Institut Riset dan Publikasi Indonesia (IRPI)
MALCOM: Indonesian Journal of Machine Learning and Computer Science
Journal Homepage: https://journal.irpi.or.id/index.php/malcom
Vol. 6 Iss. 1 January 2026, pp: 212-219
ISSN(P): 2797-2313 | ISSN(E): 2775-8575

TaxLedger A Blockchain-Based Automated Tax Reporting System Using Smart Contracts

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Received Nov 30th 2025; Revised Dec 18th 2025; Accepted Jan 18th 2025; Available Online Jan 31th 2026
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Abstract

This study aims to design and evaluate a blockchain-based automated tax reporting system that is capable of calculating, recording, and reporting tax obligations in a transparent and auditable manner. Conventional tax systems still rely on manual reporting and delayed verification, which often lead to data inconsistencies and reduced fiscal transparency. To address this problem, this research proposes TaxLedger, a system that integrates smart contracts and a hybrid on-chain and off-chain blockchain architecture. Smart contracts automate tax calculation and enforce deterministic tax rules at the transaction level, while off-chain components support efficient data aggregation and reporting. The results show that the proposed system successfully achieves the research objectives by ensuring immutable transaction records, real-time tax computation, and verifiable digital audit trails. These findings indicate that TaxLedger improves transparency, traceability, and audit efficiency, thereby providing a practical technological foundation for modern digital tax administration.

Keywords: Automation, Blockchain, Digital Audit, Smart Contract, Tax, Transparency

1. INTRODUCTION

The rapid growth of the digital economy has increased the volume of electronic transactions, posing significant challenges for conventional tax administration systems [1]. Manual reporting, delayed verification, and centralized data management reduce transparency and increase the risk of reporting discrepancies and tax gaps. These limitations indicate the need for a tax reporting mechanism that can ensure accuracy, transparency, and real-time verification in digital transaction environments, as the absence of such mechanisms increases audit complexity, administrative costs, and the potential for tax non-compliance [2].

To address these challenges, this study proposes TaxLedger, a blockchain-based automated tax reporting system that utilizes smart contracts to perform real-time tax calculation and immutable transaction recording. The system adopts a hybrid on-chain and off-chain architecture, where tax logic and verification are executed on the blockchain, while off-chain components support efficient data aggregation and reporting. Smart contracts are employed because they enable deterministic and tamper-resistant execution of tax rules, ensuring that tax calculations are automatically enforced without intermediary intervention, as supported by prior studies on blockchain-based auditing and compliance [3]. This approach minimizes manual intervention and enhances data integrity and auditability for tax authorities.

Several previous studies have explored the application of blockchain technology in taxation. [4] shows that blockchain can enhance transparency and reduce data manipulation in tax administration, while [5] demonstrates its effectiveness in improving value-added tax reporting through improved traceability. further highlights the role of smart contracts in automating audit processes through deterministic rule execution. However, these studies mainly focus on conceptual models or partial implementations and do not provide a fully automated, end-to-end tax reporting system that integrates real-time tax calculation, immutable transaction storage, and synchronized reporting within a single operational framework [6].

This research differs from previous studies by presenting an integrated and operational system that combines smart contract–based tax calculation, hybrid blockchain architecture, and synchronized off-chain reporting within a single framework. Unlike earlier research that emphasizes transparency or compliance monitoring in isolation, this study embeds executable tax rules directly into smart contracts and links them with real-time reporting and audit mechanisms. The novelty of this research lies in its end-to-end automation of tax reporting that ensures transaction-level transparency, traceability, and verifiable audit trails [7].

Based on this context, the objective of this study is to design and evaluate a blockchain-based tax reporting system capable of automatically calculating, recording, and reporting tax obligations in a transparent, reliable, and auditable manner [8]. This research aims to demonstrate that smart contracts and hybrid blockchain architecture can effectively address the limitations of conventional tax systems in the digital economy [9].

2. MATERIALS AND METHOD

This study employed a system design and engineering approach to develop TaxLedger, a blockchain-based automated tax reporting system. The methodology consisted of four stages: requirement analysis, system architecture design, smart contract development, and hybrid on-chain/off-chain integration. All steps were documented in detail to allow replication by other researchers [10].

2.1 Requirement Analysis

The functional and non-functional requirements were identified through analysis of conventional tax reporting workflows and existing digital taxation studies. The system requirements included automated tax calculation, immutable transaction recording, real-time reporting, and auditable digital trails. The business rules for tax computation, transaction categories, and reporting periods were defined as the core logic of the smart contract.

2.2 System Architecture Design

The system architecture of TaxLedger is designed using a hybrid approach that integrates both on-chain and off-chain components to achieve efficiency, transparency, and secure tax reporting automation [11]. Each architectural layer is responsible for a specific set of functions that support the end-to-end workflow from user transaction input, gateway validation, smart contract execution, blockchain confirmation, to reporting and settlement with tax authorities. This layered approach ensures optimal distribution of computational load while maintaining data integrity within the blockchain network.

Figure 1 presents the complete architecture of the TaxLedger system, consisting of six major components: Off-chain Applications, Gateway/Oracles, Blockchain Network, On-chain Smart Contracts, Regulator/Tax Authority Interface, and Payment Rails. These components interact through mechanisms such as data synchronization, event listeners, and smart contract triggers to create a seamless and automated tax-reporting pipeline.

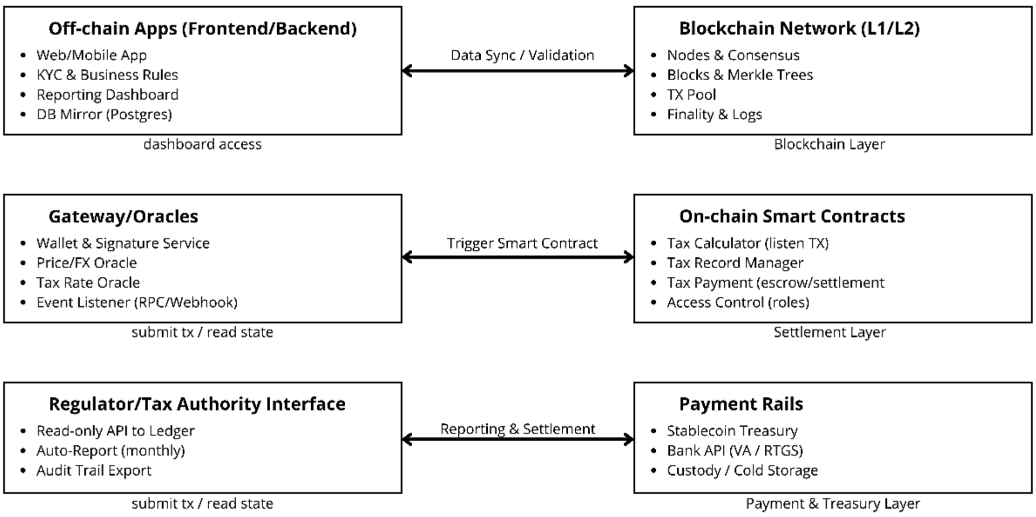

Figure 1. Hybrid blockchain system architecture of the TaxLedger platform.

2.3 Data Model (Entity Relationship Diagram)

The TaxLedger system's data model is designed to ensure consistent, transparent, and traceable management of tax-related information across on-chain and off-chain components. Figure 2 presents the Entity Relationship Diagram (ERD), which illustrates the five core entities of the system User, Transaction, Block, TaxRecord, and SmartContract and the relationships among them. These entities collectively represent the logical structure required to support automated tax calculation, transaction traceability, and auditability within the proposed framework e[12].

The User entity represents individuals or organizations registered in the TaxLedger system. Each user is uniquely identified by a wallet address and public key, which are used to authenticate transactions and ensure secure system interactions. A user may create or receive multiple Transaction records. Each transaction captures essential information, including sender and receiver identifiers, transaction amount, timestamp, transaction category, applicable tax rate, computed tax value, and execution status. To ensure blockchain traceability, every transaction is linked to a corresponding Block entity that stores verification metadata such as the previous block hash, Merkle root, timestamp, block creator, and nonce.

The TaxRecord entity is used to summarize all transactions associated with a user within a specific reporting period. It aggregates transaction data to compute total income, expenses, and tax liabilities, while also recording the reporting status for compliance purposes. This aggregation mechanism enables efficient periodic tax reporting without requiring repeated processing of individual transaction data. Meanwhile, the SmartContract entity defines the automated and deterministic logic governing tax calculation and settlement. Smart contracts are responsible for computing tax obligations at the transaction level and emitting events that trigger updates to the corresponding tax records.

The relationships represented in the ERD reflect the operational workflow of the TaxLedger system, in which user-initiated transactions are validated and grouped into blockchain blocks, subsequently aggregated into periodic tax records, and processed through smart contract–based tax logic. By modeling these relationships explicitly, the data model maintains consistency between blockchain events and off-chain storage. As a result, the proposed data model supports transparent audit trails, ensures data integrity, and enables deterministic execution of tax rules throughout the TaxLedger system.

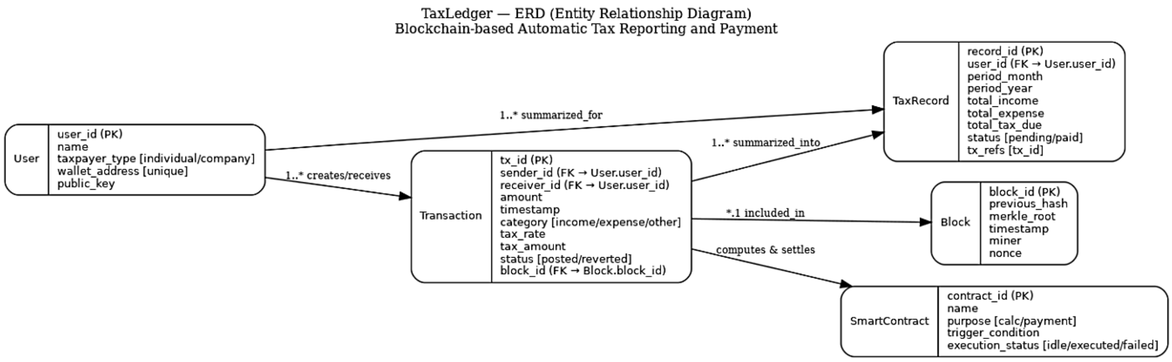

Figure 2. Entity Relationship Diagram of the TaxLedger System

2.4 Smart Contract Development

Smart contracts were implemented using Solidity and deployed on a private Ethereum-based blockchain. The main contract modules included *TaxCalculator*, *TaxRecordManager*, and *TaxPayment*. Each contract performed deterministic functions, including transaction validation, retrieval of tax rates from oracles, automatic computation of tax obligations, and emission of events (*TaxCalculated*, *TaxPaid*). All logic was coded to ensure reproducibility and deterministic execution [13].

2.5 Workflow and Process Modeling

The workflow of the TaxLedger system is modeled using Business Process Model and Notation (BPMN) to illustrate the automated sequence of tax calculation, validation, transaction recording, and payment settlement. The BPMN diagram captures the interactions between the User, Gateway System, Smart Contracts, Blockchain Network, and the Regulator. This workflow demonstrates how tax obligations are processed automatically without manual reporting.

Figure 3 presents the BPMN workflow of the TaxLedger process. The workflow begins when a user initiates a financial transaction. The Gateway System receives and records the transaction request as the first off-chain validation step. After initial validation, the request is forwarded to the on-chain TaxCalculator smart contract, which automatically computes the applicable tax based on predefined rules and available tax rate data.

The smart contract then evaluates whether the transaction and tax rate are valid. If the tax rate is missing or outdated, the system queries the TaxRate Oracle to update the rate before the calculation continues. If the data is valid, the transaction and computed tax information are stored on the blockchain as part of a new block once consensus is reached.

2.6 UML Diagrams of the TaxLedger System

UML diagrams are used in the TaxLedger system to model the structural and behavioral aspects of the blockchain-based tax reporting workflow. These diagrams help illustrate how users interact with the system, how internal processes occur between components, and how smart contracts and off-chain modules collaborate to produce automated tax reporting and settlement.

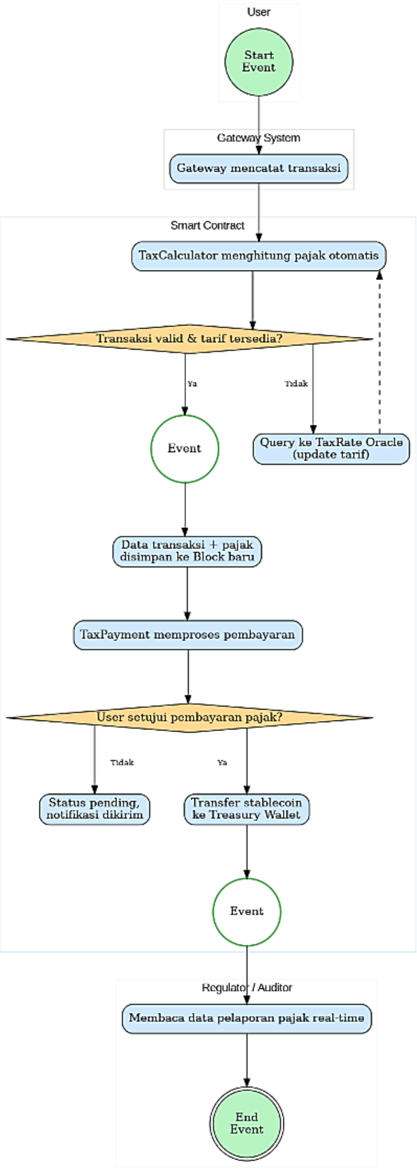

Figure 3. BPMN workflow of automated tax calculation, validation, and payment settlement in the TaxLedger system.

2.6.1 Use Case Diagram

The Use Case Diagram illustrates the interaction between the main actors and the core functionalities of the TaxLedger system. The primary actors include the User or Taxpayer, Gateway API, Smart Contract System, Tax Authority, and Auditor. Users submit financial transactions through the system, which are validated and digitally signed by the Gateway API before being processed on-chain. Smart contracts are responsible for automatically calculating tax obligations, executing tax settlements and fund transfers, and generating tax records. Tax authorities are able to perform real-time verification of reported transactions, while auditors can independently review ledger data for compliance and accountability purposes. Overall, the diagram defines the functional boundaries of each actor and clarifies the distribution of responsibilities between off-chain services and on-chain smart contracts.

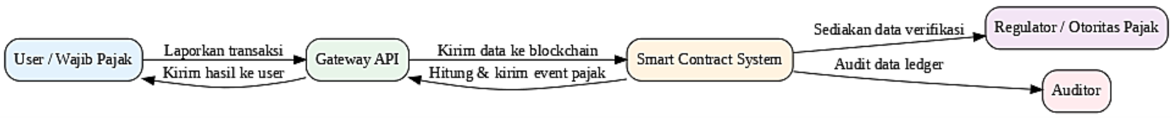

Figure 4. Use Case Diagram of the TaxLedger System.

2.6.2 Sequence Diagram

The Sequence Diagram represents the chronological flow of interactions in the tax processing workflow within the TaxLedger system. It illustrates how the Gateway API first validates the user-submitted transaction data before forwarding it to the blockchain. The validated transaction is then processed by the TaxCalculator smart contract, which computes the corresponding tax obligation and emits calculation events. Both transaction and tax data are subsequently confirmed into a blockchain block, ensuring immutability and traceability. Upon user authorization, the TaxPayment contract executes the tax settlement process. Throughout this sequence, regulators receive relevant event logs that support real-time reporting and verification. This behavioral model demonstrates how synchronous off-chain validation and asynchronous blockchain event processing are integrated to achieve a fully automated tax reporting workflow.

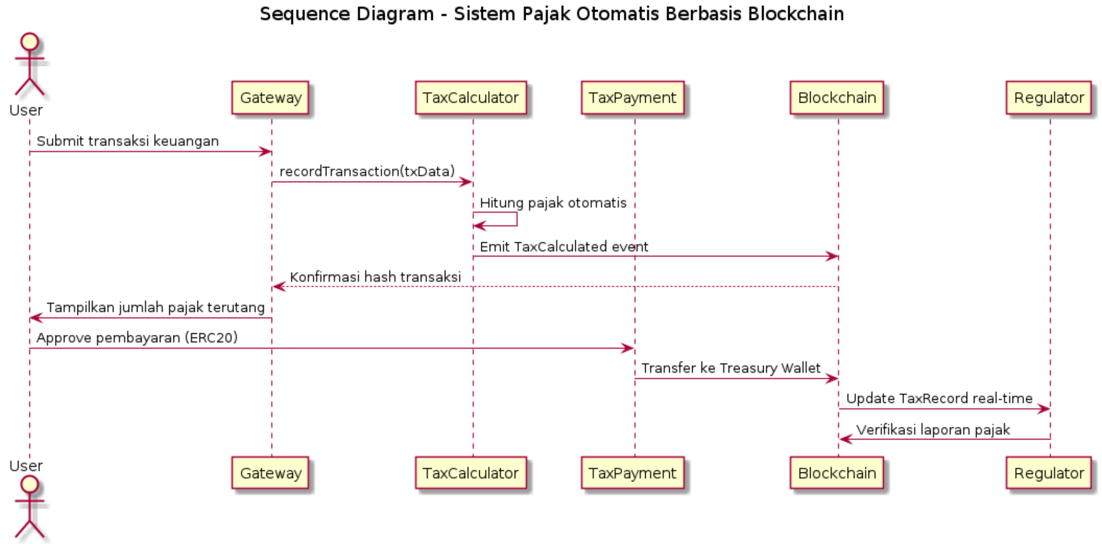

Figure 5. Sequence Diagram of automated tax processing in TaxLedger.

2.6.3 Class Diagram

The Class Diagram illustrates the structural components of the TaxLedger system by defining its core data entities and smart contract modules. The User class represents registered taxpayers and stores identity and authentication attributes such as user identifiers, wallet addresses, taxpayer types, and public keys. The Transaction class captures financial transaction details, including sender and receiver information, transaction amount, timestamp, category, applicable tax rate, and execution status. Periodic tax summaries are represented by the TaxRecord class, which aggregates income, expenses, and tax liabilities for a given reporting period [14]. Blockchain-related metadata is modeled through the Block class, which records block identifiers, previous hashes, Merkle roots, timestamps, miner information, and nonces to ensure transaction traceability and integrity. In addition to these data entities, the system incorporates several smart contract modules that encapsulate core tax processing logic, including tax calculation, tax record management, tax payment execution, and access control. The diagram also illustrates the associations among these classes, particularly the relationships between users and transactions, transactions and blocks, and the interactions between smart contract modules and underlying data structures. Together, these components define the structural foundation of the TaxLedger system.

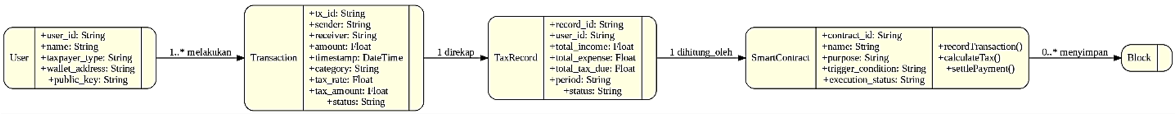

Figure 6. Class Diagram of the TaxLedger System

2.7 Replicability

All methods, including architecture configuration, blockchain network setup, smart contract logic, and data schemas, were documented to enable other researchers to reproduce the system in similar experimental environments. Established techniques such as BPMN modeling and distributed ledger consensus were applied according to referenced standards [15].

2.8 Literature Review

Blockchain technology has been increasingly studied as a solution for improving transparency, accountability, and efficiency in tax administration systems. Yayman [4] explains that blockchain can reduce data manipulation in taxation by providing immutable and distributed transaction records. Similarly, Lyutova and Fialkovskaya [2] highlight that blockchain adoption in tax administration strengthens legal certainty and improves trust between taxpayers and authorities by minimizing centralized control over fiscal data. Several studies emphasize the role of smart contracts in automating tax-related processes. Zheng et al. [3] describe smart contracts as deterministic programs that execute predefined rules without intermediary intervention, making them suitable for automated tax calculation and enforcement. Setyowati et al. [5] demonstrate that smart contracts can significantly improve value-added tax (VAT) reporting by ensuring real-time computation and traceable transaction flows. These findings indicate that smart contracts are effective tools for reducing manual reporting errors and improving compliance.

Research on blockchain-based auditing further supports the use of distributed ledger technology for fiscal transparency. Georgiou et al. [8] show that blockchain improves audit efficiency by enabling continuous and verifiable audit trails, while Kusyanti et al. [19] confirm that smart contract–based systems enhance data integrity and accountability in financial applications. Sardju and Nursansiwi [11] also argue that integrating blockchain into financial reporting increases trust and reduces reconciliation complexity.

Despite these contributions, most existing studies focus on conceptual models, literature reviews, or specific aspects of taxation such as VAT, audit trails, or regulatory analysis. Dharma [7] and Maxmudjanovna and Shokhista [9] note that practical implementations of blockchain-based tax systems remain limited, particularly those that integrate automated tax calculation, immutable transaction storage, and synchronized reporting within a single operational framework. Additionally, Alharby and Van Moorsel [13] highlight that many smart contract applications lack comprehensive system-level integration.

Based on these limitations, this research extends prior studies by proposing an end-to-end blockchain-based automated tax reporting system. By integrating smart contract–based tax rule execution, hybrid on-chain and off-chain architecture, and real-time auditability, the proposed TaxLedger system addresses gaps identified in previous research and provides a practical foundation for modern digital tax administration.

3. RESULTS AND DISCUSSION

3.1. Result

This section presents the implementation results of the TaxLedger system and evaluates how the proposed hybrid blockchain architecture supports automated, transparent, and auditable tax reporting. The results demonstrate that the system can process digital transactions by automatically calculating tax obligations in real time via smart contracts. Each transaction is recorded immutably on the blockchain, ensuring that tax-related data cannot be altered after confirmation and preserving data integrity from the initial transaction stage. The integration of off-chain data management with on-chain execution significantly improves system efficiency. Transaction data that does not require immutable storage is managed off-chain, allowing the system to perform efficient aggregation and reporting without repeatedly querying the blockchain. This design enables fast retrieval of periodic tax summaries while maintaining consistency between on-chain records and off-chain representations through cryptographic transaction references. As a result, the system supports scalable tax reporting even under high transaction volumes without compromising traceability or auditability.

The synchronization between on-chain and off-chain components is achieved through automated communication mechanisms that respond to blockchain events. When transactions are confirmed or tax calculations are executed on-chain, corresponding updates are reflected in the off-chain environment in near real time. This mechanism reduces manual reconciliation effort and ensures that reporting data remains consistent with blockchain records. The results indicate that this synchronization approach effectively supports real-time reporting and regulatory oversight. Smart contracts play a central role in enforcing deterministic tax rules within the TaxLedger system. They are responsible for validating transactions, calculating applicable taxes, and generating verifiable event logs that support audit processes. Access control mechanisms embedded in the smart contracts ensure that only authorized users can initiate tax-related transactions.

These features collectively enhance transparency and trust by minimizing opportunities for data manipulation and ensuring that all tax calculations follow predefined rules. Overall, the implementation results confirm that the proposed TaxLedger system successfully achieves the research objectives. By combining automated tax computation, immutable transaction recording, and synchronized reporting within a hybrid blockchain architecture, the system provides a practical and auditable solution for digital tax administration. The broader implications and comparative advantages of this approach over existing tax reporting methods are further analyzed in the following discussion section.

3.2. Discussion

The results demonstrate that the hybrid blockchain architecture effectively addresses key limitations of conventional tax reporting systems. Real-time tax calculation through smart contracts reduces reliance on manual reporting processes, which are often prone to delays and human error. This finding supports prior studies that highlight blockchain's ability to improve transparency and operational efficiency in taxation systems [1], [6]. Compared to earlier studies that primarily present conceptual frameworks or partial implementations, the TaxLedger system offers an integrated and operational solution. The combination of immutable on-chain records and scalable off-chain data management balances transparency and performance, confirming the importance of hybrid architectures for practical blockchain applications as noted in previous research [10], [11]. Smart contract–generated event logs enhance auditability by enabling real-time verification of transactions and tax obligations. This mechanism aligns with findings by Kovács [7] and Georgiou et al. [8], which emphasize the role of blockchain in improving audit efficiency and regulatory oversight. Automated enforcement of tax rules also reduces opportunities for data manipulation, strengthening trust between taxpayers and authorities.

Despite these advantages, the system is currently evaluated in a controlled private blockchain environment, which may differ from large-scale public deployments. Regulatory integration and interoperability with existing tax systems remain challenges that require further investigation. Future research may focus on performance evaluation at scale, regulatory integration, and advanced analytics to enhance compliance monitoring.

5. CONCLUSION

This study aimed to design and evaluate a blockchain-based automated tax reporting system that is transparent and auditable. Based on the results and analysis, the research demonstrates that TaxLedger can automate tax calculation, transaction recording, and reporting using smart contracts and a hybrid blockchain architecture. The system provides immutable transaction records, real-time tax computation, and verifiable digital audit trails. The main novelty of this research lies in its end-to-end integration of smart contract–based tax rule execution, secure transaction storage, and synchronized reporting within a single operational framework. Unlike previous studies that are largely conceptual or partially implemented, this work presents a comprehensive and implementable solution. Future research is recommended to evaluate the system at a larger scale and to examine regulatory and interoperability aspects with existing tax administration systems.

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