Green Secure Land Registration Scheme for Blockchain-enabled Agriculture Industry 5.0

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Abstract

The land is a highly valued asset worldwide. It is a scarce resource, crucial for agriculture and livelihood, serving as a foundation for economic activity, a valuable investment, and a source of security. However, it sustains several challenges, such as lack of ownership, traceability, and possession. Organizations that manage land ownership are mainly centralized and not formally digitized to maintain large land records, including pasture, agriculture, and industrial lands, leading to land forgery, thievery, fraudulent activities, and conflicting issues in land management. To overcome the aforementioned issues, we proposed a blockchain-enabled land registry scheme that efficiently stores the land records to tackle security and conflicting concerns of the land management systems. The proposed scheme utilizes the decentralized nature of blockchain to dilute the significant shortcomings of the current land management systems in the agriculture industry 5.0. It uses robust programmable smart contracts that eradicate the need for third-party intermediaries during the entire process of the land registry system. In addition, the essential characteristics of blockchain, i.e., decentralization, immutability, and transparency, solve single-point failure, track all the land ownership records, and offer secure data storage to both agricultural and industrial land. Also, the smart contracts are assessed using vulnerability assessment tools to find any loophole the attackers can exploit. Moreover, incorporating an interplanetary filesystem (IPFS) strengthens off-chain data storage and improves the response time and scalability of the proposed scheme. Further, the proposed scheme is evaluated using different performance parameters, such as blockchain scalability, sustainability, and block size comparison. Compared to the traditional approach, the proposed approach shows an energy consumption of 780 Terawatt-hours (for ten years), 10000 ms to transact 300 blocks (scalability), and a minimum gas cost of 100000 wei in deploying smart contract functions. These attainments show that the proposed decentralized scheme holds the potential to significantly mitigate land forgery and ownership issues within the landscape of agriculture industry 5.0.

Index Terms

Blockchain; Ethereum; Smart Contracts; Distributed ledger; Land Registry System; Agriculture Industry 5.0

I. Introduction

THe land is an important natural resource for everyone across the globe for numerous reasons, such as economic value where land is used for residential and commercial use; possesses environmental, cultural, and recreational value, and agriculture industry 5.0. Particularly in the agriculture sector, adversaries seize the barren land for their own benefit and forge the land documents, leading to disputes over ownership rights, hampering productivity and investment. However, developing countries use this natural resource for economic and political benefits. Some countries have used their land resources to achieve economic growth by developing large-scale agricultural and mining operations, as well as intensive utilization across various use cases in Industry 5.0. Nevertheless, sustainable development goals aligned with agriculture and Industry 5.0 promote green practices, thereby minimizing land degradation, conserving natural resources, and reducing the impact of industrial activities on the land ecosystem. Therefore, some tractable solutions must be required to manage irresponsible land usage in agriculture and industry 5.0. Many countries have recognized the importance of sustainable land use practices and have implemented policies and programs (i.e., land registry systems) to promote responsible land use. This includes measures such as land

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conservation, preservation, sustainable agriculture, forestry practices, and the restoration of degraded land. Every country has its own set of rules and regulations for registering land, transferring land ownership, and land usage. However, the traditional land registry systems are trivial and precarious from the security and privacy perspective. It has issues, such as double spending, involvement of untrusted third parties, untrackable lands, and multiple land owners for the same land. Security is the major issue with the traditional land registration system. For instance, in various states of India, e-government projects were implemented to e-enablement of property registration (dynamic website) [1]. The major objective for the e-enablement of property is to automate the complete process of property registration and make the registration process fast and efficient.

This initiative from the central and state government of India has been praiseworthy; however, the approach has many shortcomings, such as being geographically restricted, lack of participation from the stakeholders, centralized storage, security, and absence of scalability. To strengthen the security of the above-mentioned approach, researchers have adopted encryption techniques to obfuscate the land registry data [2]. Transforming raw land data into encrypted data reduces cyber attacks on the land registration centers' servers and online storage systems.

In Sri Lanka, to address the challenges associated with land registry verification, a biometric-based authentication approach was proposed [3]. This approach generates biometric-based asymmetric keys from a user's fingerprint that can be used for digitally signing and verifying land registry data. The proposed approach utilizes the Rivest-Shamir-Adleman (RSA) algorithm, which is an asymmetric key algorithm that supports both encryption and digital signature procedures. The proposed scheme guarantees land ownership integrity and authenticity. However, the security of the approach may still be vulnerable as encryption algorithms can be decrypted by using powerful computing systems, and land records data may become susceptible to such attacks. Further research is required to improve the security of the approach and prevent potential vulnerabilities.

The registration of land ownership has always been a critical issue in many countries, including India, due to various fraudulent activities such as black money rotation, illegal property transactions, and cheating of dishonest landowners. To address these issues, a big data-based authentication approach was proposed [4]. The proposed approach monitors the entire money transaction process through Aadhaar numbers, and if any illegal money transaction is detected, the system will block the land registration process. Furthermore, this approach also prevents cheating by dishonest owners who sell the same piece of land to multiple buyers. This method provides transparency in the land registration process; however, it still lacks in security as it stores all the data in a big centralized database that may be vulnerable to attacks or single point failures, which could result in significant loss to all stakeholders. Thus, further research is required to ensure the security and scalability of this approach in the land registration process.

Recently, blockchain technology has overgrown in the information technology (IT) industry due to its salient features, such as decentralization, immutable, transparency, and offering security against data integrity attacks [5] [6] [7]. Hence, to overcome the aforesaid issues, many researchers have adopted this tampered-proof technology (i.e., blockchain) to integrate it with the land registry system [8]. For example, the authors of [9] proposed a solution addressing land registry issues in villages by implementing a transparent blockchain-based management system. The system designates the government authority as a super administrator responsible for registration. The proposed approach is fully transparent, and transactions only occur between two clients. Despite this, the authors admit that updates to the land registration records are manually made in villages, which increases the likelihood of human error and may compromise the safety of their proposed approach. The authors of [10] highlighted the shortcomings of the current land registry management process, such as minimal transparency, lack of accountability, incoherent datasets among different government departments, and delays.

To address these issues, they emphasized the importance of implementing a smart contract for a land registry using blockchain technology. Their proposed approach is highly transparent, as it does not involve any third parties. However, the authors noted that storing all data in Ethereum nodes can result in slower data storing and retrieval processes; also, the cost of storing data on Ethereum nodes can be high. Further, to digitize the land registry documentation process in Bangladesh, the authors proposed a blockchain-based solution that improves upon existing land registry systems by utilizing the delegated proof-of-stack consensus protocol [11]. This approach offers benefits such as data transparency and immutability, which can help to prevent 51% attacks. However, the authors noted that their proposed approach has limitations in terms of scalability and requires an uneven number of nodes to enable successful Byzantine Fault Tolerance. Additionally, storing all data on Ethereum-based blockchain nodes can result in slower processes and higher costs.

The aforementioned issues motivate us to propose a blockchain-based secure and reliable scheme for the land registry system for agriculture and industry 5.0 that overcomes the shortcomings of the existing state-of-the-art works. In the proposed work, we develop a smart contract consisting of various user-defined functions that verify and validate the data from the entities (i.e., buyer, seller, etc.) of land registry systems. The smart contract validates all the users; only verified users (buyers, sellers) and verified land records are allowed to participate in the selling and buying activity of the land registry system. The smart contract is assessed using code vulnerability tools, i.e., slither that provides loopholes in the developed smart contract [12]. Accordingly, we modified the smart contract functions, so the attackers do not easily manipulate them. Once validation is successfully done, the data is forwarded to the interplanetary file system (IPFS) that enhances the storing and fetching operations. Further, the hash value of the IPFS data is forwarded to the immutable blockchain ledger to protect it from data integrity attacks. The proposed scheme is evaluated with various performance metrics, such as scalability, sustainability, code vulnerability, block size, IPFS bandwidth utilization, gas consumption, and hash rate. In this manner, the proposed scheme seeks to foster sustainable land use practices, thereby creating a resilient approach that balances economic growth with environmental and social responsibility in agriculture and industry 5.0.

A. Research contributions

The following are the major contributions of this paper.

- We proposed a blockchain-based secure and reliable land registry system for agriculture and industry 5.0 to overcome the issues (e.g., centralized, not transparent, slower, and insecure) of traditional land registry systems.
- The proposed scheme comprises of a smart contract with different user-defined functions that play an essential role in data validation. Further, we utilized fast data storage and access using an interplanetary file system (IPFS) to achieve low bandwidth and high throughput for data access.
- The proposed scheme is assessed using slither tool for any severe code vulnerability issues that raise security issues in the blockchain-based land registry system.
- The proposed scheme is evaluated using different performance parameters, such as scalability, sustainability, gas cost consumption, and block size comparison. Moreover, the proposed scheme uses a recent Ethereum version, i.e., Ethereum proof-of-stake (PoS) due to that the proposed scheme has better performance than the existing works.

B. Organization

The remaining paper is organized as follows. Section II discusses the related work. Section III discusses the system model and problem formulation. Section IV presents the proposed scheme, i.e., blockchain-based secure land registration system. Section V talks about results and discussion. Finally, Section VI concludes the paper and discusses future research directions.

II. Literature review

This section investigates various state-of-the-art approaches proposed by various authors for the land registry system. Table I shows the relative comparison table of various state-of-the-art approaches. Nandi et al. [13] address the land registration issues in the traditional land registry system and provide an implementation-based system for a secure land registry. Their proposed system is fully decentralized and secure. They also provided smart contract implementation for their proposed approach. However, they are using Ethereum blockchain nodes to store all their user's data and transactions, which makes data processing very slow and costly as Ethereum blockchain nodes are very slow and hard to maintain for large amounts of data. Further, Khan et al. [14] analyzed the increasing fraud in India's traditional land registry systems. They proposed a secure land registry system to accelerate the land registration process in India. Their proposed approach is highly secure, fast, and secure against digital fraud. However, their approach involves a third party, making it vulnerable to various security attacks (e.g., data manipulation attacks) and not a fully decentralized system.

Gollapalli et al. [15] proposed a peer-to-peer system that doesn't require third-party involvement. Their proposed approach offers high security, scalability, transparency, and sustainability. However, their proposed approach only works in permissioned environments as it is developed in a hyperledger fabric blockchain network. Further, Kusuma

TABLE I: A relative comparison of the proposed scheme with the state-of-the-art land registry systems

Author	Year	Objective	Implementation	IPFS	Fully decentralized	Pros	Cons
Nandi et al. [13]	2020	Secure mechanism to address land registration issues.	✓	-	✓	Decentralized system, Implementation based, Secure.	Slow and high cost data storage.
Khan et al. [14]	2020	To accelerate the process of land registration in India.	✓	-	-	Implementation based, Increased security, decreased frauds.	Involves third party.
Gollapalli et al. [15]	2020	Peer to peer system that doesn't require any middleman	✓	-	✓	Security, different functionalities, transparent, scalable	Works in permissioned environment only, slow storage used
Kusuma et al. [16]	2023	To strengthen the land registration process in terms of transparancy, time, money and reduce instances of fraud	✓	-	✓	In detail implementation is provided	Slow storage used without IPFS and no vulnerability assessment proof is provided
Shinde et al. [17]	2020	Secure storage for property papers.	✓	✓	-	Tamper-proof, fast IPFS storage.	Process of land registration done in person
Khalid et al. [18]	2022	Increase the reliability of land registration system.	-	-	✓	Decentralized, reliable, proof-of-concept system, secure	Conceptual framework without implementation
Singh et al. [19]	2020	Digitization of land record of the Indian scenario	-	-	✓	Peer to peer, fast, decentralized, trustworthy, transparent	No implementation provided.
Shrivastava et al. [20]	2023	Utilize blockchain technology to create a land register system	✓	-	✓	Implementation based, Secure, fast	No use of fast IPFS storage, Provided very less implementation results
Suganthe et al. [21]	2021	Blockchain enabled Digitization of Land Registration	✓	-	-	Implementation based, transparent, reliable	Involvements of third party, slow storage used
Ncube et al. [22]	2022	Land Registry Using a Distributed Ledger	✓	-	✓	Implementation based, high reliability, high security	Works in permissioned environment only, slow storage used
Mishra et al. [23]	2021	Digitalization of Land Records using Blockchain Technology	-	-	✓	Reduced fraud cases, transparent, fully decentralized	No implementation provided
The proposed approach	2023	Secure land registry system using blockchain	✓	✓	✓	Tamper-proof, fast IPFS storage., fully decentralized	-

et al. [16] proposed a blockchain-driven approach that strengthens a land registration procedure in terms of transparency, money, and time and reduces instances of fraud. Their proposed approach features great in-detail implementation. However, their proposed approach uses Ethereum blockchain nodes to store all the data, which makes the data-storing process slow and costly. Also, no smart contract vulnerability testing results are provided. Shrivastava et al. [20] proposed a blockchain technology-based land register system. Their proposed approach has blockchain qualities like persistence, immutability, and decentralization. Their proposed approach features full in-depth implementation and performance evaluation of different parameters. However, their proposed work also uses only Ethereum nodes to store the on-chain data, making their approach cost-inefficient and slow while storing or fetching data. Shinde et al. [17] proposed secure storage for property papers using blockchain technology. Their proposed approach is tamper-proof and provides interplanetary file system (IPFS) storage, making the entire process fast. However, their proposed approach to the land registration process must be made in person as it only works to store the property papers. Khalid et al. [18] increased the reliability of the land registration system in their proposed work. Their proposed work is a fully decentralized, secure, reliable, and proof-of-concepts-based system. However, their work has implementation constraints, and most of the work is based on a conceptual framework.

Singh et al. [19] proposed an approach to digitizing land records for the Indian scenario. They proposed a peer-to-peer, fast, decentralized, trustworthy, and transparent system. However, their proposed approach doesn't feature any implementation. Suganthe et al. [21] proposed blockchain-enabled digitization of land records to improve the land registration process in India. Their proposed work is based on high transparency and reliability, which makes the

TABLE II: A narrow down comparison between the existing land registry systems and the proposed blockchain-based land registry system.

Author	Year	Objective	Limitation of existing works	Novelty of the proposed work	Significant sections
Racetin et al. [24]	2022	It is a survey paper that explores the implementation details of the blockchain technology in land registry systems	The implementation of blockchain in land registry system is missing. Only the research data gathering is discussed	Included a proposed system that shows a sequential flow that helps the reader to understand the proposed system easily.	Section II - Literature review (comparison of the existing works and the propose work).
Stefanovic et al. [25]	2022	To propose a solution for managing land administration system (LAS) transactions using blockchain technology and smart contracts	No framework presented that can show the sequential flow of their proposed work. Not clearly discussed how their land records are stored on the blockchain. No vulnerability assessment and result analysis	Designed robust smart contracts to make secure and reliable land registry systems. The source code of smart contracts is shown through different algorithms	Section III - System Model and problem formulation.
Ameyaw et al. [26]	2021	To assess and identify the main challenges of the current land acquisition processes in Ghana, explore opportunities and ways to address the land acquisition challenges	Theoretical paper, where only data gathering is shown, especially for Ghana. There is no implementation details and no result discussion	Included vulnerability assessment of the smart contract in the proposed work to tackle data integrity issues.	Section IV - Proposed Scheme (Algorithms 1, 2, 3, and 4). Figure 1 - Proposed system of blockchain-based land registry system.
Bennett et al. [27]	2021	To explore the potential for the application of smart contracts, implemented using blockchain technology, for the specific land dealings inherent to land administration	The article is a review or survey type, where only theoretical concepts are molded and shown to the readers. Result section has only considered theoretical case studies	Included performance analysis of the proposed system by considering different evaluation metrics, such as scalability, sustainability, block hash rate, gas cost, smart contract functions, and IPFS bandwidth utilization.	Section V - Result and Discussion (Figure 2 - vulnerability assessment, Figures 3-9 performance analysis of the proposed scheme)

land registration process highly secure and fast in India. However, their proposed approach involves a third party that opens the system to several vulnerabilities. Ncube et al. [22] proposed a land registration system using a distributed ledger to decrease fraud in Zimbabwe. Their proposed approach provides immutability during transactions and high security without third-party involvement. However, their work is based on a private and permissioned blockchain environment which reduces the scope of the system, i.e., security solutions are not scalable. Moreover, they used blockchain nodes to store the land records data. The authors in [23] digitized the land Records using blockchain technology to reduce human errors, corruption, and human intervention. Their proposed approach helps to reduce digital fraud by using features of blockchain, such as transparency [24] [25] [26] [27]. However, it is observed that their proposed work lacks in providing implementation details of their work. Particularly, Table II is prepared to showcase the competency of the proposed work by comparing it with the recent land registry systems. In Table II, we explicitly mentioned what are the drawbacks of the existing land registry systems and how the proposed work is overcoming them. Therefore, there is a requirement for a tampered-proof, reliable, and scalable scheme that tackles the aforementioned issues in the traditional land registry systems.

A. *Limitation of the existing works*

- The existing work merely supports surveys and reviews (theoretical aspects) and has not covered all possible cases that exist in the process of the land registry system.
- It is also to be noted that a few very research articles are available showing the implementation details regarding the blockchain-based land registry systems. However, those articles have not considered the vulnerability assessment of their smart contracts and have not included any empirical results that prove the significance of their work.

- No implementation detail is presented; hence, it would be challenging for the readers to understand their work, i.e., implementing and evaluating the blockchain-based land registry system.

B. Novelty of the proposed work

- The proposed work is articulated in a way that readers can understand the motive behind the work, how it has been carried out, and whether it is assessed or not.
- For that, we first carried out a literature review that compares the proposed work and the existing work by considering recent papers and several comparable parameters, such as the objective, implementation, IPFS, fully decentralized, pros, and cons for land registry system in agriculture and industry 5.0.
- Further, a system model and problem formulation section are discussed, where we mathematically brief how the proposed system works, and its full explanation is exemplified in the proposed scheme section. Further, in the later section, we have shown different algorithms for the designed smart contracts for the land registry system in agriculture and industry 5.0. (No proposed system is created and evaluated in the articles mentioned in the existing works.)
- Each smart contract has undergone a vulnerability assessment, where we rectify if the source code poses any vulnerability or not. Moreover, we also showcase the experimentation setup and tools and how the proposed system is evaluated using different evaluation metrics, such as scalability, hash rate, sustainability, bandwidth utilization, and gas cost. (Not shown in the existing works)
- The article is framed in a way that readers can understand and measure it properly, i.e., whether the proposed work can be applied to real-life scenarios or not. Kindly note that the existing state-of-the-art work has not done any performance analysis of their proposed work particularly for land registry in agriculture and industry 5.0. In such a case, the viability and reliability of their proposed work is questionable.

III. System Model and Problem Formulation

This section discusses the system model for the proposed architecture. In the traditional land registry system, all land owners have data regarding land ownership that is mostly stored in a centralized system (C), which is managed by a single (a) or group of authorities $\{a_1, a_2, \ldots, a_k\} \in A$.

$$C \subseteq \{d_1, d_2, \ldots, d_6, \ldots, d_N\} \in D \tag{1}$$

$$A \xrightarrow{\text{manages}} C \tag{2}$$

where, L represents land records and A can be a single or group of authorities. In addition, it comprises of N users associated with their land record data, which are represented as follows.

$$\{u_1, ..., u_i, ..., u_m\} \rightarrow \{d_1, ..., d_i, ..., d_n\} \tag{3}$$

$$\forall u_i \xrightarrow{\text{has}} d_i, 1 \leq i \leq n \tag{4}$$

$$u_i \in U, d_i \in D \tag{5}$$

where, $u_i \in Uandd_i \in D$ ensures that both u_i and d_i are a part of traditional land registry systems. However, these centralized systems are always lured by attackers, wherein they perform different security attacks to gain access to the land records. This raises severe data integrity issues in the land registry system, where the attacker (α) could be an insider or hired by the insider to manipulate the land records.

$$\alpha \in \{A \text{ or } a_h\} \tag{6}$$

where, a_h could be a potential attacker from the authority set $\{a_1, a_2, \ldots, a_k\} \in A$. The main authority can also be a fraudulent person who hires attackers to manipulate land registry systems. An attacker α can steal or tamper with the data as all the data is stored in a centralized repository.

$$\alpha \xrightarrow{\text{manipulates}} C \tag{7}$$

$$\alpha \xrightarrow{\text{tampered}} \{d_1^{\alpha}, d_4^{\alpha}, \ldots, d_8^{\alpha}, \ldots, d_f^{\alpha}\} \in D^{\alpha} \tag{8}$$

Eq. 7 shows that α first manipulates C using any privilege escalation attacks, then it tampered with the land records from d_f to d_f^{α}. Therefore, there is a requirement for a tampered-proof and decentralized technology, i.e., blockchain, that tackles the data integrity issues in the land registry systems. The proposed scheme stores all the user's data and land records in the immutable blockchain ledger. The proposed scheme maximizes the security of the land registry system. Based on the above discussion, we formulated an objective function (O) that targets to maximize the security and overcomes the shortcomings of the traditional land registry systems.

$$O = \max \sum_{i=1}^{n} \Gamma(d_i \in D) \tag{9}$$

where, Γ consist of security and efficiency of the land records. The proposed work aims to maximize the security and efficiency (i.e., scalability, sustainability, faster response time, etc.) of each land records (d_i) forwarded by u_i for secure and reliable storage in the blockchain network.

IV. The Proposed Scheme

This section presents the Ethereum-based land registry system to protect land records from data integrity attacks and ensure sustainable land usage with high scalability and faster response time. Fig. 1 shows the sequential workflow of the proposed scheme, i.e., blockchain-based land registry system for agriculture and industry 5.0. A detailed description of the scheme is described as follows.

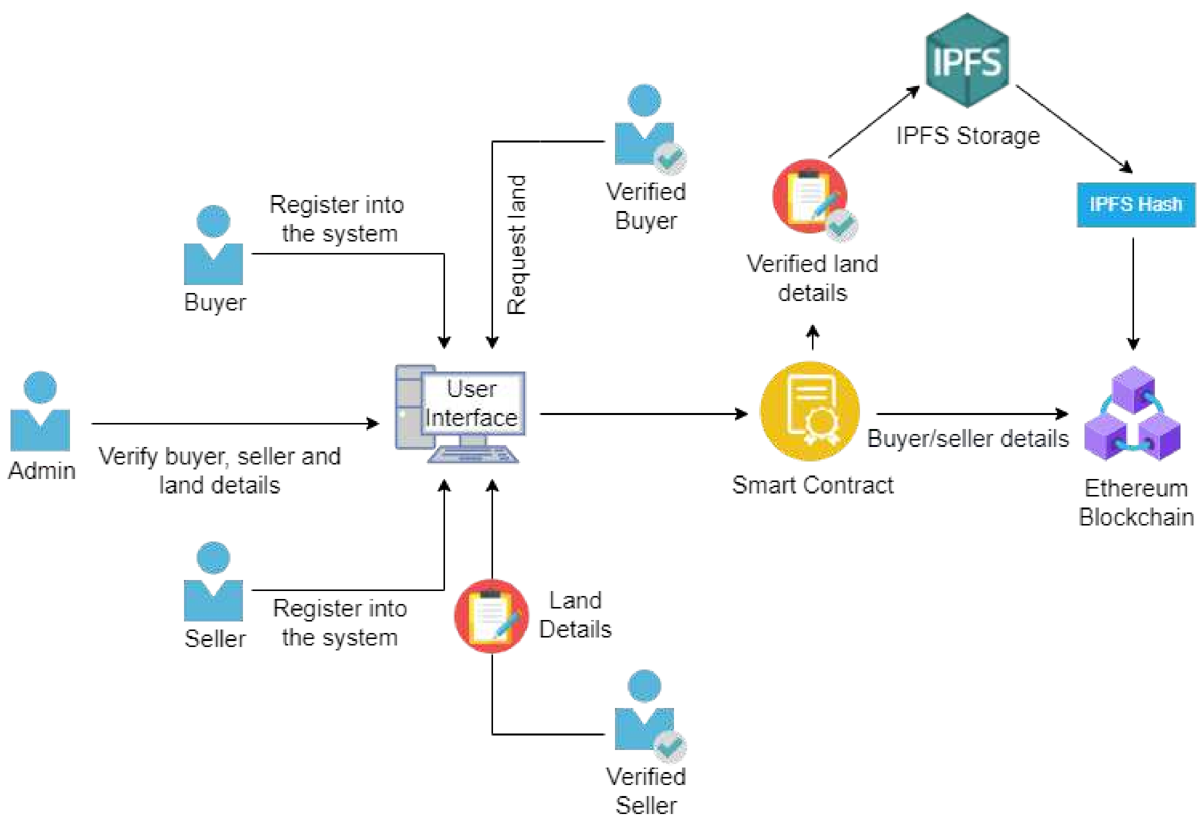


Fig. 1: Secure and Green Land Registry System using Blockchain.

A. Adding users and land with blockchain

The proposed scheme first creates an exhaustive smart contract consisting of several user-defined functions that ensure security and privacy for land registry systems [28]. Here, the developed smart contract is our proposed scheme for the blockchain-based land registry system. The first function of the smart contract is to add users (i.e., buyers and sellers) and land into the land registry system. The proposed scheme is based on a public and permissionless

Ethereum-based blockchain environment. So, any user can add themselves to the mentioned blockchain. First, the buyer and seller must register themselves into the system by providing the required mandatory details.

$$\begin{gathered}\{u_1, ..., u_i, ..., u_m\} \xrightarrow{\text{register}} \varpi \\ \{b_i, s_i\} \in u_i \in U\end{gathered} \tag{10}$$

where, ϖ denotes the blockchain-based secure land registry system and b_i, s_i denotes buyers and sellers which belongs to user entity (u_i), i.e., $\{b_i, s_i\} \in u_i$. After that, land can be added into the system by verified sellers by providing the required land details. Only verified sellers are allowed to add the land into the proposed scheme.

$$\begin{gathered}\{s_1^{'}, \ldots, s_i^{'}, \ldots s_m^{'}\} \in S^{'} \xrightarrow{d_i} \varpi \\ s_i^{'} \in S^{'} \in U^{'}\end{gathered} \tag{11}$$

where, $S^{'}$ denotes verified sellers which are part of verified users $U^{'}$. Algorithm 1 shows the functional execution of adding users and lands into the system. Different events are created for adding users and lands which can be triggered after users or land added into the system.

Algorithm 1 An algorithm for adding buyer, seller and land

Input: Buyer, Seller, LandDetails
Output: Buyer, Seller, LandAdded

procedure ADD BUYER SELLER AND LAND
 AddBuyername, age, address, email, aadharNumber, panNumber, document
 while $BuyerID \neq msg.sender$ **do**
  newBuyer = Buyer(name, age, address, email, aadharNumber, panNumber, document)
  buyerCount++;
  AddSellername, age, address, email, aadharNumber, panNumber, document
 end while
 while $SellerID \neq msg.sender$ **do**
  newSeller = Seller(name, age, address, email, aadharNumber, panNumber, document);
  sellerCount++;
  AddLandlandID, sellerID, area, city, state, country, document, propertyPID, physicalSurveyNumber, ipfsHash
 end while
 while $SellerID == msg.sender$ **do**
  newLand = Land(landID, sellerID, area, city, state, country, document, propertyPID, physicalSurveyNumber, ipfsHash);
  landCount++;
 end while
end procedure

B. Verifying users and land

After adding users (b_i and s_i) to the ϖ, the next step is to verify them so that they can participate in buying or selling activities in ϖ. Without verification, the proposed scheme is not allowed to entertain any users for buying and selling lands. For that, the owner or admin of the proposed scheme (i.e., smart contract) verifies the users.

$$\begin{gathered}\{u_1, u_2, \ldots, u_m\} \xleftarrow{\text{verifies}} \mathbf{O} \\ \{u_1^{'}, u_2^{'}, \ldots, u_l^{'}\} \in U^{'} \\ \{b_i^{'}, s_i^{'}\} \in u_i^{'} \in U^{'}\end{gathered} \tag{12}$$

where $U^{'}$ denotes the verified users and $\mathbf{O}$ denotes the owner of smart contract. After successful verification of users, the seller (s_i) can register and store their land records into the ϖ and buyer (b_i) can request the verified land details from ϖ.

$$\underbrace{\{s_1^{'}, \ldots, s_i^{'}, \ldots s_m^{'}\}}_{\text{verified sellers}} \xrightarrow{\text{adding}} \{d_1, \ldots, d_i, \ldots, d_n\} \rightarrow \varpi \tag{13}$$

$$s_i^{'} \in S^{'}$$
$$d_i \in D$$

where D denotes the land records which are added into the blockchain-based secure land registry system (ϖ) for agriculture and industry 5.0. After adding land into the ϖ the land records d_i are verified by the administrator or owner $\mathbf{O}$ of the smart contract. Only after verification the buyer b_i can request to buy that land from the seller s_i in the ϖ.

$$\begin{gathered}\{d_1, \ldots, d_i, \ldots, d_n\} \xrightarrow[\text{by}]{\text{verified}} \mathbf{O} \rightarrow \underbrace{\{d_1^{'}, \ldots, d_i^{'}, \ldots, d_n^{'}\}}_{\text{verified land records}} \\ d_i^{'} \in D^{'} \in S^{'}\end{gathered} \tag{14}$$

where $D^{'}$ denotes the verified lands into the ϖ. Furthermore, all the verified land records $d_i^{'}$ are stored in the fast interplanetary file system (IPFS) storage (ξ), and their hash values are stored in the Ethereum-based public blockchain.

$$\forall\ \{U^{'},\ D^{'}\} \in \psi \xrightarrow{d_i} \xi \tag{15}$$

where ψ denotes the smart contract which interacts with IPFS storage ξ for storing and fetching the data. Then, IPFS computes hash values for the verified land records from smart contract psi and stored inside the blockchain network. This results in faster execution time and improves the scalability of the proposed scheme.

$$\begin{gathered}\xi(f) : d_i^{'} \Rightarrow d_i^h \\ d_i^h \xrightarrow{\text{stores}} \text{Blockchain}\end{gathered} \tag{16}$$

where, $\xi(f)$ is a function that computes hash of the verified land records $d_i^{'} \rightarrow d_i^h$; (ad_i^h) is the hash of $d_i^{'}$. Then, the hashed data is forwarded to the immutable ledger of the blockchain, where it is secured from the data manipulation attacks. Algorithm 2 shows the functional execution of verifying users and lands.

Algorithm 2 An algorithm for verifying buyer, seller and land

Input: BuyerID, SellerID, LandID
Output: Buyer, Seller, LandVerified

```
procedure VERIFYING BUYER SELLER AND LAND
    VerifyBuyerbuyerID
    while owner == msg.sender do
        buyer.isVerified = true;
        verifiedBuyerCount++;
    end while
    VerifySellersellerID
    while owner == msg.sender do
        seller.isVerified = true;
        verifiedSellerCount++;
    end while
    VerifyLandlandID
    while owner == msg.sender do
        land.isVerified = true;
        verifiedLandCount++;
    end while
end procedure
```

C. Request and approve land

After users and land verification are completed, the verified buyers can request the land from the verified sellers who listed their land in the blockchain network. The requested land can then be approved or rejected by the sellers whose land is requested.

$$\begin{gathered} b_i^{'} \xrightarrow{\text{request land}} s_i^{'}\{d_i^{'}, \ldots, d_n^{'}\} \\ d_i^{'} \in D^{'}, \{b_i^{'}, s_i^{'}\} \in U^{'} \end{gathered} \tag{17}$$

where, $d_I^{'}$ denotes the requested land of seller. After requesting land, $landRequestID$ is created for request and sent to the seller whose land is requested. The seller can accept or reject the land request as per his convenience. If the seller accepts the land request, then land ownership of that particular land is transferred to the buyer and removed from the seller's ownership. The land amount is automatically transferred from the buyer's address to the seller's address upon approving the land request.

$$s_i^{'}(d_i^{'}) \xrightarrow[\text{request}]{\text{approve}} b_i^{'} \tag{18}$$

$$s_i^{'} \xrightarrow[\rho]{\text{transfer}} b_i^{'} \tag{19}$$

$$b_i^{'} \xrightarrow[\zeta]{\text{transfer}} s_i^{'} \tag{20}$$

where ρ denotes the land ownership from verified seller $S_i^{'}$ to verified buyer $b_i^{'}$, and ζ represents the transaction (amount) that buyer has to pay for the land ownership. Algorithm 3 shows the functional execution of requesting a land from seller and approving request land.

Algorithm 3 An algorithm for requesting and approving land

Input: landID, buyerID, sellerID, landRequestID
Output:land Requested, Approved

procedure REQUESTING AND APPORVING LAND RECORDS
  addLandRequestlandID, sellerID
  while $buyerIsVerified == true$ **do**
    newLandRequest = RequestLand(landRequestID, landID, buyerID, sellerID);
    landRequestCount++;
  end while
  approveLandRequestlandRequestID
  while $sellerID == msg.sender$ **do**
    landRequests.isApprovedbySeller = true;
    approvedLandbySeller++;
  end while
end procedure

V. RESULTS AND DISCUSSION

This section discusses the implementation details, such as smart contract parameters, tools, libraries, and smart contract function to develop the proposed scheme. In addition, it shows the performance of the proposed scheme using scalability, sustainability, and blockchain size comparison.

A. Experimental setup and Tools

The proposed scheme consists of different smart contract implemented in the Remix integrated development environment (IDE) [29]. The smart contracts are implemented on the public EB network using the solidity programming language with version $v0.8.16$.. It has various user-defined functions, such as $registerbuyer$, $registerseller$, $requestland$, $addland$, and many more. Next, the solidity compiler with version 0.8.17+commit.8df45f5f is used to compile the different SCs in the Remix IDE. The compiled smart contract is forwarded for deployment on the blockchain network. For that, injected provider metamask environment is selected with a gas limit of 4000000. In that regard, a metamask wallet is used to deploy smart contract on the blockchain network and to perform different smart contract transactions. Furthermore, before deploying it to the blockchain network, they are validated using the slither analyzer tool for security and privacy concerns [30]. It finds the source code vulnerabilities from smart contracts so trivial code can be modified and protects the smart contract from malicious users. Additionally, IPFS storage is used for storing off-chain land registry data to enhance the security and performance of the proposed scheme. We extract result-oriented data from the above-mentioned implementation, such as blockchain size, scalability, and sustainability, and visualize using the Python-based Matplotlib library.

B. Smart contract vulnerability analysis

The vulnerability assessment of smart contract is crucial before deploying it to the BN. In this study, smart contract is developed using Solidity programming language and is assessed for code vulnerability using the Slither Solidity source analyzer tool [30]. Slither tool checks for various code vulnerabilities, such as deep stacks, integer underflows, and wrong naming methods. Solc v0.8.16 is used for the vulnerability assessment of smart contract. Fig. 2 shows that no vulnerabilities were found after assessing the smart contract with Slither, indicating that the

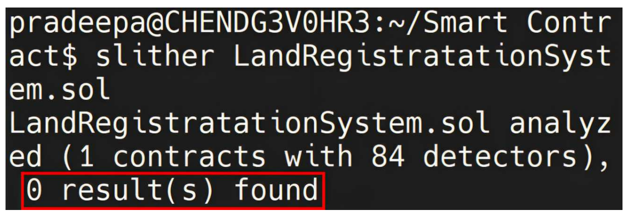


Fig. 2: Vulnerability assessment of smart contract.

developed smart contract for the proposed land registry system is secure against all code vulnerabilities.

C. Blockchain scalability comparison

Blockchain scalability is a crucial parameter that handles transactions over time without compromising security and performance. It measures the performance of the blockchain growth, i.e., whether it gets slow, congested, and vulnerable to security risks when the users and transactions increase. Fig. 3 shows the scalability comparison

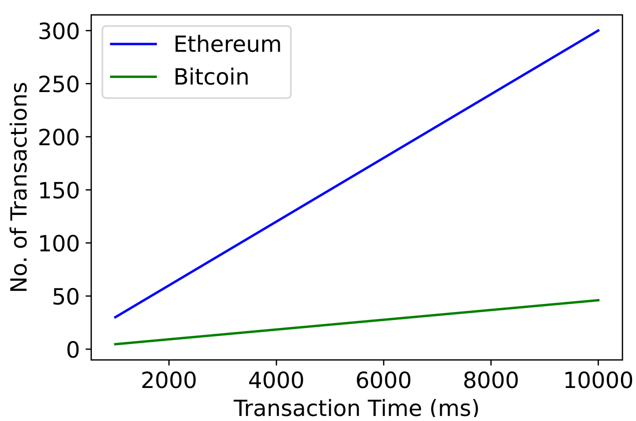


Fig. 3: Blockchain (Ethereum vs Bitcoin) scalability comparison.

between the Ethereum-based proposed scheme and the traditional blockchain network. Here, the x-axis represents the transaction time in milliseconds, and the y-axis represents the number of transactions. From the Fig. 3, it can be observed that the proposed scheme has better scalability compared to the traditional blockchain network. This is because the proposed scheme utilizes the essential benefits of IPFS, i.e., decentralized storage, reduced storage costs, and improved file availability. It allows files to be distributed across multiple nodes in the network, making it more resilient to censorship, single-point-of-failure, and other risks associated with centralized storage. The bitcoin-based traditional blockchain has not used the technological advancement that is offered in the Ethereum-based blockchain. Therefore, it has lower scalability compared to the Ethereum blockchain.

D. Blockchain sustainability comparison

Blockchain technology has to perform a lot of computation which directly affects the energy of the computing system, i.e., the higher the computation, the higher the need for energy requirement. Therefore, the blockchain sustainability parameter is utilized to measure the performance of the Ethereum-based proposed scheme. It measures

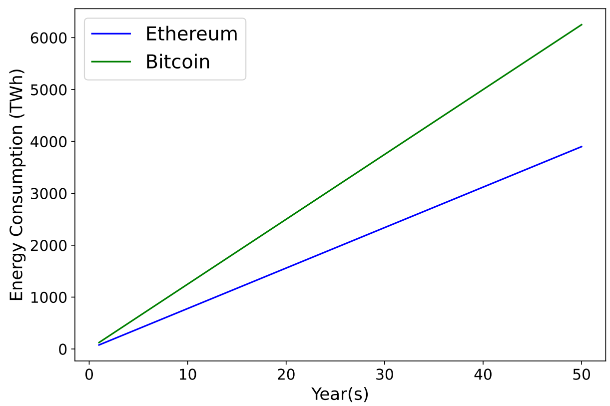


Fig. 4: Blockchain (Ethereum vs Bitcoin) sustainability comparison.

the energy consumed (in terawatt hour) for each blockchain transaction and new block generation. Fig. 4 shows the sustainability comparison between the proposed scheme and conventional blockchain. From the graph, it is evident that the proposed scheme has a better energy consumption, i.e., at 10 years, the energy consumption is 780 Terawatt-hour (TWh) and 1250 TWh for the proposed scheme and the conventional blockchain, respectively.

E. Block size optimization

Further, the block size is also an essential parameter to analyze the performance of the proposed scheme with the conventional blockchain. It refers to the maximum size of each block that can be added to the blockchain network, which in turn affects the overall capacity and efficiency of the blockchain. For instance, the Bitcoin network has a block size limit of 1 MB, and the Ethereum network has a limit of 30 KB. Increasing the block size limits strained the blockchain network in terms increases storage cost, high resource requirements, and longer validation times. On the contrary, reduced block size ensures security and decentralization because the smaller blocks are easy to validate and traverse in the blockchain network. The aim of the proposed work is to ensure a secure land registry system for agriculture and industry 5.0 using Ethereum blockchain; hence, the block size is considered small. Fig. 5 shows the average block size comparison of the proposed scheme (Ethereum) with the traditional blockchain. Here, one year sample time period is taken for comparison and visualized in the graph. It is shown that the proposed scheme has a much smaller average block size than the traditional blockchain, hence ensuring maximum security.

F. Blockchain daily transactions and hash rate

Blockchain daily transactions can determine the transaction speed and scalability. For example, a bitcoin-based blockchain typically processes $\approx$ 300,000 to 400,000 transactions per day, while an Ethereum-based blockchain processes $\approx$ 1.2 million transactions per day. This shows that the Ethereum-based blockchain has an extensive scalable network compared to bitcoin. Hence, storing land registry records in an Ethereum-based blockchain ensures high scalable network wherein more land records can be added to strengthen the land registry system. Next, the proposed scheme is evaluated based on the Proof-of-Work (PoW) algorithm, which involves business logic to solve

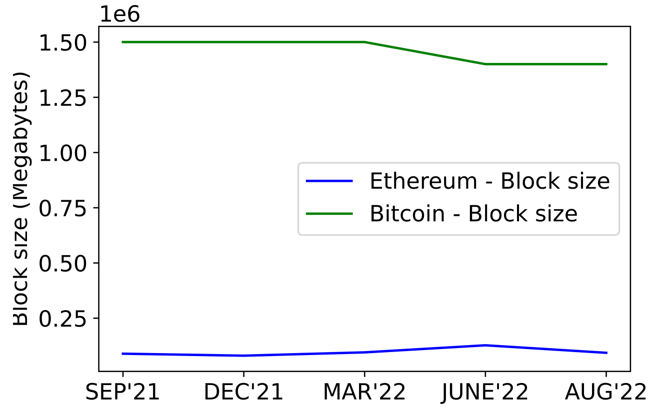


Fig. 5: Block size comparison of Ethereum with Bitcoin.

the cryptographic puzzle (i.e., hash function) to add a new block to the blockchain. Hashrate represents the total computing power a Proof-of-work (PoW) cryptocurrency network uses to process transactions in a blockchain. Both traditional (bitcoin) and Ethereum-based proposed schemes used PoW to solve a cryptographic puzzle. Fig. 6b compares the hashrate of the proposed scheme with the traditional blockchain such as Ethereum Classic and Litecoin. Here, the y-axis represents the hash rate in terahashes per second (Th/s), along with the sample period of one year shown in the x-axis. It is clear from Fig. 6b, that the proposed scheme outperforms all the traditional blockchains with the maximum hashrate, which makes the proposed scheme highly decentralized.

G. IPFS bandwidth utilization

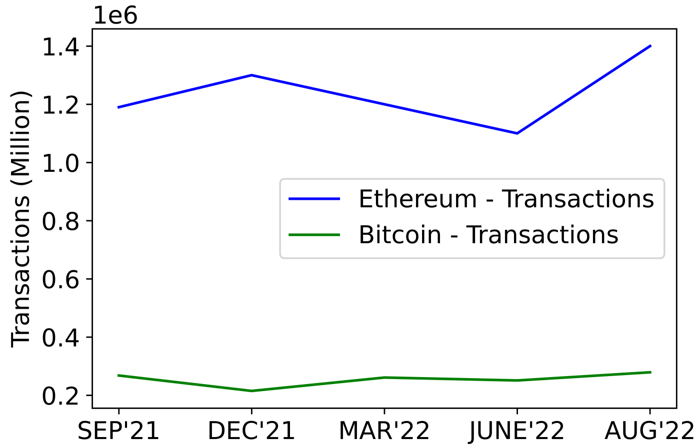
In the proposed approach, IPFS storage is utilized to reduce the cost of storing all the data in the Ethereum nodes. This results in a faster process of storing and retrieving data due to its low bandwidth utilization. For the implementation of this approach, IPFS is installed into the local system and connected with peers in a decentralized network. Data can be stored and retrieved using a hash key. Fig. 7 displays the input and output bandwidth for the data storage, with a sample time of 1 minute. The graph indicates a significantly low bandwidth usage in the proposed approach.

H. Smart Contract Implementation Interface and Gas Cost

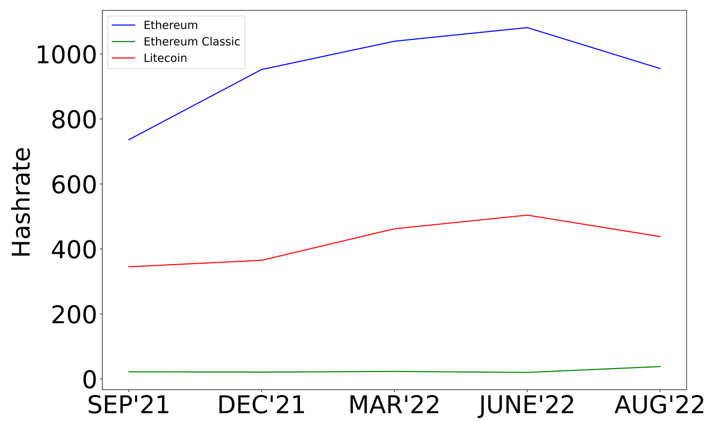
Fig. 8 shows the smart contract functions for the secure land registry systems implemented in the Remix IDE and deployed on the public Ethereum-based blockchain. These functions act as data validation by allowing only valid data to be entered into the blockchain systems. It ensure that the data is accurate, consistent, and complete, which is essential for making informed decisions based on the data. Further, all the transactions (i.e., executing the smart contract functions) performed in the blockchain require gas costs to perform the transaction. The proposed scheme uses a PoW consensus mechanism, where miners execute smart contracts on the network. However, miners need compensation for their efforts, so users must pay a transaction fee, known as gas, to cover the cost of executing the smart contract. Gas cost is calculated by the gas profiler tool provided by the Remix IDE. Fig. 9 shows the graph of transaction cost and execution cost of the main functions of the smart contract in gas units. Table III displays all the smart contract functions implemented for the proposed scheme.

VI. Discussion

This section compares the proposed approach with other existing approaches by considering different performance parameters and highlights how the proposed work outperforms other existing approaches. The proposed approach outperforms most of the existing approaches in terms of data storing, fetching speed, and transaction cost. This is because most of the existing approaches store data directly into Ethereum nodes, which raises the computational complexity of the entire blockchain network [13]–[15], [18], [19], [21]–[23], [31], [32]. Contrarily, the proposed



(a) Blockchain daily transactions comparison of Ethereum with Bitcoin.



(b) Blockchain hashrate comparison with traditional approaches.

Fig. 6: Comparison of blockchain daily transactions and hash rate.

TABLE III: Smart contract functions

Code	Function	Code	Function
F1	addBuyer	F2	addSeller
F3	addLand	F4	verifyBuyer
F5	verifySeller	F6	verifyLand
F7	addLandRequest	F8	approveLand-Request
F9	rejectLandRequest		

work utilizes the staggering benefits of IPFS, which provides on-site storage to store the data. It uses content-addressed storage (CAS) to store and retrieve data. Furthermore, it calculates the hash of the stored data and forwards it to the public blockchain, resulting in a high response time and scalability for the blockchain network. The proposed approach has higher scalability compared to the existing works. Moreover, the existing work lacks in offering security and vulnerability testing of their deployed smart contract. If the smart contract is vulnerable, an attacker can easily jeopardize the entire land registry system for agriculture and industry 5.0. Therefore, the proposed work also verifies whether the smart contract is vulnerable to code injection or manipulation attacks. For

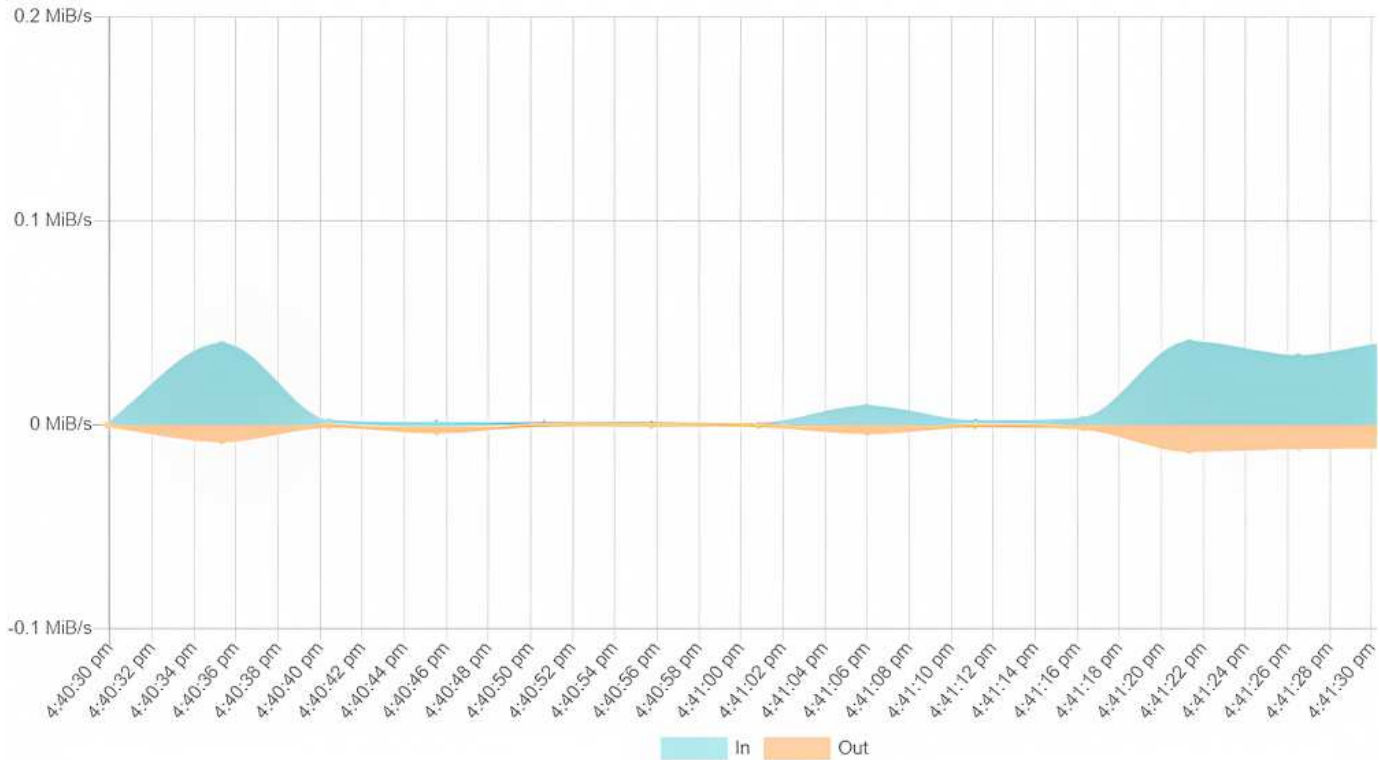


Fig. 7: Input and output bandwidth utilization by IPFS

that, a vulnerability testing tool (Slither) is utilized to check and verify if any smart contract function has any code injection vulnerability. The authors also want to remark that due to the integration of such features in the proposed approach, the proposed approach has better results compared to the existing state-of-the-art works. The proposed approach uses the latest version of Solidity language to create and compile the smart contract that, makes the proposed approach future-proof to upcoming Ethereum versions as it will adapt the future versions of Ethereum, like Ethereum proof-of-stake with minor to no change in the current implementation.

VII. Conclusion and Future work

The immutable, fully secure, and decentralized nature of blockchain technology attracts researchers to integrate it into land registration systems. Therefore, in this paper, we proposed a blockchain-based secure and reliable scheme for land registration system for agriculture and industry 5.0. First, a solidity-based smart contract is designed to register and validates the buyer-seller and their land records in the land registry systems. Then, the IPFS storage system is adopted to send the verified buyers and sellers along with their land records. Next, the IPFS computed the hash of the stored data (land records) and forwarded the hash to the Ethereum-based public blockchain. We used a proof-of-stake (PoS)-based Ethereum blockchain that provides 30 transactions per second, making our proposed scheme faster and more scalable. Lastly, the proposed scheme is evaluated using performance parameters such as scalability, sustainability, gas consumption, IPFS bandwidth utilization, and hash rate.

In the future, we will enhance the performance of the proposed scheme by integrating proof-of-work (PoW)-based Ethereum blockchain, also known as ”Ethereum 2.0,” that will offer 100,000 transactions per second making the proposed scheme extremely scalable, fast, sustainable and 99.5 percent more energy efficient.

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Data Availability declaration

No data available to carry out this reserach.

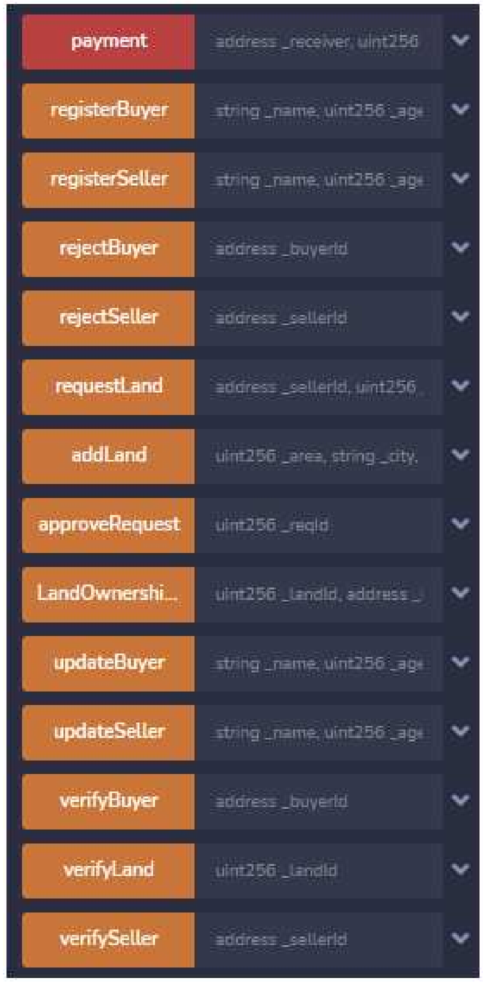

Fig. 8: Implemented functionalities interface for the proposed scheme in Remix IDE.

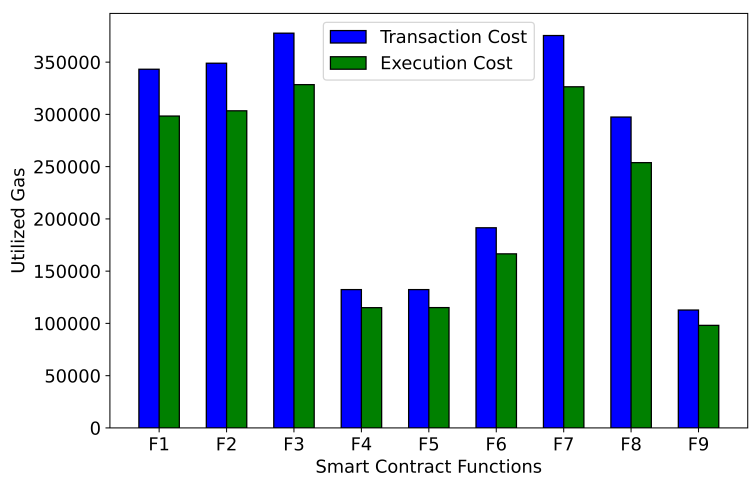

Fig. 9: Gas cost of proposed smart contract functions in terms of transaction cost and execution cost.

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