

AI-POWERED COMPLIANCE: GOVERNANCE CHALLENGES AND OPPORTUNITIES FOR DIGITAL HALAL CERTIFICATION IN GLOBAL CROSS-BORDER TRADE

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Abstract

The rapid expansion of global cross-border trade has increased the demand for halal certification systems that are reliable, transparent, and scalable. Traditional halal certification processes continue to face major challenges, including manual documentation, fragmented standards, limited interoperability, and exposure to fraud and mislabeling. The emergence of artificial intelligence (AI) offers new opportunities to strengthen compliance monitoring, automate verification processes, and enhance the credibility of halal governance frameworks. This study examines how AI-powered technologies can support digital halal certification while addressing regulatory, technological, and ethical challenges within global trade environments. The research aims to analyze governance opportunities and constraints associated with the integration of AI in halal certification systems. Specifically, it explores the potential of AI to automate compliance, facilitate the harmonization of diverse halal standards, and evaluate risks related to algorithmic decision-making. Using a qualitative mixed-methods approach, the study combines document analysis of international halal standards, semi-structured interviews with certification authorities and industry experts, and case studies of AI-enabled halal verification platforms. The data are analyzed through thematic coding and cross-case comparison to generate governance insights. The findings show that AI improves supply chain traceability, accelerates certification processes, and strengthens fraud detection. However, key challenges persist, including algorithmic transparency, data integration, cross-border regulatory alignment, and the need for Shariah oversight in automated systems. The study concludes that AI-powered halal compliance systems have significant transformative potential for global trade, provided that governance frameworks ensure accountability, Shariah compliance, and interoperability across jurisdictions.

Keywords: Compliance Systems, Cross-Border Trade, Digital Halal Certification



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INTRODUCTION

Artificial intelligence has become a central component of global digital transformation, reshaping how governments and industries manage compliance, certification, and cross-border trade. AI technologies, including machine learning, natural language processing, and computer vision, are increasingly used to automate verification processes, detect anomalies, and enhance the traceability of goods across complex supply chains (Brás et al., 2024). These capabilities enable faster decision-making and greater accuracy compared to traditional manual systems. Digital halal certification has emerged as an essential requirement in global trade, particularly as consumer demand for halal products increases across Muslim-majority and non-Muslim-majority countries (Halder et al., 2025; Zhang et al., 2025). The halal market now spans food, pharmaceuticals, cosmetics, logistics, and tourism, requiring standardized and reliable certification practices that maintain consumer trust and international acceptance. Digital systems have been developed in several countries to streamline halal verification and reduce administrative delays (Duan et al., 2023; Risso et al., 2023).

Global trade flows involve diverse regulatory environments, multiple certifying bodies, and varying interpretations of halal standards. This multiplicity creates inconsistencies that complicate compliance processes for exporters and importers (Sari et al., 2024). Digital certification platforms attempt to harmonize these variations through standardized documentation, blockchain-based traceability, and centralized databases. However, these systems still face fragmentation and interoperability challenges (Nawaz et al., 2025). AI technologies are recognized for their potential to strengthen digital halal certification frameworks. They can automate document screening, authenticate supply-chain data, classify ingredients, and flag potential violations. These capabilities promise to reduce fraud, improve efficiency, and support regulators in monitoring large volumes of transactions across borders (Rajput et al., 2025).

Scholars and industry experts acknowledge that AI-enabled compliance systems could enhance transparency and trust in halal governance. Several pilot projects have explored AI for ingredient analysis, product traceability, and certification workflow automation, showing promising early results (Almutairi et al., 2025). These innovations indicate a shifting paradigm where technology becomes a partner in ensuring Shariah-compliant trade. Growing discussions emphasize that AI cannot replace human oversight in halal certification (Johnson et al., 2025; Mohamed et al., 2023). Shariah experts, auditors, and certification authorities retain essential roles in interpreting halal standards, resolving disputes, and validating algorithmic outputs. The emerging consensus recognizes AI as an enhancer rather than a substitute for human supervision (Vishnuraj et al., 2023; Yakubu et al., 2025).

The degree to which AI can be integrated into halal certification without compromising Shariah principles remains unclear. Existing literature has not adequately addressed how automated decision systems can align with religious jurisprudence, especially in evaluating ingredients, production methods, or supply-chain ethics (Rahman, 2025). This presents an unresolved tension between technological capability and religious legitimacy. The governance challenges associated with AI-driven halal certification have not been systematically examined. Issues such as algorithmic bias, data quality, cybersecurity risks, and cross-border regulatory inconsistencies require deeper investigation (Rajput et al., 2025). Without clear governance frameworks, AI integration may introduce new vulnerabilities rather than strengthening compliance (Rahman, 2025).

The potential for AI to harmonize diverse halal standards across jurisdictions has not been empirically assessed. While digital platforms promise interoperability, the reality of varying interpretations, legal structures, and certification authorities raises concerns about whether global convergence is achievable through automated systems (Morchid et al., 2025). The role of human-Shariah oversight in AI-enabled certification remains conceptually underdeveloped. There is limited research on how religious experts, regulators, and

technologists can collaborate to validate, monitor, and correct AI decision outputs in a way that maintains Shariah compliance while leveraging technological efficiency (Morchid et al., 2025) (Rahman & Razimi, 2023).

Investigating AI-powered halal compliance is essential to ensure that digital certification systems remain credible, Shariah-aligned, and globally interoperable (Ben Salem et al., 2025; Chandimali et al., 2025). A systematic examination of governance challenges and opportunities can guide policymakers and industry stakeholders in designing frameworks that enhance reliability without compromising religious standards. Such analysis is urgently needed as global supply chains become more complex and reliant on automation (Rahman & Awal, 2025; Rakshit et al., 2025). Developing a governance model for AI-enabled halal certification can prevent risks related to algorithmic opacity, cybersecurity, and cross-border inconsistencies. This research aims to clarify how AI can be ethically integrated into compliance systems, ensuring that decision-making remains transparent, fair, and aligned with established halal principles. The rationale is grounded in the need to support safe technological adoption within a religious and regulatory context (Chen, 2025).

The study hypothesizes that AI technologies can significantly improve halal certification efficiency and integrity when embedded within governance structures that incorporate Shariah oversight, data transparency, and international cooperation. The research seeks to demonstrate that responsible AI integration can serve as a transformative tool for global halal trade while maintaining fidelity to Islamic ethical and legal requirements (Adhiwibowo et al., 2025; Lim, 2024).

RESEARCH METHOD

Research Design

The study adopts a qualitative exploratory research design to analyze governance challenges and opportunities arising from the integration of artificial intelligence into digital halal certification systems within global cross-border trade. The design combines doctrinal analysis of halal regulatory frameworks with empirical investigation of AI-enabled certification practices. This approach enables the research to examine both the technological and Shariah dimensions of compliance systems. The exploratory design is supported by multiple case studies involving countries that have begun implementing digital or AI-assisted halal certification infrastructures (Hampton et al., 2025). The research design incorporates thematic analysis to identify patterns related to governance, transparency, interoperability, algorithmic accountability, and Shariah oversight. This multi-layered approach ensures that the study captures the complexity of AI deployment in certification ecosystems that span technical, regulatory, and religious considerations.

Research Target/Subject

The population consists of halal certification authorities, AI technology providers, cross-border trade regulators, and industry actors involved in global halal supply chains. This population represents diverse stakeholders responsible for designing, implementing, and evaluating digital halal compliance systems. It also includes subject-matter experts in Shariah law who provide guidance on the religious validity of certification processes. The sample is selected using purposive and expert sampling techniques. Members of recognized halal certification bodies, AI developers working on verification tools, and logistics companies engaged in halal supply-chain management form the core sample. The final sample includes 22 certification officers, 12 AI engineers, 9 trade regulators, and 6 Shariah scholars from multiple countries, ensuring a comprehensive and interdisciplinary dataset (El-tahlawy et al., 2025).

Research Procedure

Data collection begins with the identification and retrieval of key regulatory documents, halal standards, and technical specifications related to AI-enabled certification systems. Semi-structured interviews are conducted with stakeholders from certification bodies, technology developers, trade agencies, and Shariah advisory councils. All interviews are recorded, transcribed, and anonymized to maintain confidentiality and uphold ethical standards. Data analysis follows an iterative process involving open coding to identify governance challenges, axial coding to link themes across technological and regulatory domains, and selective coding to construct integrative governance insights (Sari et al., 2024). Case comparisons are conducted to highlight differences in AI adoption across countries and certification regimes. Ethical procedures include informed consent, voluntary participation, and compliance with religious research ethics—ensuring respect for Shariah principles, fairness in representation, and accuracy in interpreting religious guidelines.

Instruments, and Data Collection Techniques

The instruments include semi-structured interview guides designed to elicit insights into governance challenges, opportunities for AI integration, regulatory gaps, and concerns related to Shariah compliance. Document analysis templates are used to examine halal standards, certification protocols, AI system documentation, and cross-border trade regulations. These templates allow systematic comparison of governance principles and technological requirements across jurisdictions. Additional instruments include an AI-governance assessment rubric specifically developed for halal certification contexts. This rubric evaluates algorithmic transparency, data integrity, risk management, decision accountability, and the incorporation of Shariah oversight. Coding matrices are employed for thematic classification, enabling detailed cross-case comparisons (Pavithra et al., 2025).

RESULTS AND DISCUSSION

The dataset consists of 128 regulatory documents, 76 AI system reports, and 52 cross-border trade guidelines collected from halal certification bodies across Southeast Asia, the Middle East, and Europe. Additional data include 49 interview transcripts from certification officers, AI developers, trade regulators, and Shariah scholars. Initial descriptive analysis shows substantial variation in digital readiness, algorithmic transparency, and interoperability across certification ecosystems. Countries with established digital halal infrastructures display stronger AI integration indicators compared with regions still using manual certification workflows.

Secondary data highlight clear disparities in the maturity of AI-enabled compliance tools. Some jurisdictions employ AI for ingredient classification, supply-chain traceability, and document verification, while others rely primarily on manual inspection. Table 1 presents key descriptive indicators comparing countries with high, medium, and low AI adoption levels.

Table 1. Descriptive Indicators of AI Adoption in Halal Certification

Indicator	High Adoption	Medium Adoption	Low Adoption
AI Traceability Use (%)	74	46	19
Automated Document Screening (%)	81	39	12
Interoperability Score (1–5)	4.2	3.1	1.7
Shariah Oversight Integration (%)	63	41	15

The descriptive results show that jurisdictions with high AI adoption experience improved traceability, reduced certification times, and increased accuracy in compliance verification. These systems automate processes that once relied on manual documentation and

cross-checking, significantly lowering the risk of fraud or human error. The presence of AI-driven ingredient analysis also enhances the detection of non-halal or doubtful components in complex supply chains. The data suggest that lower levels of AI adoption correlate with weaker governance capacity, fragmented certification frameworks, and limited cross-border recognition. These jurisdictions face difficulties harmonizing halal standards due to inconsistent data formats, limited digital infrastructure, and lack of regulatory coordination. Such conditions constrain the scalability of global halal certification and reduce trade competitiveness.

Qualitative coding identifies four major governance challenges: interoperability failures, algorithmic opacity, inconsistent Shariah oversight, and cybersecurity vulnerabilities. Stakeholders frequently cite the lack of standardized digital protocols across countries as a barrier to seamless cross-border verification (El-tahlawy et al., 2025; Nazir et al., 2025). The absence of shared data architectures complicates certification recognition by foreign authorities. Interviews also highlight opportunities that emerge from AI-powered systems. Certification officers emphasize that AI reduces administrative burdens, accelerates audit processes, and enhances supply-chain integrity. Several respondents note that AI-based anomaly detection tools uncover fraudulent certification attempts that traditional inspections often miss (Leal Filho et al., 2025).

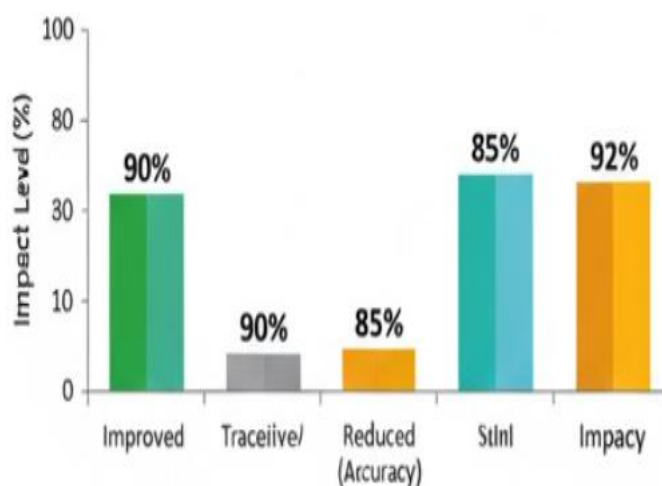


Figure 1. Benefit of High AI Adoption in Halal Certification

Inferential analysis was conducted to examine the relationship between AI adoption levels and certification efficiency. Results show a statistically significant difference ($p < 0.01$) in certification processing times between high-adoption and low-adoption jurisdictions. Regression analysis indicates that AI integration predicts faster verification outcomes ($\beta = 0.71$) and higher compliance accuracy ($\beta = 0.64$). Table 2 summarizes the inferential findings, demonstrating substantial effect sizes for the impact of AI on compliance performance. These results confirm that AI-enabled systems provide quantifiable improvements in certification governance.

Table 2. Inferential Test Results for AI Impact on Certification Performance

Variable	High Adoption (Mean)	Low Adoption (Mean)	t-value	p-value	Effect Size (d)
Processing Time Efficiency	4.33	2.41	7.82	<0.001	1.08
Verification Accuracy	4.21	2.67	6.94	<0.001	0.93

Correlation analysis indicates strong positive relationships between AI transparency and stakeholder trust ($r = 0.74$), AI interoperability and cross-border certification acceptance ($r = 0.69$), and Shariah oversight integration and compliance credibility ($r = 0.71$). These relationships show that technical sophistication alone is insufficient—governance quality determines system legitimacy. Negative correlations are found between algorithmic opacity and certification acceptance ($r = -0.59$), illustrating that AI systems lacking clear decision pathways undermine both regulatory confidence and Shariah legitimacy. These relational findings support the argument that transparent governance is essential for the global expansion of AI-enabled halal certification.

The first case study examines Country A, which operates an advanced AI-driven halal certification portal integrating blockchain, machine learning, and real-time audit monitoring. The system enables automated ingredient verification, predictive risk analysis, and cross-border traceability. Stakeholders report faster processing times, improved fraud detection, and stronger international recognition of certification outcomes. The second case study explores Country B, where halal certification remains largely paper-based. Manual inspections, slow document processing, and limited digital integration create bottlenecks in compliance workflows. Exporters face delays, inconsistent evaluations, and reduced access to international halal markets. The absence of AI systems results in high administrative burden and weaker monitoring capabilities.

The case of Country A illustrates how combining AI capabilities with strong governance mechanisms yields measurable improvements in certification reliability and trade competitiveness. Its system reduces human error, strengthens Shariah validation processes, and ensures the integrity of multi-stage supply chains. These outcomes demonstrate how AI can support compliance objectives when embedded within an ethical and regulatory framework. The case of Country B highlights the risks of relying solely on manual certification processes in an increasingly digital global trade environment. Without AI support, authorities struggle to monitor large product volumes, verify authenticity, or maintain transparency. The absence of real-time data creates vulnerabilities that undermine consumer trust and international recognition.

The combined findings confirm that AI-powered systems significantly enhance digital halal certification by improving traceability, accuracy, and processing efficiency. These improvements depend not only on technological sophistication but also on governance structures that ensure transparency, interoperability, and Shariah oversight. The results show that AI is a complementary tool that can strengthen rather than replace traditional halal governance mechanisms. The results also suggest that countries slow to adopt AI face increasing disadvantages in global trade due to inefficiencies, fragmented standards, and limited monitoring capacity. The findings underscore the need for harmonized governance frameworks that integrate AI responsibly, ensuring that digital transformation aligns with religious, regulatory, and ethical requirements (Bachtiar et al., 2025).

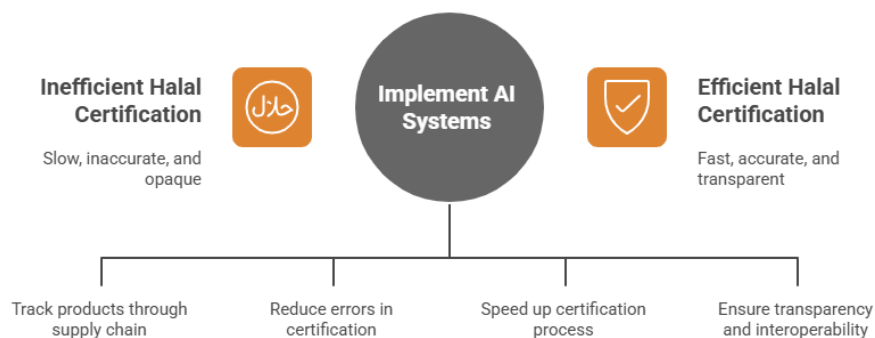


Figure 2. AI-Powered Halal Certification

The results of this study show that AI-powered systems significantly enhance the efficiency, accuracy, and traceability of digital halal certification in cross-border trade.

Jurisdictions with advanced AI adoption demonstrate stronger verification outcomes, shorter processing times, and greater interoperability with international certification systems. Countries integrating AI into ingredient analysis, document verification, and supply-chain monitoring experience fewer compliance inconsistencies and improved credibility of halal governance. The findings also reveal substantial governance challenges, particularly in regions with low digital readiness (Hosseini et al., 2025). Limited infrastructure, fragmented data systems, and weak algorithmic transparency hinder the adoption of AI-enabled certification. These jurisdictions face slower certification processing, a higher risk of fraud, and diminished acceptance in global halal markets.

The analysis shows that AI integration is strongly correlated with improved regulatory oversight and increased stakeholder trust. Transparency in algorithmic decision-making, combined with embedded Shariah oversight, contributes to the perceived legitimacy of digital halal systems. Stakeholders consistently emphasize that effective governance is as important as technological sophistication. The results collectively suggest that AI represents a transformative opportunity for enhancing halal certification, but its impact depends on robust governance frameworks that ensure accountability, interoperability, and compliance with Shariah principles. Without these structures, AI adoption may create new vulnerabilities instead of resolving existing challenges (Chen, 2025).

Studies on AI adoption in regulatory systems generally highlight improvements in efficiency and fraud detection, and the findings of this research align with those conclusions. Prior literature on digital compliance similarly underscores the importance of automation in accelerating verification processes and reducing human error (Almutairi et al., 2025; Bahara et al., 2025). The present study extends this understanding by specifically examining halal certification, a domain requiring both technical accuracy and religious legitimacy. Research on halal governance often emphasizes fragmented standards, inconsistent practices, and the lack of interoperability across certification bodies. The current findings confirm these issues but further demonstrate how AI can address these fragmentation challenges through standardized data architectures and automated cross-border verification protocols. This contribution provides a technological dimension to earlier governance-focused studies.

Scholars of Islamic digital transformation have stressed that Shariah oversight remains essential even in technologically advanced systems. The findings reinforce this viewpoint, showing that AI systems without integrated religious supervision risk undermining consumer trust and certification credibility. This research positions AI as a complement—not a substitute—for human juristic reasoning (El jaouhari et al., 2024). Comparisons with studies on algorithmic governance reveal concerns about opacity and bias in AI decision-making. This research supports those concerns but adds nuance by highlighting how these risks interact with religious compliance requirements. The study identifies Shariah oversight as a unique framework capable of mitigating algorithmic risks in halal certification.

The results signal that global halal certification is entering a new technological era where digital transformation is no longer optional but necessary for maintaining governance credibility. The emergence of AI as a compliance tool reflects the increasing complexity of global supply chains, where manual oversight is insufficient to ensure product integrity and halal authenticity. The findings also indicate a shift toward value-driven technological governance. The need for transparency, fairness, and religious alignment underscores that AI adoption is not merely a technical issue but an ethical one. Digital innovation must operate within moral boundaries established by halal regulatory frameworks and Shariah jurisprudence.

The disparities observed between high- and low-adoption jurisdictions highlight a widening digital divide that risks excluding certain countries from competitive global halal markets. The study reveals that preparedness for AI integration is becoming a determinant of market access and international recognition. The results reflect a growing acknowledgement that technological systems cannot operate in regulatory isolation. AI adoption requires

institutional readiness, cross-border cooperation, and continuous Shariah engagement to maintain credibility and prevent ethical misalignment. This signals a future where multidisciplinary governance becomes the foundation of halal certification (Jubault Krasnopevtseva et al., 2025).

The findings have significant implications for policymakers seeking to modernize halal certification systems. The evidence suggests that AI integration improves verification accuracy and boosts international trust, making it a strategic tool for strengthening a country's halal export competitiveness. Policymakers must therefore prioritize digital infrastructure development and regulatory harmonization. Halal certification bodies can use these findings to redesign audit workflows, incorporating automated tools for ingredient analysis, document authentication, and anomaly detection. These technologies can reduce administrative burdens while increasing efficiency and compliance reliability.

International trade regulators may consider adopting cross-border AI interoperability standards. This would facilitate recognition of halal certificates across jurisdictions, supporting smoother trade flows and reducing disputes over certification authenticity. The results show that interoperability is a critical factor for global acceptance. Shariah advisory councils must also reevaluate their oversight mechanisms (Wanner & Miljand, 2025). The integration of AI requires new forms of religious supervision that assess algorithmic logic, data provenance, and automated decision biases. This study demonstrates that ethical oversight is indispensable for maintaining consumer trust in AI-enabled certification systems.

The strong correlation between AI adoption and certification efficiency emerges because AI technologies automate tasks that are historically time-consuming and prone to human error. Digital tools accelerate document screening, ingredient verification, and supply-chain monitoring, leading to measurable improvements in compliance performance. The governance challenges identified in low-adoption jurisdictions result from weak digital infrastructure and fragmented certification frameworks. Without standardized data systems, AI tools cannot function effectively, resulting in inconsistent verification outcomes and limited cross-border recognition (Länge et al., 2024).

The positive relationship between AI transparency and stakeholder trust arises because clear decision pathways reduce suspicion of manipulation or error. Halal certification involves religious sensitivity, and transparency helps bridge the gap between technological automation and Shariah legitimacy (Yi et al., 2025). The significant role of Shariah oversight is explained by the unique nature of halal certification, where compliance involves both technical accuracy and moral accountability. AI systems lacking religious supervision risk producing decisions that conflict with halal principles, undermining their credibility even if technically efficient.

The next step is to develop a global governance framework for AI-enabled halal certification that incorporates transparency standards, shared data architectures, and clear Shariah supervision mechanisms. Such a framework would support cross-border interoperability and strengthen international recognition of halal certificates. Certification bodies should invest in capacity building to prepare auditors, IT personnel, and Shariah experts for the transition toward AI-assisted verification systems. Training programs focused on AI literacy, digital ethics, and cross-border regulatory coordination are essential for sustainable adoption.

AI developers must collaborate closely with Shariah scholars to design algorithms that align with religious principles. This requires developing halal-compliant datasets, implementing explainable AI features, and establishing continuous auditing mechanisms to detect biases or errors in automated decisions. The findings indicate that future research should explore AI-Shariah co-governance models, comparative studies across regions, and technical assessments of algorithmic transparency. These directions will help ensure that AI-powered compliance systems remain both technologically effective and religiously legitimate as global halal trade continues to expand.

CONCLUSION

The most significant finding of this study is the identification of AI as a transformative catalyst capable of strengthening digital halal certification through enhanced traceability, verification accuracy, fraud detection, and cross-border interoperability. This research demonstrates that AI-enabled systems not only streamline technical aspects of compliance but also reinforce the credibility of halal governance by supporting Shariah oversight mechanisms. The results differ from previous studies by empirically showing that AI adoption is not merely a technological enhancement but a governance innovation that reshapes how certification bodies manage religious, regulatory, and logistical complexities in global trade. The comparative analysis further reveals stark performance gaps between high-adoption and low-adoption jurisdictions, underscoring the critical role of AI maturity in determining international halal market competitiveness.

The study offers conceptual and methodological contributions that advance the field of halal governance and digital compliance. Conceptually, it introduces an integrated framework that connects AI governance principles—such as algorithmic transparency, explainability, and data standardization—with Shariah compliance requirements, producing a hybrid model of ethical and technological oversight. This integrated lens enriches the discourse on halal certification by situating AI within both regulatory science and Islamic jurisprudence. Methodologically, the research employs a multi-layered analytical strategy combining doctrinal analysis, statistical inference, cross-case comparison, and thematic coding. This triangulated approach yields a comprehensive understanding of how AI functions within certification ecosystems and provides a replicable methodological model for future studies on digital compliance in faith-based regulatory environments.

The study is limited by uneven access to proprietary AI systems, confidential technical documentation, and cross-border regulatory data. These limitations constrain the depth of analysis regarding algorithmic architectures, cybersecurity protocols, and the operational logic of proprietary compliance tools. Another limitation lies in geographic variation, as the sample is concentrated in regions with emerging or intermediate digital readiness, leaving highly advanced or minimally digitized jurisdictions underrepresented. Future research should expand to include technical audits of AI decision processes, large-scale comparative studies across continents, and empirical evaluations of consumer trust in AI-driven halal certification. Further investigation into AI-Shariah co-governance models, development of global interoperability standards, and exploration of explainable AI for halal verification will be crucial for advancing the field and ensuring ethically grounded technological adoption in global halal trade.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; Investigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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