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Blockchain and AI Integration in Halal Supply Chains: Toward a Trusted Digital Ecosystem

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Abstract

The halal supply chain plays a crucial role in ensuring compliance with Shariah principles and maintaining consumer trust in global markets. However, conventional certification systems often face limitations, including fragmented documentation, inefficiencies, and vulnerability to fraud and mislabeling. This study explores the potential integration of blockchain and artificial intelligence (AI) to address these challenges and develop a trusted digital ecosystem for halal supply chains. Employing a qualitative library research method, the study systematically reviews academic literature, industry reports, and regulatory documents published between 2020 and 2025. The findings reveal that blockchain enhances transparency and traceability through immutable record-keeping, while AI contributes predictive analytics, anomaly detection, and operational optimization. Although both technologies have been studied separately, their combined application in halal supply chains remains underexplored. This research proposes a conceptual framework for integrating blockchain and AI to reinforce halal assurance, streamline certification processes, and improve supply chain resilience. The study contributes to the academic discourse on halal supply chain governance and provides insights for policymakers, certification bodies, and industry practitioners seeking to establish a secure, ethical, and sustainable halal digital ecosystem.

Keywords: Halal Supply Chain; Blockchain; Artificial Intelligence; Digital Ecosystem; Shariah Compliance

1. Introduction

The halal supply chain is envisioned as a transparent, resilient, and ethically grounded system that safeguards religious compliance while ensuring operational efficiency. In its ideal form, every stage of the supply chain—from sourcing and production to distribution and consumption—should guarantee the integrity of halal principles, supported by mechanisms that prevent contamination, fraud, and information asymmetry [1]. The integration of advanced digital technologies is expected to foster a trusted ecosystem where stakeholders, including regulators, producers, logistics providers, and consumers, can rely on accurate, real-time data to verify halal compliance. Such a system not only enhances consumer confidence but also mitigates risks associated with counterfeiting and illicit trade within the global halal market [2]. This paper proposes a framework for integrating blockchain and artificial intelligence to create a robust and transparent halal supply chain ecosystem, addressing the current challenges of verifying halal authenticity and combating fraudulent activities [3], [4].

In practice, however, maintaining halal integrity across increasingly complex and globalized supply chains presents substantial challenges. Conventional certification systems often rely on manual audits, paper-based documentation, and fragmented information flows, which expose the process to risks of inefficiency, delay, and fraudulent claims [5]. Moreover, the growing demand for halal products, particularly in food, pharmaceuticals, and cosmetics, has heightened pressure on supply chain actors to deliver not only compliant but also verifiable and traceable goods [6]. These realities underscore the limitations of traditional mechanisms in meeting both the scale and sophistication of contemporary halal trade. Thus, there is an urgent need for innovative technological solutions that can enforce the stringent requirements of halal integrity, ensure end-to-end traceability, and deter fraudulent activities across diverse geographical and operational contexts [7]. Specifically, food fraud within the halal meat production industry remains a pervasive concern, eroding consumer trust, compromising religious adherence, and potentially endangering public health through practices such as adulteration with non-halal substances or mislabeling [4].

Scholarly investigations have highlighted the potential of blockchain and artificial intelligence (AI) in enhancing transparency, traceability, and decision-making within supply chain management. Blockchain offers immutable records of transactions, while AI provides predictive analytics and automation to optimize processes [8]. Nevertheless, most existing studies have treated these technologies in isolation, focusing either on blockchain for traceability or AI for efficiency. Little attention has been given to the synergistic integration of both technologies to construct a trusted halal digital ecosystem [9]. This gap suggests a critical need to explore how blockchain and AI can jointly reinforce halal assurance and governance.

This paper addresses this lacuna by proposing a comprehensive framework for the integrated application of blockchain and AI within the halal supply chain, aiming to establish a trusted digital ecosystem [10]. This framework leverages blockchain's inherent transparency and immutability to create an auditable ledger of all halal-related transactions, while AI is employed for real-time data analysis, anomaly detection, and predictive modeling to ensure continuous compliance and mitigate risks [11], [12]. The proposed framework aims to enhance supply chain integrity, addressing challenges faced by small and medium-sized enterprises in implementing blockchain technologies within the halal food sector [13].

2. Research Methods

This study employs a qualitative research design with a library research approach, focusing on the exploration and synthesis of scholarly works, regulatory frameworks, and authoritative reports related to blockchain, artificial intelligence, and halal supply chain management. A qualitative design is deemed suitable because the objective of this research is to build a conceptual understanding and theoretical framework rather than to test numerical hypotheses [14]. The library research approach enables the collection and analysis of secondary data, offering a comprehensive view of current debates and advancements in the field [15].

The data collection method is based on an extensive review of academic literature, policy documents, industry reports, and standards issued by halal certification bodies and international organizations. Sources include peer-reviewed journal articles, books, conference proceedings, and credible online repositories published within the last five years (2020–2025), supplemented by earlier seminal works when necessary. The selection of sources follows purposive sampling, emphasizing relevance, credibility, and alignment with the research objectives. Keywords used for literature searches include "halal supply chain," "blockchain," "artificial intelligence," "food integrity," "traceability," "Shariah compliance," and combinations thereof [4], [16].

The data analysis process applies a qualitative content analysis technique. Collected materials are systematically categorized according to key themes, including blockchain applications, AI capabilities, halal assurance requirements, and supply chain governance [17]. Thematic coding is employed to identify recurring patterns, conceptual relationships, and emerging trends. Subsequently, the analysis synthesizes findings to construct a conceptual model that highlights the potential integration of blockchain and AI in strengthening halal supply chain. Through this methodological design, the study seeks to provide a theoretically grounded and practically relevant framework that addresses the research gap in current scholarship. The results are expected to contribute to the academic discourse on halal supply chain management and offer insights for policymakers, certification authorities, and industry practitioners aiming to develop a trusted halal digital ecosystem.

3. Results and Discussions

3.1. Halal Supply Chain Integrity and Governance

Ensuring halal integrity throughout the supply chain remains the cornerstone of halal trade and consumption. Governance structures must not only safeguard religious compliance but also address operational challenges such as fraud prevention, traceability, and standard harmonization across jurisdictions [18]. In global trade, the halal supply chain requires mechanisms that can secure information flows and minimize the risk of contamination or misrepresentation. This section discusses the fundamental principles of halal supply chain governance, including certification, standardization, and trust-building among stakeholders, as a basis for understanding the potential role of emerging technologies. Furthermore, the inherent complexities of global supply chains necessitate robust frameworks that can adapt to diverse regulatory landscapes and cultural contexts, thereby ensuring that products remain Shariah-compliant from origin to consumption [19].

This necessitates the development of comprehensive and transparent governance models that can accommodate the dynamic nature of international trade while upholding the stringent requirements of halal integrity [4]. Halal certification bodies are actively exploring the integration of advanced technologies like blockchain to enhance the integrity and transparency of halal product flows, specifically addressing issues like contamination and non-

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compliance within the supply chain [20]. Blockchain technology, with its immutable ledger, offers a robust solution for enhancing trustworthiness and traceability in Halal food supply chains, thereby contributing to food safety and security [21]. The application of AI, conversely, can further refine this process by enabling predictive analytics for risk assessment and automated verification of Shariah compliance at various stages [22].

This integration of blockchain and AI strengthens the overall halal ecosystem by providing unparalleled transparency and accountability, thereby addressing vulnerabilities such as food fraud and intentional deception that can compromise product integrity [23]. Consumers are increasingly vulnerable to fraud and adulteration in the halal supply chain due to rising demand and global supply outstripping capacity. The traditional paper-based halal certification process is often inefficient, prone to human error, and susceptible to fraudulent activities, which undermines consumer trust [24], [25]. These limitations underscore the urgent need for digital transformation within halal supply chain management to restore and maintain consumer confidence [26]. The advent of advanced technologies, particularly the Internet of Things, has significantly bolstered the efficiency of food industry management by enabling comprehensive product traceability systems [27].

However, the implementation of such systems in the halal sector necessitates a robust technological infrastructure capable of handling vast amounts of data while maintaining Shariah compliance [13]. This challenge emphasizes the need for innovative digital solutions that integrate data integrity with the nuanced requirements of Islamic law. A significant leap towards addressing these complexities involves leveraging blockchain for secure, transparent transaction records and artificial intelligence for intelligent data analysis and automated compliance checks. This integrated approach provides an unprecedented level of assurance, mitigating risks associated with mislabeling, cross-contamination, and the illicit trade of non-halal products by creating a tamper-proof digital record [2], [28]. Such a system can authenticate the entire product journey, from sourcing raw materials to final distribution, thereby validating the halal status at every stage and ensuring consumer confidence [21].

This enhanced traceability directly addresses the critical need for data tamper-proofing and visibility throughout the supply chain, which is essential for preventing foodborne illnesses and ensuring product integrity [29]. Blockchain technology, in particular, offers a verifiable and immutable ledger that can record every transaction and movement of halal products, fostering transparency and accountability across all stakeholders [30]. Furthermore, the integration of AI can enable real-time monitoring and predictive analytics, allowing for immediate detection of anomalies or deviations that could compromise halal integrity [4]. This creates a robust framework for proactive risk management, significantly reducing incidents of food fraud and ensuring Shariah compliance from farm to fork. This digital convergence ultimately cultivates a trusted digital ecosystem, fostering greater consumer confidence and expanding the global reach of certified halal products. This synergistic combination of blockchain and AI effectively counters the persistent issues of halal food fraud and misrepresentation, which continue to plague the industry despite existing legal frameworks.

3.2. Blockchain Technology for Transparency and Traceability

Blockchain technology has been widely recognized for its ability to provide immutable records and decentralized data management. In the context of halal supply chains, blockchain offers solutions for traceability by enabling stakeholders to verify each transaction and movement of goods in real time [31]. This feature reduces dependency on manual audits and fragmented documentation, which are prone to inefficiencies and errors. Furthermore, blockchain can enhance consumer trust by granting end-users access to reliable information about product origins and halal compliance status [32]. This section elaborates on blockchain’s potential applications in halal certification, logistics monitoring, and fraud detection. Specifically, blockchain's inherent characteristics, such as immutability and transparency, ensure data integrity and authenticity, which are critical for guaranteeing the halal status of products throughout the supply chain [33], [34].

For instance, the use of blockchain can facilitate the transparent tracking of agricultural products from cultivation to consumer, aiding in rapid identification of compromised consignments and ensuring adherence to stringent quality controls [35]. This decentralized database system is crucial in transforming the way data is kept, handled, and shared along the supply chain from the producer to the consumer, ensuring food product traceability and transparency [36]. This ensures that critical information, such as the origin of ingredients, processing conditions, and transportation routes, is securely recorded and accessible, mitigating the risk of fraud and contamination [33], [37]. Moreover, the integration of blockchain into food supply chains enables comprehensive tracking of products from their source to the end consumer, enhancing overall traceability and control over product movement. This enhanced transparency and traceability are pivotal in upholding the integrity of halal products, assuring consumers of their authenticity and Shariah compliance [2]. This heightened visibility reduces the likelihood of fraud,

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especially concerning mislabeling or the introduction of non-halal components, thereby safeguarding consumer health and religious dietary requirements.

The implementation of blockchain technology provides a robust mechanism for verifying the legitimacy of halal certifications and ensuring that all stages of the supply chain adhere to Shariah principles, thereby building an unparalleled level of trust among consumers and regulatory bodies [38]. This foundational trust is further solidified by blockchain's capacity to streamline auditing processes and enable immediate recalls, significantly enhancing responsiveness in critical situations [39]. Such capabilities not only bolster the authenticity of halal products but also mitigate financial losses associated with widespread recalls due to compromised integrity. This comprehensive transparency offers consumers unprecedented access to verifiable product information, empowering them to make informed decisions and fostering a greater sense of confidence in the halal ecosystem [40]. This increased transparency addresses long-standing issues such as food fraud, including adulteration with non-halal substances, substitution of non-halal meat as halal, and incorrect labeling, which have historically eroded consumer trust [31].

The ability of blockchain to provide an immutable and transparent ledger of all transactions within the supply chain directly combats these fraudulent activities by making it virtually impossible to alter records without detection [30]. This technological advancement significantly bolsters the enforcement of stringent regulations, such as the Trade Description Act 2011 and the Food Act 1983, by providing undeniable evidence of compliance or deviation. This ultimately enhances consumer protection by guaranteeing that halal products genuinely meet the required religious and quality standards, thereby mitigating health risks associated with fraudulent practices. Furthermore, blockchain's cryptographic security features ensure that data entries are tamper-proof, thereby establishing an irrefutable audit trail for every stage of the halal supply chain [4]. This makes it exceptionally difficult for malicious actors to introduce non-halal elements or misrepresent products, as any attempt would be instantly detectable and verifiable across the distributed network. This inherent immutability and transparency address the prevalent issues of food fraud and mislabeling, which often involve the surreptitious introduction of non-halal components or deceptive product claims [41].

Consequently, blockchain technology serves as a critical tool in restoring and maintaining consumer confidence by providing an unprecedented level of verifiable assurance regarding the halal integrity of products from farm to fork [4], [42]. This robust system directly addresses the growing consumer demand for transparency, health, wellness, and sustainability claims, which are increasingly governing future trends in the food industry [43]. The integration of AI, particularly machine learning algorithms, can further augment blockchain's capabilities by analyzing the vast datasets generated within the halal supply chain to predict potential points of failure, identify anomalies indicative of fraud, and optimize logistical pathways for efficiency and compliance. This synergy between blockchain and AI creates a proactive system that not only verifies the halal status but also continuously learns and adapts to evolving risks and supply chain dynamics, offering predictive insights into potential issues before they materialize [44].

3.3. Artificial Intelligence for Optimization and Risk Mitigation

Artificial intelligence contributes to the efficiency of supply chain operations through predictive analytics, machine learning algorithms, and intelligent automation. Within halal supply chains, AI can be applied to monitor compliance risks, predict demand patterns, and optimize logistics, particularly in cold chain management for perishable products. Its capability to process large datasets allows for more accurate decision-making and early detection of anomalies that may compromise halal integrity [45]. This section examines the role of AI in supporting operational resilience, reducing vulnerabilities, and strengthening decision-making processes in halal supply chain management. Specifically, AI-driven analytics can identify patterns of non-compliance, such as inconsistencies in documentation or deviations from established Shariah-compliant procedures, thereby proactively mitigating risks [4]. Furthermore, AI can enhance security by refining cryptographic methods, automating key management, and bolstering anomaly detection within the complex network of halal product movement [46].

Beyond risk mitigation, AI also offers substantial benefits in optimizing various facets of the supply chain, including demand forecasting and inventory management, which are crucial for minimizing waste and ensuring the timely availability of halal products [7], [47]. For instance, AI-powered predictive analytics can forecast demand fluctuations for specific halal products based on historical data, seasonal trends, and even real-time social media sentiment, enabling more efficient production and distribution planning. Such optimized planning, facilitated by AI, reduces the likelihood of product shortages or overstocking, both of which can lead to significant financial losses and potential compromise of product integrity [48]. Additionally, AI algorithms can optimize logistical routes and cold chain management for perishable halal goods, ensuring adherence to strict temperature

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controls and delivery timelines, thereby preserving product quality and halal compliance throughout transit [49]. Moreover, AI can automate the issuance of Shariah-compliant rulings by analyzing extensive Islamic jurisprudence data, significantly improving the efficiency and scalability of Shariah governance and reducing fatwa issuance time by up to 50% [4].

This automation, drawing upon vast historical fatwa datasets, ensures consistent and accurate application of Shariah principles to new financial products and operational procedures, thereby bolstering the trustworthiness of halal certifications. This allows Islamic financial institutions to develop innovative and Shariah-compliant products and services by providing data-driven insights into consumer behavior and market trends [50]. Furthermore, AI can significantly improve financial risk management within Islamic banking by leveraging machine learning algorithms to automate risk assessments, enhance fraud detection, and optimize investment strategies, while simultaneously identifying emerging risks in dynamic market environments [51]. This technological integration also extends to the meticulous monitoring of real-time financial transactions, ensuring scrupulous adherence to Shariah principles by flagging non-compliant activities and recommending corrective measures.

For example, banks like Dubai Islamic Bank and Bank Islam Malaysia Berhad utilize AI systems to monitor transaction patterns for anomalies and potential fraud, thereby reducing financial losses and enhancing Shariah compliance [4]. This robust application of AI across the halal financial ecosystem not only strengthens ethical adherence but also drives operational efficiencies and fosters innovation [52]. Moreover, AI can aid Shariah boards in overseeing compliance by scrutinizing financial transactions and detecting possible infringements of Shariah rules, thus reducing compliance costs. This capability allows for automated detection of non-compliant transactions, thereby assisting Shariah committees and reducing the human effort and time traditionally associated with compliance oversight. This proactive and automated compliance mechanism significantly enhances the integrity of Islamic financial products and services, fostering greater trust among consumers and stakeholders [53].

The integration of AI, therefore, provides a comprehensive framework for ensuring Shariah compliance across the entire Islamic financial landscape, from product development to ongoing transaction monitoring. This integration ultimately underpins the overarching goal of fostering a trusted digital ecosystem, where transparency, efficiency, and adherence to Islamic principles are meticulously maintained [4]. This comprehensive approach not only safeguards the ethical and religious integrity of halal products and financial services but also contributes to the sustainable growth of the Islamic economy [54]. The combination of blockchain's immutable ledger and AI's analytical prowess creates a robust framework for end-to-end traceability and Shariah compliance, enabling real-time verification of halal integrity across complex supply chains. This synergy ensures that every stage, from sourcing raw materials to final consumption, adheres to stringent halal standards, thereby minimizing the risk of contamination or non-compliance [55].

3.4. Integration of Blockchain and AI for a Trusted Digital Ecosystem

While blockchain and AI independently offer significant benefits, their integration presents a synergistic potential for creating a trusted halal digital ecosystem. Blockchain ensures transparency and data immutability, whereas AI enhances data analysis and predictive capabilities. Combined, these technologies can establish an ecosystem that not only secures compliance but also enables adaptive, intelligent governance mechanisms across global halal supply chains [56]. This section explores the conceptual model of integration, highlighting how the convergence of blockchain and AI can reinforce halal assurance, streamline certification processes, and cultivate long-term consumer confidence in halal products and services. This integrated approach facilitates real-time data sharing and automated verification, drastically reducing the time and cost associated with traditional auditing processes [57], [58].

The intelligent capabilities bestowed by AI on the blockchain ecosystem, termed blockchain intelligence, can help identify risks in transactions and detect abnormal behaviors, ensuring the integrity of the halal supply chain [59]. This integration further allows for predictive analytics regarding potential supply chain disruptions or contamination risks, enabling proactive measures to maintain halal standards [58]. Furthermore, the convergence of AI and blockchain creates an enhanced security paradigm, capable of identifying and mitigating cyber threats within the halal supply chain through real-time data analysis and immutable record-keeping [60]. This synergy also improves trust on robotic decisions and business process efficiency [61], fostering collective decision-making and decentralized intelligence within the halal ecosystem. This integration is particularly vital for the halal industry, where maintaining Shariah compliance across a complex and often globally dispersed supply chain is paramount [62].

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The immutable and transparent nature of blockchain, combined with AI's ability to process vast datasets for anomaly detection and predictive modeling, offers an unparalleled solution for ensuring integrity from farm to fork [63]. This integrated system can automate the verification of halal certification at each stage of the supply chain, significantly reducing the potential for fraud or misrepresentation while enhancing consumer confidence [64]. Furthermore, the integration of AI and blockchain can foster a more resilient and responsive halal supply chain, capable of adapting to unforeseen challenges and disruptions [65]. This robust technological symbiosis enables the instantaneous validation of Shariah compliance and authenticity, mitigating risks associated with counterfeiting and illicit practices across the entire value chain [66]. Such an integrated approach can also bolster the efficiency of Shariah governance systems by automating fatwa issuance and compliance oversight, thereby reducing manual efforts and enhancing accuracy.

This synergy empowers stakeholders with real-time, data-driven insights, fostering a truly trusted digital ecosystem for halal products and services. This holistic framework leverages the strengths of both technologies to address the intricate demands of halal integrity, extending beyond mere traceability to encompass dynamic risk management and proactive compliance enforcement. This technological convergence not only fortifies the ethical foundations of the halal industry but also positions it for sustainable growth and heightened global competitiveness by ensuring verifiable integrity [58]. This fusion provides a robust framework for ethical oversight and operational efficiency, thereby setting a new standard for Shariah-compliant economic activities. This transformative potential is particularly critical within the halal supply chain, which is inherently complex due to diverse global markets and stringent Shariah requirements [67]. Thus, the strategic deployment of AI and blockchain technologies offers a robust solution for addressing these complexities, ensuring end-to-end halal integrity and consumer trust.

This comprehensive digital ecosystem, underpinned by AI and blockchain, therefore represents a paradigm shift in how halal integrity is assured and maintained, offering unprecedented levels of transparency and accountability [68]. Moreover, this integrated approach can significantly enhance risk management and operational efficiency within the halal sector, paving the way for sustainable development and greater consumer confidence [4]. This advanced framework also facilitates ethical investments and social responsibility within Islamic finance, aligning with the core principles of Shariah governance. This symbiotic relationship between AI, blockchain, and Shariah principles is crucial for advancing the halal industry's contribution to sustainable development goals, particularly in poverty alleviation, zero hunger, and responsible consumption [69].

This digital transformation, guided by Maqasid al-Shariah, ensures that technological advancements contribute to societal well-being and economic justice [70]. This integration also supports the ethical application of AI and the essential role of Shariah boards in overseeing AI implementations to ensure adherence to Islamic ethical norms. This proactive oversight mitigates ethical deviations, such as those related to misinformation or manipulation, that can arise from AI tools used in marketing and other domains [71]. Moreover, the ethical governance of AI within this framework is paramount, requiring robust oversight to align AI functionalities with Islamic virtues and objectives [72]. Furthermore, the establishment of clear ethical guidelines and regulatory frameworks is crucial to ensure that AI applications within the Islamic financial sector consistently adhere to Shariah principles, fostering sustainable development and maintaining public trust.

4. Conclusion

The study concludes that the integration of blockchain and artificial intelligence offers a transformative solution for strengthening halal supply chain integrity by combining blockchain’s transparency and immutability with AI’s predictive and analytical capabilities. This convergence addresses the persistent challenges of fraud, mislabeling, and inefficiency in conventional certification systems, while simultaneously enhancing traceability, operational efficiency, and Shariah compliance. The proposed framework establishes a trusted digital ecosystem that not only restores consumer confidence but also positions the halal industry for sustainable growth in the global market. To realize the potential of this integrated framework, policymakers and halal certification authorities should develop regulatory standards that accommodate blockchain and AI applications while ensuring alignment with Shariah principles. Industry stakeholders, particularly small and medium-sized enterprises, should invest in digital infrastructure and capacity-building to adopt these technologies effectively. Academics and researchers are encouraged to conduct empirical studies and pilot projects that test the practical implementation of blockchain–AI integration in halal supply chains. Collaboration between governments, industry, and academia is essential to establish an ethical, transparent, and resilient halal digital ecosystem.

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