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A review on integrating food science and law for digital halal evidence in Indonesian logistics

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ABSTRACT
The integrity of halal ingredients in cold chain logistics relies on biological safety and legally verifiable traceability for storage and transportation. Traditional halal certifications, however, still rely. Mostly on periodic manual inspection and paper, which in themselves offer only snapshot proof and cannot guarantee continuous compliance or provide legally binding digital proofs. This constrains the bridging between scientifically determined quantities and regulatory validation. The study proposes a comprehensive integrated interdisciplinary evidentiary model based on the intersection of food science measurement, Internet of Things (IoT) monitoring, and blockchain technology to convert temperature stability and segregation compliance information into legally acceptable halal digital evidence. A qualitative research design using systematic literature review (2015 – 2025), technical validation analysis, and qualitative case study evaluation of logistics monitoring practices was applied.

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INTRODUCTION

Currently, halal assurance in Indonesia has progressed from a matter of individual religious observance to an inclusive legal and economic obligation regulated by domestic law (Masri et al., 2025). Indonesia is the largest Muslim-majority country in the world and the largest halal consumer market, where the country represents a key platform of the global halal economy, with domestic consumption of halal products estimated to be more than USD 200 billion per annum. The implementation of Law No. 33 of 2014 regarding Halal Product Assurance and its implementing legislation, namely, Government Regulation No. 39 of 2021, created a mandatory system for halal certification involving production, storage, transportation, and distribution (Supriyadi et al., 2024).

The new regulations clearly assign full legal accountability to business owners, who must maintain and prove halal security throughout the supply chain (Latif & Sambas, 2025). In addition, the regulation embeds stringent administrative enforcement, which, for example, imposes a 2026 requirement for logistics businesses to obtain halal certification. If you provide no verifiable documentation of your halal compliance, you face not only loss of consumer confidence but also administrative sanctions, business restrictions, and exclusion from halal-certified markets (Nurhayati et al., 2025). As a result, there is now a need for halal assurance in Indonesia not only for biological compliance, but also for legally and quantitatively verifiable evidence, which can withstand audits and regulatory enforcement (Nihayati, 2025).

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From a food science point of view, the integrity of halal is the inseparability of *halalan tayyiban*, including its permissibility and biological safety (Tan et al., 2022; Yang & Bao, 2011). The *tayyib* concept highlights that the requirement of halal is for the food to be safe, to be wholesome, and to be clean and not to be spoiled or deteriorated.

Pajić et al. (2024) said that cold chain logistics function as a crucial biological management system in maintaining food safety and quality in storage and during transportation. Even small temperature changes ranging from -18°C to -12°C accelerate biochemical degradation such as lipid oxidation and protein denaturation, and any rise into the chilled range lets psychrotrophic pathogens such as *Listeria monocytogenes* grow. In the halal regulatory context, this biological compromise could jeopardise the halal fabric of integrity since it is against the principle of tayyiban that the container is contaminated, spoiled, or improperly stored. Thus, temperature stability needs to be more than just a quality control process; it is a basic scientific necessity for ensuring halal integrity.

But food science has robust methods for measuring temperature stability and detecting biological risks; the legal system needs evidence that can be verified and admitted as compliant (Fitri et al., 2025; Malaikhah et al., 2021). In the context of regulatory practice, integrity is determined by more than the actual biological state of the product; it requires objective, verifiable, and tamper-proof evidence that the product has followed regulations.

Traditional halal logistics monitoring systems across Indonesia depend on manual document logging, periodic inspection, and paper materials. These methods pose a tremendous evidentiary challenge due to manual records being susceptible to human error, late updates, incomplete paperwork, and manipulation. Tai (2018) also mentioned that cold chain logistics is one of the more critical and vulnerable areas of the supply chain, given the direct implications for biological safety and compliance integrity of transportation and storage conditions. If temperature changes occur between routes, with monitoring not consistently valid and verifiable, the result is a "legal liability gap," making it challenging to ascertain objectively whether halal accuracy has been preserved or breached.

This evidentiary constraint underscores the need for digital monitoring systems to provide continuous, verifiable, and legally admissible compliance data. Internet of Things (IoT) monitoring systems enable continuous automated monitoring of temperature and environmental conditions throughout the logistics process. IoT sensors can obtain fast and often high-frequency, real-time data that can offer biological verification processes that are objective and continuous (Alamsyah et al., 2022). Yet although IoT technology guarantees scientific validity, it does not automatically allow legal validity unless recorded data are secure against manipulation or change.

Blockchain is a complementary solution: through cryptographic hashing and decentralized consensus, it secures the integrity, traceability, and non-repudiation of data, so records cannot be altered retroactively without detection. Combining IoT measurement with blockchain anchoring forms a "double-verification logic": biological conditions are monitored continuously, and every stored record is written to a tamper-proof ledger. This integration makes possible the establishment of an unbroken digital chain of custody, where all temperature readings and transfers (internally or externally) are documented. This digital chain of custody offers regulators trusted and auditable evidence for better transparency, accountability, and compliance enforcement (Ali et al., 2021).

Most of the previous research either reports on the implementation of technology or policy-related issues; few works address the interdisciplinary intersection of food science with digital technology and legal evidentiary standards (Jalaluddin et al., 2024). This research fills this gap by proposing an integrated evidentiary system that could translate scientific measurements into legally valid digital evidence within the Indonesian halal regulatory setting.

Based on the systematic literature review from 2015 to 2025, complemented by a qualitative case study on Indonesian halal logistics, three main aims are the objectives of this study. First, it assesses the scientific and legal constraints of conventional manual verification systems in halal cold chain logistics (Ellahi et al., 2026; Lahmar & Al Qaruty, 2026; Tieman & Ghazali, 2014). Second, it provides a digital evidentiary approach grounded in IoT monitoring coupled with blockchain technology that caters to biological and legal admissibility obligations (Riaz et al., 2026; Tanzid et al., 2026). Third, it offers a policy-oriented framework for formal recognition of blockchain-secured monitoring data as valid primary evidence in halal regulatory audits (Alamsyah et al., 2022; Nisa' et al., 2026). Drawing

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on food science, digital technology, and legal compliance principles, the study aims to provide a scientific and legally enforceable digital halal assurance framework in support of modernizing Indonesia's halal certification system.

RESEARCH METHOD

Materials

The cocoa beans that have been fermented and dried under the same conditions were bought from a local farmer in Patuk, Gunungkidul, Special Region of Yogyakarta, Indonesia. Dried fermented cocoa beans were brought to the laboratory within two hours. To determine their physical characteristics, a random selection of healthy, uninjured samples was made. It is recommended to gather more cocoa beans than is necessary for the sample to standardize the sample in the lab (selection of cocoa beans that were possibly damaged during transport or otherwise) (Rossetti et al., 2022). All experiments in the laboratory were conducted at room temperature (25 ± 2°C).

Methods

This research employs a qualitative interdisciplinary research design following a Normative–Technical Hybrid methodology that combines food science, logistics management, information technology, and digital legal analysis. Although food science offers objectively assessed biological safety indices, including temperature stability and product separation, regulatory measures also require valid documents that comply with evidentiary standards as laid down under Indonesia's Halal Product Assurance Law (Undang-Undang Jaminan Produk Halal, UU No. 33 of 2014) and the applicable regulations. This study is based on an empirical foundation and is designed around three complementary research components to provide scientific and legal credibility: systematic technical–legal review, qualitative case study and operational observation, and analytical framework development and validation.

In Phase 1, systematic Technical-Legal Review. Phase 1 involved a systematic review of technical, legal, and regulatory literature published between 2015 and 2025 across key academic databases, including Scopus, ScienceDirect, and Google Scholar. Guided by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) principles, candidate literature was identified using search strings combining terms related to halal cold-chain logistics, IoT telemetry, blockchain cryptographic integrity, and electronic evidence (*Alat Bukti Sah*).

Literature was screened through a multi-stage qualitative filtering process, evaluating title relevance, abstract thematic alignment, and full text contextual suitability to eliminate out of scope non cold chain studies or contexts lacking legal regulatory integration. The resulting core selection of literature was synthesized to establish the theoretical and normative foundations of the Double-Verification Logic model (Figure 1).

In Phase 2, a qualitative case study and practical analysis were conducted. In addition to the theoretical and regulatory considerations in this chapter, a qualitative case study strategy was utilized to analyse how halal cold chain logistics is executed in practice, and evidentiary shortfalls were elucidated. The case study focuses on logistics providers that operate in Indonesia's cold chain sector, especially those going through their digital transformation from manual document systems to automated monitoring platforms. Data collection features semi-structured interviews with fifteen key stakeholders representing varying positions in the halal logistics environment: cold chain logistics managers, halal compliance supervisors, quality assurance personnel, and regulatory auditors.

In addition to interviewing the interviewees, direct operational observations were made at 3 main logistics premises to evaluate on-the-ground monitoring methods, workflows in documentation, and digitalisation systems application. These observations concentrated on temperature monitoring methods, record-keeping systems, and data integration between the private monitoring system and the regulatory reporting system. This qualitative approach offered insights into the "evidentiary gap" between biological monitoring and legal verification – this shows the weakness of manual monitoring systems and the potential benefits of digital monitoring technologies.

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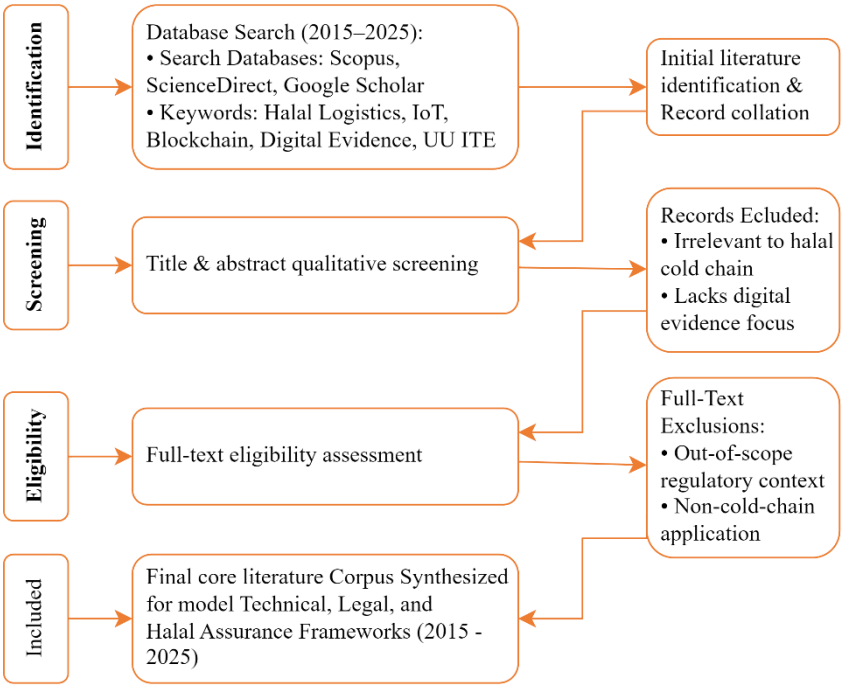


Figure 1. Qualitative PRISMA literature selection and filtering workflow (Moher et al., 2015; Page et al., 2021).

In Phase 3, the analytical framework and validation were developed. This study developed an evidentiary model based on the results of a systematic review and case study, which was termed the Double-Verification Logic Framework as the main analytical contribution. This framework combines scientific surveillance and legal scrutiny systems under a single compliance architecture. This third part comprises scientific validation for the accuracy, reliability, and frequency of IoT sensor measurements, confirming that biological monitoring data accurately matches the real environment. Continuous temperature monitoring permits the detection of deviations that could jeopardize biological safety and halal compliance. The final legal validation part is aimed at securing sensor data by hash cryptography and blockchain ledger anchoring. The framework converts sensor data into cryptographic digital records in a tamper-proof way, providing integrity, traceability, and non-repudiation of data. The framework was assessed against Indonesian legal guidelines for admissibility of electronic evidence, which include the need for data authenticity, integrity, accessibility, and reliability. This validation was designed to keep the proposed framework on the same track as the regulations on administrative enforcement and electronic documentation.

Ethical and regulatory issues study procedures: All research was conducted in accordance with the ethics-related guidelines of academic interdisciplinary research. Privacy and anonymity of interviewees were ensured in order to guarantee ethical consideration. The incorporation of regulatory factors was achieved in order to meet the criteria of the halal certificate systems in Indonesia and regulatory requirements. The developed digital evidentiary system was developed to supplement existing halal certificate principles rather than replace or change religious conformity requirements. Rather, the framework provides regulatory transparency, enhancing audit reliability and improving compliance validity through scientifically informed and technologically secure digital oversight mechanisms.

RESULT AND DISCUSSION

Diagnosing the discrepancy of legal responsibility between manual halal logistics and the manual halal system

The results of the operational evaluation demonstrate a profound structural discrepancy between the statutory mandates of the Indonesian legal system and the practical execution of halal cold chain logistics. Under Indonesia's statutory framework on halal product assurance, business operators bear

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continuous strict liability to guarantee the halal integrity of products across the entire supply chain, including storage and distribution. However, a critical legal discrepancy arises when evaluating how compliance is proven in regulatory audits and administrative proceedings: electronic records qualify as valid legal evidence only if their authenticity, integrity, availability, and non-repudiation can be mathematically and procedurally guaranteed. Conventional halal logistics monitoring relies primarily on periodic manual logbooks and paper-based physical inspection certificates. This creates a severe legal evidentiary discrepancy across four core legal dimensions:

Administrative Snapshot vs. Continuous Legal Liability.

In this situation, manual logs are recorded at discrete intervals that commonly provide only intermittent proof, leaving unrecorded time windows where temperature excursions or cross-contamination may occur without regulatory detection, as they are based on manual log-taking and periodic physical inspection-based monitoring. Where traditional halal assurance systems historically focused on manual audit and human control, modern logistics systems present highly complex ongoing biological processes of which incomplete documentation can only be reliably recorded periodically. This mismatch between biological reality and evidentiary documentation creates a significant "Legal Liability Gap".

Subjective Declaration vs. Statutory Authenticity.

Manual logs represent unverified human declarations rather than objective technical facts. Under judicial scrutiny, handwritten entries lack cryptographic origin verification, failing the authenticity threshold required for *Alat Bukti Sah*.

Susceptibility to Tampering vs. Non-Repudiation.

Paper records and unencrypted spreadsheets lack inherent tamper-proofing mechanisms. They are subject to retroactive alteration, delayed entry, data suppression, or falsification, violating the principle of non-repudiation required for statutory enforcement.

Biological Reality vs. Legal Admissibility.

From a food science perspective, temperature spikes trigger rapid microbial growth and enzymatic degradation; biologically compromised compounds may crop up without any legally verifiable evidence to prove they are true. Cold chain integrity serves as the principal biological brake stopping microbial proliferation; particularly, psychrotrophic microorganisms such as *Listeria monocytogenes*, *Pseudomonas spp.*, and *Enterobacteriaceae* are able to grow at refrigeration temperatures. Yet, in spite of the existence of scientific measuring systems capable of detecting biological deviations, the legal verification of halal compliance is based not only on the biological condition itself but also on the availability of verifiable, reliable, and admissible evidence of compliance. Under Indonesia's Halal regulation, especially Law No. 33 of 2014 that relates to Halal Product Assurance, business operators are fully responsible for the legality of the halal function, and that is also to demonstrate halal integrity. This duty covers the need to show that products are adequately handled, stored, and transported in line with halal regulations. Within this framework, compliance evidence must meet administrative evidentiary standards; specifically, authenticity, traceability, and integrity.

Manual monitoring systems fundamentally cannot meet these factual criteria. Manual logs have always been subjective human declarations, not objective technical measurements fixed against tampering in human judgment (Hasan & Latif, 2024). Insights from interviews with logistics operators also showed that temperature is recorded periodically rather than continuously (in hours, sometimes at times), as the temperature records were recorded. Manual systems of documentation are another tool for the suppression of information that is subject to tampering by human error, delayed receipt and recording, omission of documentation, and deliberate alteration (Julian et al., 2025). In the absence of tamper-resistant data, regulators cannot tell for certain if captured information reflects true environmental conditions. Thus, if they are done manually, the record will fail to offer the reliable forensic evidence necessary to support regulatory enforcement or dispute resolution. Results of this

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study support that the discrepancy between scientific monitoring capability and legal evidentiary reliability is one of the key structural weaknesses of the current halal logistics system (Li et al., 2022; Pan et al., 2021).

Table 1 presents the comparative evidentiary attributes of conventional manual monitoring systems and the digital IoT–blockchain framework.

Table 1. Analyzing common evidentiary standards in the field of halal logistics.

Evidentiary Criteria	Manual Logging (Traditional)	IoT-Blockchain Framework (Proposed)	Legal Implications (UU JPH)
Data Integrity	Highly susceptible to modification and human error (Bux et al., 2022).	Immutable through cryptographic hashing (Alamsyah et al., 2022).	Complies with non-repudiation requirement (Adhiwibowo et al., 2023; Hema & Manickavasagan, 2024).
Verification	Periodic and intermittent (Oh et al., 2025).	Continuous real-time monitoring (Anwar et al., 2025).	Encourages on-the-fly regulatory oversight (Müller et al., 2026).
Traceability	Patchy and partial (Shahid et al., 2020).	Full digital chain of custody (Tanzid et al., 2026).	Helps regulators with audit approval (Karia, 2022; Zailani et al., 2017).
Scientific Value	Subjective and estimated (Protopappas et al., 2025).	Objective and sensor-based (Islami & Rozi, 2026).	Establishes verifiable biological compliance (Zailani et al., 2017).

This comparative evaluation shows that the inherent evidentiary shortcomings of manual monitoring systems are structural deficiencies rather than procedural inefficiencies hindering the enforcement of halal laws as a basis for legal and ethical standards.

The Synergy: Conversion of biological monitoring data into legal digital evidence

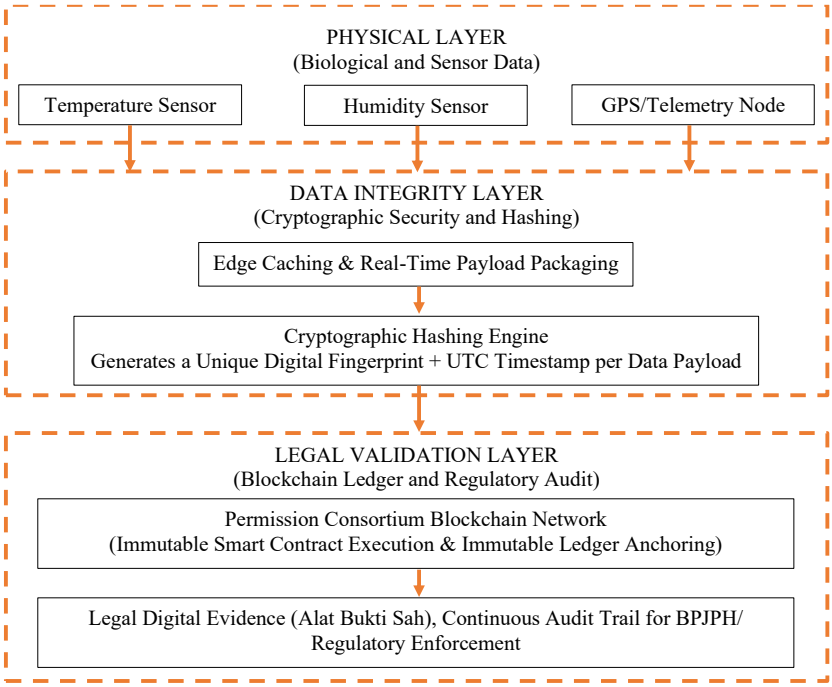


Figure 2. The double-verification logic framework.

The Double-Verification Logic framework, developed to identify the evidentiary gap in this study, demonstrates scientific measurement as well as legal validation by cryptographic means

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(Apriyani & Cahyono, 2025). As shown in Figure 2, the Double-Verification Logic framework consists of three layers sequentially, namely the physical layer, data integrity layer, and legal validation layer.

Legal Validation Layer: Blockchain Ledger and Proof Storage. Thereby, this Legal Validation Layer secures data using cryptographic proofs via a chain of hash keys and creates permanent and immutable digital records built on the blockchain (Anwar et al., 2025). Each recorded data entry is linked to previous entries through cryptographic chains, creating an unbroken sequence of verifiable information (Yakubu et al., 2025; Zhang et al., 2022). From a legal perspective, blockchain ledger anchoring provides critical evidentiary properties, including immutability, traceability, and non-repudiation. Such characteristics guarantee that recorded data can provide credible electronic evidence in regulatory auditing and administrative proceedings.

This interconnected architecture converts biological sensor measurements into certified digital evidence that meets electronic evidence admissibility requirements set by Indonesia's regulatory authorities.

Empirical Evidence on Regulatory Harmonization and the Transition to Digital Halal Certification.

Implementation and adaptation of digital monitoring technologies in halal logistics systems need not only technical integration but also to be combined with regulatory harmonization and institutional changes. Although the official regulatory framework in Indonesia acknowledges electronic information and digital documentation as valid forms of evidence, the technical framework for digital halal monitoring implementation is still in the process of development. A phased implementation approach for the inclusion of digital evidentiary standards in Indonesia's halal certification system is shown in Figure 3.

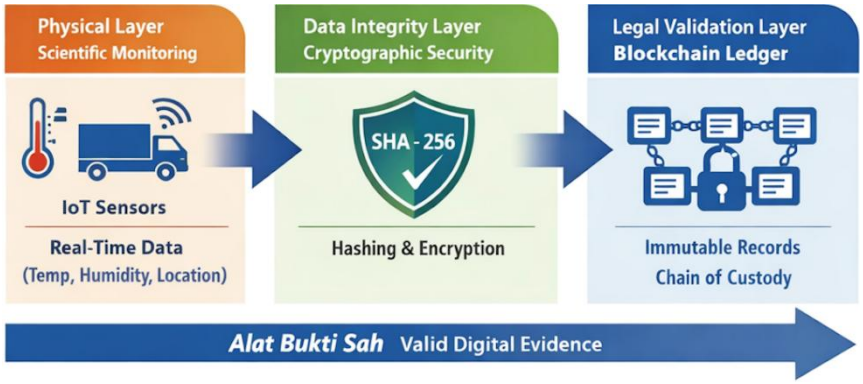


Figure 3. The double-verification logic: transforming IoT biological data into immutable digital evidence (*Alat Bukti Sah*) (Islami & Rozi, 2026; Müller et al., 2026; Oh et al., 2025).

In Phase 1, Digital monitoring protocols are standardized. The first stage is to provide universal data formats and communication protocols in place so that private monitoring systems and regulatory bodies can work with one another at the inter-platform level. Standardized data structures, such as JavaScript Object Notation (JSON) and Extensible Markup Language (XML), allow for the exchange of data across many monitoring software tools and regulators' databases across the data platforms and databases at a standardized level. Uniform standardisation means that monitoring information generated by several logistics providers can be consistently interpreted and assessed by regulators.

In Phase 2, Integration using Regulatory Application Programming Interfaces (APIs), the second step includes the establishment of secure application programming interfaces (APIs) for the integration of private monitoring systems and regulatory oversight platforms. Through OAuth 2.0 protocols, secure authentication mechanisms guarantee that only authorized and certified logistics providers are allowed to submit monitoring data. By doing so, the authentication process upholds the data integrity of the monitoring system and also prevents unauthorised data from being submitted. API integration reduces the requirement for manual data input and the potential risk of transcription errors.

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In Phase 3, Continuous digital auditing enforces regulatory standards. In the last phase, it goes from traditional periodic inspections to a seamless digital audit model. Real-time monitoring provides regulators with data on how well they are complying and enables automated compliance checks. This kind of predictive monitoring improves regulatory efficiency and compliance enforcement effectiveness (Purwaningsih et al., 2024; Rofi'ah et al., 2024).

Implications for scientific, legal, and regulatory practice for science, law, and regulation. At a scientific level, monitoring the environment throughout a day makes biological safety verification more convenient because it allows for accurate and timely detection of environmental differences. From a legal standpoint, the protective measures offered by cryptographic data security and blockchain-anchoring technology can be used as secure and admissible digital evidence to support law enforcement. From a regulatory viewpoint, digital monitoring systems allow the shift from trust-based compliance models to evidence-based regulation with respect to regulatory oversight. Continuous digital monitoring offers regulators compliance information that is reliable, objective, and verifiable, thereby improving transparency and accountability (Alamsyah et al., 2022). This new paradigm shift in halal certification systems will facilitate scalable, efficient, and reliable compliance verification to power the economic success and potential growth of the halal sector of the Indonesian economy.

Figure 4 represents a paradigm shift: by adopting the digital blueprint illustrated in the roadmap, the government can move from periodic, labor-intensive physical inspection to continuous digital auditing; regulators can have access to the blockchain ledger to verify compliance in real time, reducing the administrative burden on logistics providers and the government, allowing for faster certification renewals.



Figure 4. Strategic Roadmap for Integrating Digital Evidentiary Standards into the National Halal Certification Framework (Hema & Manickavasagan, 2024; Oh et al., 2025; Protopappas et al., 2025).

CONCLUSION

This study shows that traditional manual verification methods in halal cold chain logistics are both scientifically and legally insufficient to meet the evidentiary requirements of Indonesia's Halal Product Assurance system. The findings indicate a vital Integrity Gap where biological risks tracked by food science parameters still do not transfer to legally admissible evidence required by regulatory enforcement. Integrating IoT telemetry with blockchain-secured cryptographic validation introduces the Double-Verification Logic framework as a unique interdisciplinary evidentiary architecture in this research. The framework converts real-time biological monitoring data into a digital archive that will be immutable to meet conditions required by scientific verification and legally admissible evidence (*Alat Bukti Sah*). This digital chain of custody results in continuous verification of biological stability and data integrity, and avoids evidentiary uncertainty due to manual monitoring limitations. The proposed model has practical and regulatory implications for the ongoing development of Halal Certification in Indonesia. First, regulators need to set formal technological standards that recognize blockchain-secured digital records as primary evidence of compliance. Second, integrating logistics management systems with national halal certification platforms with standardized APIs, for instance through SIHALAL, will provide regulatory monitoring on a large scale and in real time. Third, digital monitoring technologies offer legal risk mitigation to logistics providers, as they enable objective evidence of compliance. Food science, digital monitoring, and legal evidentiary systems must be consolidated, which marks a new phase in halal governance. Indonesia can shift from trust-based certifications into a proof-based regulatory ecosystem by institutionalising scientifically validated and cryptographically secured digital evidence. This study has theoretically added a formal interdisciplinary

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bridge of food science monitoring systems to the digital evidentiary standards in halal governance. Prior research has independently worked on problems such as halal certification, cold chain monitoring, or blockchain traceability; however, this work combines biological validation and legal admissibility into a unified evidentiary architecture. The Double-Verification Logic framework forms a replicable model for transforming scientific telemetry into legally enforceable compliance evidence and fills a critical gap in halal logistics scholarship and regulatory practice.

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