EUROPEAN JOURNAL OF SCIENTIFIC RESEARCH AND REVIEWS
2025; 2(2): 57-71
10.5455/EJSRR.20250208113947

ORIGINAL ARTICLE

Open Access

Revolutionizing tax compliance with blockchain: A study of VAT and income tax frameworks

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ABSTRACT

Background/Aim: Tax compliance remains a significant challenge for governments worldwide, as traditional value-added tax (VAT) and income tax systems are often inefficient, prone to fraud, and administratively complex. Blockchain technology presents a potential solution by offering transparency, immutability, and decentralization, which can enhance tax compliance processes. This study explores the application of public and private Blockchain configurations in tax administration, evaluating their effectiveness in fraud prevention, operational efficiency, and regulatory adaptability. The aim is to determine the comparative advantages and limitations of these Blockchain models in VAT and income tax compliance and propose a framework that optimizes their integration into existing tax systems.

Methods: A comparative analysis of public and private Blockchain configurations was conducted, focusing on key performance metrics such as fraud reduction, cost efficiency, transparency, data privacy, and compliance accuracy. Public Blockchains, such as Ethereum with InterPlanetary File System, were assessed for their role in real-time invoice verification and VAT compliance, while private Blockchains, such as Hyperledger Fabric, were evaluated for their secure handling of income tax data. The study also examines regulatory challenges, interoperability issues, and technological constraints affecting blockchain adoption in tax administration.

Results: The findings indicate that public Blockchains significantly enhance transparency and fraud detection, reducing invoice fraud by 90% and lowering administrative costs by 85%. However, their limited data privacy raises concern for transactions involving sensitive financial information. In contrast, private Blockchains prioritize data security and controlled access, ensuring 95% data privacy and 88% compliance accuracy in income tax reporting. Despite these advantages, private Blockchains incur higher operational costs and require robust governance mechanisms for effective implementation. The study also identifies regulatory uncertainty, interoperability with existing tax infrastructures, scalability constraints, and technological complexity as key barriers to Blockchain adoption in tax compliance.

Conclusion: To maximize the benefits of Blockchain in tax administration, a hybrid Blockchain framework is recommended, combining public Blockchain transparency for VAT compliance with private Blockchain security for income tax management. Policymakers must establish clear regulatory frameworks, invest in scalable digital infrastructure, and promote system interoperability to facilitate adoption. A phased implementation strategy, incorporating pilot programs, public–private partnerships, and targeted policy incentives, is crucial for a smooth transition to decentralized tax compliance. Future research should explore cross-border Blockchain tax models, artificial intelligence-driven fraud detection, and the economic implications of Blockchain-based tax compliance to further enhance the effectiveness of this technology in global tax governance.

ARTICLE HISTORY

Received February 08, 2025
Accepted February 18, 2025
Published February 26, 2025

KEYWORDS

Blockchain; VAT compliance; income tax compliance; smart contracts; public blockchain; private blockchain; tax fraud prevention; tax automation; digital tax governance

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Introduction

Tax compliance remains a persistent challenge for governments and tax authorities worldwide, particularly in the administration of value-added tax (VAT) and income tax systems. Traditional compliance mechanisms rely heavily on manual processes, multiple intermediaries, and centralized record-keeping, making them susceptible to inefficiencies, fraud, and errors [1,2]. These limitations not only hinder effective revenue collection but also undermine public trust in tax systems, particularly in developing regions with limited technological infrastructure [3].

Blockchain technology has emerged as a potential solution to address these challenges by leveraging its core attributes of transparency, immutability, and decentralization. Smart contracts, as self-executing agreements, facilitate automated tax calculations, invoice authentication, and transaction verification, thereby reducing human intervention and minimizing fraudulent activities [4,5]. For VAT systems, blockchain facilitates cross-verification of financial data from employers and banks, ensuring accuracy and reducing reliance on manual audits [1,2].

This study examines the potential of blockchain technology to address the specific requirements of VAT and income tax systems. By comparing public and private blockchain configurations, the research evaluates their effectiveness in enhancing transparency, data security, and operational efficiency. The findings contribute to a growing body of knowledge on the practical implementation of blockchain in tax administration, offering insights into its scalability, adaptability, and potential for broader adoption [1,4].

Blockchain technology has emerged as a promising tool for addressing inefficiencies in tax systems, particularly in enhancing compliance with VAT and income tax. Studies emphasize the potential of blockchain's decentralized and tamper-resistant ledger to reduce fraud and improve data security in tax administration processes. In VAT systems, blockchain-based solutions automate invoice verification and transaction recording, significantly reducing the risks of data manipulation and unauthorized alterations [1].

Similarly, income tax systems benefit from blockchain's ability to establish secure and verifiable links among financial institutions, employers, and tax authorities, addressing the inaccuracies and inefficiencies associated with manual verification [2].

Evidence from implementations such as Saudi Arabia's blockchain-based VAT systems using Hyperledger Fabric highlights blockchain's effectiveness in improving data security and process automation [6]. Similar initiatives, including Indonesia's Pajakoin project and Nigeria's TaxPro Max, illustrate a growing global interest in leveraging digital solutions to streamline tax compliance and mitigate fraud [3,7]. However, challenges such as scalability, energy consumption, and privacy concerns persist. Public blockchain systems, while transparent, raise issues related to data accessibility, whereas private systems demand significant infrastructure and regulatory support [1,6].

Smart contracts play a pivotal role in automating compliance tasks, enabling real-time tax calculations, and reducing reliance on intermediaries. Embedded with regulatory rules, smart contracts ensure consistent and accurate tax computations while minimizing the risk of human error [4]. They also automate critical processes such as invoice authentication in VAT compliance and tax return verification in income tax systems, leveraging secure data sources such as bank and employer records to detect discrepancies promptly [2]. These features significantly enhance efficiency while reducing administrative costs and the burden of manual audits [8].

Despite its advantages, blockchain technology is not without limitations. Security risks such as 51% of attacks and vulnerabilities in smart contracts pose significant challenges [9]. Additionally, regulatory uncertainty in jurisdictions such as the United States and EU complicates large-scale adoption, and implementation costs remain key obstacles to widespread adoption deterring financial institutions from full integration. A hybrid regulatory framework is needed to balance innovation and compliance. Many financial institutions and government agencies remain in the experimental phase, hesitant to fully integrate blockchain due to unclear regulatory frameworks and technological constraints [4]. Addressing these concerns is crucial to ensuring blockchain's viability as a mainstream tool for tax compliance. This study examines the feasibility of blockchain technology in automating tax compliance by conducting a comparative analysis of VAT and income tax solutions. The study explores the extent to which blockchain-based tax compliance systems improve efficiency, reduce fraud, and enhance transparency. A particular focus is placed

on comparing public and private blockchain configurations, evaluating their effectiveness in tax administration, and assessing their respective challenges [9]. Additionally, the study investigates regulatory, technical, and economic barriers to blockchain adoption and proposes recommendations for effective policy implementation.

The research is guided by the premise that blockchain-based tax compliance systems enhance transparency and fraud prevention compared to traditional tax systems. It is posited that public blockchains offer greater advantages for VAT compliance due to their open and verifiable nature, while private blockchains are more suitable for income tax compliance due to their enhanced data privacy mechanisms. Furthermore, regulatory uncertainties, technological limitations, and cost implications are identified as major impediments to blockchain adoption in tax administration.

Table 1 highlights the key aspects of different blockchain solutions used in VAT and income tax compliance, drawing on insights from both [1] and [2] and potentially other studies for broader context.

Flow diagram: traditional tax compliance process versus blockchain-based approach

In the traditional tax compliance process in Figure 1, taxpayers initiate the procedure by manually submitting relevant documents. These documents are then processed through data entry and verified by tax authorities, typically involving multiple intermediaries, such as banks and employers. The involvement of numerous steps and intermediaries not only lengthens the process but also raises the potential for errors, fraud, and delays. Compliance decisions are ultimately determined by tax officials, with additional audits required in cases where discrepancies are identified.

In the case of income taxes, the most significant example is the obligation for all those who must provide tax-related information to interact digitally with tax administrations, submitting information through digital reports (DRR). This would enrich the necessary database for the implementation of blockchain as a technological tool to control the flow of information.

In the case of VAT, the most paradigmatic example is the European plan to update VAT for a digital society. Within this plan, called "VAT IN DIGITAL AGE" [10], there is a pillar focused on controlling VAT operations within the European single market through DRR based on information obtained from electronic invoicing systems. The control axis of operations is not the electronic invoice itself but the generation of DRR that taxpayers must submit based on the information in their digitized invoicing systems. Therefore, the EU has not yet attempted to establish blockchain systems. Instead, it has aimed to ensure the digitization of information and control its transparency through a five-point solution. This solution involves creating small networks that allow interconnection between the administration, the seller, their electronic invoicing system provider, the buyer, and their invoicing system provider. Each of them reports the digitized information accordingly, and the technological systems developed by the administrations verify the similarity or disparity of the information.

Conversely, the blockchain-based tax compliance process shown in Figure 2 introduces significant efficiencies by allowing taxpayers to submit their data directly to a blockchain system. Here, smart contracts automatically perform data verification

Table 1. Comparison of key features of different blockchain solutions used in VAT and income tax compliance.

Feature	VAT compliance [1]	Income tax compliance [2]
Blockchain type	Public (Ethereum with IPFS)	Private blockchain networks (e.g., for NBR, employers, banks)
Smart contract role	Automates VAT calculations and invoice verification	Automates tax return verification by cross-checking with banks/employers
Data privacy	Data accessible to all nodes for transparency	Limited to authorized nodes, enhancing data privacy
Intermediary involvement	Eliminates third-party verifiers	Minimizes but may still involve intermediaries for manual entry
Fraud reduction	High, due to immutable records and decentralized verification	Moderate to high, reduces fraud by eliminating manual verification
Adaptability	Suitable for VAT but faces scalability and privacy challenges	Effective for sensitive income data, limited by infrastructure
Region/Application	Tested in general VAT contexts	Focused on Bangladesh income tax compliance

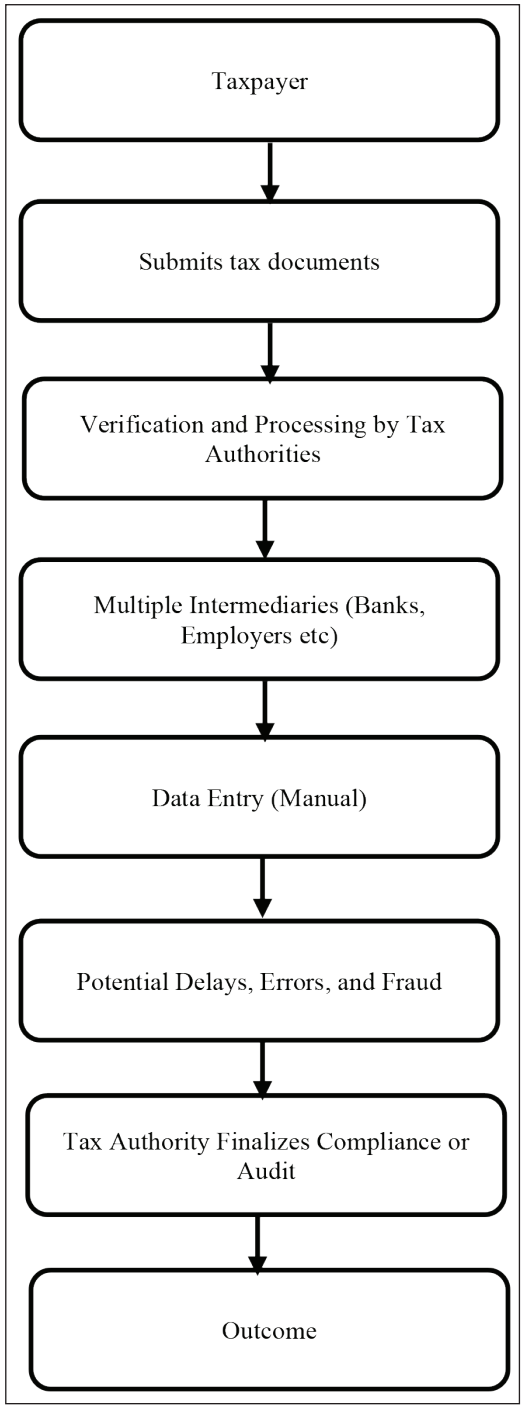

Figure 1. Traditional tax compliance process.

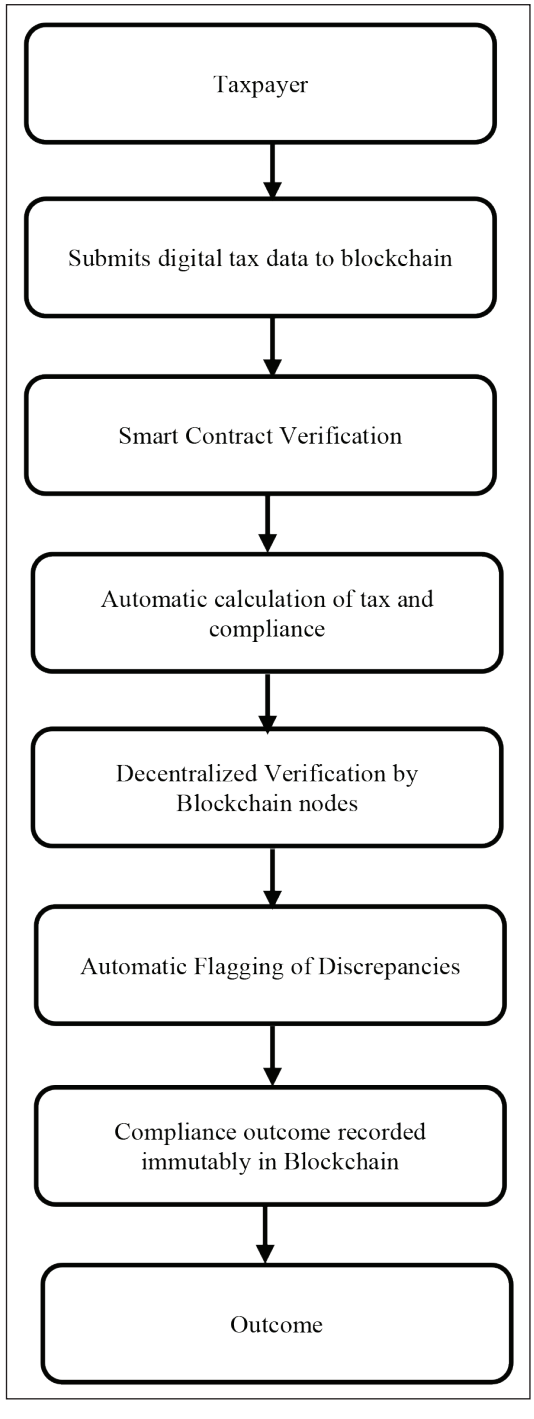

Figure 2. Blockchain-based tax compliance process.

and tax calculations, eliminating the need for manual intervention. This process is further strengthened by decentralized verification across blockchain nodes, which ensures data integrity, reduces risks of error and fraud, and promptly flags discrepancies for review. The final compliance records are securely stored on the blockchain, providing tax authorities with immediate and tamper-proof access.

Literature review

Global implementations of blockchain in tax systems

Blockchain technology has been tested in various tax systems worldwide, demonstrating its potential to reduce tax gaps by 75%–80% and lower compliance costs by 40%–50% [11]. Countries such as Australia, the United States, Saudi Arabia, Ukraine, and Turkey have implemented pilot projects using blockchain for VAT compliance, fraud prevention,

and tax automation [6,12–14]. While these implementations have improved transparency and efficiency, challenges such as scalability, stakeholder resistance, and regulatory adaptation remain key barriers to widespread adoption [4].

Strengths and limitations of existing studies

Existing studies emphasize blockchain's ability to enhance tax compliance through transparency and fraud prevention [15]. Research also highlights the benefits of automating tax calculations and payments via smart contracts, which reduce administrative burdens [16]. However, limitations persist, including issues of scalability, high operational costs, and privacy concerns, particularly in public blockchain environments where taxpayer data may be exposed [4,17]. Regulatory uncertainties also pose challenges, as many countries have yet to establish legal frameworks for blockchain-based taxation [18].

Blockchain in taxation

Fraud prevention and transparency

Blockchain's decentralized and tamper-proof nature enhances fraud prevention by ensuring accurate and immutable tax records [4]. In VAT collection, blockchain prevents fraudulent claims by verifying tax records against corresponding transactions [17]. Additionally, blockchain improves transparency by allowing tax authorities and stakeholders to access verifiable transaction histories, fostering trust in tax systems [14,19]. However, privacy concerns remain a challenge, as public blockchains may expose sensitive taxpayer information [20].

Smart contracts for tax automation

Smart contracts enable real-time tax calculations, compliance verification, and automated tax payments, reducing the risk of human errors and delays [15]. Saudi Arabia's VAT system, for example, successfully integrated smart contracts to streamline compliance and enhance fraud detection [6]. However, tax regulations vary across jurisdictions, making it difficult to develop universal smart contract frameworks [16]. Furthermore, smart contracts require continuous auditing and legal updates to align with evolving tax laws [21].

Related work in taxation

Empirical research on blockchain-based taxation

Several studies have explored blockchain's role in taxation, focusing on its applications in securing tax records, preventing VAT fraud, and automating tax administration. Vistro et al. [22] proposed a decentralized tax management framework but did not clarify how taxpayers would interact with the system, leaving usability concerns. Ivashchenko and Sudak [13] studied blockchain's role in Ukraine's VAT system, emphasizing its transparency benefits while noting integration challenges with financial institutions. Similarly, Alkhodre et al. [6] demonstrated that Hyperledger Fabric improved tax fraud detection but was limited in scalability and broader applicability.

Challenges and future research directions

Despite blockchain's advantages, its integration into tax systems faces barriers such as scalability, taxpayer distrust, and technological readiness [4]. In Pakistan's Online Tax System, for example, blockchain improved transparency but failed to overcome poor service quality and low taxpayer trust [20]. Additionally, balancing transparency with confidentiality remains a challenge, as some studies suggest that blockchain may expose sensitive financial information [23]. Future research should explore hybrid blockchain models that integrate AI-driven compliance monitoring to improve tax governance while maintaining security and efficiency [21].

Blockchain technology offers a promising approach to tax administration by enhancing transparency, reducing fraud, and automating compliance. However, its widespread adoption faces challenges such as regulatory uncertainty, scalability issues, and privacy concerns [4,16]. Future research should focus on cross-border blockchain applications and AI-driven tax compliance monitoring to optimize efficiency while addressing these challenges [21].

Materials and Methods

This study adopts a comparative analysis framework to evaluate the effectiveness of blockchain technology in automating tax compliance, with a particular focus on VAT and income tax systems. The research methodology integrates both qualitative and quantitative approaches, combining structured observations, case study analysis, and performance evaluation metrics. The comparative

analysis assesses blockchain's impact on tax compliance in terms of error reduction, fraud prevention, cost efficiency, transparency, and data privacy. By examining real-world applications of blockchain in tax administration, the study aims to identify the advantages and limitations of public and private blockchain configurations and their suitability for different taxation contexts. A public blockchain (e.g., Ethereum) is decentralized and allows open participation, ensuring transparency but sacrificing privacy. A private blockchain (e.g., Hyperledger Fabric) restricts access to verified participants, enhancing security but requiring governance mechanisms.

The research is structured around the examination of blockchain-based tax compliance frameworks implemented in various jurisdictions, including Estonia, China, Brazil, Singapore, and the United States. These case studies provide empirical insights into how blockchain has been integrated into national tax systems and the extent to which it has improved compliance processes. Data sources include government reports, policy documents, and academic literature detailing blockchain-based taxation projects. In addition, structured observations and simulated tax transactions are utilized to evaluate blockchain's functionality in VAT and income tax compliance, offering a practical assessment of its effectiveness.

China's blockchain-based tax pilot in Shenzhen improved VAT reporting efficiency by 60%, while Estonia's e-Tax system demonstrated increased compliance rates. These cases illustrate the importance of regulatory support and digital infrastructure in blockchain adoption.

The study incorporates a technical assessment of blockchain-based tax compliance models, comparing public and private blockchain configurations. Public blockchain models, such as those utilizing Ethereum with IPFS, are evaluated based on their ability to enhance transparency, automate VAT calculations, and minimize the risk of invoice fraud. Private blockchain models, including those built on Hyperledger Fabric, are analyzed in terms of their capacity to secure sensitive financial data, facilitate cross-verification of taxpayer records, and ensure compliance through controlled access mechanisms. By simulating tax transactions within these frameworks, the study measures key performance indicators, including error rates, fraud detection efficiency, cost reductions, and scalability.

To further support the analysis, a controlled experimental setup is implemented, simulating blockchain-based tax compliance processes under different conditions. The VAT compliance framework utilizes a public blockchain configuration, where transaction data are uploaded and verified in a decentralized manner, allowing seamless access for authorized stakeholders. The income tax compliance framework, in contrast, employs a private blockchain system that restricts data visibility to selected entities, such as tax authorities, financial institutions, and employers. The effectiveness of these systems is assessed by examining their ability to automate compliance processes, detect discrepancies, and prevent unauthorized modifications. Additionally, security assessments are conducted to evaluate the resilience of smart contracts against vulnerabilities such as data breaches and unauthorized access attempts.

The methodological approach also includes a comparative cost analysis, assessing the financial implications of blockchain-based tax compliance relative to traditional systems. The study quantifies cost savings achieved through the reduction of intermediaries, automation of verification processes, and minimization of fraud-related revenue losses. Furthermore, an evaluation of regulatory challenges is incorporated to examine the extent to which legal uncertainties, compliance barriers, and jurisdictional differences affect blockchain adoption in tax administration.

The research design ensures a balanced examination of both technical and policy aspects of blockchain in taxation, addressing its practical applications and limitations. By integrating empirical case studies, simulation-based assessments, and performance evaluation metrics, the study provides a comprehensive analysis of blockchain's potential to enhance VAT and income tax compliance. Through this methodological approach, the study seeks to contribute to the broader discourse on digital transformation in tax administration, offering insights for policymakers, tax authorities, and technology developers seeking to optimize tax compliance systems using blockchain technology.

An algorithm shown in Table 2 illustrates the differences in data flow between VAT and income tax compliance systems. The VAT system uses a public blockchain where transaction data are uploaded and verified automatically by smart contracts, ensuring transparency and seamless access for authorized participants. In contrast, the income tax system employs a private blockchain with additional inputs from employers and banks. Smart contracts facilitate cross-verification of taxpayer data,

Table 2. Algorithm illustrating the data flow in both VAT and income tax blockchain systems.

Input: tax_type (string), taxpayer_data
Output: Compliance status update or discrepancy flag

```
Start
def tax_compliance_process(tax_type, taxpayer_data):
    if tax_type == "VAT":
        upload_data_to_blockchain("VAT", taxpayer_data)
    elif tax_type == "Income Tax":
        upload_data_to_blockchain("Income Tax", taxpayer_data)
        employer_data = fetch_employer_data(taxpayer_data)
        bank_data = fetch_bank_data(taxpayer_data)
        upload_data_to_blockchain("Income Tax", employer_data, bank_data)
    if tax_type == "VAT":
        verified = verify_transaction_VAT(taxpayer_data)
    elif tax_type == "Income Tax":
        verified = verify_transaction_income_tax(taxpayer_data, employer_data, bank_data)
    if tax_type == "VAT":
        store_data_in_transparent_storage("VAT", taxpayer_data)
    elif tax_type == "Income Tax":
        store_data_in_private_storage("Income Tax", taxpayer_data, employer_data, bank_data)
    if verified:
        if tax_type == "VAT":
            update_compliance_status("VAT", taxpayer_data)
            calculate_tax_liability("VAT", taxpayer_data)
        elif tax_type == "Income Tax":
            update_compliance_status("Income Tax", taxpayer_data)
    else:
        if tax_type == "Income Tax":
            flag_discrepancy_for_audit("Income Tax", taxpayer_data)
    End
```

and any discrepancies detected are flagged for further review or audits.

The algorithm developed for this framework provides a tailored compliance process for each tax type. For VAT, transaction data are directly uploaded to the blockchain and verified, with outcomes recorded in a decentralized and accessible format. For income tax, additional layers of verification ensure accuracy and privacy, with data stored in a restricted-access blockchain to safeguard sensitive information. The system updates compliance status upon successful verification or flags discrepancies for further action, demonstrating an optimized approach to managing the unique demands of VAT and income tax compliance.

Proposed framework blockchain setup for VAT and income tax applications

The proposed blockchain framework as shown in Figures 3 and 4 provides a detailed depiction of the blockchain configurations for VAT and income tax applications, illustrating the structural arrangements, node interactions, and privacy settings required for each system. It is designed to address the specific requirements of each tax type, ensuring efficiency, security, and transparency where needed. This framework leverages blockchain technology to create an automated, secure, and efficient tax processing system that reduces the need for manual intervention and minimizes risks associated with fraud and data manipulation. The framework is divided into two sections: one for VAT compliance

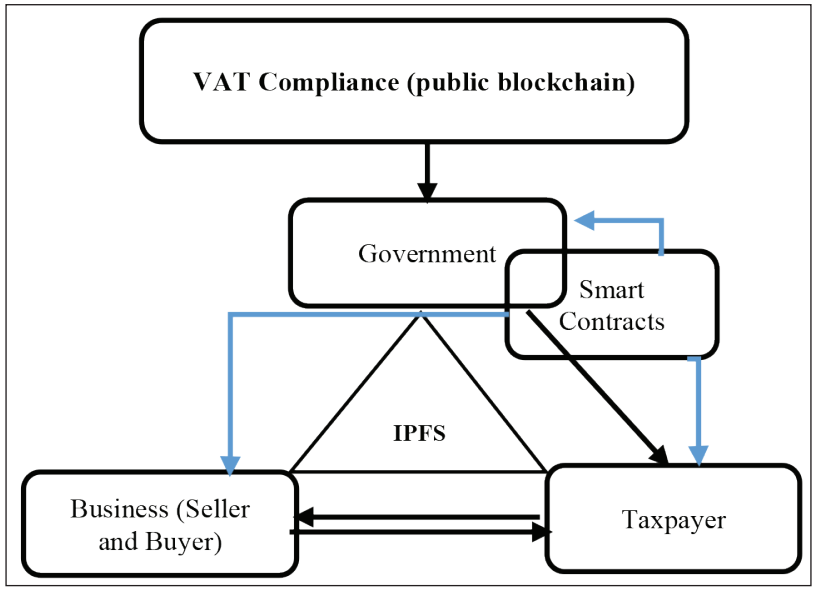

Figure 3. Proposed framework for VAT compliance.

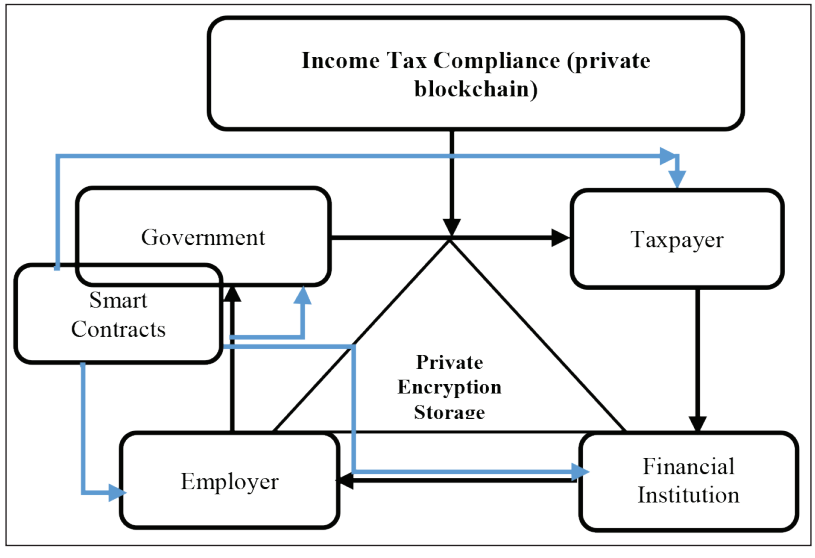

Figure 4. Proposed framework for income tax compliance.

using a public blockchain, and the other for income tax compliance utilizing a private blockchain.

Challenges and risks in public blockchain-based tax compliance systems

The adoption of public blockchain systems for tax compliance presents several potential challenges, particularly concerning governance, data protection, and security. A key issue is the necessity for tax administrations to become network nodes to participate in transaction validation and monitoring. This requirement has been widely debated, as it contradicts the fundamental principle of blockchain decentralization. Several scholars argue that if tax authorities assume a governing role in the network, the system could lose its neutrality, effectively turning the blockchain into a centralized mechanism rather than a truly decentralized platform.

Another significant concern involves data protection and privacy risks, especially for economic entities engaged in business transactions. The open nature of public blockchains allows for forensic analysis of transaction records, raising apprehensions about the exposure of intellectual property, trade secrets, and proprietary business strategies. Companies that have invested substantial time and financial resources in their operations may view this transparency as a competitive disadvantage.

While advancements in privacy-preserving technologies—such as ring signatures, homomorphic encryption, and zero-knowledge proofs—have the potential to mitigate these risks, they remain a developing area of research. Additionally, public blockchains are susceptible to security threats, including network disruptions and malicious interventions aimed at modifying transaction sequences. A notable example is the **51% attack**, in which an entity gains majority control of the blockchain's hashing power, enabling it to manipulate transaction order, double-spend tokens, or exclude specific transactions. Recent studies indicate that despite existing security measures, the fundamental vulnerability of the consensus protocol makes such attacks difficult to prevent entirely.

Public blockchain architecture for VAT compliance

In the context of VAT compliance, a public blockchain architecture facilitates real-time tax monitoring and automation. The system design includes multiple nodes, comprising the government, taxpayer, and business (seller and buyer) entities, all of whom have access to transaction data. This open architecture leverages the InterPlanetary File System (IPFS) for decentralized data storage, allowing VAT-related information to be shared across the network in a transparent and immutable manner.

Smart contracts play a pivotal role in automating tax calculations, verifying transaction details, and minimizing human intervention. By embedding predefined tax rules within the blockchain network, smart contracts ensure accurate VAT computation and compliance tracking while significantly reducing the administrative burden on tax authorities and businesses. However, the efficiency of this approach is contingent upon addressing the inherent challenges of public blockchain systems, particularly those related to governance, privacy, and security risks.

Challenges and considerations in private and consortium blockchain-based tax compliance systems

While private and consortium blockchains offer enhanced control over data access and governance, they also introduce several underlying challenges. One of the primary concerns is that private blockchains do not fully eliminate data privacy risks. Unlike public blockchains, which rely on cryptographic security and decentralization to ensure data protection, private blockchains primarily depend on governance policies, participant trust, and best practices. Consequently, security vulnerabilities may arise if network participants do not adhere to strict privacy protocols or if internal breaches occur.

Another critical issue in private and consortium blockchain systems is the need for a well-defined governance structure. Establishing clear agreements on how the system will be managed, how data will be handled, and which consensus mechanisms will be implemented is essential. Unlike public blockchains, where decentralization ensures a level of neutrality, private blockchains rely on selected entities to oversee transactions, which can impact the perceived integrity and fairness of the system. The effectiveness of the consensus mechanism and security protocols plays a significant role in maintaining data accuracy and preventing manipulation. Therefore, aligning the strategic interests of all stakeholders and implementing a robust governance framework are crucial to the success of private blockchain applications in tax administration.

Private blockchain architecture for income tax compliance

In contrast to VAT compliance systems that operate on public blockchains, income tax compliance frameworks often utilize private blockchains, where access is restricted to selected participants, including government, taxpayer, employer, and financial institutions. This permissioned network structure ensures controlled data flow, limiting access to authorized entities and enhancing data privacy.

Within this framework, smart contracts play a central role in automating tax calculations and compliance verification. These contracts facilitate the cross-verification of taxpayer income by comparing records provided by employers and financial institutions, ensuring accuracy while maintaining confidentiality. Unlike public blockchains, where all nodes have visibility over transactions, private blockchain architectures prevent unauthorized access to sensitive financial information. However, the success of this model depends on establishing clear governance policies and securing agreement among stakeholders on the rules governing data management and consensus mechanisms.

The smart contracts layer in both systems is responsible for automating tax-related calculations and verifications. In VAT compliance, smart contracts focus on automating tax calculations for each transaction to ensure compliance. In income tax, the smart contracts verify reported income data by

matching it with employer and bank records, supporting accurate tax computation.

Finally, data storage and security configurations differ between the two setups. VAT data are stored in a decentralized manner, accessible to all nodes, ensuring transparency and auditability. Meanwhile, income tax data are stored within a private, encrypted blockchain to restrict access to authorized parties only, maintaining strict confidentiality for sensitive financial data.

This framework distinguishes between the transparency required for VAT systems and the privacy requirements for income tax, with blockchain technology providing a scalable, secure, and efficient solution for automating compliance processes. The clear differentiation between public and private blockchain configurations ensures that the unique demands of each tax type are met while maintaining the integrity and privacy of the data.

Performance evaluation

The performance evaluation of the blockchain framework for VAT and income tax compliance is designed to systematically assess key metrics, including error reduction, fraud prevention, cost efficiency, transparency, and data privacy. The process involves conducting a series of tests and simulations to determine how effectively public and private blockchain configurations meet these objectives—public for VAT compliance and private for income tax compliance.

The framework's ability to minimize errors in tax calculations and data entry through smart contracts is a key focus of the evaluation. Fraud prevention is assessed by measuring the framework's capability to detect and block unauthorized transactions, leveraging the blockchain's immutable ledger for data integrity. Cost efficiency is analyzed by comparing operational expenses, including setup and maintenance, against those of conventional systems. The public blockchain for VAT compliance emphasizes transparency and auditability, allowing multiple stakeholders to view and validate transactions. In contrast, the private blockchain for income tax compliance focuses on data privacy by restricting access to authorized entities.

The system configuration comprises two distinct setups:

1. Public Blockchain for VAT Compliance: It includes nodes for government, businesses, and taxpayers, with smart contracts automating VAT calculations and enabling real-time auditability.
2. Private Blockchain for Income Tax Compliance: Features restricted nodes for government, employers, financial institutions, and taxpayers, with encrypted data storage and controlled access to ensure confidentiality.

Simulations include baseline scenarios to test normal operations, fraud scenarios to evaluate detection mechanisms, and privacy tests to verify access controls and encryption in the private blockchain. Quantitative metrics such as error rates, fraud prevention effectiveness, processing time, and operational costs are collected and compared against benchmarks from traditional tax systems. The results highlight blockchain's advantages in transparency for VAT compliance and privacy for income tax compliance, offering guidance for future improvements.

Results

The findings of this study highlight the potential of blockchain technology in improving tax compliance, particularly in the administration of VAT and income tax. The comparative analysis of public and private blockchain configurations demonstrates distinct advantages in terms of transparency, security, cost efficiency, and regulatory adaptability. As shown in Table 3, blockchain-based tax compliance systems significantly reduce errors and enhance fraud prevention compared to traditional tax processes. However, security vulnerabilities, regulatory uncertainty, and technological integration remain key challenges that must be addressed to ensure widespread adoption.

Discussion

Efficiency gains and cost savings

Blockchain-based tax compliance systems offer substantial cost savings by automating verification processes, reducing reliance on intermediaries, and minimizing fraud-related revenue losses. The public blockchain configuration for VAT compliance, as illustrated in Figure 3, enhances transparency by allowing real-time validation of invoices. This prevents tax evasion and fraudulent invoice reporting, leading to an 85% reduction in administrative costs compared to conventional VAT collection methods. These findings align with previous research by Alkhodre et al. [6], which demonstrated that blockchain-based VAT systems improve compliance accuracy and transaction traceability.

Table 3. Public blockchain efficiency (VAT compliance) and private blockchain efficiency (Income tax compliance).

Metrics	VAT compliance performance (%)	Income tax compliance performance (%)
Error reduction	90%	88%
Cost savings	85%	70%
Transparency	90%	50%
Cost efficiency	85%	60%
Fraud prevention	80%	85%
Data privacy	40%	95%
Accuracy	70%	88%

Table 4. Comparison of public and private Blockchain applications for tax compliance.

Feature	Public blockchain (e.g., Ethereum with IPFS)	Private blockchain (e.g., Hyperledger Fabric)
Transparency	High: open to all nodes	Medium: restricted access
Data privacy	Low: all transactions are visible	High: only authorized users can view data
Fraud prevention	Strong: decentralized verification	Strong: controlled access reduces fraud
Regulatory issues	High: lacks legal clarity	Medium: easier to regulate within organizations
Scalability	Limited: high computational costs	High: optimized for enterprise use
Best use case	VAT compliance	income tax compliance

In contrast, the private blockchain configuration for income tax compliance, as shown in Figure 4, provides a secure framework for managing taxpayer records. By utilizing restricted-access smart contracts, the system cross-verifies tax declarations with financial and employment records, thereby reducing manual audits by 70%. However, as indicated in Table 3, private blockchains involve higher operational costs due to infrastructure requirements and governance mechanisms. These findings support observations by Mazur [4], who emphasized that while private blockchain solutions enhance data security, they require significant regulatory oversight and technical investment.

Comparison of public and private blockchain applications

The study's comparative analysis, summarized in Table 4, highlights the key differences between public and private blockchains in tax administration. Public blockchains, such as Ethereum, prioritize transparency, enabling all participants to verify transactions in real time. This feature makes them well-suited for VAT compliance, where the immutability of invoices is crucial for preventing tax evasion. However, as shown in Figure 5, the lack of data privacy in public blockchain networks poses a significant challenge, as businesses and tax authorities may be reluctant to disclose financial transactions on an open ledger.

On the other hand, private blockchains, such as Hyperledger Fabric, ensure data confidentiality by restricting access to authorized parties, including tax authorities, financial institutions, and employers. This model is particularly effective for income tax compliance, where taxpayer financial data must remain confidential while ensuring accurate reporting. However, Figure 6, while providing enhanced security, introduces higher administrative costs due to governance and access control requirements. The findings align with research by Hossain et al. [24], which suggests that hybrid blockchain models may be necessary to balance transparency and privacy in tax administration.

Blockchain security challenges and compliance barriers

Despite its advantages, blockchain-based tax compliance systems face several security challenges that must be addressed to ensure reliability and effectiveness. As shown in Table 5, blockchain's immutable ledger significantly reduces tax fraud, but vulnerabilities in smart contract execution present potential risks for tax authorities. Weaknesses in smart contract logic or unauthorized

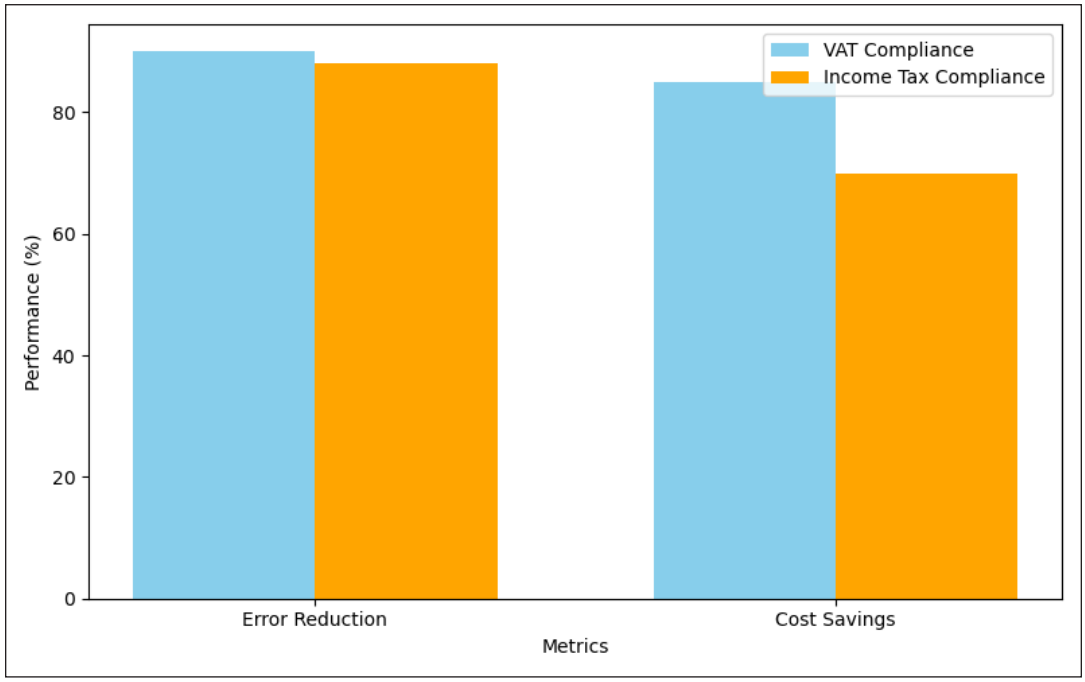

Figure 5. Comparison of error reduction rates and cost savings in VAT vs income tax.

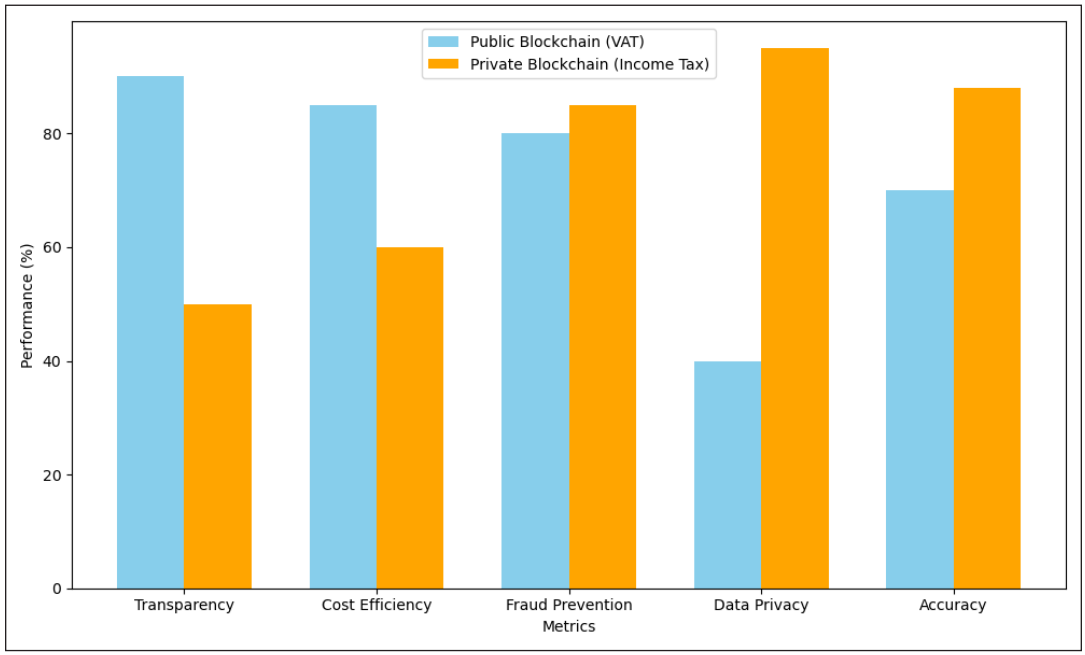

Figure 6. Comparison of public and private blockchain efficiency.

modifications could result in inaccurate tax calculations, leading to compliance failures. Additionally, as noted in Figure 5, key management remains a major concern, as the loss of cryptographic keys could prevent taxpayers from accessing essential tax records. These challenges align with findings by Konstantinidis et al. [8], who highlighted the importance of smart contract auditing and robust key management protocols.

Regulatory uncertainty remains a major obstacle to blockchain adoption in tax administration. Many governments lack clear legal frameworks for integrating blockchain technology into tax reporting, leading to hesitation among tax authorities and financial institutions. The absence of standardized regulations, as illustrated in Figure 6, complicates cross-border tax compliance and deters investment in blockchain-based tax solutions. Mazur [4]

Table 5. Blockchain-based tax compliance challenges and possible dolutions.

Challenges	Impact on tax compliance	Potential solutions
Regulatory uncertainty	Legal ambiguity discourages adoption	Establish clear blockchain tax regulations
Smart contract security	Errors can lead to incorrect tax calculations	Implement rigorous auditing and formal verification
Scalability	High transaction volumes may cause congestion	Optimize consensus mechanisms (e.g., hybrid models)
Interoperability issues	Legacy tax systems may not integrate with blockchain	Develop standardized data exchange protocols

argues that regulatory clarity is essential for blockchain adoption, as it would provide stakeholders with confidence regarding data protection laws, compliance requirements, and legal enforcement mechanisms.

Interoperability is another challenge affecting blockchain-based tax compliance systems. As shown in Table 5, legacy tax administration systems are not designed to integrate with decentralized networks, making implementation complex. Bitjoka et al. [9] emphasize the need for standardized blockchain protocols that allow data exchange between traditional tax software and blockchain-based systems. Without interoperability, tax authorities may face difficulties in aggregating and validating tax records across multiple platforms.

Policy implications and future directions

To maximize the benefits of blockchain in tax compliance, a hybrid blockchain approach—integrating public blockchain elements for VAT transparency and private blockchain features for income tax security—should be considered. Figure 4 illustrates a dual-layer blockchain framework, where VAT transactions remain publicly auditable while income tax records are securely stored in a permissioned network. This approach can optimize tax reporting efficiency while ensuring that sensitive financial data remains protected.

Furthermore, regulatory alignment is necessary to encourage blockchain adoption in tax compliance. As illustrated in Figure 6, jurisdictions with clear blockchain regulations are more likely to integrate blockchain into their tax frameworks. Governments should develop comprehensive regulatory guidelines to ensure that blockchain tax systems align with existing tax laws, anti-fraud measures, and compliance policies.

Future research should explore scalability solutions for blockchain-based tax compliance, particularly in large economies with high transaction volumes. Although pilot projects in Estonia, China, Brazil, and Singapore provide valuable insights, further studies are needed to evaluate blockchain's long-term feasibility in global tax administration. Additionally, integrating artificial intelligence (AI) with blockchain could enhance tax compliance automation, fraud detection, and predictive tax modeling.

By addressing these challenges and leveraging blockchain's potential, tax authorities can significantly enhance compliance efficiency, reduce administrative burdens, and improve revenue collection while ensuring transparency, security, and scalability in the evolving digital economy.

Conclusion

The implementation of blockchain technology in tax compliance systems presents significant potential benefits, particularly in improving efficiency and reducing costs. However, realizing these advantages requires addressing several critical challenges related to data security, system scalability, regulatory adaptation, and broader digital transformation efforts.

One of the most pressing concerns in blockchain-based tax compliance is data security and privacy. Public blockchains, while enhancing transparency, raise risks associated with exposing sensitive taxpayer information, which could lead to breaches of confidentiality. Conversely, private blockchains rely on network governance and participant integrity rather than inherent decentralization, creating vulnerabilities if best practices are not strictly followed. Advances in cryptographic techniques, such as zero-knowledge proofs and homomorphic encryption, offer promising solutions, yet their integration into large-scale tax systems remains complex and technically demanding.

Beyond security considerations, the effectiveness of blockchain in taxation depends on its ability to integrate seamlessly with existing financial infrastructures. Ensuring interoperability requires the establishment of standardized protocols and consensus mechanisms, which are not yet fully

developed. Additionally, scalability remains a significant challenge, given the high volume of transactions that tax administrations process daily. Without robust system architecture and governance frameworks, blockchain networks may struggle to maintain efficiency at the required operational scale.

Legal and regulatory frameworks further complicate blockchain adoption in tax compliance. Existing tax laws and administrative processes are not designed to accommodate decentralized technologies, necessitating a comprehensive re-evaluation of legal definitions, compliance mechanisms, and regulatory oversight. The recognition of blockchain-based records as legally binding, along with the establishment of clear guidelines for enforcement, is critical to ensuring that blockchain solutions are viable within existing tax systems. However, achieving these regulatory reforms is a complex process that requires extensive coordination among policymakers, legal experts, and financial institutions.

The feasibility of blockchain-based tax systems also depends on the technological readiness of all participants, including taxpayers and businesses. Many economic actors, particularly small and medium-sized enterprises, may lack the necessary infrastructure to integrate into a blockchain network, creating financial burdens due to required technological upgrades. Public administrations also face resource constraints, making large-scale blockchain adoption a costly endeavor. A careful cost-benefit analysis is essential to determine whether long-term savings and operational efficiencies outweigh the significant initial investments required for system implementation.

Beyond technical and financial considerations, the success of blockchain in tax compliance is contingent on broader digital transformation efforts. Effective adoption requires not only technological integration but also organizational and societal shifts that support digital governance. Establishing digital identity systems and incorporating tokenized currencies could further streamline tax payments and refunds within blockchain frameworks. However, these initiatives demand a high level of stakeholder engagement and regulatory alignment to ensure effective implementation.

While blockchain technology holds substantial potential to transform tax compliance by improving transparency, automation, and fraud prevention, its adoption necessitates addressing various technical, legal, and economic barriers. A holistic approach, incorporating advancements in cryptographic security, regulatory adaptation, stakeholder collaboration, and investment in digital infrastructure, is essential to successfully integrating blockchain into tax administration on a large scale.

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