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Smart Government For Green Financing: A Distributed Ledger Technology Architecture To Prevent Greenwashing In Government Green Securities

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Abstract

Public funds are raised in the name of environmental objectives, yet evidence of green performance is generated across multiple government organisations and disclosed mainly through issuer reporting with periodic external assurance. This creates an integrity gap shaped not only by verification limits but also by information asymmetry between fiscal authorities and implementing ministries, siloed processes, and incentives that may privilege compliance and budget absorption over substantive environmental accountability. This study examines how distributed ledger technology (DLT) can mitigate that gap through a qualitative, comparative-adaptive document study using purposive selection. The analysis identifies five supporting facilities: atomic settlement, potential cost efficiency through process disintermediation, transparent and tamper-evident transaction records, smart-contract-supported coupon processing, and auditability by design. DLT cannot verify the truth of off-chain data or make environmental impacts real-time. Its implementation therefore requires regulatory and institutional readiness, interoperability with sovereign financial infrastructure, trusted oracle and ESG-data governance, cybersecurity and data sovereignty safeguards, and reconfiguration of actor roles without displacing substantive public authority.

Keywords: digital governance, distributed ledger technology, government green securities, greenwashing, public financings

1. INTRODUCTION

The financial capacity of government determines its ability to establish, maintain, and modernise the physical facilities of public services, since budget adequacy constitutes a vital aspect of physical facility development (Edwards III, 1980; Nurnawati, Sabaruddin, & Nurrahman, 2024). Limited fiscal capacity compels the state to undertake regulatory reform and to shift towards more efficient and sustainable governance (Kurdi & Irfan Polem, 2025), while global scholarly attention affirms that environmental sustainability is a principal condition for durable economic and social development (Judijanto & Dhesta Kusuma Dewi, 2026; Śleszyński, 2023). Indonesia has affirmed its status as a state party complying with the Paris Agreement through the ratification of Law Number 16 of 2016, translated into the Enhanced Nationally Determined Contribution (ENDC), which

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commits the country to an emission reduction target of 31.89 per cent unconditionally and 43.20 per cent with international support. That commitment generates a financing gap in which the funding required for climate mitigation action is estimated to reach USD247 billion by 2030, while the achievement of the overall SDGs target requires USD400–750 billion (Republic of Indonesia, 2021). In this setting, the governance architecture proposed for sovereign green financing also has prospective relevance for subnational governments, particularly where fiscal decentralisation requires stronger accountability for locally financed climate projects. A future extension could therefore adapt the architecture to municipal or regional green bonds, subject to the distinct legal, market, and fiscal constraints governing subnational borrowing in Indonesia.

The government has responded through the issuance of government green securities, comprising green bond and green sukuk instruments, supported by a regulatory ecosystem that developed in stages from the Roadmap for Sustainable Finance (OJK, 2014), the Green Bond and Green Sukuk Framework (Republic of Indonesia, 2018), and the SDGs Government Securities Framework (Republic of Indonesia, 2021), to the Sustainable Government Securities Framework published in April 2025, accompanied by a Second Party Opinion confirming its alignment with the ICMA and ACMF principles. The nominal quantity of issuance in each year is highly fluctuating and is adjusted to the funding needs of projects that have been planned.

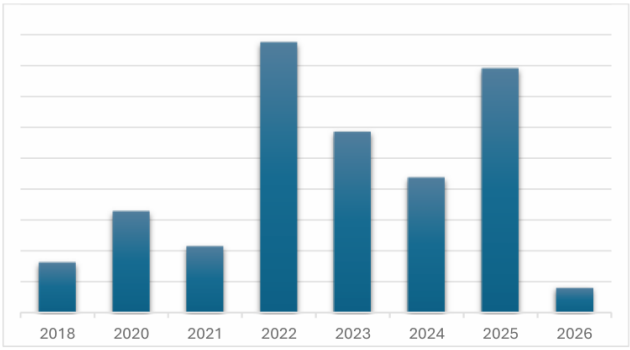

Figure 1. Nominal Value of Government Green Securities Issuance. Source: Bloomberg (2026)

The principal problem of that issuance concerns the accountability of the use of funds allocated to green projects (Muñoz-Muñoz et al., 2026). The use-of-proceeds phase becomes a critical point of accountability, extending from budget tagging conducted by government institutions to the report on the use of funds and environmental benefits, which is verified through third-party assurance on an ex-post basis once a year (Republic of Indonesia, 2021). The resulting integrity gap is not simply a weakness in verification technology. It also reflects an institutional information problem: fiscal authorities need reliable evidence from implementing ministries, while technical ministries possess more granular information about project execution and environmental conditions. Where reporting incentives emphasise formal compliance, budget absorption, or completion of administrative targets rather than substantive environmental outcomes, the distance between fiscal oversight and implementation can create room for green claims that are difficult to independently test. This information asymmetry can increase greenwashing risk even where reporting requirements formally exist. The credibility of the green bond market may consequently be weakened when verification remains periodic, fragmented, and dependent on information produced within the same administrative chain (Schmittmann & Gao, 2022).

To mitigate that gap, the adoption of Distributed Ledger Technology (DLT) becomes relevant as a digital governance solution that can connect stakeholders through a shared, tamper-evident record. Such applications have been explored in Hong Kong through tokenised green bond initiatives and in research on smart sukuk and chain-based bonds, with reported potential for transaction-cost reduction and process standardisation (Cisar et al., 2025; Delle Foglie et al., 2025; Namoniuk & Matei, 2025). Through smart-contract-based tokenisation, DLT can make approval states, allocation records, and transaction histories more consistently traceable across the financing cycle (Malamas

et al., 2024). The contribution should nevertheless be stated carefully: DLT can support near-continuous traceability of recorded financial transactions and administrative events, but environmental outcomes such as emissions reductions, ecosystem recovery, or land rehabilitation remain physical phenomena that require measurement over appropriate temporal intervals. DLT can preserve and expose the provenance of such evidence once it is validated and entered into the system; it cannot make the underlying environmental measurement itself real-time or automatically truthful. This distinction is essential to avoid technological determinism and to position DLT as an accountability infrastructure rather than a substitute for substantive verification. This constraint can be described as a temporal and spatial data latency: DLT can guarantee the provenance, that is, the origin and integrity, of recorded documentary evidence, but it can never overcome the natural latency of ecological recovery processes that unfold across physical space and biological time; no claim of real-time environmental-impact reporting should therefore be made on the strength of the ledger alone.

Prior research has extensively criticised the vulnerability of green financing instruments to greenwashing owing to weak verification mechanisms, and technical studies of DLT demonstrate its capacity to deliver forensic-by-design. Implementation nevertheless remains confined to the issuance of corporate financing instruments on a small scale, so that no study has specifically mapped a DLT architecture into the government green securities ecosystem. To bridge that gap, this study is built upon a crucial problem formulation derived into the following three questions: 1) At which points in the issuance and reporting cycle of government green securities are greenwashing gaps structurally opened? 2) To what extent is a DLT architecture able to close greenwashing gaps, and at which point does failure occur? 3) What governance prerequisites must be fulfilled so that DLT adoption produces accountability rather than mere process digitisation?. Through that problem formulation, this study aims to design the architectural framework and institutional prerequisites that ensure DLT adoption is able to lock the integrity of public fund utilisation.

2. LITERATURE REVIEW

a. Public Financing and the Shift towards Thematic Instruments

Governments use debt financing to bridge long-term expenditure needs with available fiscal capacity, particularly when development benefits accrue across periods (Kose, Kurlat, Ohnsorge, & Sugawara, 2017). The benefit of financing, however, is not determined solely by the magnitude of funds raised. The quality of governance determines whether debt supports growth and public services or instead increases the fiscal burden. Musa, Sohag, Said, Ghapar, & Ali (2023) demonstrate that the impact of public debt on growth depends on governance quality, while Tawiah & Soobaroyen (2024) show that the credibility of fiscal information is associated with access to international financing. The relationship between government as issuer and investors is therefore not only financial but also informational, because financing credibility depends on the government's capacity to demonstrate the use and accountability of funds in a verifiable manner. That requirement becomes increasingly important for thematic financing instruments. Unlike conventional securities, which fundamentally finance general fiscal needs, thematic instruments link issuance proceeds to specific policy objectives. Lukšić, Bošković, Novikova, & Vrbensky (2022) position such instruments as a means of mobilising sustainable development financing that simultaneously raises demands for transparency and accountability. For green instruments, investors assess not only the government's capacity to meet financial obligations but also require information on project selection, fund allocation, and the environmental outcomes achieved. Consequently, the credibility of thematic instruments depends on the capacity of their governance system to maintain the linkage between the funds raised, the activities financed, and the impacts reported.

b. Government Green Securities and Indonesia's Green Financing Governance

In this study, government green securities (GGS) refer to green securities issued by government to finance or refinance expenditures that meet green criteria. In the Indonesian context, GGS encompass government green bonds and government green sukuk. Both sit within the same green management framework, which covers four principal components, namely use of proceeds, the process of evaluating and selecting expenditures, the management of issuance proceeds, and the reporting of allocation and impact (Republic of Indonesia, 2021). That commonality provides the basis for analysing both as a single GGS group without disregarding the differences in their instrument structures. Commonality of green governance does not mean that green bonds and green sukuk are identical instruments. Green sukuk combine environmental requirements with sharia structure and compliance that are not present in conventional bonds. Xu & Liu (2022) demonstrate that the development of green sukuk draws upon the international green bond regime to build its green credibility. Adoption of that framework broadens the acceptance of green sukuk but also keeps relevant some of the integrity problems present in the green bond market, including greenwashing risk. This article therefore distinguishes two layers of analysis: the green governance components that apply to all GGS, and the instrument components that require specific adaptation for green sukuk.

The need for traceability becomes more complex in GGS because information flows across government organisations. In Indonesian issuance, the identification of green expenditures involves technical ministries and agencies, budget tagging, evaluation of alignment with climate policy, management of allocation by the Ministry of Finance, and reporting and assessment by external parties (Republic of Indonesia, 2021). Fragmentation can be reinforced by a silo mentality in which ministries optimise their own mandates, systems, and reporting routines even when the financing instrument depends on a single fund-to-impact chain. Raeni et al. (2022), through a study of Indonesia's sovereign green sukuk, demonstrate that accountability requires linkage between financial data and environmental achievement through chains of decisions within and between organisations. A DLT architecture can therefore be conceptualised as a boundary-spanning instrument: rather than eliminating hierarchical authority, it establishes a shared transaction and evidence layer through which participating ministries can expose agreed data, validation states, and responsibility trails to one another. In this sense, DLT can support a transition from purely hierarchical coordination towards networked governance, where inter-organisational visibility is created by common records, defined access rights, and traceable validation events. The technology does not itself remove silo behaviour; it creates an institutional infrastructure in which cross-ministerial coordination becomes more observable and therefore more difficult to separate from accountability.

c. Integrity Risk and Greenwashing in Government Green Securities

Greenwashing risk is rooted in information asymmetry between issuer and investor. Investors cannot directly observe whether all funds claimed as green genuinely support activities that meet environmental criteria, or whether the impacts reported correspond to actual conditions. Under such conditions, the green label functions as a credible signal only when adequate verification mechanisms and consequences for deviation exist (Schmittmann & Gao, 2022). That credibility also relates to the greenium, namely the condition in which investors are willing to accept lower yields on certain green instruments, thereby delivering a funding cost advantage to the issuer. The economic value of the green label therefore depends on the market's capacity to distinguish credible instruments from those that merely deploy environmental claims. The corporate green bond literature provides evidence of the importance of verification mechanisms, although those findings cannot be used directly to measure the level of greenwashing in GGS. Bachelet et al. (2019) show that issuer reputation and third-party verification reduce information asymmetry as well as suspicion of greenwashing. Deng et al. (2020) likewise show that investors differentiate instruments based on the credibility of their green claims. Conversely, voluntary certification that is not supported by adequate incentive mechanisms may have limited effectiveness as a credibility signal (Zhu, Zhao, &

Wu, 2023). The analytical distinction between private and public issuers is important. A corporation may have a direct financial incentive to secure a greenium, protect reputation, or lower funding costs. A government issuer faces those market considerations but also operates under political and administrative incentives, including the need to demonstrate policy credibility, fulfil climate commitments such as the Paris Agreement, preserve fiscal legitimacy, and sustain public trust. Greenwashing risk in the public sector is consequently more political and bureaucratic in character: it may arise not only from market-oriented misrepresentation, but also from institutional fragmentation, compliance-oriented reporting, and the distance between policy claims and implementation outcomes. Corporate evidence is therefore used in this study to illuminate information and verification mechanisms, while the distinct political-administrative motivation of government is retained as a boundary of generalisation.

The greatest vulnerability emerges after the instrument is issued, because validation of green credentials then depends on the quality of information concerning the realisation of fund use and its impact. Hunt (2024), on a sample of United States dollar-denominated corporate green bonds over the 2019–2022 period, found issuances that provided neither post-issuance reporting nor third-party attestation. A more fundamental problem is the limited granularity of information. Petucco, Schaubroeck, Gibon, Popescu, & Benetto (2025) analysed 1,600 corporate green bonds and found only 32 bonds with project-level information adequate for life-cycle assessment-based testing. Of those testable projects, approximately 73 per cent of the reported climate change impact claims exceeded LCA-based estimates. Those findings do not prove the same problem in Indonesian GGS, but they demonstrate that impact reports which fail to provide sufficiently granular data constrain the capacity of external parties to independently re-examine environmental claims.

For public issuers, the risk configuration differs because investors also confront the character of government financial management. Baldi & Pandimiglio (2022) show that greenwashing risk is also relevant to public-sector green bonds and that the distance between the sovereign issuer and beneficiary communities may weaken investors' direct control. In the green sukuk context, Liu & Lai (2021) show that adoption of the Green Bond Principles does not automatically eliminate greenwashing vulnerability. Meanwhile, the study by Raeni et al. (2022) on Indonesia affirms the importance of traceability of fund flows and environmental information across organisations. The synthesis of that literature indicates that the principal problem of GGS is not the existence of greenwashing proven in every issuance, but rather the integrity gap that forms when information on allocation, realisation, and impact originates from separate systems, is reported periodically, and obtains verification only after the event.

d. Distributed Ledger Technology for the Information Integrity of GGS

Distributed ledger technology (DLT) provides a shared recording mechanism that enables several parties to maintain a consistent transaction history. Within a DLT architecture, changes to records can be recorded chronologically and verified by participants holding access rights, while smart contracts enable specified rules to be executed once predetermined conditions are met (Egelund-Müller, Elsman, Henglein, & Ross, 2017; Priem, 2020). Immutability in this context does not mean that every item of information recorded is necessarily true, but that changes to information already agreed upon can be detected and traced. That characteristic renders DLT relevant when governance problems reside in record fragmentation, low traceability, and the need for multi-party coordination. In securities markets, that function has begun to be translated into DLT-based issuance designs. Malamas et al. (2024) developed a green bond architecture that integrates issuer, investor, validator, auditor, and regulator into the same network. The approval of specified parties can be positioned as a process prerequisite, while the issuance record forms an audit trail available to the supervisory function. Christodoulou, Psillaki, Sklias, & Chatzichristofis (2023) developed a similar approach for monitoring EU green bonds. Both studies demonstrate the potential of DLT to transform verification from an exchange of separate documents into a validation process connected to

transaction history. Both are used here, however, as technical benchmarks rather than as empirical evidence that DLT has succeeded in eliminating greenwashing in sovereign issuance.

From a governance perspective, the principal value of DLT for this study lies in traceability, auditability, and integration of the supervisory function. Auer (2019) terms that possibility embedded supervision, namely the condition in which supervisors can obtain compliance information through the ledger without depending entirely on the collection of separate reports from market participants. For GGS, a similar principle has the potential to connect information on activity selection, validation, allocation, and reporting within a single traceable chain of records. DLT thus does not replace the substance of project evaluation nor the function of the auditor, but changes the way the results of that evaluation and those transactions are recorded, shared, and supervised.

The principal limitation of DLT lies in the relationship between on-chain information and actual conditions outside the network. Caldarelli (2020) explains the oracle problem: blockchain can preserve the integrity of information once data has entered the ledger, but cannot ensure that the external data serving as its input has depicted the true condition. That problem is highly relevant to GGS because information on expenditure realisation, project progress, and environmental impact continues to originate from activities outside the ledger. Financial transactions may be recorded with high temporal frequency, but many environmental indicators are inherently periodic or longitudinal and may require months or years before a meaningful change can be established. DLT therefore does not eliminate the need for substantive verification or transform environmental impact into real-time data. It shifts part of the point of trust from periodic document reconciliation towards the governance of data sources, validators, oracles, measurement protocols, and the evidentiary chain through which environmental information enters the ledger. The research gap subsequently addressed in this article is therefore how DLT functions can be mapped onto the Indonesian GGS cycle while preserving this distinction between transaction traceability and impact verification, and between common GGS functions and those requiring adaptation for green sukuk.

3. METHODS

a. Approach and Research Design

This study employs a qualitative approach with a conceptual, document-based research design and a comparative-adaptive framework. The qualitative approach was selected because the research aims to identify integrity gaps within the GGS cycle and to assess how DLT functions can be used to mitigate those gaps, rather than to test statistical relationships between variables (Creswell, 2014). Literature review is employed as a methodology for synthesising knowledge from the fields of sustainable financing, securities markets, public governance, and DLT, which have not been integrated within a single empirical study (Snyder, 2019). The principal object of the research is the issuance and reporting ecosystem of Indonesian GGS, encompassing government green bonds and government green sukuk. The unit of analysis is established at the functions and stages within the GGS cycle, namely pre-issuance, issuance, fund allocation, and post-issuance. Selection of that unit is aligned with the research questions, which focus on the location of integrity gaps along the GGS cycle. Differences between green bonds and green sukuk are analysed as instrument variation within the same object, not as two separate research objects.

The framework of Malamas et al. (2024) is used as the principal technical benchmark rather than as a comparison object equivalent to Indonesian GGS. Its selection rests on three grounds. First, that framework explicitly connects blockchain architecture with the problem of green credibility. Second, its design encompasses processes from issuance initiation to post-transaction recording. Third, regulators and validators are positioned as part of the information architecture. Because the object of Malamas et al. (2024) is green bonds, the components of their framework are subsequently decomposed into components that are neutral with respect to instrument type and components

requiring adaptation for green sukuk. Literature on tokenisation and smart sukuk is used to support that adaptation process (Delle Foglie et al., 2025; Khan et al., 2022).

b. Data Sources and Data Collection Technique

The research data consist entirely of secondary data gathered through document analysis. Document analysis is employed as a systematic procedure for reviewing, evaluating, and synthesising information from various types of sources (Bowen, 2009). The research sources comprise peer-reviewed scholarly literature on GGS, green bonds, green sukuk, greenwashing, environmental verification, and DLT; policy documents and official frameworks of the Government of Indonesia, principally the Republic of Indonesia Green Bond and Green Sukuk Framework and the SDGs Government Securities Framework; and issuance reports and data published by the Ministry of Finance. The use of several types of document enables triangulation between academic findings, formal provisions, and the Indonesian institutional context. Corporate literature continues to be used where empirical evidence on sovereign issuers is not yet adequate. Its use is confined to identifying problem mechanisms, such as information asymmetry, reporting quality, and verification effectiveness. Corporate findings are not used to estimate the level or prevalence of greenwashing in Indonesian GGS. Conversely, literature on sovereign green securities and green sukuk is prioritised where the analysis concerns the character of government, the management of public funds, or sharia structures.

c. Literature Selection Technique

Documents were selected purposively on a criterion basis, taking into account the relevance of their information to the research questions (Palinkas et al., 2015; Patton, 2015). Literature was grouped by analytical function rather than by the theoretical–technical dichotomy used in the initial design. The first group constitutes problem evidence, namely studies of greenwashing, information asymmetry, third-party verification, and post-issuance reporting. The second group constitutes DLT technical benchmarks, namely studies that develop or evaluate DLT architectures in securities markets. The third group constitutes instrument adaptation literature, principally studies of sukuk, smart sukuk, and the tokenisation of sharia instruments. The fourth group constitutes institutional context, in the form of government frameworks, regulations, and official Indonesian data. Blockchain studies addressing only crypto assets without connection to securities issuance or governance were excluded.

Table 1. Classification of Principal Literature as the Basis of Analysis

Source	Object	Analytical Function	Contribution to the Study	Generalisation Boundary
Bachelet et al. (2019)	Green bond	Problem evidence	Role of reputation and external verification	Predominantly corporate
Deng et al. (2020)	Green bond	Problem evidence	Credibility of the green label and investor assessment	Corporate
Baldi & Pandimiglio (2022)	Public and corporate green bond	Problem evidence	Connects greenwashing risk with public issuers	Not Indonesia-specific
Hunt (2024)	Corporate green bond	Problem evidence	Weaknesses in post-issuance reporting and attestation	United States corporate
Petucco et al. (2025)	1,600 corporate green bonds	Problem evidence	Demonstrates limitations of project-level data and impact verification	Corporate
Raeni et al. (2022)	Indonesian sovereign green sukuk	GGS context	Need for cross-organisational traceability and the fund–impact relationship	Indonesian case study

Liu & Lai (2021)	Green sukuk	Instrument adaptation	Relationship of green sukuk with the green bond regime and integrity risk	Malaysia
Malamas et al. (2024)	Blockchain-based green bond	DLT benchmark	Principal architecture for actors, validation, and audit trail	Design, not GGS implementation
Christodoulou et al. (2023)	EU green bond	DLT benchmark	Blockchain framework for green bond monitoring	European Union
Khan et al. (2022)	Tokenised sukuk	Instrument adaptation	Feasibility of smart contracts in sukuk structures	Not sovereign green sukuk
Delle Foglie et al. (2025)	Sukuk industry	Instrument adaptation	DLT, tokenisation, and sharia compliance	Sukuk in general
Auer (2019)	Tokenised markets	DLT governance	Concept of embedded supervision	Conceptual model
Caldarelli (2020)	Blockchain and oracles	DLT limitation	Explains the oracle problem and the limits of immutability	Cross-application

Source: Processed by the authors, 2026

d. Data Analysis Technique

The analysis was conducted in five stages. The first stage is identification of integrity gaps, namely the mapping of problems at each GGS phase on the basis of the literature and Indonesia's official frameworks. The second stage is extraction of DLT functions, namely the identification of DLT architectural capabilities relevant to traceability, validation, auditability, and supervision. The third stage is functional comparison, namely the comparison between the functions present in existing GGS mechanisms and the functions offered by a DLT architecture, with Malamas et al. (2024) as the principal benchmark and other literature as comparators. The fourth stage is instrument decomposition and adaptation. At this stage, DLT components are separated into components applicable to both forms of GGS and components requiring adjustment to the character of green sukuk. The fifth stage is contextualisation, namely assessment of the design's alignment with Indonesia's GGS framework, the availability of actors performing the related functions, and the requirements of data and institutional governance. The results of those five stages are subsequently presented through three dimensions of analysis, namely actor configuration, process cycle, and architectural procedures.

4. RESULTS AND DISCUSSIONS

a. Objectives of DLT Use in Government Green Securities

Analysis of DLT use in GGS is conducted through three interrelated dimensions, namely actor configuration, process cycle, and architectural procedures. The framework of Malamas et al. (2024) is used as a technical benchmark and is subsequently compared with the Indonesian GGS mechanism regulated in the Green Bond and Green Sukuk Framework and the SDGs Government Securities Framework. Because the comparator framework was developed for green bonds, each of its components is distinguished between functions applicable to both GGS instruments and functions requiring adaptation for green sukuk.

1) Actor Configuration in Government Green Securities

The Indonesian GGS mechanism involves a series of actors with differing functions, from expenditure selection through to reporting. The Ministry of Finance acts as issuer while also managing the allocation of issuance proceeds and preparing reports. Technical ministries and agencies, together with government planning elements, play a role in identifying and assessing expenditures through budget tagging, while the alignment of activities with national environmental commitments proceeds through the validation process established in the government framework.

That framework also involves a second party opinion prior to issuance and independent parties in providing assurance over reporting (Republic of Indonesia, 2021). The integrity of GGS is therefore, from the outset, the product of multi-party work rather than the function of a single issuer. Within the proposed DLT architecture, the institution issuing that second party opinion (for example, CICERO or an accredited local rating agency) can be explicitly mapped as a dedicated pre-issuance validator node, whose cryptographic digital signature constitutes a mandatory precondition before the instrument may be tokenised. That structure applies as a green governance layer for both green bonds and green sukuk, but green sukuk possess an additional dimension of sharia compliance. Literature on DLT in sukuk demonstrates that digitisation of the instrument does not eliminate the need to ensure the conformity of its structure and execution with sharia principles (Delle Foglie et al., 2025; Khan et al., 2022). A single architecture for GGS may therefore use the same functions for environmental validation, allocation, and reporting, but must provide an additional validation function for green sukuk. This difference matters because the framework of Malamas et al. (2024) was developed for green bonds and does not incorporate a sharia compliance function.

The existing configuration leaves integrity problems unresolved, principally because validation and reporting proceed through different actors and information systems. The credibility of green claims remains heavily dependent on the quality of information prepared and transmitted along that chain. Bachelet et al. (2019) show that external verification reduces information asymmetry, but Zhu et al. (2023) caution that certification lacking adequate incentive and supervisory mechanisms may lose its effectiveness as a signal. In GGS, that problem is compounded by the need to connect financial and environmental information across government organisations, as found by Raeni et al. (2022). The principal need is therefore not the elimination of intermediary actors, but assurance that the decisions and validations made by each actor can be traced within consistent records. The architecture of Malamas et al. (2024) offers change through the placement of issuer, investor, validator, auditor, and regulator as participants in the same network. Validation and approval functions are no longer demonstrated solely through document exchange but are recorded as part of the process history. That concept is relevant to GGS because it enables each institutional function to be retained while simultaneously providing a shared record of the decisions produced. DLT need not, therefore, be understood as a mechanism of total disintermediation. Its principal change is the reconfiguration of information relationships: actors continue to exercise their respective authorities, while the results of their actions can be recorded and traced through the ledger.

In the Indonesian context, the mapping of existing functions onto a DLT network must be distinguished from the institutional functions currently in force. The Ministry of Finance factually performs sovereign financing and related reporting functions, whereas its placement as an issuer node within the DLT constitutes a design proposal. Likewise, actors currently conducting environmental evaluation or validation may be mapped as nodes with defined validation rights, but those technical permissions do not automatically create new legal authority. Treating fiscal authorities as mere blockchain nodes would risk institutional resistance because public officials exercise discretion under statutory mandates, accountability rules, and established administrative procedures. Institutional readiness should therefore be assessed along at least three dimensions: legal authority, organisational capability, and inter-organisational coordination. The architecture should first preserve the existing chain of authority and then digitise the evidentiary trail supporting that authority. For example, statutory and regulatory provisions governing government securities, public financial management, and administrative decision-making may need interpretation, harmonisation, or—where necessary—targeted amendment before a tokenised issuance process can have legal effect. DLT is consequently best introduced as an enabling layer within the public-finance control framework, not as a mechanism that transfers governmental discretion to software. For green sukuk, the network additionally requires a specific sharia-compliance function before the programmed process may proceed. Under that approach, the objective of DLT use in the actor dimension is to build connectedness and auditability between actors without removing substantive authorities already established by law.

2) Issuance and Reporting Cycle of Government Green Securities

The GGS cycle can be mapped into four interconnected phases. The pre-issuance phase encompasses the determination of green expenditure categories, the identification and evaluation of activities, budget tagging, and external assessment of the framework. The issuance phase encompasses the offering process and settlement of the securities transaction. The allocation phase connects issuance proceeds with expenditures meeting the criteria and records their allocation in a register. The post-issuance phase encompasses allocation reporting, impact estimation, and external assurance (Republic of Indonesia, 2021). Those four phases constitute the green governance layer usable for analysing both green bonds and green sukuk, while instrument differences emerge in processes relating to sharia structure and compliance. That mapping demonstrates that integrity risk is not concentrated in a single stage. . At pre-issuance, the quality of decisions depends on the data used to assess the eligibility of activities. To avoid bias in defining what qualifies as green, eligibility determination at this stage should be explicitly mapped onto and aligned with Indonesia's sustainable finance taxonomy issued by the Otoritas Jasa Keuangan, so that the eligibility logic encoded into the DLT reflects the national taxonomy definition rather than an independently constructed standard (Otoritas Jasa Keuangan, 2014, 2026). At the allocation phase, issuance proceeds must be reconciled with government expenditure and recorded consistently throughout the financing period. At the post-issuance phase, a lag exists between the realisation of activities and the publication of the annual report, so that investors obtain information after the activities have occurred. The need for traceability becomes increasingly important when financial and impact information originates from different organisational units. The study by Raeni et al. (2022) on Indonesia's green sukuk demonstrates that the accountability of that instrument requires a connector between financial data and environmental achievement along the organisational chain.

The corporate literature demonstrates why the post-issuance phase warrants attention, although that evidence cannot be generalised directly to GGS. Hunt (2024) found reporting and attestation gaps in a sample of United States dollar-denominated corporate green bonds. Petucco et al. (2025) demonstrate a more fundamental problem in the form of low availability of project-level data that would enable environmental claims to be tested independently. The issue relevant to GGS is not the prevalence figure but the mechanism: the greater the distance between occurrence, recording, reporting, and verification, the greater the dependence of external parties on the issuer's representation of information. DLT changes the character of that process by making recording and validation part of the transaction flow. Within the framework of Malamas et al. (2024), the approval of authorised parties can be positioned as a prerequisite that must be fulfilled before the process continues. Christodoulou et al. (2023) employ a similar principle to construct blockchain-based green bond monitoring. If adapted to GGS, substantive functions such as activity selection, environmental validation, and approval continue to be performed by authorised actors. The difference lies in the manner in which the results of those functions are recorded: from stages based on document exchange towards a validation history formed along the process.

At the allocation and post-issuance phases, the ledger has the potential to shorten the distance between occurrence and recording. Information currently reconciled to form registers and periodic reports can be linked to transaction history on a more continuous basis. That principle aligns with the embedded supervision of Auer (2019), namely the use of ledger information as one source of supervision without awaiting the resubmission of all information in the form of separate reports. The principal benefit of DLT in the process dimension therefore lies in enhanced traceability and auditability of financial and administrative events. This should not be confused with real-time environmental impact verification. Transaction and allocation events can be recorded as they occur, whereas impact indicators may still require scheduled measurement, field inspection, modelling, or ex-post evaluation. Efficiency in time, cost, or transaction settlement remains a potential benefit, but is not the principal mechanism connecting DLT with the mitigation of greenwashing risk. Higher traceability nevertheless does not guarantee the truth of the information recorded. Data on activity

realisation and environmental impact originate from activities outside the network, so that DLT processes still require a mechanism for bringing such data onto the ledger. Caldarelli (2020) demonstrates that the oracle problem arises when smart contracts depend on external information whose truth cannot be determined by the blockchain itself. In the GGS context, DLT therefore reduces problems of record alteration and fragmentation but does not eliminate the need for measurement, verification, and governance of data sources.

3) Architectural Procedures for Government Green Securities

The need to connect several institutions with differing access rights renders a permissioned architecture more relevant than a public network without participation restrictions. Malamas et al. (2024) employ a permissioned topology to ensure that participant identity and transaction authority can be controlled. For GGS, that choice is not merely a technical decision. Network topology determines who may enter data, who is authorised to validate, who may read particular information, and how accountability for decisions may be established. The governance question therefore shifts from the mere location of data storage towards the distribution of access and validation rights. The second principle is the use of programmed validation. Approvals that substantively remain the authority of institutions can be established as conditions before subsequent processes are executed. In both forms of GGS, this principle can be used to record the fulfilment of environmental and administrative requirements. In green sukuk, an additional layer exists because the instrument structure must also satisfy sharia requirements. The sukuk tokenisation literature demonstrates that the use of DLT must still be adjusted to the contract structure and economic rights of the instrument, so that token designs for bonds cannot be applied identically to sukuk (Delle Foglie et al., 2025; Khan et al., 2022). The neutral parts of the architecture are therefore the mechanisms of access rights, validation, and audit trail, whereas digital representation and sharia requirements require instrument adaptation.

The third principle is record integrity. Large documents or data need not be stored in their entirety within the ledger; what matters more is the capacity to connect data with cryptographic proof and a verifiable history of changes. That approach enables forensic-by-design, namely the formation of an audit trail as the process proceeds, rather than the reconstruction of an entire history only when examination is conducted (Malamas et al., 2024). That audit trail, however, proves what has been recorded and approved by the system rather than automatically proving that environmental conditions in the real world correspond to the records. Governance of validators and data sources remains a prerequisite for substantive integrity. Institutional readiness should also be treated as a condition for the architecture itself. A permissioned ledger requires an agreed governance charter defining who may operate validator nodes, who may approve or reject transactions, how exceptions are handled, how legal or administrative discretion is exercised when smart-contract conditions are not met, and who is accountable for correcting erroneous off-chain data. In practical terms, the design should begin with a legal and business-process mapping of existing GGS authorities and control points. Only after those controls are mapped should they be encoded as smart-contract conditions. This preserves the principle that code can automate the execution of an authorised rule, but cannot independently create, override, or legitimise public authority.

Table 2. Comparison of Existing and DLT-Based GGS Mechanisms

Dimension	Existing GGS Mechanism	DLT-Based Mechanism	Status Regarding the Two Instruments
Actor configuration	Information and validation dispersed across several institutions and external parties	Actors continue to perform substantive functions, but the results of decisions are recorded on a shared ledger with defined access rights	Common to GGS; green sukuk require an additional sharia compliance function
Process cycle	Selection, issuance, allocation, and reporting proceed through	Validation can be established as a process prerequisite and	Largely neutral with respect to instrument; sharia

	different processes and systems; principal reports are periodic	transaction history is formed along the cycle	compliance stage specific to green sukuk
Architectural procedures	Reconciliation depends on records and documents across systems	Permissioned network, programmed validation, cryptographic proof, and continuous audit trail	Topology and audit trail are neutral; digital representation of the instrument requires adjustment
Data integrity	Truth and consistency depend on the processes of reporting, reconciliation, and verification	Immutability preserves the integrity of records once data has entered	Both continue to require validation of external data/oracles

Source: Processed by the authors, 2026

Those three dimensions demonstrate that the principal contribution of DLT to GGS is not the elimination of all intermediaries but the strengthening of traceability, validation integration, and information auditability along the financing cycle. Its boundary is equally clear: the ledger can preserve the integrity of data already recorded, but the truth of the initial data continues to depend on the governance of information sources, validators, and oracles. Most of those functions can be applied to green bonds as well as green sukuk, but the comparator architecture does not yet accommodate the instrument structure and sharia compliance function required by green sukuk. Those architectural procedures therefore require further translation into a system design that accommodates the dual-instrument character of Indonesian GGS.

b. DLT Implementation in Government Green Securities

1) System Architecture Design

The architectural procedures set out in the preceding subsection are translated into a system design designated the GGS-Smart Contract (GGSC), an adaptation of the framework of Malamas et al. [2024] adjusted to the dual-instrument characteristics of Indonesian government green securities, namely green bonds and green sukuk. As in its reference framework, GGSC retains five core roles, namely issuer, investor, external validators, auditor, and regulator, each of which maintains an account and digital wallet address as its transaction identity. The principal difference lies in the addition of a sharia advisor node dedicated to handling sharia principle compliance in green sukuk issuance, given the dominance of that instrument within Indonesia's sovereign green portfolio. The GGSC workflow, as presented in Figure 2, proceeds in ten stages. Issuer and investor register with the system and obtain a unique identifier (UID) through the registration function, after which the issuer submits a bond or sukuk issuance request to the smart contract. The auditor performs Know Your Customer (KYC) examination of both parties, while external validators assess the issuer's impact prediction report and transmit their approval back to the contract. The regulator receives the approval request and returns its compliance decision before the instrument is tokenised and published. For green sukuk specifically, the flow is interposed with a sharia-compliance review represented by the Dewan Syariah Nasional–Majelis Ulama Indonesia (DSN-MUI) in the proposed architecture, reflecting the established role of DSN-MUI in providing or coordinating sharia conformity for sovereign sukuk structures.

The node should be understood as an institutional representation of the relevant sharia authority, not as a newly created discretionary entity. The compliance output becomes an additional prerequisite before tokenisation, consistent with the need to preserve the underlying akad and sharia requirements when digital infrastructure is introduced (Delle Foglie et al., 2025; Khan et al., 2022). Because sharia compliance in green sukuk extends beyond the initial contractual structure, the architecture should also record a periodic post-issuance sharia-audit checkpoint through which DSN-MUI, or its authorised representative, confirms that allocated proceeds have not been comingled with non-halal activity during project implementation, with the audit outcome logged on the ledger alongside the standard allocation and impact-reporting cycle. In this design, the external-validator node explicitly represents the institution providing the second party opinion referenced in

Section 4.1.1, such as CICERO or an accredited local rating agency, so that its cryptographic digital signature becomes a mandatory precondition before the instrument is tokenised and published, rather than a generically labelled validation role.

At the technical layer, the proposed architecture may represent bonds and sukuk as fungible digital units following the ERC-20 pattern used in the reference framework, issued only after all required approvals have been fulfilled, while supporting documents are stored on decentralised or controlled off-chain infrastructure with cryptographic hash values recorded on-chain to preserve document integrity (Malamas et al., 2024). This technical representation should nevertheless be treated as a design assumption for a future regulated environment rather than as evidence that Indonesian sovereign securities may presently be issued as ERC-20 tokens. Existing Indonesian market infrastructure is built around established electronic securities settlement and registration arrangements, while tokenisation is still being explored through financial-sector innovation and sandbox mechanisms (Bank Indonesia, 2025; Otoritas Jasa Keuangan, 2026). Accordingly, the legal definition of ownership, settlement finality, custody, and enforceability must precede any migration from a proof-of-concept token to a legally operative sovereign security. The feasibility of tokenisation for sharia instruments is further discussed by Khan et al. (2022), but the economic and legal rights embedded in the token must remain consistent with the underlying sukuk structure.

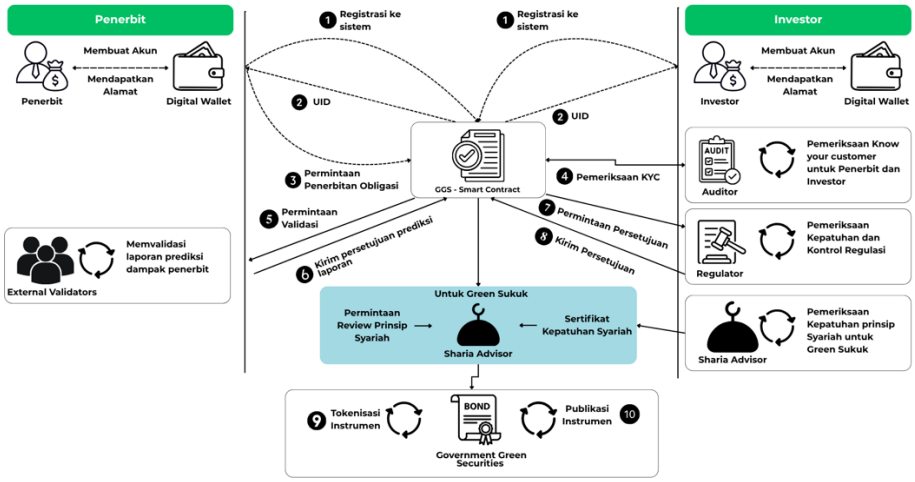

Figure 2. GGS-Smart Contract Architecture for the Issuance of Government Green Securities
(Processed by the authors, 2026, adapted from Malamas et al., 2024)

2) Facilities of DLT Application

That DLT architecture generates five facilities that directly address weaknesses associated with fragmented and predominantly ex-post verification. First, low-friction or atomic settlement can reduce settlement and counterparty exposure because the transfer of ownership and payment can be designed to occur as a coordinated ledger event, although legal finality and liquidity risk remain dependent on the surrounding market infrastructure. Second, cost efficiency may arise from reducing duplicated reconciliation and some layers of record-handling, rather than from eliminating all intermediaries. Cisar et al. (2025) report lower transaction costs in an Ethereum-based bond prototype, while Delle Foglie et al. (2025) discuss process streamlining in tokenised sharia instruments. Third, transparency and tamper-evident records can function as an anti-greenwashing mechanism because authorised records and their change history become easier to inspect and harder to alter undetected. This can strengthen green credibility, but it does not make the recorded claim true unless the underlying evidence has been appropriately validated, which remains consistent with the concern raised by Bachelet et al. (2019). Fourth, smart-contract-supported coupon processing can automate the generation and validation of payment instructions once contractual and timing conditions are met, but it should not bypass public-finance authorisation. In

the Indonesian APBN environment, payment execution remains embedded in the treasury control chain, including SPM and SP2D processes and the accounting and approval controls of the Sistem Perbendaharaan dan Anggaran Negara (SPAN).

Current SPAN 2.0 developments already emphasise electronic validation, approval, and automation rather than removal of public authority (Directorate General of Treasury, 2026). The GGSC should therefore function as a trigger, verification, or instruction layer that interoperates with SPAN, while the legally mandated treasury system retains the authoritative payment and accounting record until the regulatory framework explicitly recognises a DLT-based settlement layer. Fifth, forensic-by-design through a separate forensic contract can create a persistent audit trail alongside the flow of funds rather than relying exclusively on retrospective annual reconstruction. The relevance of these functions to development financing is reinforced by Chen & Volz (2022), who show how ledger-based recording can strengthen the transparency of fund mobilisation. Because smart contracts are inherently deterministic and rigid, the architecture should also embed an emergency override protocol: a multi-party, legally authorised mechanism, for example requiring joint authorisation from DJPPR and the fiscal authority, that can pause, adjust, or redirect programmed payment or allocation logic under force majeure conditions such as a pandemic or natural disaster that necessitates emergency budget refocusing. Such a safeguard ensures that the deterministic, code-is-law property of the smart contract does not foreclose the state's constitutional and statutory discretion to reallocate public funds in an emergency.

The system design and the application facilities of GGSC therefore operate complementarily rather than as two separate layers. The reconfiguration of actor roles and the programmed stages at the design layer constitute technical prerequisites for the five facilities to function, while those five facilities constitute the operational manifestation of the integrity objective underlying the design. Together, they can reduce the structural distance between transaction occurrence, recording, validation, and subsequent reporting. They do not, however, create instantaneous verification of environmental impact. The proposed contribution is better understood as continuous traceability of governed financial and administrative events combined with appropriately timed, independently validated impact reporting. This distinction keeps the architecture anchored in accountability rather than technological determinism.

c. Challenges in the Application of DLT to Government Green Securities

The implementation of DLT in Government Green Securities (GGS), whether in the form of green bonds or green sukuk, offers potential to improve the transparency, efficiency, and accountability of government green financing. Through distributed recording, tamper-evident histories, and smart-contract-supported process automation, DLT can address weaknesses in fragmented and predominantly document-based workflows. The transformation is nevertheless institutional as much as technological. The principal challenges concern regulation, interoperability, data validity, cybersecurity, data sovereignty, human-resource capacity, organisational culture, and the ability of public institutions to translate existing mandates into a networked governance environment. DLT will not by itself eliminate silo behaviour, improve ESG judgement, or guarantee truthful environmental reporting. The feasibility of the proposed architecture therefore depends on whether technological controls are embedded within a credible public-sector governance regime.

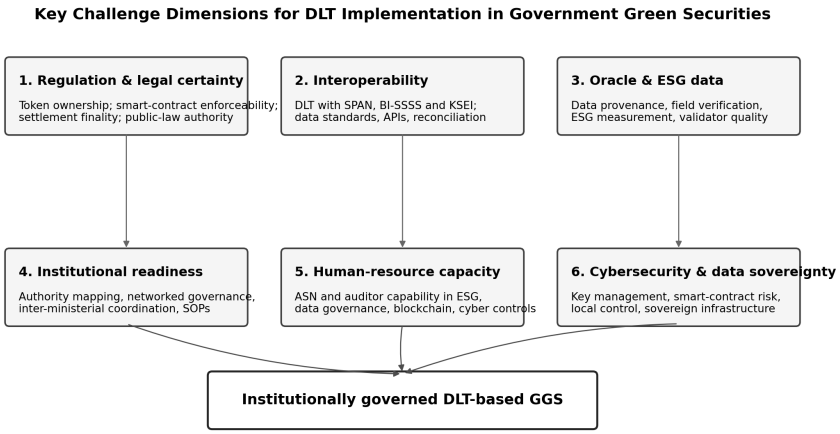

Figure 3. Mapping of the Challenges of DLT Implementation in Government Green Securities (Processed by the authors, 2026)

The first challenge relates to regulation and legal certainty. Indonesia's financial-sector innovation framework is already experimenting with tokenisation and related digital-asset models through regulatory sandbox arrangements, including models involving tokenisation of government securities, but this should not be equated with a fully operative legal regime for tokenised sovereign GGS issuance (Otoritas Jasa Keuangan, 2026). This caution is more pressing for sovereign instruments than for typical fintech sandbox use cases, because a technical failure in a tokenised government-securities pilot carries potential systemic macroeconomic consequences, including possible spillover effects on Indonesia's sovereign credit rating; sandbox experimentation involving sovereign debt therefore warrants a more conservative scope, stronger safeguards, and closer supervisory oversight than is customary for private fintech innovation. For a production-scale GGSC, legal certainty is required regarding the legal status of the token, the identity of the securities holder, settlement finality, custody, the evidentiary status of smart-contract execution, and the relationship between DLT records and the authoritative records maintained by existing market infrastructure. The proposal therefore does not assume that existing laws automatically permit tokenised issuance. Instead, it implies a staged legal-gap assessment covering the Government Securities framework, public-finance and treasury rules, capital-market regulation, payment-system arrangements, sharia requirements for SBSN, and administrative-law principles governing public discretion. Where current rules are insufficient, targeted regulatory harmonisation or amendment would be required before the architecture could operate as a legally binding sovereign issuance mechanism.

A further challenge of no less importance is interoperability between the DLT platform and existing financial market infrastructure. In the issuance and settlement of Government Securities, institutions such as DJPPR, Bank Indonesia, KSEI, custodian banks, primary dealers, regulators, and environmental assessment bodies operate systems with different data models, control requirements, and legal functions. Bank Indonesia's BI-SSSS already provides an integrated electronic infrastructure for securities settlement, registration of ownership, and coupon or principal payments, while current policy work is exploring the broader role of digital securities and DLT-based tokenisation (Bank Indonesia, 2025). GGSC should therefore be designed as an interoperable layer around authoritative financial infrastructure rather than assuming that the blockchain can immediately replace every existing system. This requires common data definitions, identity standards, event schemas, API or messaging interfaces, reconciliation rules, and a clear hierarchy determining which system is authoritative for which record.

On the other hand, DLT implementation faces the challenge of guaranteeing the validity of data recorded into the blockchain network. Although the ledger can preserve data once recorded, it cannot independently determine whether the data reflects actual conditions. In the Government

Green Securities context, the oracle function should therefore be understood as an institutional and technical gateway through which verified off-chain evidence enters the ledger. This may involve ASN personnel, internal auditors, external assessors, field inspectors, environmental experts, and other authorised data providers, depending on the indicator being reported. The resulting risk is a classic garbage-in, garbage-out problem: weak ESG measurement capacity, poor field verification, conflicts of interest, or weak data governance can cause incorrect evidence to be preserved rather than corrected. Capacity building is consequently a core implementation requirement. Public officials and assurance providers need training in ESG measurement, environmental evidence, data governance, blockchain controls, cybersecurity, and the interpretation of smart-contract exceptions. Capacity development should be embedded in the operating model, certification requirements, and quality-assurance procedures of the architecture rather than treated as an optional training programme after deployment.

Beyond technical challenges, the application of DLT also demands change in institutional governance. Contrary to the assumption that blockchain can replace the entire role of existing institutions, DLT-based implementation of Government Green Securities requires closer collaboration among stakeholders. DJPPR continues to exercise its substantive sovereign-financing functions, regulators continue to supervise, external reviewers continue to provide second-party or assurance functions, DSN-MUI continues to represent the sharia-compliance function for green sukuk, auditors continue assurance activities, and KYC/AML service providers remain responsible for investor verification. For retail-oriented instruments such as Green Retail Sukuk, that verification function is, in practice, carried out by distribution partners (Mitra Distribusi/Midis), namely commercial banks, securities companies, and fintech platforms, rather than by DJPPR directly. The architecture should therefore assign Midis a defined role, such as an API-gateway node, so that retail-investor onboarding and KYC/AML data can be transmitted directly into the DLT without duplicating verification across intermediaries. The principal change lies in the information architecture: authorised actions, approvals, exceptions, and data provenance become visible and traceable across institutional boundaries. In this sense, DLT can operate as a boundary-spanning governance infrastructure that supports networked coordination while preserving hierarchical legal accountability. The transition nonetheless demands new operating standards, role definitions, escalation procedures, and organisational incentives so that greater transparency does not become a source of institutional conflict or culture shock.

Further challenges relate to cybersecurity, implementation cost, and data sovereignty. Permissioned blockchain can provide controlled participation, but risks such as private-key compromise, smart-contract vulnerabilities, validator-node attacks, insider threats, and leakage of investor or transaction information remain. Because the proposed network concerns sovereign financing, its architecture should adopt a sovereign-data principle: core validator nodes and sensitive authoritative records should, as a default, be hosted and administered under Indonesian jurisdiction and within infrastructure that meets the government's applicable security and data-governance requirements. Cross-border cloud or processing arrangements, where contemplated, should be subject to explicit legal, security, and risk assessments rather than assumed to be permissible. This is consistent with the wider SPBE governance environment, which places emphasis on information security, data management, ICT asset management, and central government digital infrastructure (Ministry of Communication and Digital Republic of Indonesia, 2026). In addition, development requires substantial investment in network construction, integration, security audits, resilience, and human-resource training. The success of DLT-based GGS is therefore determined not only by technical sophistication, but by the combined maturity of regulation, institutions, people, data governance, and sovereign infrastructure. Because these requirements entail substantial capital expenditure for network construction, system integration, and the retraining of civil servants (ASN), implementation should be preceded by a rigorous cost-benefit analysis that weighs the magnitude of this transition cost against the fiscal value of the greenwashing and misallocation risk the

architecture is intended to prevent; without such an efficiency justification, fiscal authorities have limited grounds to prioritise DLT investment ahead of competing budget needs.

5. CONCLUSION

This study aims to design a framework for the implementation of Distributed Ledger Technology (DLT) in Indonesia's Government Green Securities (GGS), encompassing green bonds and green sukuk, as part of the digital transformation of government green financing. The analysis identifies that the central integrity problem is not simply the absence of reporting, but the distance between fiscal authority, implementing ministries, transaction records, and evidence of environmental performance. This distance is reinforced by information asymmetry, fragmented systems, periodic reporting, and institutional incentives that may emphasise compliance over substantive impact accountability. Against that problem, DLT is positioned as governance infrastructure capable of linking authorised decisions, financial events, allocation records, validation states, and audit trails through a permissioned network. Its principal contribution is stronger traceability and auditability, not the replacement of substantive public authority or environmental verification. Environmental impacts remain dependent on appropriate measurement intervals and trusted off-chain evidence.

The proposed GGSC architecture therefore retains existing institutional authority while changing the way information moves between institutions. DJPPR and other authorised government actors remain responsible for substantive fiscal decisions; ; regulators retain supervisory authority; external reviewers and auditors retain assurance functions; DSN-MUI represents the sharia-compliance function for green sukuk; KYC/AML providers retain identity-verification responsibilities; and investors remain users and beneficiaries of the transparency mechanism. In this configuration, auditors should be understood, in Indonesia's sovereign context, as institutions holding constitutional and statutory audit mandates, principally the Badan Pemeriksa Keuangan (BPK) and the Badan Pengawasan Keuangan dan Pembangunan (BPKP); their access permissions within the DLT must not be constrained or gated by smart-contract logic, since BPK's audit authority derives from the 1945 Constitution rather than from network-level consensus. Similarly, the sharia-compliance function represented by DSN-MUI should extend from pre-issuance structural review to a periodic post-issuance sharia audit confirming that allocated proceeds have not been comingled with non-halal activity during project implementation.The DLT network becomes a shared evidentiary layer through which those functions can be recorded, validated, and audited. This design also supports a boundary-spanning form of networked governance that can reduce the opacity created by inter-ministerial silos without abolishing the hierarchical accountability required by public law. Because GGS proceeds originate from public funds (APBN/APBD), accountability under this design should extend beyond investors and regulators to encompass democratic accountability to citizens. The architecture should therefore incorporate a public block explorer, a read-only interface exposing non-sensitive allocation and impact-reporting data, so that civil society organisations and environmental NGOs can independently monitor the flow of green financing as a form of public participation, without compromising the confidentiality safeguards required for sensitive transaction or investor data. The architecture is thus institutionally conservative in authority but digitally transformative in information governance.

On the basis of the research results, implementation of DLT in Government Green Securities requires a coordinated roadmap that combines technology, regulation, institutional transformation, and human-resource development. The Ministry of Finance, through DJPPR, is advised to begin with a legal and business-process gap assessment, followed by a proof of concept and a controlled pilot focusing on a limited financing and reporting cycle. The roadmap should run on two parallel tracks. The first is a technology and market-infrastructure track covering permissioned-network design, interoperability with existing securities and treasury systems, cybersecurity, oracle governance, and controlled tokenisation. The second is an institutional and human-capital track covering authority

mapping, inter-ministerial data standards, revised operating procedures, validator and oracle competency standards, role redefinition, change management, and training for officials involved in ESG assessment and financial control. OJK, Bank Indonesia, KSEI, and the Ministry of Finance should subsequently align the legal framework governing tokenised government securities, smart-contract enforceability, digital ownership, settlement, data governance, and interoperability. This two-track roadmap is important to prevent culture shock during the transition from siloed administration towards a more networked information architecture.

From the technological side, implementation should preferably employ a permissioned architecture with validator nodes operated by authorised principal institutions and hosted according to Indonesian sovereign-data and security requirements. Trusted oracle standards should be developed so that expenditure, project-progress, and environmental information entering the ledger is accompanied by identifiable provenance, quality controls, and appropriate external verification. Smart contracts should interface with SPAN and other authoritative systems rather than bypass statutory treasury controls, while future settlement arrangements should be tested for legal finality, operational resilience, and reconciliation. Strengthening human-resource capacity in blockchain, cybersecurity, ESG measurement, data governance, and public financial management is equally important. Further research should develop and empirically test a prototype using Hyperledger Fabric or a comparable permissioned platform, evaluating not only cost efficiency and settlement speed but also data quality, ESG reporting reliability, control effectiveness, interoperability, stakeholder acceptance, and the institutional conditions under which automation improves rather than merely digitises existing processes.

Limitations

This study does not conduct empirical testing of a DLT architecture in Indonesian GGS issuance, so its findings concerning the benefits of DLT are analytical and prescriptive rather than observed performance. The framework of Malamas et al. (2024), which serves as the principal benchmark, is likewise an architectural design, so its effectiveness in sovereign transactions cannot yet be assumed. In addition, much of the empirical evidence concerning reporting and verification failure originates from the corporate green bond market. Those findings are used to identify risk mechanisms, but their generalisation to GGS is bounded through triangulation with sovereign literature, green sukuk literature, and official Indonesian documents. The study also does not empirically test the legal enforceability of tokenised sovereign securities, the behavioural response of public officials to networked governance, the accuracy and timeliness of environmental oracle data, or the cybersecurity and data-sovereignty performance of a production network. These dimensions remain important because the success of the proposed architecture ultimately depends on institutional and data quality as much as on distributed-ledger functionality.

Further research is therefore required to test the proof of concept and governance effectiveness of the proposed architecture within the domestic issuance environment. Such testing should use staged pilots to examine whether the architecture improves the traceability of funds, the quality and provenance of ESG evidence, the reliability of cross-agency controls, and the efficiency of settlement without weakening legally mandated approval and accounting procedures. Comparative testing across green bonds and green sukuk, and eventually across sovereign and subnational applications, would also help determine which components of the architecture are generic and which require context-specific adaptation.

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AI Usage Statement

The preparation of this article made limited use of generative artificial intelligence. Claude (Anthropic) was used for language editing, paraphrasing, and the alignment of writing format, while Consensus was used for the preliminary search of scholarly literature. That use did not extend to the formulation of ideas, the construction of arguments, analysis, or the drawing of conclusions. All scholarly substance in this article is the product of the authors' own reasoning. Artificial intelligence was not used to generate data, quotations, or reference list entries, and every reference has been verified by the authors against its original source. The authors accept full responsibility for the entire content of the article, including for any artificial intelligence output used.

Author Contributions

Tri Yofan Agusti Rahmat Dani: conceptualisation, introduction, analysis of DLT implementation, visualisation, writing — original draft. **Sarah Anami Girsang**: literature review, methodology, comparative analysis, writing — review and editing. Both authors contributed to validation and have read and approved the final version of the manuscript.

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Conflict of Interest

The authors declare no financial, commercial, or personal relationships that could be construed as a potential conflict of interest in relation to this research.

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