flexibility of the grid, as stressed by Islam et al, 2024 (Islam & et al, 2024).
- Cyber protection of the grid devices in order to keep data traffic and transactions safe and systems operationally intact was and is to be enhanced.

By putting all these components into place, smart grids enable the reallocation of energy resources, optimize reliability, and facilitate the world's achievement of sustainable energy. While smart grids heavily rely on digital communications and information, Waseem and others (2023) argue that blockchain technology can be instrumental in securing smart grid (SG) transactions (Waseem & et al, Incorporation of blockchain technology for different smart grid applications: Architecture, prospects, and challenges, 2023). However, major obstacles hinder widespread adoption (see **Table 1**). The advanced computational requirements and delays associated with real-time computation may make it impossible to achieve SG applications in real time. Consequently, there must be frameworks that are designed in a way to blend both security and efficiency.

Table 1. Cybersecurity Threats to Smart Grids Based on the CIA Triad (Confidentiality, Integrity, and Availability according to (Waseem & et al, Incorporation of blockchain technology for different smart grid applications: Architecture, prospects, and challenges, 2023).

CIA	Attack
Confidentiality	Social Engineering, Eavesdropping, Traffic Analysis, Unauthorised Access, Password Pilfering, MITM, Sniffing, Replay, Masquerading, and Data Injection
Integrity	Tampering, Replay, Wormhole, False Data Injection, Spoofing, Data Modification, Time Synchronization, Load Drop, MITM, and Masquerading
Availability	Wormhole, Jamming, Denial of Service (DoS), LDoS, Buffer Overflow, Teardrop, Smurf, MITM, Spoofing, Puppet, Time Synchronization, and Masquerading

Moreover, to facilitate interoperability and reduce cybersecurity risks, standardized regulations are crucial, making blockchain an essential yet still evolving technology for the future evolution of SG. Khalid et al. (2024) argued that the shifts in energy supply and demand, the incorporation of renewable resources, and the limitation of turbine capacity present significant challenges. The research suggests that the transition to SG is crucial for the automation and digitalization necessary to integrate new renewable resources and promote sustainability. However, operational flexibility, regulatory compliance, and user participation remain emerging challenges for efficient execution of the implementation strategies. Critical issues, such as planning, security, and the integration of various systems, also require attention, which necessitates standard rules and contingency plans (Khalid, 2024). Smart grids collect data from multiple sources, including sensors, meters, and control systems. Treated effectively, such data could aid real-time decision-making. There is a need for prompt data storage, processing, and analysis. Conventional cloud-based mechanisms can lead to security and latency challenges, which creates a need for a shift to a decentralized solution such as blockchain and federated learning, as explored by Ahmed et al. (2022) (Ahmed & et al, 2022).

3. Blockchain Technology in Smart Grids

The decentralized ledger system of blockchain maintains a distributed network of several nodes, which ensures that data remains tamper-resistant and transparent while securing all transactions. Each transaction undergoes encryption and timestamping before being connected to other transactions, so that any alteration requires a network-wide consensus to be successful. According to Musleh (2019), various blockchains can be utilized for data protection across different smart grid tiers. Figure 2 illustrates that a distinct blockchain aggregator is responsible for each smart grid tier. The study concluded that by offering a dependable and secure platform for data storage, these blockchains should secure the smart grid. Furthermore, the identification of the particular consumer or producer is not directly connected to their identity within the blockchain environment. As a result, it will make the power system more resilient and less susceptible to hostile attacks (Musleh & et al, 2019).

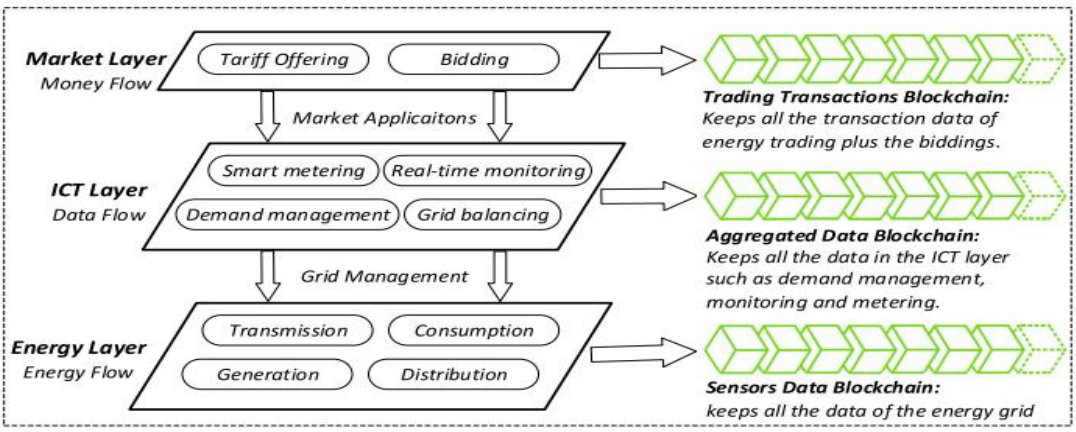

Figure 2. The Blockchain applications framework in smart grid security and data protection

According to Waseem et al. (2023), blockchain implements cryptographic principles with Proof of Work (PoW) and Proof of Stake (PoS) consensus mechanisms to achieve security controls as well as protected access in smart grid (SG) environments (Waseem & et al, 2023). Blockchain enables peer-to-peer (P2P) energy trading, through which prosumers, who engage in both production and consumption, can exchange their excess energy without the need for utility provider intermediaries. Wu et al. (2022) demonstrated that P2P energy trading facilitated through blockchain technology enhances decentralized power systems and promotes the adoption of renewable energy sources, alongside improved electricity delivery. The research outcomes confirmed that decentralized energy management benefits from a six-layered blockchain architecture because it delivers safe, automated transactions that perform efficiently. Anjimoon (2024) discovered that every measured metric of the AI-enhanced system had significantly improved. He stated that the decline in SAIFI and SAIDI demonstrated a notable increase in system reliability. While the rise in prediction accuracy validated the efficacy of AI in demand and supply forecasting, this also showed a drop in transmission and distribution losses and an increase in operational efficiency as presented in Figure 3 (Anjimoon & et al, 2024).

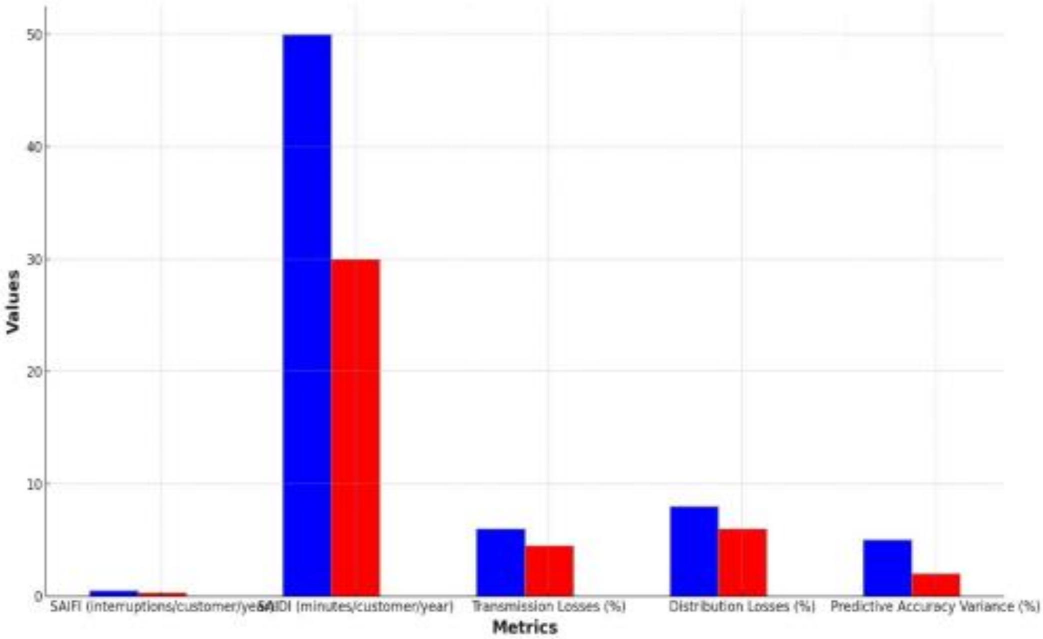

Figure3. Comparative Analysis of Grid Performance Metrics

The system establishes three levels of energy management: between households for individual use, within communities for internal exchange, and between communities for external energy transactions. The energy transaction method supports large-scale energy exchanges, combining resilience and security as it extends to the transportation, building, and industrial sectors (Figure 4) (Wu & et al, 2022).

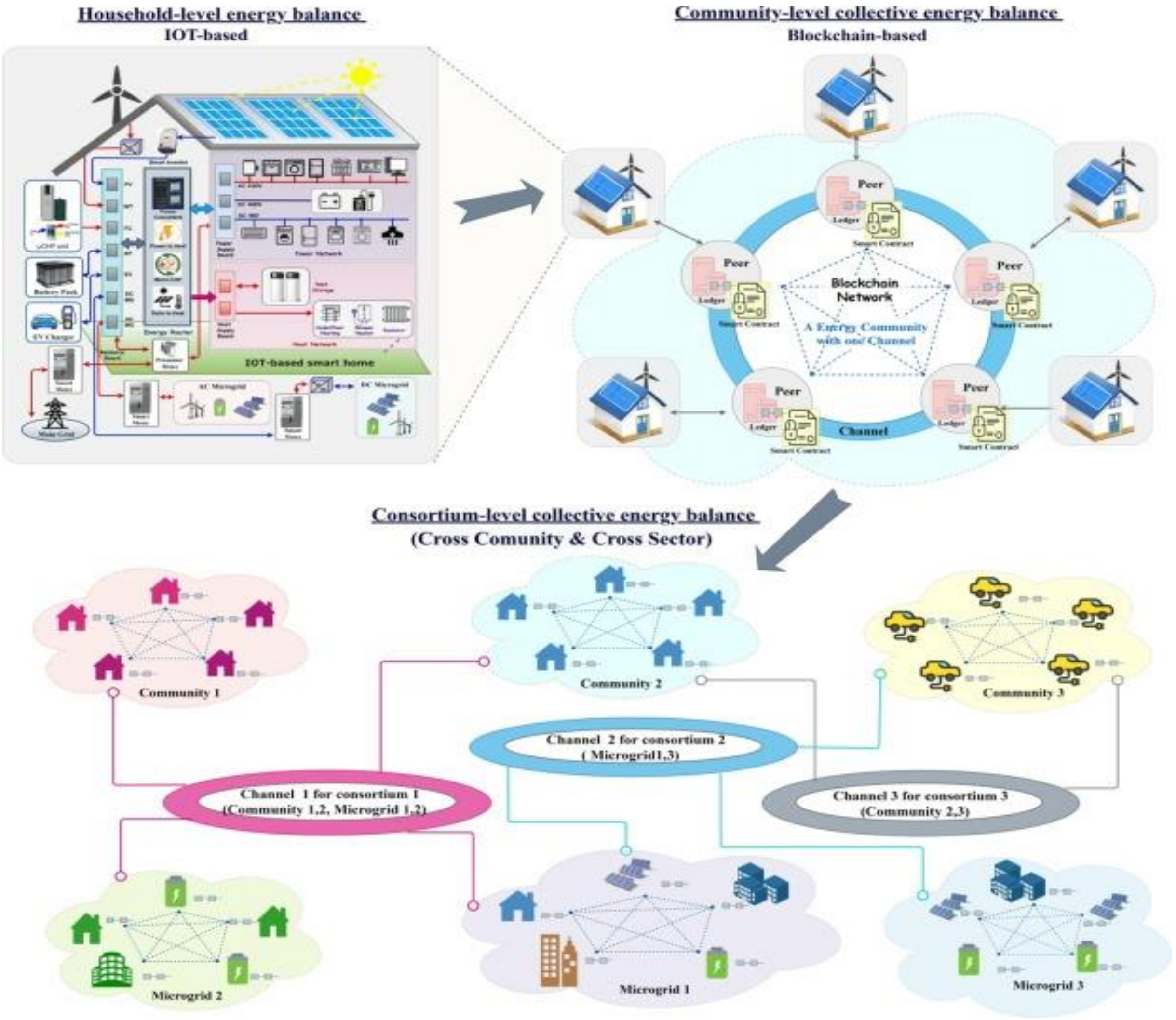

Figure 4. The hierarchical architecture based on Blockchain for a framework for cross-border energy networking

Smart grids benefit from enhanced security and transparent data management when utilizing blockchain, as it establishes a decentralized system that is free from single points of vulnerability and protects data from tampering. Research by Ferdous et al. (2023) has demonstrated that smart grids powered by blockchain technology decrease the exposure to cyberattacks which involve unauthorised access as well as data breaches and fraudulent energy results (Ferdous & et al, 2023).

Large-scale smart grid applications cannot function with traditional blockchain models and their Power of Work implementation because these systems require unrestrained computational power. According to Treiblmaier (2023), the Bitcoin network operates its Proof of Work consensus mechanism at an energy consumption level equivalent to small nation states, which justifies the implementation of PoS or Delegated Proof of Stake (DPoS) to achieve energy savings (Treiblmaier, 2023).

The transaction speed restrictions and throughput limitations faced by blockchain networks make it challenging for them to handle the rapidly increasing transactions that are crucial to smart grid operations. Hafid et al. (2020) demonstrate in their studies that Layer-2 solutions, including off-chain transactions and network partitioning, should boost blockchain scalability (Hafid & et al, 2020).

Appearing as a disruptive energy-market mechanism, blockchain enhances energy transaction security and raises transparency as well as accelerates operational efficiency. Its applications in P2P energy trading, smart contracts, and decentralized data management offer promising benefits for the future energy landscape. The adoption of blockchain technology faces three main barriers: high power consumption requirements, scalability, and regulatory compliance framework issues.

Future investigations in blockchain technology need to optimize framework implementations with energy-conscious consensus components and develop standardized policy frameworks to advance smart grid development.

Table 2. Comparison between Related Works in AI and Blockchain for Smart Grids**.**

Reference	Main Results	Research Gap
Ferdous et al. (2023)	Utilisation of Self-Sovereign Identity (SSI) and Distributed Ledger Technology (DLT) for enhancing the reliability of Renewable Energy Certificates (RECs), ensuring transparency and security in tracking renewable energy sources.	Lack of large-scale real-world implementations and interoperability challenges between different energy markets.
Hafid et al. (2020)	Addressed blockchain scalability issues through sharding, sidechains, and layer-2 solutions, improving the efficiency of smart grid applications.	Need for integration of AI-driven optimisation to further enhance blockchain performance and reduce energy consumption.
Prakash et al. (2022)	Investigated the role of blockchain in cybersecurity, protecting smart grids from data tampering, MITM attacks, DoS attacks, and unauthorised access.	Limited focus on AI-enhanced security mechanisms to predict and mitigate cyber threats proactively.
Treiblmaier (2023)	Analysed blockchain energy consumption and economic implications, highlighting challenges posed by high computational costs and environmental concerns.	Need for energy-efficient consensus mechanisms (e.g., Proof of Stake, Federated Learning) to make blockchain viable for smart grids.
Waseem et al. (2023)	Reviewed blockchain architectures, applications, and challenges in smart grids, with a focus on peer-to-peer (P2P) energy trading and decentralised energy markets.	Lack of AI-powered predictive models to enhance the efficiency of blockchain-enabled smart grids.
Wu et al. (2022)	Explored blockchain-based microgrid energy communities, facilitating decentralised energy transactions beyond traditional P2P trading.	Need for machine learning-based optimisation techniques to enhance energy dispatch and load balancing in blockchain-enabled smart grids.

The majority of research investigates blockchain characteristics or AI features independently, yet fails to establish a single framework that connects AI with blockchain for smart grids. The primary impediment to adoption consists of substantial power consumption; therefore, new methods to enhance smart grid consensus mechanisms must be developed. The implementation of blockchain technology at a large scale is minimal, while achieving energy market interoperability remains an essential technical challenge.

4. ANN Technology in Smart Grids

Artificial Neural Networks (ANNs) enhance the intelligence and efficiency of smart grids by improving energy forecasting, defect detection, and optimal power distribution. They are well-suited to handling complex and non-linear energy patterns, enabling renewable energy integration, load forecasting, and voltage stability analysis. Several studies have demonstrated that ANN-based models surpass statistical models in both short-term and long-term load forecasting. Almalaq et al. (2017) confirmed that ANNs outperformed traditional regression models in predicting changes in power requirements based on temperature, historical data, and customer behaviour (Almalaq & et al, 2017). Research by Gürbüz et al. (2019) found that ANN-based models enhanced energy distribution by reducing prediction errors in a smart grid application by 15-20%. ANNs are also commonly applied in a smart grid for problem detection and power quality analysis (Gürbüz, 2019). Research by Gil-González et al. (2020) indicates that ANN-based fault detection systems significantly enhance grid reliability by identifying faults within milliseconds (Gil-González & et al, 2020). Similarly, Haghnegahdar et al. (2018) found that ANN models achieved over 95% accuracy in detecting normal and problem states in the grid—outperforming conventional security systems. Smart grids also benefit from better integration of solar, wind, and hybrid power systems by utilizing artificial neural networks to predict power output and enhancing energy storage (Haghnegahdar & et al, 2020). Singh et al. (2021) found that ANN-based application in solar and wind power prediction improved grid stability by reducing power fluctuations by up to 30%. Additionally, artificial neural network-based demand response strategies help shave peak loads and improve energy efficiency. Ali et al. (2023) demonstrated that ANN-based DSM systems minimized energy wastage by 18% through analysis of customer demand patterns and real-time power supply dynamics (Ali & et al, 2023). In summary, artificial neural networks have significantly advanced smart grids in demand response optimization, defect detection, renewable energy management, and energy forecasting. Previous research shows that ANN-based solutions can improve the performance of renewable energy, minimize energy losses, and maximize grid resilience.

5. Integration of Blockchain and Neural Networks in Smart Grids

Smart grids have attracted substantial interest due to the combination of blockchain technology and neural networks, as they present opportunities to enhance performance while strengthening protective measures and prediction capabilities. The combination of blockchain technology provides decentralized, transparent power transactions that remain tamper-proof, alongside neural networks that perform pattern recognition and detect anomalies, as well as automated grid environment decision processes. When smart grids employ this dual-technology framework, they optimize energy management functions and enhance real-time data processing features, while also improving cybersecurity protection standards. Blockchain and neural networks significantly enhance the security, predictive maintenance, and efficiency of the smart grid. The tamper-evident feature ensures integrity and privacy, utilizing a decentralized ledger of the blockchain that is secure from unauthorized access. Neural networks apply sophisticated data analysis to provide predictive maintenance with early failure detection and efficient resource allocation (Abdellatif & et al, 2025). For example, research has been dedicated to utilizing blockchain technology to ensure data integrity and security through the development of a distributed learning paradigm based on blockchain, aiming to enhance the efficiency and security of the smart grid. Moreover, studies prove that the convergence of blockchain technology with deep learning offers secure data exchange as well as intruder identification in smart grids. Smart grid operations are made safer, more reliable, and more efficient by such connections (Kumar & et al, 2023). The primary drawback of blockchain for smart grids is its slow processing speed and insufficient computational power when handling transactions. Neural networks enhance blockchain performance by optimizing consensus mechanisms, such as Proof of Work (PoW) and Proof of Stake (PoS), thereby reducing the power consumption required for transaction authentication (Ahmed et al., 2022). Using AI models for prediction helps determine transaction levels and optimize block validation uptime, thereby improving overall operational efficiency (Hafid et al., 2020). AI-cueled adaptive smart contracts enable the analysis of historical energy consumption data to inform pricing models in peer-to-peer (P2P) trading systems, thereby enhancing energy market responsiveness and reducing costs, as noted by Wu et al. (2022). The combination of predictive maintenance and artificial intelligence with blockchain technology allows data analysis of IoT sensors to authenticate maintenance records, thereby reducing grid failure risks and cyberattack threats (Almasoudi, 2023). The reliability of smart grids (Waseem et al., 2023) depends upon the implementation of these measures, as they stop man-in-the-middle (MITM) attacks, spoofing, and false data injection. Both blockchain technology and AI, when combined, can transform decentralized energy trading and predictive maintenance. Blockchain technology provides secure, transparent, and tamper-evident transactions, making it ideal for such use cases. Meanwhile, AI models are able to process vast amounts of grid data in real time and make more intelligent choices. Another common application is peer-to-peer (P2P) energy trading, in which the blockchain technology enables consumers and producers (prosumers) of energy to directly trade without an intermediary. The trading is executed by smart contracts, providing bilateral rates to both entities while introducing trust among stakeholders. Moreover, using blockchain's tamper-proof ledger with the anomaly detection function of AI escalates predictive maintenance levels significantly. For the detection of anomalies and anticipating any failure before it occurs, machine learning models analyse data from smart meters and grid assets. Storage of the outcome in a blockchain guarantees integrity of data and supports auditing and regulatory uses by tracing events. Such technologies transform the grid into an efficient grid, reduce operating expenses, and increase the reliability of power. Real-world applications, such as Power Ledger's P2P platform and AI-aided maintenance in renewable energy farms, demonstrate the utility and feasibility of this synergy, paving the way for a more innovative and robust energy infrastructure.

Behavioral energy management receives important applications through the combination of AI and blockchain systems. The combination of AI models brings the ability to predict energy needs, which also includes optimizing demand distribution while simultaneously executing energy delivery in decentralized environments (Islam & et al, 2024). AI utilizes past and current electricity usage data to predict maximum usage periods for blockchain platform smart contracts, thereby optimizing power delivery efficiency. Demand response mechanisms benefit from enhancement through supply-demand-based price adjustments, which decrease consumer costs without destabilizing the power grid (Ferdous & et al, 2023). The effectiveness of uniting blockchain technology with AI within smart grids becomes clear through existing practical applications as follows:

- IBM and TenneT (Germany & Netherlands) created blockchain-powered AI prediction algorithms for managing decentralised power grid balance (Alotaibi & et al, 2020).
- LO3 Energy introduced their P2P energy trading initiative featuring AI predictive analytics that enables customers to reach energy efficiency in their usage (Wu & et al, 2022).
- The Australian technology company Power Ledger applied blockchain along with machine learning to boost distributed energy resource management to deliver more accessible and practical solutions (Treiblmaier, 2023).
- The EU H2020 Platone Project executed blockchain and AI technology to enhance energy storage operations and manage power demand, which created a stronger, adaptable power system (Khalid, 2024).

The implementation of blockchain and neural networks in smart grids encounters obstacles related to processing expenses as well as interface matters and regulatory adherence requirements. Escalation problems persist in artificial intelligence models that implement blockchain-based solutions, as noted by Hafid et al. (2020). Standardization of protocols together with data privacy concerns act as significant impediments to blockchain-based adoption throughout the industry (Ferdous & et al, 2023). Research needs to create light blockchain protocols and decentralized AI frameworks and energy-efficient neural networks for eliminating technological obstacles in modern energy systems (Javaid & et al, 2018).

Through their strategic union, blockchain technology holds promise as a secure and intelligent system that enhances the efficiency of smart grids. The details of present technical requirements and governing standards can transform energy control systems while creating paths for moving toward distributed renewable power networks.

5. 1. The Role of AI-driven Neural Networks in Improving the Scalability and Efficiency of Blockchain-based Smart Grid Systems

In Germany's Brooklyn Microgrid, peer-to-peer (P2P) energy trading based on blockchain and optimised by AI anticipates user demand and enables the transactions with increased efficiency and reduced latency. This ensures the effectiveness of integration between blockchain and artificial intelligence.

The State Grid Corporation of China applies neural networks to recognise patterns of energy transactions on a blockchain platform, detecting cyber-attacks and fraud in real time. AI neural networks offer groundbreaking solutions to scalability and efficiency issues in blockchain-based smart grids. Through consensus optimisation, computational efficiency improvement, and predictive maintenance assistance, AI enhances grid reliability and performance. Table 3 shows the comparison between Traditional Blockchain Smart Grid and AI-Driven Blockchain Smart Grid.

Table 3. Traditional Blockchain Smart Grids and AI-Driven Blockchain Smart Grids

Aspect	Traditional Blockchain Smart Grid	AI-Driven Blockchain Smart Grid
Transaction Speed	Slow due to high computational demand	Faster with AI-optimised consensus mechanisms
Energy Consumption	High, especially with PoW consensus	Reduced via reinforcement learning-based energy allocation
Data Management	Inefficient storage and retrieval	AI-enabled data compression and smart indexing
Security	Vulnerable to fraudulent transactions	AI-enhanced anomaly detection for real-time threat prevention
Predictive Capabilities	Limited to predefined algorithms	Advanced forecasting and automated grid optimisation

6. Challenges and Potential Solutions

The integration of blockchain and neural networks for intelligent grids is highly promising, offering improved repair prediction, enhanced efficiency, and increased security. Integration is not without issues, primarily related to interoperability, scalability, and computational complexity.

- Interoperability is a problem due to a difference in protocol and architecture between the distinct elements and parties of smart grids. It may hinder smooth data and system integration. To control it, utilizing a standardized communication protocol and developing middleware solutions to connect divergent technologies play significant roles (Belchior & et al, 2021). Such standardization contributes to seamless interactions between heterogeneous systems for intelligent and efficient operations in smart grids.
- Intensive processing required by blockchain's consensus algorithms and deep models in neural networks forms computational complexity. Such conditions can strain the computing resources of smart grid infrastructure. The solution for this problem is the application of federated learning. In this method, edge devices or local servers are trained using local models, and aggregated information is transmitted to a central system. This method reduces data transfer requirements, minimizing computational strain while maintaining data privacy.
- Scalability remains an issue, as blockchain networks have sometimes struggled with processing throughput in large smart grids (Ressi & et al, 2024). The blockchain architecture, in which each node verifies each transaction, can cause bottlenecks as the network expands in size. Sidechains and sharding have been suggested as potential scaling solutions for blockchain. Sidechains enable the offloading of transactions from the primary blockchain onto secondary parallel chains, thereby clearing up and increasing efficiency. Sharding is the division of the blockchain network into several small partitions (shards), each of which is capable of independently processing transactions, thus increasing overall processing capacity (Sanka & et al, 2021).

By effectively addressing such issues through utilizing standardized protocols, federated learning, and utilization of scalability technology such as sidechains and sharding, smart grids can be empowered to utilize the complete capabilities of the blockchain technology and neural networks. This convergence can enhance security, efficiency, and predictive maintenance ability in smart grids, ultimately leading to smarter and safer energy systems.

7. Results and Discussion

Research into blockchain and neural network implementation in smart grids highlights both promising features with their application and important difficulties they present. The analysed scholarly works indicate that blockchain technology strengthens electrical grid protection, shows all monetary transactions, and allows peer-to-peer electricity exchanges. Meanwhile, artificial intelligence enables better power usage management, improves fault identification systems, and creates forecasting capabilities to stabilise the power network. Several critical problems still need resolution in this field because of high operational expenses, regulatory barriers, scalability limitations, and data compatibility problems. According to Prakash et al. (2022) and Almasoudi (2023), blockchain technology provides fundamental protection against cyber threats, including MITM attacks as well as spoofing activities and unauthorised data modification. Zhang et al. (2018) supported this concept by explaining that decentralised ledgers can both protect smart grids from data modification attempts and increase security measures. Blockchain encryption methods, however, face serious issues in terms of computational efficiency. Researchers have incorporated AI-based encryption measures in addition to fraud detection algorithms in designing blockchain security protocols which maintain high efficiency levels. AI-based prediction models, as mentioned by Javaid et al. (2018), demonstrate capability in analysing real datasets for predictive load balancing systems in addition to demand-side management, as noted by Ahmed et al. (2022). The deep learning protocols also show capacity in predicting energy demand variations, as investigated by Sun et al. (2019), yielding better efficiency in intelligent grids. The application of AI in real-time operations faces implementation issues, as mentioned by Islam et al. (2024), due to slow processing rates in addition to delayed operations. Research by Siano et al. (2020) indicates how edge computing, when applied to AI-smart contracts, resolves these issues by enhancing distributed energy management in real-time operations using decentralised infrastructure. The integration of blockchain technology allows intelligent grids to enable direct peer-to-peer (P2P) energy trading between prosumers. Alotaibi et al. (2020) and Wu et al. (2022) further reveal how blockchain-based energy markets improve power flexibilities by disrupting monopolies in energy supply by incumbents. The large-scale implementation of distributed energy markets meets network utilisation issues and complexity in regulation in conformity with Waseem et al. (2023). Research by Ferdous et al. (2023) and Hafid et al. (2020) ventures simplistic blockchain protocols and regulatory measures to address these implementation issues and develop standard blockchain integration in intelligent grids. Blockchain technology faces a significant scalability challenge, particularly in high-rate transactions within energy markets of intelligent grids. Treiblmaier (2023) and Khalid (2024) analyse how blockchain mining and consensus operations strain environmental resources. The application of Proof-of-Work (PoW) and Proof-of-Stake (PoS) mechanisms receives optimisations through the use of AI to mitigate energy requirements, as mentioned by Ahmed et al. (2022). Improved blockchain scalability is made using layer-2 blockchain implementations as mentioned by Hafid et al. (2020), while maintaining the same level in terms of computational efficacy. The implementation of blockchain technology and neural networks is a promising solution for developing a decentralized and less risky power distribution network. Efficient use of this network is possible only by solving scalability issues, improving calculation effectiveness, and outlining regulatory frameworks for processing real-time information of AI. Studies by Zhang and others in 2018, Sun and others in 2019, and Siano and authors in 2020 suggest three innovative solutions for overcoming common shortcomings in intelligent grids: AI-capable blockchain enhancements, decentralised networks of markets and edge-computing-based administration of power grids. Future investigations need to create lightweight blockchain systems that integrate real-time AI analytics with the establishment of worldwide regulatory frameworks to support practical and scalable deployment within smart grids. Table 4 shows the challenges identified in previous studies along with the proposed strategies and solutions in each reference.

Table 4. Comparison of Previous Studies on Blockchain and Neural Networks in Smart Grids

Reference	Objective	Results	Challenges	Proposed Solutions
Ahmed et al. (2022)	AI-driven blockchain optimisation in SG	AI can optimise PoW and PoS to reduce energy consumption and improve transaction speed	High computational cost	Adaptive AI-based consensus mechanisms
Almasoudi (2023)	AI-enhanced cybersecurity in SG	AI detects anomalies and prevents MITM, spoofing, and data injection attacks	Privacy concerns & regulatory challenges	Blockchain-based AI authentication & encryption

Alotaibi et al. (2020)	AI and blockchain in P2P energy trading	Smart contracts enable efficient, decentralised energy transactions	Scalability of blockchain for large-scale energy markets	AI-driven predictive load balancing
Ferdous et al. (2023)	Blockchain for renewable energy certificates	Distributed ledger improves traceability & transparency in energy trading	Standardisation & legal barriers	Regulatory frameworks for blockchain adoption
Hafid et al. (2020)	Scaling blockchain in smart grids	Layer-2 solutions can enhance transaction efficiency	Energy-intensive computations	Optimised lightweight blockchain protocols
Islam et al. (2024)	AI in smart grid stability and energy storage	AI predicts energy demand and prevents grid overload	Limited real-time implementation	AI-powered smart contracts for automated energy dispatch
Javaid et al. (2018)	AI-based DSM (Demand Side Management)	AI optimises demand-side response for SG efficiency	Data interoperability	Unified blockchain-based AI energy management
Khalid (2024)	Smart grid integration with blockchain & AI	Improved energy distribution through AI-enhanced smart contracts	Regulatory compliance	Blockchain governance frameworks for energy markets
Prakash et al. (2022)	AI-enhanced blockchain security	Text mining analysis on blockchain-based cybersecurity models	Complexity in implementation	AI-driven encryption and fraud detection models
Treiblmaier (2023)	Bitcoin's energy use in blockchain applications	AI improves energy efficiency in blockchain-based transactions	Environmental concerns	AI-driven energy-efficient mining protocols
Waseem et al. (2023)	Blockchain in various SG applications	AI-powered energy trading enhances efficiency and security	Network congestion issues	Distributed AI-assisted consensus mechanisms
Wu et al. (2022)	Blockchain & AI for microgrid management	Blockchain and AI enable collective energy balance and decentralised transactions	Cross-sector interoperability issues	Standardised blockchain interfaces for microgrids

8. Conclusion

Smart grids that adopt neural networks alongside blockchain acquire several capabilities to protect energy systems and enhance operational performance with decentralised power management functions. Blockchain technology united with AI capabilities enables data authentication, enhances systems visibility, lets peers conduct safe power purchases, and improves grid optimisation processes. Major obstacles emerge during large-scale implementation because they link with high computational expenses and regulatory barriers which create limitations to scalability. Energy trading transformation features various edge computing, advanced AI analytics, and lightweight blockchain design approaches that intend to reduce network delays and reinforce power distribution system reliability. Academic research in the future needs to work on blockchain infrastructure flexibility and the introduction of artificial intelligence data analytics in real-time operation along with standard regulatory frameworks. Smart grids operate sustainably at maximum efficiency through decentralised energy markets when implemented with innovative technologies that ensure secure operational efficiency of their energy system.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Disclosure

The authors report no conflicts of interest for this work.

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