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The Role of Blockchain and AI in the Future of Energy Trading: A Technological Perspective on Transforming the Oil & Gas Industry by 2025

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Abstract

The convergence of blockchain and artificial intelligence (AI) is poised to revolutionize energy trading in the oil and gas industry by 2025. These technologies are enhancing transaction efficiency, improving market transparency, and enabling more secure and automated trading processes. Blockchain, through decentralized ledgers and smart contracts, ensures immutable transaction records, reducing counterparty risks and enabling real-time settlements. AI-driven predictive analytics optimize energy trading strategies by processing vast datasets, detecting market patterns, and forecasting price fluctuations with high accuracy. Smart contracts, self-executing agreements embedded in blockchain networks, eliminate intermediaries, reducing transaction costs and mitigating fraudulent activities. These digital agreements automate trade settlements based on predefined conditions, expediting contract execution while ensuring compliance with regulatory requirements. Additionally, AI-powered algorithmic trading enhances market responsiveness, enabling energy companies to make data-driven decisions in real-time. By leveraging machine learning and deep learning models, traders can optimize portfolio management, anticipate supply chain disruptions, and manage price volatility more effectively. Moreover, blockchain fosters trust among stakeholders by providing a tamper-proof audit trail of transactions, enhancing regulatory compliance, and reducing operational inefficiencies. The integration of AI with blockchain-enabled trading platforms allows for automated risk assessment, fraud detection, and enhanced liquidity management. These innovations collectively contribute to a more resilient and adaptive energy trading ecosystem, accommodating the growing complexity of global oil and gas markets. Despite these advantages, challenges such as regulatory uncertainties, interoperability issues, and cybersecurity risks persist. The successful implementation of blockchain and AI in energy trading requires standardized frameworks, industry-wide collaboration, and robust cybersecurity measures. Nonetheless, early adopters stand to gain a competitive edge by capitalizing on these technologies to optimize trading strategies, improve asset utilization, and enhance operational efficiency. As the oil and gas industry embraces digital transformation, blockchain and AI are becoming indispensable tools for modernizing energy trading. Their potential to foster transparency, streamline operations, and mitigate risks underscores their role in shaping the future of energy markets. Companies that integrate these technologies effectively will be better positioned to navigate evolving market dynamics and achieve sustained growth in a rapidly digitalizing energy sector.

Keywords: Blockchain, Artificial Intelligence, Smart Contracts, Energy Trading, Oil and Gas, Digital Transformation, Market Transparency, Predictive Analytics, Algorithmic Trading, Decentralized Ledgers

1. Introduction

The global energy sector is currently experiencing a profound transformation, driven by technological advancements, regulatory changes, and an increasing demand for efficient and transparent trading mechanisms. Energy trading, particularly within the oil and gas industry, is crucial for ensuring that supply meets demand effectively. Traditionally, energy trading has depended on centralized systems characterized by numerous intermediaries, extensive documentation, and prolonged settlement periods. These conventional processes often suffer from inefficiencies such as data discrepancies, fraud risks, and

operational delays, which contribute to heightened costs and diminished trust among stakeholders (Shan, 2024; Boumaiza, 2024) [186, 74].

Despite the energy trading sector being a multi-trillion-dollar industry, it remains hampered by outdated infrastructures that do not fully exploit emerging technologies. The reliance on manual processes and fragmented supply chains, compounded by regulatory compliance challenges, exacerbates inefficiencies in market operations (Ayorinde, 2023) [70]. Furthermore, the dependence on intermediaries not only escalates transaction costs but also prolongs settlement times, thereby limiting the industry's capacity to adapt swiftly to market fluctuations. Security concerns regarding data integrity and cyber threats further complicate the landscape, underscoring the urgent need for more robust and transparent solutions (Wang *et al*., 2018; Rahman, 2023) [209, 173].

Recent advancements in digital technologies, particularly blockchain and artificial intelligence (AI), offer unprecedented opportunities to revolutionize energy trading. Blockchain technology, with its decentralized ledger system, enhances transaction transparency, security, and efficiency, effectively eliminating the need for intermediaries (Al-Saif *et al*., 2021) [43]. AI facilitates predictive analytics, automated decision-making, and real-time optimization of energy transactions, thereby streamlining trading operations and reducing costs (Wang *et al*., 2019) [210]. The integration of these technologies, alongside smart contracts, has the potential to mitigate fraud and ensure regulatory compliance, paving the way for a more resilient, efficient, and secure energy trading ecosystem (Son *et al*., 2020; Zia *et al*., 2020) [189, 212].

This paper aims to explore how blockchain, AI, and smart contracts can optimize energy trading within the oil and gas industry, presenting a transformative approach to market efficiency, security, and sustainability. By analyzing current industry challenges and the potential benefits of these technologies, the study seeks to provide insights into the future landscape of energy trading, emphasizing the critical role of digital innovation in shaping the sector's evolution by 2025 (Shan, 2024; Boumaiza (2024)) [186, 74]. (Rahman, 2023) [173].

2.1 Methodology

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency and rigor in examining the role of blockchain and artificial intelligence (AI) in the future of energy trading, with a specific focus on their transformative impact on the oil and gas industry by 2025. The PRISMA approach was employed to systematically collect, screen, and analyze relevant literature from reputable databases and sources.

A comprehensive literature search was conducted across databases including Scopus, IEEE Xplore, ScienceDirect, Springer, and Google Scholar, focusing on peer-reviewed articles, conference proceedings, and industry reports published between 2013 and 2025. Keywords such as “blockchain in energy trading,” “AI in oil and gas,” “blockchain for peer-to-peer energy,” and “machine learning in energy optimization” were utilized to refine the search. The search was further complemented by a manual review of reference lists in selected articles.

Studies were screened based on their relevance to blockchain and AI applications in energy trading. Inclusion criteria included studies that explored blockchain's role in secure and decentralized energy trading, AI-driven predictive analytics for optimizing energy transactions, and case studies demonstrating practical implementations in the oil and gas sector. Exclusion criteria eliminated articles that lacked empirical evidence, non-English publications, and studies with outdated technological discussions.

Following screening, eligible studies underwent data extraction, focusing on core themes such as blockchain-based smart contracts, AI-driven predictive analytics for energy trading, and integration models for sustainable and efficient energy transactions. The extracted data were synthesized through qualitative analysis, identifying common trends, technological advancements, and challenges associated with implementing blockchain and AI in energy markets.

A quality assessment of the selected studies was conducted using a risk-of-bias evaluation, considering factors such as sample size, research design, and data reliability. Studies presenting empirical models and real-world implementations were prioritized to ensure a robust and practical discussion of findings. To present the systematic review process, the PRISMA flowchart was developed to illustrate the selection process, from the initial identification of studies to final inclusion. The flowchart outlines the number of records identified, screened, excluded, and included in the final analysis.

Finally, the synthesized findings were critically analyzed to explore the feasibility, limitations, and opportunities of blockchain and AI in revolutionizing energy trading, particularly in the oil and gas industry, within the projected timeframe of 2025. This methodological approach ensures a structured and comprehensive evaluation of emerging technologies in energy markets. The PRISMA flowchart shown in Fig 1 illustrating the systematic review process has been generated.

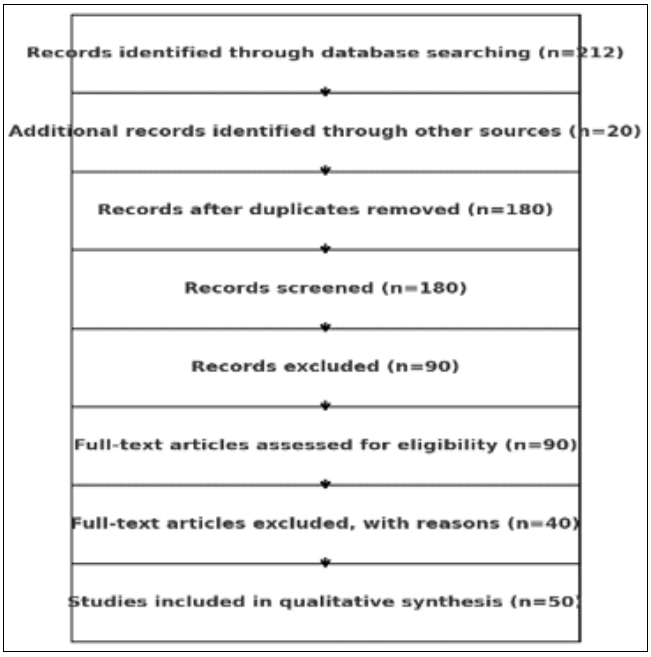

Fig 1: PRISMA Flow chart of the study methodology

2.2 Overview of Emerging Technologies in Energy Trading

The rapid evolution of digital technology is significantly reshaping the energy trading landscape, particularly within the oil and gas sector. As global energy demands continue to rise, traditional energy trading methods struggle with inefficiencies, high transaction costs, and security vulnerabilities. The integration of blockchain technology, artificial intelligence (AI), and smart contracts is revolutionizing the industry, offering enhanced security, transparency, and efficiency (Ajiga, *et al*., 2024, Oluokun, *et al*., 2024, Oyewole, *et al*., 2024). These technologies provide innovative solutions to long-standing challenges, allowing market participants to optimize trading operations while reducing risks and costs.

Blockchain technology is emerging as a transformative force in energy trading, primarily due to its decentralized and transparent nature. In traditional energy markets, transactions typically involve multiple intermediaries, extensive documentation, and long settlement times (Arinze, *et al*., 2024, Oyenuga, Sam-Bulya & Attah, 2024). These complexities often lead to increased costs, inconsistencies in trade records, and susceptibility to fraud. Blockchain addresses these issues by utilizing decentralized ledgers that enable peer-to-peer transactions without the need for intermediaries (Attah, *et al*., 2024, Oluokun, *et al*., 2024, Onyebuchi, Onyedikachi & Emuobosa, 2024). Every transaction is securely recorded in a distributed ledger, ensuring that all parties involved have access to the same real-time data, thereby eliminating discrepancies and reducing the likelihood of disputes. Fig 2 shows Digital transformation oil and gas supply chain based on blockchain technology presented by (Zakharkina, *et al*., 2022) [211].

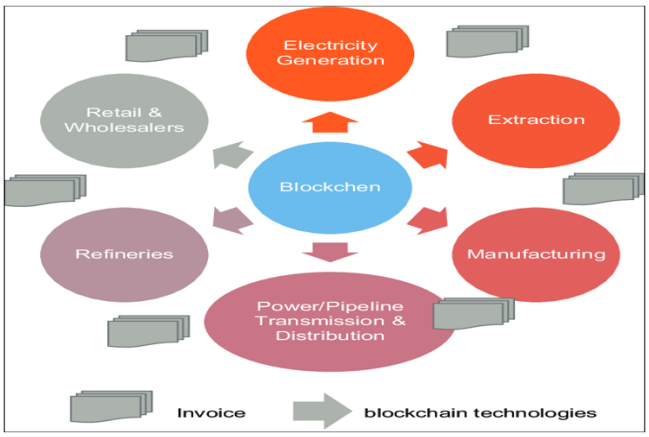

Fig 2: Digital transformation oil and gas supply chain based on blockchain technology (Zakharkina, *et al*., 2022) [211]

The immutability of blockchain technology is another critical advantage. Once a transaction is recorded on a blockchain, it cannot be altered or deleted, providing an indisputable and permanent trade record. This feature enhances trust among trading participants, as each party can verify the authenticity of transactions without relying on third-party validation. Transparency within blockchain-based energy trading systems ensures that all trades are securely documented, reducing the risk of fraud and enhancing regulatory compliance (Akintobi, Okeke & Ajani, 2023 [24], Onukwulu, Agho & Eyo-Udo, 2023). This level of security and transparency is particularly vital in the oil and gas sector, where complex transactions and contractual obligations require precise documentation to prevent financial losses and legal disputes.

Beyond transaction security, blockchain technology also facilitates the development of decentralized energy trading platforms. These platforms allow producers and consumers to trade energy directly, bypassing traditional centralized energy markets. By eliminating intermediaries, blockchain-powered trading networks can significantly reduce costs and improve efficiency. Additionally, smart grids integrated with blockchain technology can enable real-time energy pricing based on supply and demand dynamics, leading to more optimized market operations (Alabi, *et al*., 2024, Olutimehin, *et al*., 2024, Onyebuchi, Onyedikachi & Emuobosa, 2024). These innovations hold immense potential for reshaping the energy industry by fostering a decentralized and secure trading environment.

Artificial intelligence (AI) is another game-changing technology in the energy trading sector, particularly in market forecasting and risk management. Energy markets are inherently volatile, with prices influenced by geopolitical events, supply chain disruptions, regulatory changes, and fluctuating demand. Traditional forecasting models often fail to capture the complexity of these dynamic factors, leading to inaccurate predictions and suboptimal trading decisions (Akinsooto, 2013 [18], Onukwulu, Agho & Eyo-Udo, 2021). AI-driven predictive analytics leverages vast amounts of data from various sources, including historical price trends, market sentiment analysis, weather patterns, and economic indicators, to generate highly accurate market forecasts. Schletz, *et al*., 2020, presented Blockchain-based decentralised P2P energy trading system as shown in Fig 3.

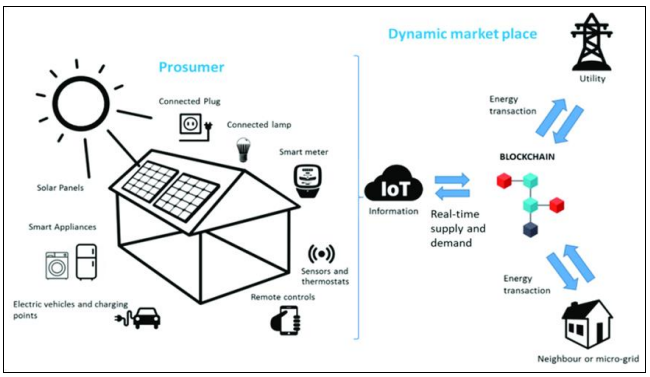

Fig 3: Blockchain-based decentralised P2P energy trading system (Schletz, *et al*., 2020) [184]

Machine learning models play a crucial role in refining energy trading strategies by continuously analyzing market conditions and adjusting predictions based on new data. These models can identify emerging trends and anomalies that may impact energy prices, allowing traders to make informed decisions. By automating data analysis and trend identification, AI reduces human biases and enhances trading efficiency. The ability to process and interpret real-time data enables traders to react swiftly to market fluctuations, thereby mitigating risks and maximizing profitability (Austin-Gabriel, *et al*., 2024, Olutimehin, *et al*., 2024, Onyebuchi, Onyedikachi & Emuobosa, 2024).

Risk assessment is another critical area where AI is making significant strides in energy trading. Traditional risk management approaches often rely on static models that fail to adapt to rapidly changing market conditions. AI-powered

risk assessment tools use machine learning algorithms to evaluate market risks dynamically, providing traders with real-time insights into potential threats (Anaba, *et al*., 2025, Oyenuga, Sam-Bulya & Attah, 2025) [44, 156]. These tools assess factors such as geopolitical instability, supply chain disruptions, and economic downturns, allowing companies to adjust their trading strategies accordingly. Additionally, AI-driven risk models help optimize pricing strategies by analyzing historical trading patterns and current market conditions, ensuring that energy assets are traded at optimal prices (Ajiga, *et al*., 2024, Onita, Ebeh & Iriogbe, 2024, Soremekun, *et al*., 2024).

The integration of AI with blockchain further enhances the capabilities of energy trading platforms. AI-powered smart contracts can automate trading processes by executing transactions based on predefined conditions. For example, AI can analyze market trends and automatically trigger smart contract execution when specific price thresholds are met. This level of automation minimizes human intervention, reduces transaction delays, and enhances overall market efficiency (Alonge, Dudu & Alao, 2024, Olutimehin, *et al*., 2024, Ugochukwu, *et al*., 2024 [199]). By combining AI's predictive analytics with blockchain's secure and transparent infrastructure, energy trading platforms can achieve unprecedented levels of efficiency and reliability. The roadmap for blockchain technology integration within the Energy 5.0 framework presented by Mourtzis, *et al*., 2022, is shown in Fig 4.

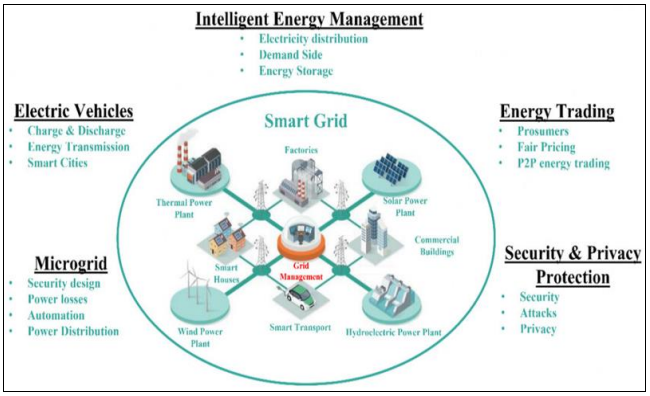

Fig 4: Roadmap for blockchain technology integration within the Energy 5.0 framework (Mourtzis, *et al*., 2022) [75]

Smart contracts are another revolutionary technology transforming the oil and gas energy trading landscape. These self-executing agreements are powered by blockchain technology and automatically enforce contract terms without the need for intermediaries. In traditional energy trading, contract execution often involves multiple stakeholders, extensive documentation, and manual verification processes, leading to inefficiencies and increased transaction costs. Smart contracts streamline this process by automating trade execution based on predefined conditions, ensuring that contractual obligations are met without delays or disputes (Attah, *et al*., 2024, Olutimehin, *et al*., 2024, Onyebuchi, Onyedikachi & Emuobosa, 2024).

One of the most significant advantages of smart contracts is their ability to eliminate intermediaries, reducing the complexity and cost of energy trading transactions. By automating trade settlements and payment processes, smart contracts enhance operational efficiency and minimize the risk of human errors. Additionally, the use of smart contracts ensures that all contractual terms are immutable and transparent, reducing the likelihood of disputes and fraudulent activities (Apeh, *et al*., 2024, Olutimehin, *et al*., 2024, Oyewole, *et al*., 2024). This level of automation is particularly valuable in the oil and gas sector, where contractual agreements often involve intricate terms related to pricing, delivery schedules, and regulatory compliance.

Ensuring compliance with industry regulations is another key benefit of smart contracts in energy trading. The oil and gas industry is subject to stringent regulatory requirements, and non-compliance can result in substantial financial penalties and reputational damage. Smart contracts can be programmed to incorporate regulatory rules and automatically verify compliance before executing transactions. By embedding compliance mechanisms into the contract execution process, smart contracts help energy companies adhere to industry standards and avoid regulatory pitfalls (Alex-Omiogbemi, *et al*., 2024, Olutimehin, *et al*., 2024, Uloma, *et al*., 2024 [200]).

Furthermore, smart contracts facilitate cross-border energy trading by automating complex international transactions. Traditional cross-border energy trades often involve lengthy settlement processes, currency exchange risks, and compliance challenges (Alabi, *et al*., 2024, Oyewole, *et al*., 2024, Sam-Bulya, *et al*., 2024). Smart contracts streamline these transactions by enabling seamless execution and verification across different regulatory jurisdictions. This capability is particularly beneficial in the global oil and gas market, where energy trades often span multiple countries and regulatory frameworks (Akinade, *et al*., 2021 [15], Onukwulu, *et al*., 2021).

The convergence of blockchain, AI, and smart contracts is poised to revolutionize the energy trading industry by 2025. These technologies offer a powerful combination of security, transparency, efficiency, and automation, addressing many of the challenges that have long plagued traditional energy markets. Blockchain's decentralized ledger system ensures secure and transparent transactions, AI-driven predictive analytics enhances market forecasting and risk assessment, and smart contracts streamline trade execution while ensuring regulatory compliance (Akinade, *et al*., 2022 [16], Onukwulu, Agho & Eyo-Udo, 2022).

As the energy sector continues to embrace digital transformation, the adoption of these emerging technologies will become increasingly critical for maintaining competitiveness and achieving sustainable growth. Energy companies that leverage blockchain, AI, and smart contracts will be better equipped to navigate market uncertainties, optimize trading operations, and drive innovation in the evolving energy landscape (Akinyemi & Onukwulu, 2025, Oluokun, *et al*., 2025 [78]). By integrating these advanced technologies, the oil and gas industry can unlock new opportunities for efficiency, cost reduction, and improved market dynamics, setting the stage for a more resilient and technologically advanced energy trading ecosystem.

2.3 Impact of Blockchain and AI on Energy Trading Practices

The integration of blockchain and artificial intelligence (AI) is revolutionizing energy trading practices in the oil and gas industry, bringing about significant improvements in efficiency, security, transparency, and cost reduction. The traditional energy trading landscape has long been burdened by inefficiencies stemming from manual processes, reliance

on intermediaries, and the complexity of cross-border transactions (Alao, *et al*., 2024 [35], Olutimehin, *et al*., 2024, Oyewole, *et al*., 2024). The emergence of digital technologies is addressing these challenges, offering innovative solutions that streamline trading operations, enhance market transparency, and drive greater liquidity. By leveraging blockchain's decentralized ledger system and AI's predictive analytics, energy companies can optimize trading practices, reduce costs, and mitigate risks in ways that were previously unattainable (Ajiva, Ejike & Abhulimen, 2024, Paul, *et al*., 2024, Soremekun, *et al*., 2024).

One of the most transformative impacts of blockchain and AI on energy trading is the automation of contract settlements, significantly reducing transaction times and costs. Traditional contract execution in the oil and gas sector is often delayed by lengthy verification processes, requiring multiple intermediaries to validate transactions and ensure compliance with regulatory standards (Attah, *et al*., 2024, Omokhoa, *et al*., 2024, Ozowe, Daramola & Ekemezie, 2024). These delays not only increase operational costs but also expose trading participants to risks associated with market fluctuations. Blockchain-powered smart contracts automate the execution of agreements by enforcing predefined rules and conditions without human intervention. Once the conditions of a trade are met, the smart contract is automatically executed, ensuring a seamless and instantaneous settlement process (Akinsooto, Ogundipe & Ikemba, 2024, Raji, *et al*., 2024).

The automation of contract settlements eliminates the need for third-party intermediaries, which have historically played a crucial role in verifying and facilitating transactions in energy trading. Brokers, clearinghouses, and financial institutions that traditionally mediate trades add layers of complexity and costs to the process. By removing these intermediaries, blockchain enables direct peer-to-peer transactions, reducing transaction fees and increasing the efficiency of energy trading (Ajirotutu, *et al*., 2024, Omokhoa, *et al*., 2024, Umana, Garba & Audu, 2024). This shift not only enhances cost savings but also empowers energy producers and consumers by giving them greater control over their transactions. The reduction in intermediary involvement translates into lower administrative expenses and fewer instances of settlement disputes, further strengthening the financial sustainability of energy trading firms (Ajiga, *et al*., 2024, Oyewole, *et al*., 2024, Shoetan, *et al*., 2024) [187].

Beyond cost reduction, blockchain technology enhances transparency and security in energy trading by providing immutable transaction records that facilitate auditability and compliance. One of the persistent challenges in traditional energy markets is the difficulty of maintaining accurate and tamper-proof trade records. Errors in data entry, manipulation of records, and fraudulent activities pose significant risks to market participants (Alabi, *et al*., 2024, Omokhoa, *et al*., 2024, Onyebuchi, Onyedikachi & Emuobosa, 2024). Blockchain's decentralized ledger system ensures that once a transaction is recorded, it cannot be altered or deleted. Each trade is permanently stored on a distributed ledger, providing an auditable history that can be verified by all relevant stakeholders. This level of transparency is invaluable for regulatory compliance, as authorities can easily track and verify transactions without relying on centralized databases that are vulnerable to breaches (Onoja, Ajala & Ige, 2022 [108], Onukwulu, *et al*., 2022).

The immutability of blockchain records also plays a critical role in reducing fraud and counterparty risks. In traditional energy trading, counterparty risk arises when one party fails to fulfill contractual obligations, leading to financial losses and legal disputes. Blockchain's smart contracts mitigate this risk by ensuring that transactions are only executed when all predefined conditions are met (Alex-Omiogbemi, *et al*., 2024, Omokhoa, *et al*., 2024, Umana, et l., 2024). Furthermore, the transparent nature of blockchain reduces opportunities for fraudulent activities such as double trading, contract manipulation, and false reporting. AI further strengthens fraud detection mechanisms by analyzing trading patterns, identifying anomalies, and flagging suspicious activities in real-time (Attah, *et al*., 2024, Onukwulu, *et al*., 2024, Solanke, *et al*., 2024 [188]). This combination of blockchain's security and AI's analytical capabilities significantly reduces the risks associated with energy trading, fostering greater trust among market participants.

In addition to enhancing security and transparency, blockchain and AI improve market efficiency and liquidity by enabling real-time decision-making and peer-to-peer (P2P) energy trading. Traditional energy markets often suffer from inefficiencies due to delayed data processing, manual trade execution, and the lack of real-time price discovery mechanisms (Azubuike, *et al*., 2024, Oyedokun, *et al*., 2024, Sam-Bulya, *et al*., 2024). AI-driven algorithmic trading addresses these challenges by leveraging machine learning models to analyze vast amounts of market data, predict price movements, and execute trades with minimal latency (Ajiga, *et al*., 2024, Omokhoa, *et al*., 2024, Oyewole, *et al*., 2024). These AI-powered trading systems can process real-time information on supply-demand dynamics, geopolitical events, and market sentiment, allowing traders to make data-driven decisions that optimize profitability and reduce exposure to market risks.

AI-driven trading algorithms are particularly effective in enhancing liquidity by identifying optimal trading opportunities and executing transactions at the most favorable prices. Market participants benefit from improved price efficiency, reduced bid-ask spreads, and minimized volatility risks. The automation of trading decisions eliminates human biases and emotional trading, leading to a more stable and predictable energy market (Ajiva, Ejike & Abhulimen, 2024, Omokhoa, *et al*., 2024). Furthermore, AI-powered trading systems continuously learn from historical data and adjust their strategies based on changing market conditions, ensuring that energy traders remain competitive in a dynamic industry landscape (Alabi, *et al*., 2024, Oyedokun, *et al*., 2024, Urefe, Odonkor & Agu, 2024 [208]).

Blockchain further enhances market liquidity by facilitating decentralized P2P energy trading, which allows buyers and sellers to transact directly without relying on traditional energy markets. In conventional trading systems, energy producers often face barriers to market entry due to restrictive regulations, high transaction costs, and the dominance of large trading firms (Audu & Umana, 2024, Osundare, *et al*., 2024, Soremekun, *et al*., 2024). Blockchain-enabled P2P platforms democratize access to energy trading by creating decentralized marketplaces where participants can freely buy and sell energy based on real-time demand and supply conditions (Attah, *et al*., 2024,

Omokhoa, *et al*., 2024, Oyeyemi, *et al*., 2024). This model not only enhances market efficiency but also fosters greater inclusivity, enabling smaller energy producers to compete on an equal footing with established market players.

The combination of AI and blockchain in P2P energy trading also facilitates dynamic pricing mechanisms that optimize market efficiency. AI algorithms analyze market trends, weather patterns, energy consumption behavior, and supply chain disruptions to determine optimal pricing structures. These insights are then executed through blockchain-based smart contracts, ensuring that energy trades are conducted at fair and transparent prices. Additionally, the automation of settlement processes eliminates the need for manual reconciliation, further reducing operational bottlenecks and improving cash flow for energy traders (Austin-Gabriel, *et al*., 2021 [69], Onukwulu, *et al*., 2021).

The adoption of blockchain and AI in energy trading is accelerating the transition towards a more decentralized and sustainable energy market. As renewable energy sources become increasingly integrated into the energy mix, blockchain and AI play a crucial role in managing the complexities of distributed energy resources. AI-powered grid optimization systems analyze energy demand patterns and adjust supply allocation in real-time, ensuring efficient energy distribution across multiple market participants (Onita, *et al*., 2023, Onukwulu, Agho & Eyo-Udo, 2023). Blockchain-based trading platforms enable seamless tracking of renewable energy certificates and carbon credits, promoting transparency in sustainability initiatives and encouraging investment in clean energy projects.

Despite the significant benefits of blockchain and AI in energy trading, challenges remain in terms of regulatory acceptance, technological scalability, and industry adoption. Regulatory frameworks for blockchain-based trading are still evolving, and compliance with existing financial regulations remains a key consideration for energy companies (Arinze, *et al*., 2024, Onukwulu, *et al*., 2024, Sule, *et al*., 2024). Moreover, the integration of AI and blockchain requires significant infrastructure investments, and companies must navigate the complexities of interoperability between different digital platforms (Alonge, Dudu & Alao, 2024, Omowole, *et al*., 2024, Umana, et l., 2024). However, as technological advancements continue to accelerate, these challenges are expected to be addressed through collaborative efforts between industry stakeholders, regulatory bodies, and technology providers.

Looking ahead, the impact of blockchain and AI on energy trading practices will continue to expand, driving greater efficiency, security, and market accessibility. The ability to automate contract settlements, enhance transaction transparency, and enable real-time trading decisions will redefine how energy is bought and sold in global markets (Akinsooto, De Canha & Pretorius, 2014 [19], Onukwulu, *et al*., 2021). As energy companies increasingly embrace these digital innovations, the oil and gas industry is poised to become more resilient, adaptive, and competitive in an era of rapid technological transformation. The continued integration of AI-driven predictive analytics and blockchain's decentralized infrastructure will shape the future of energy trading, ushering in a new paradigm of digital efficiency and transparency (Onukwulu, Agho & Eyo-Udo, 2022, Oyegbade, *et al*., 2022).

2.4 Challenges and Barriers to Adoption

The integration of blockchain and artificial intelligence (AI) in energy trading presents immense potential for transforming the oil and gas industry. However, despite the significant benefits these technologies offer, their widespread adoption is hindered by several challenges. These obstacles range from regulatory and compliance issues to technical implementation difficulties and cybersecurity risks (Ajiga, *et al*., 2024, Omowole, *et al*., 2024, Ozowe, Daramola & Ekemezie, 2024). The complexity of energy markets, the need for standardized legal frameworks, and concerns surrounding data privacy and network security create barriers that energy companies must address to fully realize the potential of these emerging technologies. Overcoming these challenges requires a coordinated effort from industry stakeholders, regulators, and technology developers to create a sustainable and secure ecosystem for blockchain and AI-driven energy trading (Alex-Omiogbemi, *et al*., 2024, Osundare & Ige, 2024, Sule, *et al*., 2024).

One of the most pressing challenges in adopting blockchain and AI for energy trading is the lack of standardized legal frameworks and government policies governing blockchain-based transactions. Energy markets are highly regulated, and any new technology that seeks to alter market structures must comply with existing regulatory requirements (Apeh, *et al*., 2024, Omowole, *et al*., 2024, Oyeyemi, *et al*., 2024). The decentralized nature of blockchain presents a significant challenge in this regard, as it operates without a central authority, making it difficult for regulatory bodies to enforce compliance. Many governments and regulatory agencies are still in the process of evaluating the implications of blockchain technology in financial and energy markets, leading to uncertainty and hesitation among market participants (Attah, *et al*., 2024, Osundare & Ige, 2024, Raji, *et al*., 2024).

Without clear legal guidelines, companies face risks related to contract enforceability, taxation, and regulatory approvals when implementing blockchain-based trading systems. For instance, smart contracts, which are self-executing agreements recorded on a blockchain, must align with existing contract laws to be legally binding. However, variations in legal interpretations across different jurisdictions create complications in cross-border energy trading (Anaba, *et al*., 2023 [45], Onita & Ochulor, 2023). The absence of standardized frameworks also poses challenges in dispute resolution, as traditional legal processes may not be well-equipped to handle conflicts arising from blockchain transactions. Additionally, concerns about anti-money laundering (AML) and know-your-customer (KYC) requirements further complicate the adoption of blockchain-based energy trading, as regulators seek to prevent illicit activities within decentralized networks (Ajirotutu, *et al*., 2024, Osundare & Ige, 2024, Soremekun, *et al*., 2024).

Government policies on blockchain-based trading remain a significant barrier to adoption, as many authorities are cautious about endorsing technologies that disrupt existing financial and energy market structures. Some regulatory bodies view blockchain as a potential risk to market stability, given its decentralized nature and lack of oversight (Azubuko, *et al*., 2023) [73]. This has led to slow regulatory approvals for blockchain-based energy trading platforms,

with some countries imposing restrictions on cryptocurrency transactions and digital asset exchanges (Attah, *et al*., 2024, Omowole, *et al*., 2024, Umana, et l., 2024). Furthermore, energy companies operating in multiple jurisdictions must navigate a complex regulatory landscape, where blockchain adoption may be encouraged in some regions but restricted in others. The lack of regulatory clarity discourages investment in blockchain-based trading solutions, as companies remain uncertain about the legal implications and potential compliance risks associated with these technologies.

In addition to regulatory challenges, the implementation of blockchain and AI in energy trading is hindered by technical limitations, particularly in terms of scalability and interoperability. Blockchain networks, while offering enhanced security and transparency, often struggle with scalability due to the high computational requirements of distributed ledger systems (Akinrinola, *et al*., 2024 [17], Osundare & Ige, 2024, Sam-Bulya, *et al*., 2024). Traditional blockchain infrastructures, such as Bitcoin and Ethereum, have faced issues related to transaction speed and network congestion, limiting their ability to process large volumes of energy trades in real time (Austin-Gabriel, *et al*., 2024, Omowole, *et al*., 2024). The energy trading sector requires high-speed transaction processing capabilities to support dynamic market operations, and current blockchain solutions may not yet meet the demands of large-scale trading environments.

Interoperability between blockchain platforms and existing energy infrastructure presents another significant challenge. Energy trading ecosystems rely on multiple legacy systems for transaction processing, contract management, and data analytics. Integrating blockchain technology with these existing infrastructures requires significant modifications to market structures, which can be both costly and time-consuming (Alabi, *et al*., 2024, Osundare & Ige, 2024, Raji, *et al*., 2024). Additionally, different blockchain networks often operate on distinct protocols, making it difficult for trading participants to engage seamlessly across platforms (Arinze, *et al*., 2025, Onukwulu, *et al*., 2025). Achieving interoperability between blockchain systems is crucial for enabling efficient energy trading, but current technological limitations create barriers to seamless integration.

The adoption of AI in energy trading also faces technical challenges, particularly in terms of data accuracy and system reliability. AI-driven predictive analytics and machine learning models rely on vast amounts of historical and real-time data to generate insights for market forecasting and risk assessment. However, inconsistencies in data quality, incomplete datasets, and biases in training algorithms can lead to inaccurate predictions, undermining the effectiveness of AI-driven trading strategies (Alabi, *et al*., 2024, Omowole, *et al*., 2024, Umana, et l., 2024). Energy companies must invest in high-quality data management systems and robust AI training models to ensure the reliability of AI-powered trading solutions. Moreover, AI implementation requires skilled personnel with expertise in data science, machine learning, and blockchain technology, creating an additional barrier for organizations that lack the necessary talent and resources (Onukwulu, Agho & Eyo-Udo, 2025).

Cybersecurity risks and data privacy concerns further complicate the adoption of blockchain and AI in energy trading. While blockchain's decentralized architecture enhances security by reducing the risk of centralized data breaches, it is not immune to vulnerabilities (Oyeniyi, *et al*., 2021) [153]. Decentralized networks are still susceptible to cyberattacks, including 51% attacks, where a single entity gains control over the majority of a blockchain's computing power and manipulates transactions (Akinade, *et al*., 2025 [14], Onukwulu, *et al*., 2025). Additionally, smart contract vulnerabilities, such as coding errors and security loopholes, can be exploited by malicious actors to manipulate trading agreements or siphon funds from blockchain networks.

Data privacy is another critical concern in AI-powered energy trading, as trading platforms must process and analyze vast amounts of sensitive market data. AI-driven trading algorithms require access to proprietary data, market trends, and pricing information to make informed decisions. However, unauthorized access to confidential trading data poses significant risks, as competitors or cybercriminals could exploit this information for financial gain (Alex-Omiogbemi, *et al*., 2024, Onita & Ochulor, 2024). Ensuring data privacy in AI-driven energy trading platforms requires robust encryption protocols, secure data-sharing mechanisms, and compliance with data protection regulations such as the General Data Protection Regulation (GDPR).

To mitigate cybersecurity risks, AI-driven security measures are being developed to enhance the protection of blockchain-based energy trading platforms. AI-powered threat detection systems analyze network activity in real-time, identifying suspicious transactions and potential security breaches. Machine learning algorithms can detect anomalies in trading behavior, flagging irregular patterns that may indicate fraudulent activities (Akinsooto, Ogundipe & Ikemba, 2024, Onita & Ochulor, 2024). Additionally, AI-enhanced cybersecurity frameworks can automate incident response mechanisms, enabling energy companies to respond swiftly to cyber threats and prevent data breaches. However, the effectiveness of these AI-driven security solutions depends on continuous improvements in threat detection models and proactive security measures (Akinsooto, Ogundipe & Ikemba, 2024, Raji, *et al*., 2024).

Despite these challenges, the adoption of blockchain and AI in energy trading is expected to grow as technological advancements address existing barriers. Regulatory bodies are increasingly recognizing the potential of blockchain and AI to improve market transparency, reduce fraud, and enhance trading efficiency (Ajiga, *et al*., 2024, Onita & Ochulor, 2024). Industry collaborations between energy companies, technology providers, and regulatory agencies are fostering the development of standardized legal frameworks to support blockchain-based trading. Furthermore, advancements in blockchain scalability solutions, such as layer-two protocols and hybrid blockchain models, are improving transaction processing speeds and interoperability between platforms (Attah, *et al*., 2024, Osundare & Ige, 2024, Sule, *et al*., 2024).

The energy sector is also investing in AI research and development to enhance predictive analytics, optimize trading strategies, and improve cybersecurity defenses. As AI algorithms become more sophisticated, their ability to process complex market data and mitigate risks will continue to improve. Additionally, partnerships between AI developers and energy market participants are accelerating the adoption of AI-driven trading solutions, enabling companies to leverage cutting-edge technologies to optimize

market operations (Ajirotutu, *et al*., 2024, Oyedokun, Ewim & Oyeyemi, 2024).

While the adoption of blockchain and AI in energy trading faces significant challenges, these obstacles are not insurmountable. Regulatory uncertainties, technical limitations, and cybersecurity concerns present barriers to widespread adoption, but ongoing innovations and industry collaborations are paving the way for a more secure and efficient energy trading ecosystem (Onukwulu, *et al*., 2022, Oyegbade, *et al*., 2022). The successful integration of blockchain and AI will require a concerted effort from industry leaders, policymakers, and technology developers to create a transparent, scalable, and secure framework for the future of energy trading (Attah, *et al*., 2024, Oyenuga, Sam-Bulya & Attah, 2024). As these challenges are progressively addressed, blockchain and AI are poised to play a pivotal role in shaping the next generation of digital energy markets, driving efficiency, transparency, and sustainability in the oil and gas industry by 2025.

2.5 Future Outlook and Strategic Adoption

The integration of blockchain and artificial intelligence (AI) into energy trading is set to transform the oil and gas industry by 2025, creating a more transparent, efficient, and secure trading environment. As technology continues to evolve, energy companies must strategically position themselves to leverage these advancements for competitive advantage. The future of energy trading will be shaped by AI-enhanced blockchain solutions, decentralized trading platforms, and industry-wide collaboration (Onukwulu, Agho & Eyo-Udo, 2023). The success of these innovations will depend on strategic investments, regulatory support, and the ability of early adopters to drive market transformation. By embracing digital solutions, energy firms can position themselves at the forefront of a rapidly evolving industry landscape (Ajiga, *et al*., 2024, Onukwulu, *et al*., 2024, Soremekun, *et al*., 2024).

One of the most promising advancements in energy trading is the development of AI-enhanced blockchain solutions that leverage predictive market analysis. AI and machine learning models are already being used to forecast energy prices, assess market risks, and optimize trading strategies. When combined with blockchain technology, AI-driven insights can be securely recorded and executed through smart contracts, allowing for automated trading decisions based on real-time market conditions (Alade, *et al*., 2024 [34], Oyedokun, Ewim & Oyeyemi, 2024). AI-powered predictive analytics can process vast amounts of market data, including supply and demand fluctuations, geopolitical events, and environmental factors, to provide traders with actionable insights. This integration of AI and blockchain enhances decision-making efficiency and minimizes market risks by enabling data-driven strategies that optimize trading outcomes (Onukwulu, Agho & Eyo-Udo, 2023, Sanyaolu, *et al*., 2023).

Another key innovation shaping the future of energy trading is the expansion of decentralized energy trading platforms. Traditional energy markets are controlled by centralized entities, such as utilities and large financial institutions, which manage transactions and pricing mechanisms. Blockchain-based decentralized platforms disrupt this model by enabling peer-to-peer (P2P) trading, where energy producers and consumers can engage in direct transactions without intermediaries (Azubuike, *et al*., 2024, Oyewole, *et al*., 2024, Urefe, *et al*., 2024). Decentralized trading platforms offer several advantages, including lower transaction costs, increased market accessibility, and enhanced transparency. Smart contracts ensure that trades are executed automatically based on predefined conditions, eliminating the need for third-party verification and reducing settlement delays. As the energy sector moves toward increased decentralization, blockchain-based platforms will become a fundamental component of future trading ecosystems (Arinze, *et al*., 2024, Oriekhoe, *et al*., 2024 [137], Segun-Falade, *et al*., 2024 [185]).

To fully capitalize on these technological advancements, energy companies must invest in blockchain infrastructure that supports secure, scalable, and interoperable trading networks. Implementing blockchain solutions requires significant investment in software development, cybersecurity protocols, and network integration with existing trading platforms (Audu & Umana, 2024, Onyekwelu, *et al*., 2024, Raji, *et al*., 2024). Companies that allocate resources toward developing robust blockchain infrastructures will be better positioned to enhance transaction security, automate contract settlements, and improve data management processes (Alabi, *et al*., 2024, Onita, *et al*., 2024, Paul, *et al*., 2024). Additionally, energy firms must focus on developing AI-driven trading algorithms that enhance market predictions and optimize trading efficiency. By investing in AI-powered analytics, companies can gain a competitive edge in forecasting price movements and making informed trading decisions.

Collaboration between oil and gas companies, regulators, and technology firms is another crucial factor in driving blockchain and AI adoption. Given the complex regulatory landscape of energy trading, it is essential for industry stakeholders to work together to develop standardized frameworks that support the integration of digital technologies. Governments and regulatory bodies must establish clear guidelines on the use of blockchain in trading transactions, ensuring compliance with financial regulations while promoting innovation (Onukwulu, Agho & Eyo-Udo, 2021, Oyegbade, *et al*., 2021). Technology firms specializing in AI and blockchain solutions can play a vital role in designing secure, scalable systems that align with industry requirements. By fostering collaboration, the energy sector can accelerate the adoption of blockchain and AI while mitigating risks associated with regulatory uncertainty and technological limitations.

The role of early adopters in gaining a competitive advantage cannot be overstated. Companies that integrate blockchain and AI into their trading operations ahead of the curve will position themselves as industry leaders in the digital transformation of energy markets. Several energy firms and trading platforms have already begun implementing blockchain-based solutions to streamline operations and enhance market transparency. For example, major oil companies and energy consortiums have piloted blockchain projects aimed at automating trade settlements and reducing transaction costs (Akinsooto, Pretorius & van Rhyn, 2012, Tula, *et al*., 2004 [198]). These early adopters are setting a precedent for the industry, demonstrating how digital technologies can enhance efficiency and security in energy trading.

Case studies on industry leaders provide valuable insights into the long-term benefits of integrating AI and blockchain. For instance, some multinational oil and gas companies have

successfully implemented blockchain-based platforms for crude oil trading, significantly reducing settlement times and improving trade verification processes. These early adopters have reported increased operational efficiency, cost savings, and enhanced market transparency as a result of their blockchain investments (Akinyemi & Onukwulu, 2025, Onukwulu, *et al*., 2025). Similarly, energy trading firms leveraging AI-driven analytics have gained a competitive edge by optimizing pricing strategies and minimizing market risks. By learning from these pioneers, other energy companies can develop their own digital strategies to stay ahead in an increasingly data-driven trading environment.

The long-term benefits of digital transformation in energy trading extend beyond immediate cost savings and operational efficiencies. Companies that embrace blockchain and AI will be better equipped to navigate the evolving energy landscape, where decentralized markets, smart grids, and real-time data analytics will play a critical role in shaping trading dynamics. Digital transformation enables energy firms to respond more agilely to market fluctuations, regulatory changes, and emerging opportunities in renewable energy integration (Onita, Ebeh & Iriogbe, 2023, Sanyaolu, *et al*., 2023). As blockchain and AI continue to mature, their applications in energy trading will expand, offering new avenues for growth and sustainability.

Looking ahead, the energy sector must proactively address the challenges associated with blockchain and AI adoption while seizing opportunities for innovation. Regulatory bodies must work toward developing standardized frameworks that facilitate digital transactions without compromising market integrity. Industry stakeholders must invest in cybersecurity measures to protect blockchain networks from cyber threats and ensure data privacy in AI-driven trading platforms (Alex-Omiogbemi, *et al*., 2024, Oyewole, *et al*., 2024). Additionally, energy firms must prioritize workforce training and talent development to build expertise in blockchain and AI technologies. By fostering a culture of digital innovation, companies can create a resilient, technology-driven trading ecosystem that supports long-term industry growth.

The future of energy trading will be defined by the seamless integration of AI and blockchain, driving greater efficiency, security, and transparency in global markets. As the industry moves toward digital transformation, companies that strategically adopt these technologies will gain a competitive edge, positioning themselves as leaders in the evolving energy landscape (Attah, *et al*., 2024, Onukwulu, *et al*., 2024, Paul, *et al*., 2024). By investing in blockchain infrastructure, fostering collaboration, and learning from early adopters, energy firms can unlock new opportunities for innovation and operational excellence. As we approach 2025, the convergence of blockchain and AI will reshape energy trading, paving the way for a smarter, more efficient, and more transparent market ecosystem (Attah, *et al*., 2024, Oyedokun, Ewim & Oyeyemi, 2024).

2.6 Conclusion

The integration of blockchain and artificial intelligence (AI) into energy trading is driving a fundamental shift in the oil and gas industry, offering new levels of efficiency, transparency, and security. This transformation is dismantling traditional barriers in energy markets by eliminating intermediaries, automating contract settlements, and optimizing trading strategies. The key findings from this study highlight that blockchain's decentralized ledger system enhances transaction security and transparency, while AI-driven predictive analytics enables real-time market decision-making and risk assessment. Smart contracts, operating on blockchain networks, streamline the execution of trade agreements, ensuring compliance and reducing settlement delays. These technologies collectively address inefficiencies in conventional energy trading, reducing costs and increasing market accessibility.

Looking ahead, the role of AI and blockchain in energy trading will continue to expand, with further advancements in AI-powered blockchain solutions, decentralized trading platforms, and automated market intelligence. AI will enhance blockchain's capabilities by providing advanced predictive models that analyze energy consumption patterns, geopolitical events, and market fluctuations, allowing for more precise trading strategies. Blockchain will continue to evolve with scalability improvements, ensuring faster transaction processing and seamless integration with existing energy infrastructures. Decentralized peer-to-peer (P2P) energy trading will become more prevalent, allowing producers and consumers to engage in direct transactions, reducing reliance on centralized exchanges and increasing market liquidity. As regulatory frameworks evolve, governments and industry stakeholders will need to establish standardized policies that support the adoption of blockchain-based trading while ensuring market stability and compliance.

The digital evolution of the oil and gas industry is inevitable, with AI and blockchain at the forefront of this transformation. Companies that strategically invest in these technologies will gain a competitive advantage, positioning themselves as leaders in an increasingly data-driven market. Collaboration between energy firms, technology providers, and regulatory bodies will be essential to overcoming adoption challenges and fostering innovation. As the industry embraces digital solutions, energy trading will become more transparent, efficient, and resilient, driving long-term sustainability and economic growth. By 2025, AI and blockchain will no longer be emerging technologies but fundamental pillars of a redefined energy trading ecosystem, shaping the future of the oil and gas sector in ways that were once unimaginable.

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