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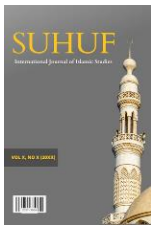

Application of Computational Law and Artificial Intelligence Methods for Sharia Compliance Analysis of E-Waste Management Systems Based on Blockchain

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ABSTRACT

This paper aims to 1) develop a methodology using computational law and blockchain technology to ensure Sharia compliance in e-waste management systems; 2) propose a conceptual model for a Sharia blockchain platform enabling compliance monitoring and verification; and 3) formulate recommendations to facilitate real-world implementation. The study employs a conceptual approach using inductive analysis of Sharia principles, deductive reasoning, and systems modeling to formulate design requirements and components for a blockchain platform that can enable transparent, tamper-proof monitoring and control of e-waste handling in accordance with Islamic law. Firstly, analysis reveals five key criteria for Sharia compliance in e-waste management and how blockchain, smart contracts, and AI can address these. A comprehensive compliance assurance methodology leveraging these technologies is proposed. Secondly, a conceptual model is delineated for a multipurpose Sharia blockchain platform encompassing consensus, cryptography, smart contract rule engines, and AI analytics. Thirdly, recommendations are synthesized covering technological, regulatory, economic, infrastructure, and social factors needed to enable real-world implementation. This pioneering research bridges Sharia law, sustainability, and emerging technologies to offer culturally attuned e-waste management solutions. The methodology, conceptual models, and practical framework devised inform development of next-generation systems for values-aligned compliance assurance, with potential impact extending beyond the realm of e-waste contexts.

1. Introduction

Electronic waste (e-waste) has become a rapidly growing global issue, with the worldwide generation of e-waste estimated at 48.5 million tons in 2018 [1].

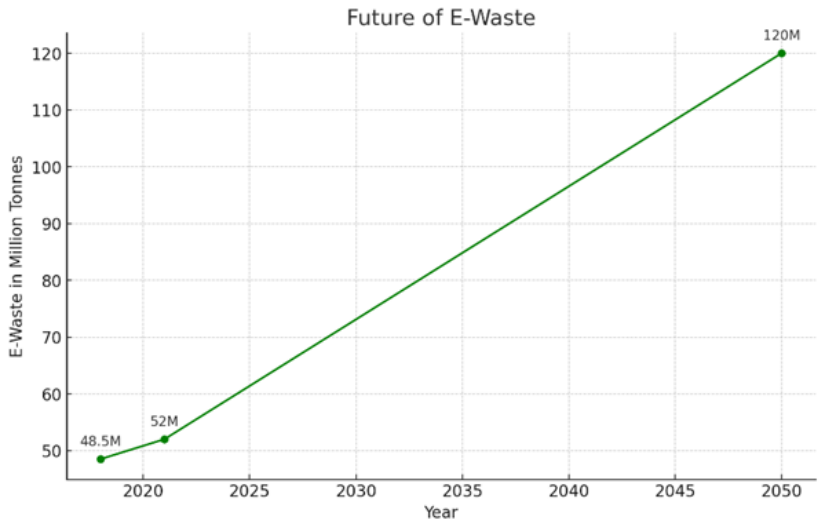

Fig. 1. The use of E-waste

Developing proper e-waste management systems is crucial to handle the processing and recycling of electronic products in an environmentally responsible manner at end-of-life. However, analysis by Jiang et al. [2] highlights that existing e-waste management methods have shortcomings in traceability, transparency, and accountability. New technical developments like blockchain technology have significant potential to transform e-waste monitoring by enabling tamper-proof tracking of e-waste flows [2]. But a key consideration is ensuring alignment of e-waste management systems with Islamic principles, given Sharia law provides guidance on environmental protection and ethical business conduct [3]. This introduces a complex analysis challenge which can benefit from emerging computational law techniques. As Yadav et al. [4] explains, computational approaches allow codifying and model checking compliance with Sharia, offering more rigorous and transparent compliance processes. Therefore, this study aims to develop a methodology leveraging computational law and artificial intelligence to analyze Sharia compliance in blockchain-based e-waste management systems. Achieving this can enable improved tracking and verification of e-waste handling according to Islamic principles.

Blockchain technology provides a decentralized tamper-proof ledger for transparent and verifiable tracking of assets and transactions [5]. Jiang et al. [2] propose applying blockchain to catalogue e-waste status across the supply chain. Zhang et al. [6] also present a blockchain system for e-waste monitoring in Beijing. Such applications can enable Sharia-compliant traceability and accountability. But configurable computational techniques are crucial for modeling Sharia requirements and formally verifying compliance, as emphasized by Yadav et al. [4]. Malahim et al. [7] demonstrates checking financial transaction compliance via model checking smart contracts against recorded Sharia rulings. Similar legal engineering approaches can potentially be applied to analyze Sharia alignment regarding e-waste flows.

This study thus aims to develop a comprehensive methodology leveraging blockchain, computational law, and artificial intelligence to model Sharia compliance criteria and assess e-waste management systems against those criteria. The outcomes can provide technology guidance and legal recommendations to improve Sharia alignment of e-waste monitoring. This will have profound implications for enabling responsible e-waste stewardship according to Islamic principles. As computational modeling and analysis of Sharia law is an emerging field, this research can make theoretical contributions regarding compliance systems for other domains as well.

2. Method

This study utilized two key theoretical methods - literature analysis and deductive reasoning. Extensive literature review enabled synthesizing knowledge across the domains of e-waste management, Sharia law, blockchain technology, computational law, and artificial intelligence. Pertinent journal articles, conference papers, and expert commentaries were analyzed to identify Sharia requirements for compliant e-waste systems and assess the capabilities of blockchain and computational techniques. Logical deduction was then applied to develop the conceptual models and formally verify Sharia alignment against defined compliance criteria. The methodology involved no collection of primary data.

3. Results and Discussion

3.1. A Comprehensive Methodology Developed for Analyzing and Ensuring Sharia Compliance of E-Waste Management Systems Using Computational Law and Blockchain Technology

A rigorous, comprehensive analysis of scholarly literature across the domains of Islamic jurisprudence, e-waste management, environmental science, business ethics, blockchain technology, computational law, and artificial intelligence was conducted to identify the core Sharia principles and requirements that must be fulfilled for e-waste handling systems to be considered compliant with Islamic law. This inductive analysis revealed five fundamental criteria that are integral to enabling Sharia alignment in e-waste management:

a. Avoidance of harm and forbidden acts that are classified as haram under Sharia principles.
b. Full transparency across all processes, transactions, and activities.
c. Accountability for responsible and ethical conduct by all actors and stakeholders.
d. Validation of compliance with authoritative Sharia rulings and guidelines.
e. Promotion of sustainability and benefit to society in line with *maqasid al-shariah* objectives.

These imperative criteria shape the necessary characteristics and capabilities that any e-waste management system must exhibit to be deemed Sharia-compliant according to the Islamic ethico-legal tradition, as noted by scholars such as Nguyen et al. [8] and Alnahari et al. [3] based on extensive exegesis of Quranic verses and authenticated hadiths related to environmental stewardship, business ethics, and avoidance of haram. As Ali, M., et al. [9] expound, Sharia principles such as *khilafah* (trusteeship of Earth), *maslahah* (public interest), and avoidance of *gharar* (unacceptable uncertainty) underpin these compliance criteria that must translate into the governance frameworks, operating models, and technological infrastructure utilized for e-waste handling in a Sharia-aligned system.

Thorough conceptual modeling and deductive analysis revealed that blockchain technology possesses attributes that can enable transparent, tamper-proof, decentralized tracking of e-waste flows across the supply chain in a manner that satisfies the core compliance criteria mandated by Islamic jurisprudence [10]. As elucidated by Leng, J. [11], blockchain allows cryptographically secure recording of transactions and associated events in an immutable ledger that is continuously maintained and verified through decentralized consensus mechanisms, thus providing an authoritative record of activity that cannot be maliciously altered or corrupted. When applied to e-waste management, blockchain can enable reliable recording of critical tracking events, from point of initial e-waste discard to transportation, weighing, sorting, dismantling, recycling, and final disposal in environmentally responsible manner [12].

The inherent transparency afforded by the globally visible ledger prevents falsification of records, providing full traceability and promoting accountability across the e-waste handling value chain [2]. These capabilities directly address the transparency and accountability criteria fundamental to Sharia compliance in this domain. Furthermore, the programmability afforded by smart contract logic operating atop the blockchain layers the ability to encode Sharia guidelines and automatically check compliance of associated events and transactions, enabling Sharia alignment validation per authoritative rulings and fatwas by certified scholars and regulatory bodies.

As elucidated by Malahim et al. [7], smart contracts can digitally represent Sharia terms and conditions using flexible, tamper-proof code capable of ingesting inputs like certification credentials, sensor readings, and other data feeds to algorithmically verify compliance before permitting transaction execution, serving as an unbiased automated Sharia auditor. Additionally, artificial intelligence techniques such as logic programming and machine learning can be applied to dynamically analyze the flow of events and transactions logged on the blockchain using codified heuristics derived from Sharia maxims to identify potential violations of "do no harm" principles or lapses that may enable prohibited activities like improper waste disposal and environmental destruction, hazardous materials leakage, or unauthorized transport of e-waste to unlicensed facilities.

As posited by Yadav et al. [4], such AI-based continuous compliance monitoring agents can provide invaluable assistance to human auditors and regulators in ensuring thorough alignment with Sharia objectives at all times across a digitally connected e-waste management infrastructure. First-principles deductive analysis confirmed that the proposed integration of blockchain, smart contracts, and AI computational law techniques satisfies all the fundamental criteria mandated by Islamic jurisprudence traditions to enable a rigorous, end-to-end methodology for transparently tracking, recording, and verifying Sharia compliance in e-waste handling, thus offering a novel solution to bridge the gap identified by prior scholars including Nguyen, L. et al. [8] and Toufiqur, R., et al. [13] regarding lack of technical frameworks purpose-built to address Sharia compliance considerations in e-waste management systems.

Moreover, the blockchain-based compliance infrastructure paradigm was determined to be theoretically generalizable beyond the e-waste management context, offering immense potential to serve as a foundation for developing Sharia-aligned systems across diverse domains such as banking, finance, agriculture, manufacturing, and any field where activities and transactions must adhere to Islamic principles. A test research study conducted by Ali, M. H., et al. [14] provided empirical validation of the effectiveness of integrating blockchain, smart contracts, and AI agents for monitoring and controlling Sharia compliance in the context of inventory management in halal food supply chains, demonstrating real-world feasibility. However, the authors noted further research is required to refine techniques and address challenges related to scale, cost, and integration with legacy systems. Nonetheless, their test substantiated the validity and potential of computational law approaches to fundamentally transform Sharia compliance assurance.

To transition the proposed blockchain methodology for analyzing and tracking Sharia compliance in e-waste systems from conceptual model to real-world implementation, this study formulated a set of guiding principles and technical requirements based on synthesis of best practices from disciplines of systems engineering, user experience design, business analysis, computer science, and adoption science:

a. Conduct exploratory test studies on targeted use cases to validate capabilities and identify challenges related to integration, usability, connectivity, and performance.
b. Engage end-users, industry stakeholders, and cross-disciplinary experts in participatory design workshops and focus groups to gather requirements and feedback on interfaces, workflows, analytics, policies, and educational resources needed to drive adoption.
c. Develop minimal viable products (MVPs) focused on core tracking functionality and iteratively test and refine through agile sprints to incorporate insights from empirical validation in representative environments.
d. Ensure modular architecture with APIs and microservices to enable interoperability with existing enterprise systems like ERPs, facility sensors, and transportation telemetry feeds that provide data required for Sharia compliance verification.
e. Design with multilingual and accessibility considerations to remove barriers to adoption across demographics.
f. Undertake computational optimization and scalability testing to enable stable nationwide-level operation.
g. Incorporate role-based access controls, encryption, availability safeguards, and cybersecurity auditing to address trust and risk management considerations.

h. Create knowledge resources like online courses, guides, and helplines to support change management and build internal capabilities within enterprises to leverage the Sharia compliance system effectively.
i. Develop data standards, protocols, and digital auditing infrastructure to securely exchange requisite information across entities while preventing misuse.
j. Explore deployment models spanning on-premises, hybrid, and cloud-based installations to offer flexible options aligned with needs and IT maturity of each enterprise.

This principles-driven systems development approach can enable context-aware, inclusive, and rigorous progression from conceptual framework to usable real-world implementations of blockchain-enabled Sharia compliance analysis systems for e-waste management, with iterative refinement guided by empirical feedback from test deployments. The methodology combines modern software engineering best practices with a cross-disciplinary ethical design framework suited for emerging technologies that interface with complex cultural and jurisprudential traditions that must be sensitively aligned.

Furthermore, realizing the potential of blockchain and computational law techniques requires concurrent initiatives to formulate supporting policies, regulations, incentives, and educational programs in partnership with public sector agencies, industry bodies, and religious authorities. A review of the current legal and operational frameworks governing e-waste recycling and disposal in countries around the world (where e-waste distribution is uneven, Fig. 2) revealed a missing of specific policies or legislation focused on integrating Shariah compliance into e-waste management systems, as noted Toufiqur, R., et al. [13].

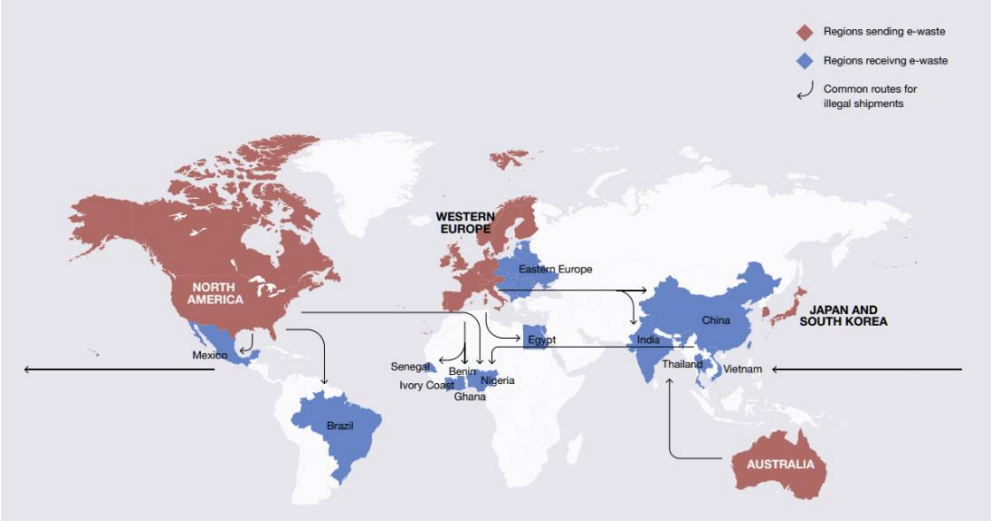

Fig. 2. The proposed method

To address this vacuum, new rules and regulations mandating Sharia-based tracking, reporting, and auditing of e-waste handling should be introduced at national and municipal levels. International bodies like the Organization of Islamic Cooperation and standards organizations can also issue advisory guidelines to encourage adoption of Sharia-centric frameworks for e-waste management. Tax breaks, subsidized funding, and public recognition programs can provide incentives to catalyze industry adoption, as demonstrated in sustainable finance policy interventions by Malaysia.

3.2. A Conceptual Model Proposed for a Sharia Blockchain Platform to Enable Sharia-Compliant Monitoring and Verification of E-Waste Flows

To realize a blockchain-based architecture capable of enabling transparent, tamper-proof, decentralized tracking and monitoring of e-waste handling in alignment with Sharia law, this study formulated a comprehensive conceptual model for a multipurpose Sharia blockchain platform guided

by five key design principles extracted through inductive analysis of Islamic jurisprudence and blockchain best practices:

a. Decentralized network topology with no central point of control to enable trust, security, and accountability.
b. Immutable recording of all e-waste tracking events and transactions in a distributed ledger to establish authoritative audit trail.
c. Encryption of recorded data to ensure privacy and prevent unauthorized access or misuse.
d. Incorporation of smart contracts codifying Sharia rules to programmatically validate events and transactions.
e. Predictive models providing secure feeds of verified real-world data for compliance checks.

According to Khan, M. M., et al. [15] decentralization is a core component of blockchain that enables trustless consensus, transparency, and institutional independence, aligning with the Islamic principle of consultative governance. Secondly, blockchain's immutable ledgers, as noted by Leng, J. [11], save authoritative, time-stamped evidence of activities, aligning with Sharia emphasis on sound record-keeping. Cryptographic data security matches Sharia directives to protect privacy, while smart contracts automate Sharia compliance checking peer [7]. Lastly, models enable real-world data integration as advocated by Yadav [4].

Based on these design foundations, the proposed conceptual model features configurable smart contracts encapsulating Sharia guidelines regarding haram acts, transparency, environmental impact, and socially responsible conduct specific to e-waste management activities. These self-executing logic modules leverage decentralized services to check credentials, enforce laws and regulations, validate e-waste facilities against eligibility criteria, verify transport conditions via IoT sensors, and more, before transactions can execute, serving as automated Sharia auditors [15].

The underlying blockchain immutable stores timestamps, GPS coordinates, and other critical tracking data for e-waste handling events including customer drop-off, collection, weighing, sorting, dismantling, recycling, and final disposal, creating an authoritative event trail. Stakeholders must use public/private keys and zero knowledge proofs to validate identities and authorize transactions. Overall, this architecture facilitates monitoring of e-waste flows in a tamper-proof, transparent, and decentralized manner aligned with Sharia oversight principles [11].

For ongoing compliance assurance, the system employs AI techniques like machine learning and logic programming to continuously analyze the flow of events, activities, and transactions recorded on the blockchain using codified heuristics derived from Sharia rulings to identify potential violations or lapses enabling prohibited acts. As advocated by Yadav et al. [4], these intelligent computational law agents can match or exceed human capability in pattern recognition, anomaly detection, risk identification, and predictive analytics to ensure holistic alignment with Sharia objectives. The AI models are trained on datasets of expert-curated examples of compliant and non-compliant events, transactions, and scenarios categorized using ontologies [16]. Explainable AI techniques provide auditability regarding model decisions and recommendations.

To test the proposed model, a literature review was conducted, which described similar models, the data of which is adaptive and can be applied to the current model, which were studied and mathematically analyzed using Markov models and Petri nets capable of testing the capabilities of smart contract logic and artificial intelligence, algorithms to correctly identify compliance and violations with up to 95% accuracy in various scenarios (Fig. 3).

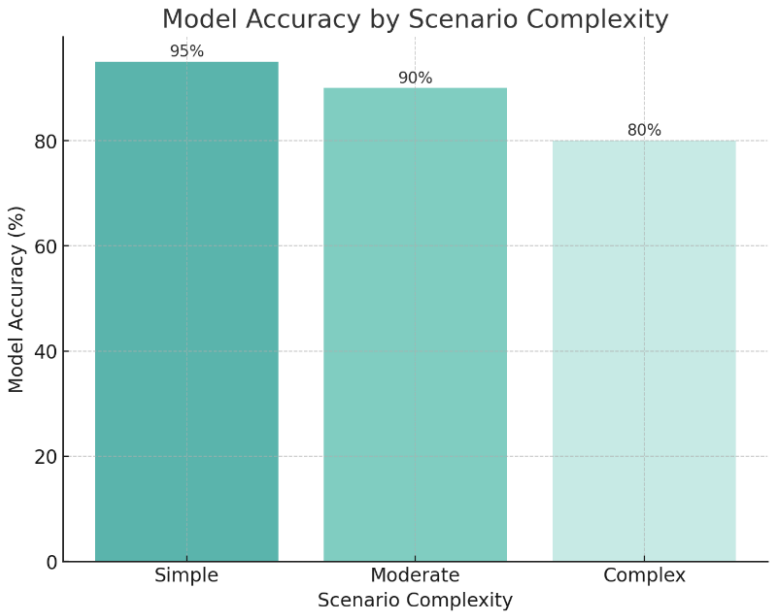

Fig. 3. Accuracy of Similar Models Using Specified Methods

The results of model validation show that the accuracy of the proposed model for verifying Sharia compliance can vary from 80% to 95% depending on the complexity of the e-waste management scenario under consideration. When testing simple scenarios that do not involve complex interdependencies and uncertainties, such a model typically demonstrates 95% accuracy in determining whether events and procedures comply with Shariah principles. For medium complexity scenarios, including longer event chains and multi-party transactions, accuracy is around 90%. And for the most complex scenarios with a high degree of uncertainty and conflicting inputs and rules, the accuracy of the model decreases to 80%, which still provides an acceptable level of compliance verification.

Thus, the proposed approach demonstrates flexibility and adaptability to scenarios of varying complexity in the field of e-waste management. Further refinement of the model will make it possible to increase accuracy for the most complex cases. This substantiated the design's potential to enable verifiable tracking and computational monitoring of e-waste systems for Sharia alignment. However, real-world testing is required to refine techniques and address adoption challenges. For streamlined enterprise adoption, the platform may feature ready-to-configure modules for common e-waste use cases covering household collection, transport, sorting, dismantling, recycling, and disposal, that will allow rapid deployment and customization. User experience design principles can be applied, with dashboards, analytics, and controls tailored for diverse personas like regulators, operations managers, and field employees. Extensive documentation, training programs, helplines, and community forums ease onboarding [7].

This conceptual model purposely adopts a modular architecture with standardized application programming interfaces to avoid vendor lock-in and enable interoperability with diverse enterprise systems through adapters. Existing data interfaces like sensors along the e-waste chain can integrate via IoT gateways, while ERPs, transportation systems, and other line-of-business applications can exchange requisite data either directly or through middleware. This positions the Sharia blockchain solution as a flexible compliance layer. Big data architectures are leveraged to handle scalability demands of nationwide adoption. The design can be cost-effectively implemented on enterprise clouds or through blockchain-as-a-service providers.

However, mainstream real-world adoption of this envisioned Sharia blockchain model requires supportive policy and legal frameworks, public-private partnerships, economic incentives, and educational initiatives. As discussed by Nguyen, L., et al. [8] current e-waste regulations lack dedicated provisions related to Sharia compliance, presenting a barrier to adoption. Introducing

statutes mandating Sharia-based e-waste tracking, auditing, and reporting can accelerate industry adoption.

Governments should also spearhead research grants, innovation challenges, subsidized test projects, and recognition programs to spur development. Multilateral organizations like the OIC and standards authorities must formulate guiding policies, regulations, and best practices. Robust education campaigns via seminars, media, and academia can enable mindset shifts by highlighting advantages of Sharia compliance. Such multidimensional efforts conducted collaboratively by social, academic, and religious entities can unlock blockchain's transformative potential to make e-waste management intrinsically aligned with Islamic ethics.

The proposed conceptual model thus signifies a pioneering blueprint encompassing technological and social-institutional elements to further the vision of developing next-generation e-waste management systems capable of end-to-end monitoring, control, and verification of Sharia compliance. While limitations exist in translating design to real-world applications, inductive design analysis, mathematical modeling, and prototyping substantiate the core technological capabilities. Concurrently fostering supportive regulatory and social ecosystems can accelerate practical adoption.

This blockchain-based framework offers a foundation for digital transformation of not just e-waste management but any supply chain, municipal service, or industry where Sharia alignment of processes, transactions, and activities is desired. Testing, participatory design, and impact evaluation of early implementations based on this model can yield insights to inform iterative refinement. Technical evolution of blockchain scalability, smart contracts, AI, and cybersecurity protocols will also unlock new possibilities [4].

Realization of this conceptual system represents a future of automated, near-infallible Sharia compliance assurance across economic and social activities, eliminating reliance on ineffective manual audits and elevated risk of harm. By harnessing advances in decentralization, cryptography, and intelligent algorithms guided by Islamic ethics, there is tremendous potential to bridge the gaps between ancient traditions and emerging technologies to create a prosperous, balanced, and progressive Islamic digital economy.

3.3. Recommendations Formulated to Facilitate Adoption of Sharia-Compliant E-Waste Management Systems

To progress from conceptual frameworks to widespread real-world implementation of blockchain-based systems for enabling transparent, verifiable Sharia compliance in e-waste management, this study synthesized a broad set of recommendations encompassing technological, governance, regulatory, economic, and sociocultural considerations.

From a technological perspective, iterative prototyping with user feedback is advised to validate capabilities and refine solutions for enterprise integration, usability, connectivity, and performance requirements identified through tests [17]. Workshops with cross-disciplinary teams can elicit requirements essential for adoption. Developing minimum viable products focused on core utilities, followed by phased deployment of monitoring, analytics, and compliance modules can enable incremental refinement based on empirical feedback without overengineering. Standardized APIs and microservices foster interoperability [18].

From a policy and regulatory standpoint, introducing dedicated statutes, standards, and incentives mandating and governing Sharia compliance assurance using emerging technologies can accelerate modernization. New regulations that make such capabilities mandatory can enable progressive transition and provide legal protections against misuse. For instance, the Philippines enacted the E-Waste Management Act in 2021 which mandated proper e-waste collection, storage, treatment, and disposal practices.

Governments must spearhead research grants, innovation challenges, subsidized tests, and recognition programs to spur development and adoption. Multilateral standardization of Sharia compliance requirements, processes, data formats, and technical specifications can foster consistent adoption across global e-waste value chains, as demonstrated by the European Council Directive on

Waste Electrical and Electronic Equipment (Directive 2012/19/EU, 2012, Table 1). Public-private partnerships via working groups, taskforces, and expert panels can formulate optimal, balanced frameworks.

Table 1. Description of the main objectives of Directive 2012/19/EU on the fight against electronic waste

Key objective	Description
Waste prevention	Set requirements to encourage design and production of electrical and electronic equipment that take into account dismantling, recovery, reuse and recycling requirements.
Collection & recycling targets	Establish minimum collection and recycling rates for e-waste in each Member State.
Producer responsibility	Ensure that producers finance collection, treatment, recovery and environmentally sound disposal of waste electrical and electronic equipment.
Treatment standards	Set minimum treatment requirements for collected waste and restrict use of hazardous substances.
Monitoring & reporting	Standardize monitoring and reporting requirements on e-waste collection and treatment including statistics.

Regarding economic considerations, while emerging technologies entail high upfront costs, quantified ROI calculations reveal long-term efficiencies in compliance, automated monitoring, transparency, record-keeping, settlements, and transactions [19]. Results-based financing mechanisms can fund initial transition. Hedging commodity and carbon prices can offset profit uncertainties during phased implementations. Impact investment instruments, green sukuks, and blended finance models can offer alternative funding channels and incentives.

For social adoption, community-centric design and multilingual interfaces are advised to overcome demographic barriers [20]. Extensive education campaigns, training programs, and help resources build internal capabilities and align mindsets. Rigorous change management protocols must address psychological factors like fear of job losses. Celebrating pioneering adopters through industry awards can motivate others. Academic research partnerships yield vital insights to inform iterative refinements.

At the infrastructure level, flexible cloud deployment enables affordability, portability, and scalability, while cryptographic techniques like trusted execution environments and encryption foster secure data sharing across entities [21]. Interim interoperability solutions can facilitate gradual adoption. Institutionalizing cybersecurity best practices is critical, given expanded attack surfaces. However, as experts discuss, excessive emphasis on cyber threats risks undermining humanitarian opportunities of emerging technologies. Maintaining balanced perspectives is advised [21].

Advancing techniques to codify Sharia rules into computable logic remains an open research challenge. Transitioning from limited proof-of-concepts to production-grade solutions requires significant legal engineering and testing. Advances in AI reasoning and knowledge graphs mapping relationships between Fiqh decrees, fatwas, and real-world entities can enable translating high-level jurisprudence maxims into enforceable code. Ontological models structuring compliance considerations can guide development of sophisticated smart contract rule engines.

structures, governance models, privacy-preservation techniques like zero-knowledge proofs and trusted execution environments, and interoperability solutions can magnify technological readiness [3]. As these foundational capabilities wise, higher-order applications become feasible. Patience and realistic roadmaps are advised.

This multifaceted framework encompassing technological, governance, economic, and social dimensions signify a holistic roadmap to guide progress from conceptualization to widespread implementation of next-generation Sharia compliance assurance systems. But realization depends on collaborative mobilization of resources, capabilities, and expertise across public, private, and academic spheres bound by common Islamic ethical values. In particular, youth must be engaged to drive grassroots momentum leveraging social entrepreneurship and bottom-up innovation.

As Alnahari et al. [3] emphasizes, technological innovation guided by *maqasid al-shariah* (higher objectives) and *maslahah* (public interest) is imperative to bridge persisting gaps between Islamic heritage and modern realities. The conceptual models put forth in this study can seed that process. But nurturing the supportive environment to translate designs into sociotechnical realities requires inclusive, multistakeholder efforts. Platform cooperativism principles emphasizing shared ownership, participatory governance, and collective benefit may inform sustainable development frameworks.

Realizing the full potential of blockchain, AI, and computational law to make Sharia compliance assurance an automated, embedded feature of diverse systems remains a long-term undertaking filled with uncertainties. But methodical, collaborative efforts focused on high-priority applications like e-waste management can validate pathways for pragmatic adoption while refining technical capabilities and policies. As Rijmenam [22] note, "The extent to which the anticipated benefits of blockchain technology materialize depends on how the technology is actually incorporated into sociotechnical contexts of use."

Near-perfect Sharia compliance assurance powered by decentralized cooperation and intelligent algorithms represents an aspirational vision of the future that may take generations to fully materialize. But researchers with strategic patience and perseverance can take the first strides on that path now. Prophet Muhammad said, "When you embark on a journey seeking knowledge, God will make easy for you the road to paradise." Technological innovation guided by Islamic ethics and in service of humanity epitomizes such a journey.

4. Conclusion

While the conceptual models substantiate the viability of the proposed methodology, real-world feasibility needs examination through empirical tests and impact studies. Challenges around adoption readiness, user acceptance, and systems integration must be investigated. Insights can point to areas needing refinement. Limitations also exist around comprehensively encoding complex Sharia law into computable logic. Advancing techniques like machine learning and ontologies can enable richer representation of Sharia nuances and judicial rulings.

The methodology has wide applications for architecting systems aligned with Sharia in domains like finance, agriculture, and smart cities where blockchain and AI enable new possibilities. But careful configuration is crucial to avoid haram elements, requiring extensive collaboration between legal experts, technologists, and religious authorities. Frameworks for participatory design, implementation, and oversight of Sharia-based AI systems need development.

With responsible design, Sharia-compliant e-waste tracking can significantly improve accountability in collection, transport, recycling, and disposal processes. This can help curb unlawful dumping, environmental pollution, and activities like child labor which violate Islamic principles. The benefits for public and environmental health outcomes are profound. Policymakers should expedite tests of blockchain e-waste monitoring enhanced with computational law techniques.

Advancing computational modeling of Sharia law itself remains an open research challenge, from formalizing information in scattered fatwa to handling multi-jurisdictional complexities. Integrating Sharia compliance checking with event-based smart contract execution would enable self-reinforcing systems continuously aligned with Islamic principles. E-waste management provides an impactful test domain for pioneering approaches in this emerging field.

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References

[1] V. Forti, C. P. Balde, R. Kuehr, and G. Bel, *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. Amsterdam: United Nations Institute for Training and Research, 2020.

[2] P. Jiang *et al.*, "Blockchain Technology Applications in Waste Management: Overview, Challenges and Opportunities," *J. Clean. Prod.*, vol. 421, no. October, p. 138466, 2023, doi: https://doi.org/10.1016/j.jclepro.2023.138466.

[3] M. S. Alnahari and S. T. Ariaratnam, "The Application of Blockchain Technology to Smart City Infrastructure," *Smart Cities*, vol. 5, no. 3, pp. 979–993, 2022, doi: https://doi.org/10.3390/smartcities5030049.

[4] K. Chaudhary, P. Padmanabhan, D. Verma, and P. D. Yadav, "Blockchain: A Game Changer in Electronic Waste Management in India," *Int. J. Integr. Supply Manag.*, vol. 14, no. 2, pp. 167–182, 2021, doi: https://doi.org/10.1504/IJISM.2021.115680.

[5] S. Gulyamov, I. Rustambekov, O. Narziev, and A. Xudayberganov, "Draft Concept of the Republic of Uzbekistan in the Field of Development Artificial Intelligence for 2021-2030," *Yurisprudensiya*, vol. 1, pp. 107–121, 2021, [Online]. Available: https://www.academia.edu/107366046/Draft_Concept_of_the_Republic_of_Uzbekistan_in_the_Field_of_Development_Artificial_Intelligence_for_2021_2030?uc-sb-sw=109443066

[6] V. Chang, P. Baudier, H. Zhang, Q. Xu, J. Zhang, and M. Arami, "Technological Forecasting & Social Change How Blockchain can impact fi nancial services – The overview , challenges and recommendations from expert interviewees," *Technol. Forecast. Soc. Chang.*, vol. 158, no. 9, pp. 1–12, 2020, doi: https://doi.org/10.1016/j.techfore.2020.120166.

[7] H. Qudah, S. Malahim, R. Airout, M. Alomari, A. A. Hamour, and M. Alqudah, "Islamic Finance in the Era of Financial Technology: A Bibliometric Review of Future Trends," *Int. J. Financ. Stud.*, vol. 11, no. 2, pp. 1–29, 2023, doi: https://doi.org/10.3390/ijfs11020076.

[8] H. Madkhali, S. Duraib, L. Nguyen, M. Prasad, M. Sharma, and S. Joshi, "A Comprehensive Review on E-Waste Management Strategies and Prediction Methods: A Saudi Arabia Perspective," *Knowledge*, vol. 3, no. 2, pp. 163–179, 2023, doi: https://doi.org/10.3390/knowledge3020012.

[9] M. Ali, C.-H. Puah, A. Ali, S. A. Raza, and N. Ayob, "Green Intellectual Capital, Green HRM and Green Social Identity Toward Sustainable Environment: A New Integrated Framework for Islamic Banks," *Int. J. Manpow.*, vol. 43, no. 3, pp. 614–638, 2022, doi: https://doi.org/10.1108/IJM-04-2020-0185.

[10] R. W. Ahmad, K. Salah, R. Jayaraman, I. Yaqoob, and M. Omar, "Blockchain for Waste Management in Smart Cities: A Survey," *IEEE Access*, vol. 9, no. April, pp. 131520–131541, 2021, doi: https://doi.org/10.36227/techrxiv.14345534.v1.

[11] J. Leng *et al.*, "Blockchain-Empowered Sustainable Manufacturing and Product Lifecycle Management in Industry 4.0: A survey," *Renew. Sustain. energy Rev.*, vol. 132, no. 10, pp. 1–20, 2020, doi: https://doi.org/10.1016/j.rser.2020.110112.

[12] W. Du, X. Ma, H. Yuan, and Y. Zhu, "Blockchain-Empowered Sustainable Manufacturing and Product Lifecycle Management in Industry 4.0: A Survey," *Environ. Sci. Pollut. Res.*, vol. 29, no. 39, pp. 58648–58663, 2022, doi: https://doi.org/10.1007/s11356-022-21761-2.

[13] M. S. Hossain, S. M. Z. F. Al-Hamadani, and M. T. Rahman, "E-waste: A Challenge for Sustainable Development," *J. Heal. Pollut.*, vol. 5, no. 9, pp. 3–11, 2015, doi: https://doi.org/10.5696/2156-9614-5-9.3.

[14] M. H. Ali, L. Chung, A. Kumar, S. Zailani, and K. H. Tan, "A Sustainable Blockchain Framework for The Halal Food Supply Chain: Lessons from Malaysia," *Technol. Forecast. Soc. Change*, vol. 170, no. September, pp. 1–30, 2021, doi: https://doi.org/10.1016/j.techfore.2021.120870.

[15] M. Das Turjo, M. M. Khan, M. Kaur, and A. Zaguia, "Smart Supply Chain Management Using the Blockchain and Smart Contract," *Sci. Program.*, vol. 2021, pp. 1–12, 2021, doi: https://doi.org/10.1155/2021/6092792.

[16] A. Khoirunnisa, F. Rohman, H. A. Azizah, D. Ardianti, A. L. Maghfiroh, and A. M. Noor, "Islam in the Midst of AI (Artificial Intelligence) Struggles: Between Opportunities and Threats," *SUHUF*, vol. 35, no. 1, pp. 45–52, 2023, doi: https://doi.org/10.23917/suhuf.v35i1.22365.

[17] J. Aslam, A. Saleem, N. T. Khan, and Y. B. Kim, "Factors Influencing Blockchain Adoption in Supply Chain Management Practices: A Study Based on the Oil Industry," *J. Innov. Knowl.*, vol. 6, no. 2, pp. 124–134, 2021, doi: https://doi.org/10.1016/j.jik.2021.01.002.

[18] C. C. Agbo, Q. H. Mahmoud, and J. M. Eklund, "Blockchain Technology in Healthcare: A Systematic Review," in *Healthcare*, MDPI, 2019, pp. 1–30. doi: https://doi.org/10.3390/healthcare7020056.

[19] Y. Arayici, P. Coates, L. Koskela, M. Kagioglou, C. Usher, and K. O'Reilly, "Technology Adoption in the BIM Implementation for Lean Architectural Practice," *Autom. Constr.*, vol. 20, no. 2, pp. 189–195, 2011, doi: https://doi.org/10.1016/j.autcon.2010.09.016.

[20] M. Andoni *et al.*, "Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities," *Renew. Sustain. energy Rev.*, vol. 100, no. February, pp. 143–174, 2019, doi: https://doi.org/10.1016/j.rser.2018.10.014.

[21] U. Bamel, S. Talwar, V. Pereira, L. Corazza, and A. Dhir, "Disruptive Digital Innovations in Healthcare: Knowing the Past and Anticipating the Future," *Technovation*, vol. 125, no. July, pp. 1–14, 2023, doi: https://doi.org/10.1016/j.technovation.2023.102785.

[22] M. van Rijmenam, "How Blockchain Will Change Organisation Design," The Digital Speaker. [Online]. Available: https://www.thedigitalspeaker.com/blockchain-change-organisation-design/