Block Chain and Smart Contacts for Transparency in Oil and Gas Transactions

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.908000431

Received: 07 August 2025; Accepted: 15 August 2025; Published: 15 September 2025

ABSTRACT

Purpose: This paper assessed the potential of blockchain and smart contracts to enhance transparency, decrease costs, and improve legislative compliance within the oil and gas sector. The study aimed at elucidating the notion of ledger decentralization to improve record permanence and prevent data modification.

Methodology: The research employed secondary or desk-based research to examine the role of blockchain and smart contracts in addressing compliance, fraud prevention, and cost reduction within the oil and gas sector. The literature analysis indicates that desktop research involves using the resources of others, including their financial contributions, time, and effort, without incorporating insights from primary research conducted via surveys within the target community, and thus, it is cost effective, speed, and capacity for extensive data collection.

Findings: The study demonstrated that blockchain enables the following through its characteristics: data immutability, time-stamping, and the irreversibility of transactions. Payments and compensation for a certain smart contract are executed automatically, requiring minimal time and devoid of external intervention. Nonetheless, there are some limits to the comprehensive implementation: elevated costs, legal system challenges, and infrastructure deficiencies. The study also revealed that issues arise from comprehensive compliance solutions that are unsuitable for blockchain; therefore, existing compliance models should be integrated with blockchain.

Unique Contribution to Theory, Practice, and Policy: Consequently, it is recommended that governments legitimize blockchain transactions and smart contracts to enhance their implementation. Governments must deploy and cultivate both technical and human capital in the blockchain sector to address these deficiencies. Therefore, to conduct operations and mitigate fraud, the oil industry could implement decentralized ledger operational models in conjunction with current compliance solutions, as hybrid models. To address these vulnerabilities while enhancing the strengths of sustainability, efficiency, and transparency in its promotion, enterprises could implement energy-efficient blockchain technology.

Keywords: Blockchain Technology, Smart Contracts, Regulatory Compliance, Oil and Gas Transactions, Supply Chain Management, Decentralized Ledger, Digital Transformation

INTRODUCTION

Study Background

The Oil and Gas Industry is now facing several challenges. Potential solutions to address these issues include: Blockchain and smart contracts possess the ability to address certain issues prevalent in the oil and gas sector (Abutu, 2023; Oleru, 2024).

The oil and gas industry is one of the most complex and capital-intensive sectors globally; thus, issues related to transparency, fraud, inefficiency, and legal compliance (Abutu, 2023) are highly pertinent. This sector involves third-party transactions, which prolong the process due to associated costs and potential discrepancies between the two contracting parties. The decentralization of assets discussed above, the security provided by

blockchain technology, and the enhanced efficiency afforded by smart contracts mitigate these disadvantages. The Blockchain, as a distributed database, ensures that recorded data cannot be updated or manipulated without prior public approval, hence eliminating forgery in transaction management (Gunawan, 2024).

The protracted supply chain in the oil and gas sector necessitates third-party endorsement for financial transactions, contracts, and other supply chain management operations, rendering the process onerous and time-consuming (Vishwakarma & Dwivedi, 2024). Smart contracts utilize the principles of blockchain technology to execute agreements and conduct transactions solely when conditions are met, enabling parties to engage without the need for intermediaries (Kaura et al., 2024). It possesses a little risk of fraud, is highly efficient in implementation, and facilitates essential cross-border operations crucial for the worldwide oil industry.

Furthermore, it improves overall adherence to these standards, as transactions must be recorded in a manner that is immutable, which is appropriate for environmental and governmental oversight in the oil and gas sector (Abutu, 2023). In this context, this technology enables the government, investors, and industry regulators to assess the current and anticipated capacities of crude oil production, carbon emissions footprints, and royalty payments and tax remittances (Oleru, 2024). In conclusion, the implementation of novel technologies such as blockchain and smart contracts holds significant potential to disrupt the oil and gas industry by improving security, visibility, and reducing transaction costs. Nonetheless, its broader implementation depends on addressing other challenges, including impediments to technological adoption, cybersecurity threats, and legislative restrictions specific to the sector.

Problem Statement

This document demonstrates involvement in corrupt practices such as opacity, ineffectiveness, fraudulence, elevated costs, non-compliance, and transactional disputes (Lobo & Rao, 2024). The conventional trade execution method in the industry involves written trade contracts, three intermediates, and manual processing; this renders the sector susceptible to contract fraud and delayed payments, as observed by Gabriel and Thompson (2024). Blockchain technology and smart contracts are anticipated to influence the existing sector by providing secure and transparent methods for completing automated transactions. It is noteworthy that health care organizations encounter numerous challenges with these technologies, including technological obstacles, political or governmental concerns, and organizational culture challenges or resistance to change (Shereen et al., 2024).

Nonetheless, Blockchain faces several hurdles, the primary issue being the absence of laws, which exacerbates problems related to contract law, data protection, and cross-border transactions (Abdelhamed et al., 2024). Oil and gas organizations frequently encounter several challenges regarding the implementation of blockchain technology, including cybersecurity risks, compatibility with legacy systems, and potential costs associated with transitioning to a new platform (Suakanto et al., 2024). Smart contracts encompass code and legal tendering, which create opportunities for coding challenges, legal tendering issues, and discrepancies that might disrupt the efficient execution of smart contracts in business, perhaps resulting in ongoing financial losses (Le et al., 2024).

Secondly, the challenges of scalability and interconnectivity remain fundamentally tied to the technological complexities associated with ISO 20022. The vast majority of current blockchain technology solutions face challenges with the quantities and frequency in the global oil trade, which may render their use impractical (Nkiwane, 2024). Limited connection with other businesses hinders the advancement of blockchain, rendering its implementation infrequent. This indicates a necessity for enhanced legislation, improved technology, and collaboration from oil and gas businesses to advocate for decentralized digital solutions, aiming to achieve comprehensive transparency, security, and efficiency in transactions.

Study Objectives

1. To ensure real-time, immutable, and auditable transaction records that eliminate fraud, corruption, and data manipulation in oil trading.

2. To implement smart contracts that automate financial transactions, enforce compliance, and eliminate intermediaries in oil trade settlements.
3. To minimize operational costs, eliminate paperwork, and streamline the oil and gas supply chain by digitizing asset tracking and transactions.

LITERATURE REVIEW

Theoretical Review

Theory of Transaction Cost Economics (TCE)

Transaction Cost Economics, abbreviated as TCE, was initially contemplated by Williamson in 1975 and then elaborated upon in 1985. This indicates that these theories assert that corporations want to minimize transaction costs, which encompass expenses linked to contract development, enforcement, monitoring, and other inefficiencies associated with contracts. This suggests that by analyzing costs, organizations can decide between market transactions and conducting the operation internally. Previous research has utilized Transaction Cost Economics (TCE) to analyze supply chain management, e-commerce, and automated digital contracts, where the degree of outsourcing is reduced. An illustration is the application of this method in examining digital procurement as a strategy for minimizing contracting expenses within industrial enterprises. The advantages of the idea include the seamless negotiation of contracts, reduced likelihood of employing intermediaries, and the comparatively low cost of implementation. Nevertheless, several weaknesses include the following: it neglects to address technological disruption and does not presume that enterprises act rationally. This study advocates for the integration of TCE with blockchain as it facilitates the eradication of paperwork, automates financial transactions in the oil and gas sector, and diminishes costs related to fraud and operational inefficiencies.

Institutional Theory

Institutional Theory, established by Richard Scott in 1995, emphasizes how firms acquire new technology and processes through external pressures such as regulations, industry standards, and societal expectations, rather than solely for economic motives. This idea posits that businesses should seek clearance from regulatory agencies and attain social acceptability to maintain relevance and legitimacy. Moreover, corporate governance, digital transformation, and the adoption of sustainability have been shown to extensively utilize Institutional Theory in academic study. Studies on CSR institutions indicate that green policies within corporations are regulated by public and governmental influence rather than solely by the firms' self-interest. Institutional Theory effectively elucidates the rationale for the use of particular technologies for regulatory compliance, making it particularly relevant to firms that are subject to regulation. However, it did not address the financial viability of this method and presupposed that all firms would adhere to the standards. Consequently, in the realm of information technology, the implementation of blockchain in the oil and gas sector is motivated by the necessity for enhanced regulation and the fulfillment of legal obligations to combat fraud and ensure adherence to policies and laws, as companies primarily employ this technology for legal compliance and admissibility.

Empirical Review

Enhancement of transparency using blockchain technology and smart contracts in oil and gas transactions.

Abutu (2023) published a paper on Netflix QC and advocated analyzing the deregulation of Nigeria's downstream oil and gas business by the application of blockchain technology. This project aimed to eliminate all instances of corruption, fraud, and the general inconveniences associated with oil trading transactions by implementing blockchain technology for commodities. Examined the facets of Nigeria's oil marketing and distribution industry, focusing on the role of regulatory bodies and the unethical activities prevalent in the sector. The paper was derived from transaction cost theory, specifically focusing on cost avoidance strategies such as the implementation of smart contracts. A survey research design was employed to assess the viability

of using blockchain inside the operational framework of oil organizations. The audience would comprise participants from oil marketing corporations, regulators, and other appropriately recognized and selected supply chain managers utilizing the purposive sampling method. The data collection encompassed both primary data, comprising structured interviews, and secondary data, represented by transactional data. The analysis conducted was classified as qualitative thematic data analysis. The study revealed that blockchain technology mitigated the risk of trading fraud, facilitated real-time trade confirmations, and enhanced the efficiency of oil sales; however, regulatory challenges emerged concerning the implementation of blockchain in the oil sector. The authors stated that the implementation of blockchain should encompass the following characteristics: ease of policy adoption, the initiation of necessary infrastructures, and the construction of coordination mechanisms with other departments.

In his work, Oleru (2024) examined the potential to enhance the organization of the midstream oil and gas sector through the implementation of blockchain and smart contracts in relation to transparency and transactions. The primary objectives of the research were to eliminate several intermediaries and their associated costs, mitigate fraud, and ensure accurate tracking of the crude oil market. This report examines African oil refinery and logistics companies. The study was conducted based on supply chain management theory, focusing on the concepts of supply and trade through digital changes. The research focused on certain features of blockchain utilization, making it appropriate for a case study design. The participants were chosen from key sub-disciplines, including logistics managers, supply chain analysts, and regulatory officers. A stratified sampling technique was employed during the study. The instruments employed for gathering primary study data comprised questionnaires and blockchain transactional data, with descriptive statistics and regression analysis utilized for the analysis. Additional findings indicated that blockchain technology could diminish instances of unauthorized oil evasion, enhance compliance, and expedite transaction validation times. The components include the application of blockchain in the sector, governmental backing for the promotion of blockchain, and the education of oil experts.

In this study, Kaura et al. (2024) examined innovative technologies in the blockchain within the oil and gas industries, emphasizing the application of this technology to improve sector transparency. The objective was to minimize transactional conflicts, enhance and maintain clear audit trails, and ensure compliance through auditable and sealed processes. Targeted standards makers included global oil trading companies, regulatory bodies, and cross-border petroleum enterprises. It was established in relation to the framework of institutional theory, which delineates the process of managing emerging technologies to address institutional challenges. A survey research method was utilized to broaden the understanding of blockchain implementation in various organizations within the oil industry. The participants used for this study included oil takers, legal consultants, and compliance officers, picked randomly to ensure fairness in the research. The study was conducted using structured questionnaires and interviews with specialists, and the analysis was executed by structural equation modeling (SEM). Research conducted on the adoption of blockchain in a case study revealed that it enhanced transaction integrity, expedited settlement times, and addressed compliance issues, albeit with significant implementation costs. The study demonstrated that further areas might be explored to enhance cooperation and coordination between oil companies and regulators about techniques and financial incentives related to the implementation of blockchain technologies.

Reduction of Operational Costs with Blockchain and Smart Contracts in Oil and Gas Transactions Hassan and Ibrahim (2023) elucidated the application of smart contracts in minimizing costs associated with financial transactions and improving the efficiency of oil trade settlements. This inquiry aims to explore methods for reducing bureaucracy and mitigating potential conflicts through the implementation of smart contracts. The research context pertained to the finance and settlement of oil commerce among multinational petroleum corporations. The study uses agency theory to illustrate how smart contracts mitigate the issues of information asymmetry and the expenses associated with intermediaries. The selected research design for the proposed study was the case study, particularly due to its aim to investigate the implementation of smart contracts in oil trading. The target respondents were finance officers, trade specialists, and compliance managers across various organizations; the study employed a stratified random sampling technique to ensure a broad representation, not restricted to firms with blockchain projects. Documents were obtained by requesting copies of those utilized in smart contract transactions and conducting interviews with clients. The research revealed

that smart contracts significantly reduced the necessary financial verifications and decreased the time required to resolve financial disputes by 25%. The researchers proposed the development and enactment of smart contract regulations and legislation, the implementation of smart contracts in the banking and financial sectors, and the enhancement of awareness among oil trading organizations regarding smart contracts.

Shereen and Abdelhamed found that Ethereum-based blockchain models enhance transaction costs in the oil and gas sector in their study conducted in 2024. The study aimed to: establish the efficacy of resource allocation procedures; reduce the occurrence of power in numerous processes through smart contracts; and ensure data security via smart contracts. It concentrated on the oil exploration and production sector, namely any company that integrates innovative technologies, such as blockchain, into its supply chain operations. The study employed a systems theory paradigm, as it focuses on enhancing integrated organizational interactions using digitized solutions. Exploratory research was employed due to its emphasis on an alphabetic case study approach, which illustrates how organizations in the oil business utilize blockchain technology. The target demographic comprised IT managers from oil businesses, supply chain professionals, and financial officials, with specific blockchain-enabled organizations selected through purposive selection. The data was gathered from real transactions via document inspection and responses, interviews with affiliates, and an analysis of the operational impact suffered. The implementation of blockchain in procurement revealed that the automated generation of contracts, including the Request for Proposal, resulted in an average cost reduction of 25 percent, while also enabling further savings in operations such as automated procurement cost reconciliation. This study indicates that the oil industry should implement blockchain to improve transaction security and that governments should promote blockchain infrastructures.

Zhang et al. (2022) indicate that it is feasible to employ cost reduction methods and enhance logistics in oil production and distribution through the digital supply chain utilizing blockchain technology. The study's reference hypothesis was to investigate the impact of blockchain on supply chain transparency, time efficiency, and the reduction of inventory holding costs. Targets denote the clientele of crude oil and the global service providers or partners, namely the stakeholders along the supply chains that may necessitate the implementation of blockchain technology for inventory management and transit monitoring. The study was based on the resource-based theory (RBT), which asserts that enterprises should capitalize on viable technical advancements to improve competitiveness. The study aimed to collect quantitative data, which was obtained from literature sources and oil businesses, thereby employing a survey research approach. The target demographic comprised supply chain managers, IT specialists, and oil field operators, for which random sampling was conducted. Survey questionnaires and data from the supply chain management blockchain were utilized to collect information, thereafter analyzed through basic statistical methods and structural equation modeling. The blockchain-assisted study identified several benefits: a reduction in logistics mistakes within the supply chain, elimination of data duplication, and a cost savings of 18-22% in the supply chain. The study advised blockchain developers to engage with oil companies to create tailored solutions for the industry, invest in the advancement of the digital supply chain, and conduct further research to explore the effects of blockchain on Just-In-Time (JIT) systems.

Regulatory compliance, security, fraud prevention, and the application of blockchain and smart contracts in oil and gas transactions.

Mohammadi (2023) examined smart contracts, focusing on their impact on compliance and fraud within the oil and gas sector. The study was designed to examine how smart contracts reduce regulatory violations, mitigate fraud risks, and facilitate legal compliance, in response to the aforementioned problem and aligned with the established research question. A study subject has been selected in alignment with the research purpose and objectives, specifically the 'Petrochemical and Refinery Sector.' The investigation is grounded in legal contract theory, which examines the potential for legalizing contracts in a virtual environment. This necessitated the utilization of a qualitative study approach, as it facilitates the elucidation of the legal ramifications associated with contract generation via blockchain technology. Consequently, purposive sampling was employed to guarantee the inclusion of relevant subject matter experts from the domains of legal professionals, compliance officers, and blockchain developers within the target population. The document examination, interviews, and case law analysis were performed, and the research data was analyzed through content analysis and legal compliance assessment. Smart contracts are advantageous as they diminish instances of fraud in reporting,

compliance, and tax remittances, while also reducing occurrences of contract breaches by becoming them legally enforceable and facilitating greater compliance. They proposed proposals such as the establishment of a legal standard for smart contracts, the enhancement of relationships between oil companies and regulators, and the integration of a checks and balances mechanism utilizing artificial intelligence.

According to Ahmad et al. (2022), the following elucidates how blockchain promotes security and mitigates fraud in the oil and gas business. The purpose was to acquire knowledge on how blockchain mitigates cybersecurity threats, eliminates fraud, and maintains data integrity in the petroleum industry. This was a critical security necessity for the upstream and midstream sectors of oil and gas industries, as operational security relies on safe data storage. The research was conducted utilizing cybersecurity risk management theory, which pertains to the safeguarding of computer-based systems against fraud and hacking. This study employed a case research design to assess the security application of blockchain within certain oil firms, aiming to ascertain its practical implementation in security measures. The participants included Information Technology security professionals, blockchain experts, and risk managers, since random selection was employed irrespective of their academic qualifications in the IT and technology sector. The data was gathered from the security audit, interviews with key informants, analysis of threats and risks, a risk assessment model, and general cybersecurity rules and metrics. It also decreased cyber fraud attempts by 40 percent, improved the records of immutability, and strengthened the efficacy of encryption-based secured transactions. The essay proposed implementing additional levels of blockchain security to establish unique identities for individuals, enabling them to authorize transactions exclusively. Furthermore, it recommended enhancing security measures at the supply chain level.

Alqahtani et al. (2022) investigated the potential use of consortium blockchain models to improve compliance with oil and gas transaction laws. The research sought to determine how networks created by the deployment of blockchain among oil companies, regulators, and financial institutions may enhance compliance oversight and overall operational risk. The scope concentrated on the exploration of oil and significant projects, along with their funding, which must align with national policy imperatives and international standards. The research was grounded in institutional theory, which investigates the influence of regulatory institutions on the selection of technologies for adoption. The justification for employing the survey research approach was that it facilitated a clear understanding of compliance adoption across diverse businesses and enabled the collection of varied impressions from multiple viewpoints. Analysis of expatability about self-completion questionnaires. The target demographic includes heads of regulatory agencies, auditors, corporate governance experts, and scholars, with participants selected through stratified random selection to ensure equitable representation from each strata. The surveys utilized tightly organized questionnaires, supplemented with compliance reports, while blockchain transactions were examined through the Statistical Compliance Scoring System and Correlation Analysis. It was also seen to improve fps by 35% in the generation of regulatory reports, eradicate the issues of tax evasion, and autonomously verify compliance in the financial management of oil. The authors forecasted several measures to enhance blockchain regulation, including the establishment of compliance standards, regulation of blockchain utilization across all industries, integration of compliance systems across various sectors, and the development of training protocols for compliance officers overseeing blockchain.

The literature study indicates that contemporary research on blockchain and smart contracts in the oil and gas sector predominantly emphasizes attributes such as efficiency, trust, and anti-fraud mechanisms pertinent to streamlined compliance regulations. However, there are numerous constraints for the extensive implementation of blockchain technology in the oil and gas sector. This study demonstrates that the energy consumption associated with blockchain, particularly with Proof of Work (PoW), constitutes an environmental issue. Conversely, self-enforcement of contracts in smart contracts is flawed, as coding errors, hacking, and legal interpretational conflicts might result in contract failure or conflict. These are frequently not elaborated upon, so omitting a crucial element of the real-life experience of blockchain, despite public awareness of its numerous advantages.

Another concern is the lack of primary emphasis on legal and regulatory viewpoints in cross-country comparisons; instead, the chapters repeatedly addressed regulation and fraud. Blockchain is highly beneficial for compliance; yet, most traditional and statutory regulations does not recognize smart contracts as legally binding in oil and gas transactions. The combination of insufficient IT technical expertise among oil and gas

companies, the substantial costs associated with adopting electronic data systems, and organizational resistance to change is often overlooked in studies that presume the industry has fully adopted comprehensive e-business solutions. Numerous firms, particularly in the developing world, experience significant infrastructural deficiencies and limited financial resources to implement blockchain technologies; yet, the literature offers no alternative for those companies unable to effect this transition.

Moreover, there is a greater emphasis on theoretical breakthroughs, and based on the cases presented, most research lacks information regarding the extensive application of blockchain technology in oil and gas transactions. These business plans do not encompass long-term scenarios such as blockchain compatibility, threats posed by quantum computing, or substantial transaction volumes. Similarly, blockchain enhances decentralization; thus, any advocacy for centralization inside oil and gas businesses may result in conflicts in management and decision-making. It is essential to emphasize practical applications, cost-effectiveness, and a balanced approach to decentralization in relation to the requirements of various sectors within countries.

Knowledge Deficiency

Lack of geographical and industry generalization: Another limitation of previous research on blockchain and smart contracts is that the majority utilize hypothetical data and are confined to a particular geographical area or industry, specifically the Oil and Gas sector. The majority of the study has been conducted in industrialized nations, like the United States, European countries, and certain regions of Asia, due to their advanced digital technologies, robust regulation, and greater organizational adaption to Blockchain solutions. Nevertheless, there is a paucity of research concentrated on emerging regions where challenges such as poor management, flawed regulations, and inadequate technological infrastructure affect the oil and gas sectors. Moreover, prior studies addressing the deployment of blockchain technology neglect to segment the markets, so overlooking issues pertinent to oil and gas companies, such as cross-border activities, volatility, and geopolitical risks. It is essential to examine it within specific legislative and operational contexts pertinent to diverse geographical regions and entities.

Previous studies have been deficient due to limited sample sizes and analyses categorized as qualitative or philosophical interpretations of substantial empirical evidence from large-scale applications. Although the research on examples and theoretical frameworks on blockchain is illuminating, it fails to provide figures that demonstrate the efficacy of blockchain in terms of cost savings, fraud prevention, and legal compliance. Furthermore, there is a paucity of research employing both quantitative and qualitative analyses, as mixed-method research utilizing statistical analysis and industry concepts remains underutilized. Nonetheless, the research studies utilized in this investigation exhibit certain limitations: Furthermore, contemporary researchers inadequately focus on the recent concepts of blockchain and production innovation regarding scalability, interoperability, and hybrid blockchain architecture.

The literature evaluation of previous research studies reveals that many are grounded in Transaction Cost Economics (TCE) Theory and Institutional Theory, although they neglect several technological, legal, and operational difficulties that may be overlooked. Although significant, this paper's emphasis on strategic objectives and adherence to legal requirements in both external and internal contexts neglects the dangers, opportunities posed by cyber-attacks, vulnerabilities of smart contracts, and blockchain governance issues. Nonetheless, there exists a barrier in applying theories to the practical integration of technological innovation and legislation in the discourse surrounding blockchain, notwithstanding the potential for intensification. Consequently, it is essential to advance the development of mixed methodologies that encompass risk management, cybersecurity, and digital transformation theories to enhance comprehension of the potential challenges associated with blockchain in oil and gas transactions.

METHODOLOGY (DESKTOP RESEARCH)

Research Methodology

This research employs secondary or desk-based research to examine the role of blockchain and smart contracts in addressing compliance, fraud prevention, and cost reduction within the oil and gas sector. The literature

analysis indicates that desktop research involves using the resources of others, including their financial contributions, time, and effort, without incorporating insights from primary research conducted via surveys within the target community (Sekar & Baiju, 2022).

The justification for conducting desktop research includes its cost-effectiveness, speed, and capacity for extensive data collection. The fundamental advantage of desktop research over primary research, such as field surveys and interviews, is its extensive access to peer-reviewed sources and industry analyses (Amiri Ara et al., 2022). This approach allows the user to acquire more extensive and cross-national data on the application of blockchain in the oil and gas sector, given the sensitivity of such information (Hunter et al., 2023). It is essential to accurately describe the study's issue, incorporate sufficient data in the methodology, and provide an analytical explanation of the consequences of blockchain.

Methods of Data Collection

The study employs both secondary and primary data collection methods; however, secondary data is obtained from databases, reports, and government sources. The selected data sources include scientific publications, trade journals, government reports, and handbooks.

Initially, databases containing peer-reviewed journals, such as Google Scholar, along with research papers from platforms like JSTOR and ScienceDirect, provide numerous articles and conference proceedings/dissertations addressing the application of blockchain in the oil sector. Certain sources provide theoretical insights and research studies regarding the effectiveness of this technology in enhancing clarity, improving functionality, and ensuring legal compliance.

Secondly, the secondary sources comprise the websites of the International Energy Agency, the Organization of the Petroleum Exporting Countries, the U.S. Energy Information Administration, and the World Bank in the authorship of this report (Uba, 2023). These offer detailed insights into the methods for adopting blockchain technology, regulatory frameworks, and cost-reduction tactics within global energy markets. Thirdly, the metrics of actual compliance are derived from the regulations and stipulations established by EU sources and governmental papers pertaining to the US oil business (Zuo and Qi, 2021). These sources guarantee that the study encompasses elements such as legislation, security, and fraud-prevention measures that ascertain the feasibility of employing blockchain technology in the sector.

Criteria for Literature Selection

The literature evaluated, including articles and papers, was selected based on inclusion and exclusion criteria to assess its relevance to the implementation of blockchain in oil and gas transactions.

Initially, it is essential to determine whether the article pertains to blockchain and smart contracts within the oil and gas industry. The study examines research that investigates the significance of blockchain in improving transparency, mitigating fraud, and ensuring compliance in petroleum trade and financial transactions within the global oil and gas industry, as referenced in a specific paper (Wang et al., 2021). This study excluded several studies that examine scenarios in which entirely unrelated blockchain applications are utilized in healthcare, banking, and other sectors. Secondly, the publication period of 2022-2025 indicates that only the most recent advancements and findings in the relevant field, as well as contemporary applications of blockchain, are taken into account (Miao et al., 2020). Research publications published prior to 2022 will be omitted from this study unless they provide a greater grasp of blockchain adoption models.

The third category involved a compulsion to seek credibility and knowledge from peer-reviewed sources, including papers published in academic journals. This study particularly limits the review and analysis to journal papers, including a prominent government document. In this context, peer-reviewed studies, scientific publications, and reports from other esteemed institutions (Aldarwish et al., 2024). In the process, informal works, including features and blogs, as well as pieces reflecting the author's personal opinions and any speculative articles, are eliminated from the validation of results for academic reasons. The degree of regional and industrial specialization is analyzed. The analysis utilizes data from both developed and developing

countries in oil production to mitigate bias in the model (Lu et al., 2019). Consequently, literatures that do not pertain to the specificities of the petroleum business are inconsequential. The literature addressing blockchain in a broad context.

Finally, investigations must provide actual facts, case descriptions, or comparisons rather than relying on conceptual analysis devoid of data. The selections facilitate the study's relevance by employing pertinent, contemporary, and scholarly material concerning the applicability of blockchain in the oil and gas industry.

Methodology for Data Analysis

This study employs two techniques for analyzing secondary data: thematic analysis and comparison analysis, to yield relevant interpretations.

Content analysis is employed to examine the themes and patterns of blockchain about regulation, misconduct, and operating costs (Bazaee et al., 2022). The study examines the literature to see how blockchain mitigates the identified difficulties, categorizing the review into four main areas: transparency, manual processes, and compliance. Secondly, the comparison technique, as elucidated by Amiri Ara et al., 2022, is employed for anticipating differential regional adoption. A theoretical cross-country analysis of the employed approaches is conducted to elucidate the differing frameworks of blockchain in industrialized and developing oil economies. This approach facilitates the identification of strengths and limits across various courses and the extent of blockchain utilization under diverse legal frameworks in different nations.

Consequently, the suggested CDA methodology enables a comprehensive and systematic analysis of blockchain within the oil and gas sector.

Constraints of the Research

Nevertheless, the subsequent restrictions are likely to be encountered with the employment of secondary data in the execution of the study, specifically in reference to desktop research methodologies.

This research relies on secondary data; hence, it does not directly obtain information from blockchain developers, oil companies, and regulators, as suggested by Hunter et al. (2023). This strategy of restricting verification to firsthand perspectives of the sector has a drawback. The generalization of the results is constrained by the limitations of CGI due to limiting regionalism. Mathematically, it is observed that the majority of research pertaining to blockchain focus on North America, Europe, and Asia, whereas countries in the emerging phase of oil production, such as Nigeria, Venezuela, and Middle Eastern states, are underrepresented (Aslam et al., 2022). Consequently, this geographic spread has hindered studies on the adverse consequences of blockchain technologies in emerging markets. The issue may have sprung from discrepancies in data quality, necessitating careful study. Nonetheless, certain research employ varying blockchain models, methodologies, or cases, which diminishes the clarity of relative comparisons (Wang et al., 2021). Moreover, several features identified in the analyzed research concerning outcomes and methodological quality may influence the obtained results.

Fourthly, there exists a comparative risk of antagonism about the regulatory environment. Consequently, certain laws remain in development as the government refines the policy (Miao et al., 2020). Future study should incorporate questionnaires for primary data collection and the dissemination of upstream surveys to assess the evolution of blockchain adoption over time.

RESULTS & DISCUSSION

Augmentation of Transparency with Blockchain and Smart Contracts in Oil and Gas Transactions

Opacity in oil and gas transactions has arisen from numerous intermediaries, bureaucratic processes, and the extensive documentation involved (Abutu, 2023). Records of oil trading, ownership transfer, and payment information are maintained in extensive databases that may be subject to updates, susceptible to fraud, and

prone to resource wastage (Alves et al., 2024). Blockchain enables a viable digital tracking system that records transactions, ensuring they are relevant, safe, immutable, and accessible solely to end-users, as described by Amiri Ara et al. (2022). Smart contracts enhance transparency as contractual agreements are executed only when the specified conditions are fulfilled (Oleru, 2024).

Among the advancements introduced by blockchain, real-time tracking stands out as a noteworthy innovation for enhancing transparency. Utilizing blockchain technology in IoT devices enables enterprises to track the transportation of crude oil from extraction sites to processing facilities while regulating fluctuations in quantity and ownership (Bazaee et al., 2020). An experimental study into Nigeria's downstream oil sector indicated that blockchain technology diminished occurrences of contaminated fuel and inaccurate records (Abutu, 2023, p.87). Similarly, there has been improved oversight of global oil trading platforms and a decrease in fraud incidents due to the implementation of smart contracts (Hunter et al., 2023).

This indicates that blockchain enhances the inclusivity of financial operations by eliminating the need for time-consuming third-party validation (Ahmad et al., 2022). This excludes situations where one party modifies certain agreed-upon provisions in the contract or withholds or deducts a portion of the payment to profit from the disparity. The distribution of blocks in the blockchain necessitates the permanent storage of transaction information, so rendering it credible to buyers, sellers, and regulatory agencies (Uba, 2023). Furthermore, due to block chain’s independence from trust-based validation, each transaction is promptly authenticated by a separate individual on the public ledger (Amiri Ara et al., 2022).

Besides enabling payments, blockchain also enhances. Digitization of oil production contracts, together with other agreements, taxes, and royalties. The governments of many oil-rich nations are known to misappropriate or occasionally neglect to allocate sufficient revenues to the rightful beneficiaries, while these oil companies are reported to inadequately deliver or evade fair royalties (Alves et al., 2024). In blockchain, the application of royalties is exact, and in conjunction with taxes, the outcomes are reported based on actual oil production (Oleru, 2024). Similar to many organizations, governments conduct real-time evaluations of the extent of implementation of various environmental standards by analyzing records related to carbon emissions and sustainability reports pertaining to climate and trade policies (Hunter et al., 2023).

Unfortunately, the implementation of this concept has been perceived by numerous organizations as influenced by the following factors: It indicates that the majority of oil companies, particularly emerging firms in developing nations, are unable to adopt blockchain due to a deficiency in skills and resources within the companies (Lu et al., 2019). Furthermore, the legal disputes among governments about smart contracts associated with blockchain remain ambiguous in numerous countries, hindering the effective application of smart contracts in the international oil trade (Amiri Ara et al., 2022). The expense, coupled with significant opposition from established market participants, results in delayed adoption due to the intricate interconnections within the oil trade sector (Ahmad et al., 2022).

Nevertheless, the discussion indicates that using blockchain can enhance openness in the oil and gas business, hence reducing the incidence of fraud. Baron: Governments are independently advancing legislation in the petroleum sector, while companies are initiating investments in blockchain technology. Consequently, this presents an opportunity to ensure that these sectors are entirely safeguarded against falsification and corruption, both nationally and globally (Uba, 2023).

Reduction of Operational Costs with Blockchain and Smart Contracts in Oil and Gas Transactions

They have applied pressure for cost efficiency in oil and gas transactions due to intricate operational expenses, supply chain complexities, and bureaucratic procedures (Shereen & Abdelhamed, 2024). The traditional oil and gas sector is predominantly reliant on paper, necessitates third-party verification, and utilizes intermediaries, resulting in significant bureaucratic hurdles that impede corporate operations (Gallegos et al., 2024). This is accomplished through some elements of blockchain and smart contracts, specifically the trade settlement process, which eliminates intermediaries and reduces the potential for errors. The implementation of blockchain technology results in centralized records that mitigate conflicts, enhance verification processes, and expedite contract execution (Ahmad et al., 2022).

Among the four conditions, the most emphasized factor by which blockchain usage can result in reduced costs is the elimination of intermediaries. Traditional oil transactions include interactions with multiple stakeholders, including financial institutions, legal counsel, brokers, and others, leading to elevated overhead expenses (Hassan & Ibrahim, 2023). Blockchain transportation obviates the necessity for a central authority or intermediary due to the capabilities of smart contracts to execute monetary transactions following the fulfillment of specified conditions (Zhang et al., 2022). Thus, it expedites settlement times and diminishes transaction costs, reducing the duration of settlements from days to mere minutes and lowering the overall administrative expenses (Amiri Ara et al., 2022). For example, a research conducted by Ahmad et al. (2022) on the oil supply chain utilizing blockchain illustrated how companies significantly profited by minimizing transaction handling costs and enhancing efficiency in automating payment reconciliation and contract execution.

Entities throughout the supply chain can benefit from blockchain as it diminishes procurement duration and inventory, along with documentation. Manual paperwork is prevalent in many businesses, resulting in delays in document processing, increased risk of human errors, and potential forgery (Amiri Ara et al., 2022). Blockchain technology in the supply chain management of oil companies can facilitate real-time cargo monitoring and inventory management across suppliers, refineries, and distribution channels (Bazaee et al., 2020). This leads to decreased inventory costs, fewer delivery issues, and improved supply chain transparency (Uba, 2023).

Furthermore, blockchain is crucial in monitoring and securing the industry's vital assets, including the ownership records of crude oil reserves, refinery production, and the transportation infrastructure (Shereen & Abdelhamed, 2024). This decreases operational time, minimizes the risk of unlawful access to the barrel, and facilitates the demonstration of ownership for each unit of oil from production to consumer level (Lu et al 2019). Automated payments, akin to taxes and royalties, assist in adhering to monetary regulations on the blockchain, hence reducing penalties and administrative burdens (Hunter et al., 2023).

This indicates that there are sustainability concerns, particularly regarding the costs associated with blockchain implementation. The establishment of blockchain infrastructure necessitates the acquisition of diverse hardware, software, human resources, and integration expenses, rendering the development financially burdensome for small and medium-sized oil companies, despite its advantages, as noted by Uba (2023). Ultimately, processes like block mining and transaction validation are resource-intensive, particularly for energy consumption, and carry the potential of legal and regulatory violations (Kang et al., 2019). Although there are other tiny energy-efficient consensus mechanisms, such as the Proof-of-Stake (PoS), which remains in development and has not yet achieved significant commercial momentum, it also presents a substantial negative in the form of large initial capital investment.

Notwithstanding these hurdles, the long-term financial advantages of blockchain integration surpass the upfront expenditure. Several advantages observed in firms that implemented the technology include reduced operational costs, increased transaction rates, and diminished instances of contractual disputes (Zs, & Mahmoud, 2034). Consequently, enhancing the alignment between these factors and the anticipated outcomes of adopting blockchain technology will encourage more oil companies and regulatory bodies to implement blockchain, resulting in reduced operating costs and improved financial sustainability of oil and gas transactions (Ahmad et al., 2022).

Regulatory Compliance, Security, and Fraud Mitigation via Blockchain and Smart Contracts in Oil and Gas Transactions

Petro-business transactions frequently encounter compliance issues and fraud due to their association with elevated corruption, illegality, and contractual conflicts (Mohammadi, 2023). The globalization of the petroleum industry, ambiguity in international legal frameworks, and the lack of transparency in financial transactions render the sector particularly susceptible to regulatory noncompliance and fraudulent activities (Ahmad et al., 2022). Blockchain enhances company compliance in operations such as record keeping, tax remittances, and other compliance documentation due to the irreversible nature of each write operation on the blockchain ledger (Alqahtani et al., 2022). This is due to the fact that real-time data enables the blockchain to

eliminate fraudulent records and tax evasion while also adhering to environmental regulations (Amiri Ara et al., 2022). Smart contracts facilitate the monitoring of compliance with various conditions outlined in a contract, thereby preventing legally mandated or prohibited settlements and ensuring that financial transactions are executed without encountering legal or regulatory obstacles or fulfilling specific contractual stipulations (Alqahtani et al., 2022).

It also provides enhanced security to mitigate fraud and illegal access to the system. Conventional oil trading platforms, particularly those reliant on local databases, are exceedingly vulnerable to hacking, data manipulation, and internal fraud (Maon et al., 2019). The safeguarding of the oil trading sector from cyber-attacks has emerged as a significant concern due to the proliferation of cyberspace (Lu et al., 2019). This implies that no node exists that can b3e targeted for an attack, nor can a fraudster or any individual with malicious intent coordinate an assault (Uba, 2023). Business organizations who have adopted blockchain-based security measures for compliance monitoring in the oil and gas sector observed a 40% reduction in financial record fraud and a 30% enhancement in record security (Amiri Ara et al., 2022).

Furthermore, it enhances cross-border regulation by adopting standardized trade document formats and streamlining customs processes (Hunter et al., 2023). The existing regulations for cross-border oil transactions remain ambiguous, posing challenges for international trade, settlements, and taxation (Bazaee et al., 2020). The integrity and integrated computation of smart contracts, along with self-executing and self-verifying systems in blockchain, facilitate the rectification of erroneous declarations regarding customs duties, VAT, and royalties, while also mitigating corrupt practices (Ahmad et al., 2022). Additionally, governments can utilize blockchain to conduct transactions and monitor CO_2 emissions, requiring oil companies to report the actual carbon stored in accordance with established environmental standards (Shereen & Abdelhamed, 2024).

Nonetheless, certain issues exist concerning the legal application of blockchain and the combat against fraud. Smart contracts are largely considered invalid in numerous legal systems across various nations, rendering their legal validity in the context of international business a contentious issue (Hunter et al., 2023). Furthermore, regulatory bodies for blockchain compliance necessitate substantial investment in personnel training and digital infrastructure, which many oil-producing nations are unable to afford (Bazaee et al., 2020). Furthermore, the application of blockchain in compliance with data privacy regulations has persistently hindered its adoption (Amiri Ara et al., 2022). However, there has been an increase in discussions within the global regulatory landscape regarding the acceptability of blockchain in legal regulation (Uba, 2023). In accordance with regulatory rules that have facilitated the implementation of blockchain technology and the government's augmented investment in this area, the utilization of blockchain for security, antifraud measures, and compliance is anticipated to improve. This will enhance transparency, security, and legal compliance in the global oil and gas industry, while significantly reducing the risks of fraud in cross-border energy contracts (Shereen & Abdelhamed, 2024).

Contrasting Results with Prevailing Literature

This aligns with previous social scientific research examining the efficacy of blockchain technology in improving efficiency, reducing costs, and assuring compliance with regulatory requirements in the enhanced trade of the oil and gas sector. The author asserts that blockchain resolves an issue by preventing alterations to data, safeguarding transactions, and enhancing supply chains (Abutu 2023, Alves et al., 2024). Oleru (2024) observed that eliminating intermediaries and improving contract performance efficiency both highlighted in this study are crucial to the discussion on cost reduction. The automation of trade settlements, as shown in the current literature, is recognized as an effective application of smart contracts to eliminate manual errors and expedite financial transactions (Amiri Ara et al., 2022).

Nevertheless, the present study exhibits several distinctions from prior studies regarding the following aspects. Hunter et al. (2023) characterized regulatory issues as central to hindering blockchain use; nevertheless, this research highlights high implementation costs and infrastructural limitations as equally significant factors. Implementing blockchain technologies in developing nations is deemed unfeasible and has been mostly neglected in numerous studies (Lu et al., 2019). While Zhang et al. (2023) contended that smart contracts pose no compliance risk, this research demonstrates legal issues that impede optimal adaption. Most jurisdictions

have not recognized government-based contracts, hence encountering legal issues in the international oil trade (Amiri Ara et al., 2022).

This study provides new insights by emphasizing integrated solutions that leverage current oil industry compliance methods associated with Blockchain technology. Contrary to previous studies such as those by Gao & Low (2023), which advocate for the potential of knowledge management from a perspective of possibility, there exist tangible prohibitions and constraints, including costs, supplementary legal requirements, and the adverse attitudes from other industries, as noted by Uba (2023).

The current research substantiates both the direct and indirect impacts of blockchain in improving transparency, reducing costs, and mitigating fraud within the oil and gas sector, while also recognizing the obstacles to its legal recognition, the expenses associated with its implementation, and apprehensions stemming from emerging cybersecurity threats. Consequently, the study suggests the necessity for further investigation and modifications of legal frameworks to enable the extensive adoption of blockchain in oil and gas transactions (Amiri Ara et al., 2022).

CONCLUSIONS AND RECOMMENDATIONS

Synopsis of Principal Discoveries

This paper aims to assess the potential of blockchain and smart contracts to enhance transparency, decrease costs, and improve legislative compliance within the oil and gas sector. The study demonstrates that blockchain enables the following through its characteristics: data immutability, time-stamping, and the irreversibility of transactions (Abutu, 2023). Payments and compensation for a certain smart contract are executed automatically, requiring minimal time and devoid of external intervention. Nonetheless, there are some limits to the comprehensive implementation: elevated costs, legal system challenges, and infrastructure deficiencies (Hunter et al., 2023). The existing research advocates for modifications to the regulatory framework and enhanced collaboration among industry and research entities to optimize the implementation of blockchain technology in the oil and gas sector (Amiri Ara et al., 2022).

Recommendations for Policy and Industry

Consequently, it is recommended that governments legitimize blockchain transactions and smart contracts to enhance their implementation (Zhang et al., 2023). Governments must deploy and cultivate both technical and human capital in the blockchain sector to address these deficiencies (Uba, 2023). Therefore, to conduct operations and mitigate fraud, the oil industry could implement decentralized ledger operational models in conjunction with current compliance solutions, as hybrid models, according to Lu et al. (2019). To address these vulnerabilities while enhancing the strengths of sustainability, efficiency, and transparency in its promotion, enterprises could implement energy-efficient blockchain technology (Amiri Ara et al., 2022). This encompasses the logically articulated and conveyed efforts of the regulators and the oil and technology groups.

Prospective Research Avenues

Future research should examine multiple pilots that assess the impact of blockchain on the economics of the oil and gas sector (Hunter et al., 2023). They should also contemplate the issues of smart contract legislation, the interpretation and enforcement of smart contracts, international trade and legal frameworks, and integration (Bazaee et al., 2020). This research study posits that block chain’s integration into traditional and regulatory frameworks of financial systems will augment its applicability (Ahmad et al., 2022). Moreover, it is anticipated that the implementation of smart contracts in artificial intelligence, particularly in fraud and risk detection, will enhance the integrity and appropriateness of petroleum-related contracts (Shereen & Abdelhamed, 2024). These sectors will enhance the adoption of blockchain technology in the global energy industry.

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