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Pioneering Emission Trading in Africa: An Architectural Design of a Blockchain-Powered Carbon Trading System

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Abstract
To achieve carbon neutrality by 2050 and reduce greenhouse gas (GHG) emissions to a range of 350–420 megatons of carbon dioxide equivalent, South Africa, the largest emitter of GHG in Africa, introduced a carbon taxation system in June 2019. However, within just 3 years, it has become evident that the system faces significant challenges, with less than 6% of the estimated tax returns reaching the government. This issue raises concerns about potential corruption and manipulation within the system. To address these challenges, this study presents a comprehensive framework for a carbon trading and taxation system leveraging blockchain technology (BCT). Designing this framework from the government's perspective ensures efficient monitoring and oversight. Notably, the proposed system operates automatically, eliminating the need for third-party intermediaries. This study also identifies a crucial research gap and lays the foundation for future studies. It empirically implements the system as a decentralised application) using the Hedera and Solana blockchain networks. Complemented by JavaScript for the user interface. Python, through Django, was used to handle the server-side system implementation. Thus, this research aims to address the shortcomings of Africa's current carbon taxation system through a novel, government-centric approach powered by BCT. The proposed system's potential to enhance transparency and efficiency justifies further exploration in future studies.

Keywords: *Blockchain, Blockchain Technology, Africa, South Africa, Greenhouse Gas, Carbon Taxation, Carbon Market, Carbon Trading System, Carbon Finance, Carbon Footprint.*

JEL Classifications: *Q4, Q53, Q54, Q55, P18, N7*

1. Introduction

Reports have indicated that South Africa is the largest emitter of greenhouse gases (GHG) in Africa and ranks among the world's top 20 emitters of the same. A substantial 86% of these emissions originate from the energy sector due to the country's heavy reliance on coal-fired plants for electricity generation. Without the implementation of necessary measures, this increase is projected to continue, as the GHG emission rate has risen by 67% between 1990 and 2019 and by 91% over the last decade [1]. Excessive emission of this gas has numerous adverse effects, including an increase in Earth's temperature, leading to acid rain, which can damage the atmosphere and the oceanic bodies [2].

To mitigate the emission rate and prevent the associated adverse effects, South African authorities have set a goal to reduce the emission rate to a range of 350 to 420 megatons of carbon dioxide equivalents (CO_2e) and to achieve complete carbon neutrality by 2050. The action plan to accomplish these goals includes the introduction of carbon taxation in June 2019. Initially, this system seemed a practical step towards achieving the set goals, but its problems soon became apparent. In 2022, the government expected a return of R134 (≈$8) per ton of emitted GHG. However, the amount received was just R7 (≈$0.5) per ton of emitted GHG. This performance is deficient, representing only approximately 6% of the expected returns. Consequently, the purpose of carbon taxation is undermined as emitting entities (the companies) can still exploit manipulative and corrupt means to emit CO_2e while avoiding the fees intended to regulate their emissions. These issues stem from the system being controlled by centralised authorities and institutions. These challenges are likely to escalate as the market value increases, particularly since the government plans to raise the price of carbon emissions per ton to $30 by 2030 and $120 by 2050 [1].

This potential for an exponential increase in market value necessitates an urgent solution to address possible manipulation and corruption within the system. Introducing a technology that ensures the system operates not only automatically but also securely, tamper-proof (immutable), and in a decentralised manner would be a novel solution [3]. These exceptional features are inherent to blockchain technology (BCT). BCT has demonstrated its dependability and usability in sensitive systems and is a technology that can be trusted [4]. Through its features, BCT is capable of curbing the corruption and manipulation present in the current conventional system, thereby shifting reliance and confidence from central authorities to system users and stakeholders [5].

To address the problems mentioned above, this study proposes and develops a framework for a blockchain-powered carbon trading system designed from the perspective of the South African government as a representative of the African governments. This approach ensures proper government monitoring and facilitates its adoption into the current African conventional carbon taxation and carbon trading system.

1.1 Background of Study

Carbon Tax: The carbon tax exemplifies a Pigouvian tax, which is a levy imposed by the government on businesses engaging in activities that have detrimental effects on the environment or public health, such as environmental pollution.

Consideration of South Africa's Carbon Trading Mechanism as a Sample of Africa's Carbon Trading Mechanism: South Africa not only is the largest emitter of GHG on the African continent but also ranks among the top 20 global emitters, having held the 12th position on the list. Its GHG emissions increased by more than 67% between 1990 and 2019, with the energy sector accounting for approximately 86% of total emissions. Other contributing sectors include industrial processes, agriculture, and waste. Consequently, by 2019, there was a nearly 91% increment in emissions over the previous three decades, primarily due to the energy sector's reliance on coal-fired power plants. South Africa is committed to reducing emissions to a range of 350–420 megatons of CO_2e and achieving complete carbon neutrality by 2050. This objective is supported by a strategic plan to transition to a clean and resilient economy [1].

In an effort to mitigate GHG emissions, South Africa introduced carbon taxation in June 2019. This tax was levied on 90% of the country's GHG emission systems, making South Africa the first African nation to implement a carbon tax policy. Problems with the system began to emerge towards the end of 2022. At that time, the fee imposed on GHG-emitting systems was R134 (approximately $8) per ton of CO_2e. However, the government received returns estimated at just R7 per ton of CO_2e. Among other causes, this discrepancy can be attributed to the possibility of human-induced manipulations within the system, highlighting the need for a tamper-proof system such as BCT. Implementing BCT would not only decentralise the records but also make them immutable, ensuring that all tons of CO_2e emitted by the responsible sectors are accurately accounted for, thereby making the entire tax fee payable to the government without any losses. This implementation is urgently needed before 2026 when the market value is expected to increase significantly due to the government's plan to raise the price of carbon dioxide to $20 per ton. However, the need for this technology will persist beyond 2026, as the market value of carbon trading is projected to grow exponentially, with plans to increase the value of carbon dioxide per ton to $30 by 2030 and $120 beyond 2050 [1]. Thus, BCT offers a scalable solution for the system.

Furthermore, the penalty proposed by the government for emissions exceeding the allocated carbon limit is a payment of $640 per ton of carbon dioxide emitted [1]. This fee can be avoided by companies through bidding for a carbon cap from other companies with excess quotas.

Overview of Blockchain Technology: As the name implies, blockchain is a chain of blocks linked together using cryptographic hashing. A block is structured data that records or maintains data initiated by and distributed across network entities. This record is not limited to financial information; it can also include sensor readings, diagrams from companies' applications, and government-imposed restrictions. Remarkably, it can also comprise executable source code, known as smart contracts [6]. Once the network entities reach a consensus to add a block to the chain, the information embedded within that block becomes permanently unchangeable [7]. Moreover, exact copies of the record are distributed to all network participants and kept up to date accordingly [8].

The distinctiveness of BCT lies in its capacity to enhance the security, immutability, and integrity of systems, among other exceptional, result-oriented characteristics [9]. It shifts reliance and confidence from central authorities such as institutions, governments, and companies to the system users or stakeholders [5].

The practical application of BCT in the carbon trading market is assured by its ability to secure data storage [10]. The absence of intermediaries and third-party entities facilitates secure and transparent interactions between two or more unknown parties [6]. Additionally, blockchain enhances system effectiveness by ensuring no single point of failure; entities within the network can exit and join at any time without disrupting the system's processes and the blockchain network [11].

2. Related Works

The practical application of BCT has been successfully implemented across various domains, including healthcare, identity management, and finance [12]. Its broad applicability extends to the energy and environmental sectors, which is directly related to our study, as a majority of GHG emissions are either directly or indirectly linked to the production and utilisation of energy [13]. In line with this, South Africa has set an ambitious target to achieve complete carbon neutrality by 2050 [1], underscoring the critical need to decarbonise the energy generation process in a digitalised and decentralised manner.

This context has led to the coining of the term "blockchain energy" by Teufel et al. [11], which refers to the application of BCT in the energy sector. According to the researchers, the scope of blockchain energy includes energy trading, energy record keeping, and the facilitation of energy transfer between entities. The benefits of a blockchain-powered system are evident in the independent trading of energy among small- and medium-scale prosumers, thereby mitigating the manipulation often associated with centralised authority systems.

Moreover, blockchain ensures that transactions within the system are traceable, allowing energy consumers to identify the source of their energy. The use of smart contracts enables automated agreements between multiple unknown parties, thereby eliminating the need for third-party intermediaries [5], [14]. This approach allows small- and medium-scale enterprises to participate alongside larger energy prosumers in the carbon trading market.

In a related study, Sadawi et al. [5] employed BCT to fulfil the original objectives of the carbon emission trading system, leveraging the technology's potential to design and develop an impartial and efficient carbon trading system. To facilitate government monitoring of the carbon trading market, most existing literature and studies in this domain have been developed from the government's perspective [15]. This approach enhances the system's originality and dependability, thereby reducing manipulation and corruption in carbon trading. To improve the fairness and effectiveness of the Australian carbon trading market, Hartmann proposed the integration of BCT into the carbon trading system [16]. Additionally, blockchain offers an optimised solution to the complexities of annual carbon cap allocation and system monitoring, ensuring proper revenue remittance and addressing information privacy challenges [5].

The time needed to gain mastery over BCT can be shortened if the pioneer carbon traders decide to speedily adopt the use of BCT into their system [17]. As Khaqqi [18] introduced, integrating reputation systems within blockchain operations and carbon trading gives preference to users with better reputations when allocating transaction quotas, thereby financially rewarding system users while ensuring system security.

The unique contribution of this study lies in presenting a framework for a blockchain-powered carbon trading system, proposed as a pioneering emission trading system for the African continent, with South Africa – the largest emitter of GHG – as the case study. This framework enables trade actions between prosumers and consumers without third-party intermediaries, ensuring a seamless process. By adopting a government perspective, this study designs a trustworthy carbon market system that facilitates proper government monitoring, thereby curbing manipulation and corruption associated with centralised systems.

3. Architectural Design

3.1 System Actors and Their Roles

The system comprises the governments, companies, and the system administrator. The system is targeted at aiding the company to be creative about different ways they can use to limit their emission, possibly by recycling it to generate power or sourcing for means of limiting the emission by utilising other avenues that are present at their disposal.

1. **The Government and Other Environmental Authorities**: The government, or the relevant authorities, will allocate a monthly carbon cap to each company within its jurisdiction. The volume of each company's monthly cap is determined by the annual carbon emission target, which is divided across the 12 calendar months to create smaller, more manageable goals.
2. **Companies**: Companies act as the prosumers of the carbon cap within the system, possessing the right to emit carbon within their allocated quota and to trade any surplus cap. Aware of their limited monthly GHG emission allowance, companies will be cautious about their emissions, promoting environmental responsibility. They will actively monitor and track their emissions using the company dashboard provided by the system. Should a company need to emit more carbon, it must either bid for additional carbon allocation in the market or accept an offer from another organisation with surplus carbon caps. This creates an incentive for companies to control their emissions creatively, as they can monetise any excess carbon cap in the digital carbon market. If a company exhausts its emission cap and fails to purchase additional rights from either the market or the government (at a higher cost than from another company), it will incur a tax or penalty greater than the potential market cost. The emission cap is monthly, but any unused or excess cap can be carried over to subsequent months. This allows companies to accumulate emission rights for future use, while those with deficits cannot reset their levels to zero without paying the necessary fees by acquiring quotas from the market or paying taxes to the government.
3. **System Administrator**: The system administrator possesses the technical expertise to build the system for end-users (the government and companies). The entire process is powered by BCT, moving away from conventional systems such as Microsoft Excel and centralised databases, which are susceptible to human manipulation and single points of failure, thus compromising the system's integrity. BCT is chosen for its tamper-proof and decentralised features, ensuring a transparent system where all entities involved can trust the processes. The system, programmed by the administrator, will include an alert mechanism that sends notifications to companies via SMS and email, informing them of their emission status at the end of each week, along with a summary at the end of each month.

3.2 Architecture of the Carbon Trading System

As inspired by Rachana Harish et al. [16], this consists of three primary layers, which include the blockchain-based carbon trading layer, the cyber-physical systems layer, and the information layer, as shown in Figure 1.

1. **Blockchain-Based Carbon Trading System Layer**: This component powers the entire trading system, enabling it to function as a decentralised platform. It is subdivided into three parts, which include:

    a. **Digital Access Tokenisation**: Tokens (digital assets) serve as the system's reward mechanism and medium of exchange. These digital assets can be stored for future use as cryptographic tokens, with ownership identity attached. Tokens facilitate the exchange of carbon emission rights within the decentralised system.

    b. **The Blockchain Network**: This manages peer-to-peer connections and communication among network nodes. Unlike centralised systems, storage here is distributed. In the absence of a central authority, consensus among nodes is required before accepting new records on the ledger. Additionally, the application automatically exchanges tokens as programmed, leveraging smart contracts.

    c. **The Blockchain Explorer**: The concepts mentioned above pertain to the backend logic of the application. To ensure a seamless user experience (UX) for non-technical users, a user interface (UI) is necessary. This UI acts as an intermediary between the technical components and the user, facilitating electronic trading and service exploration.

2. **Cyber-Physical Systems**: This layer integrates physical and virtual entities for the application's effective functioning. It encompasses human-induced operations such as emissions or energy purchasing decisions, machines (like the Internet of Things (IoT devices), and energy itself, that is, CO_2e, along with the transaction fee known as gas, which is necessary for communication between system nodes. System performance is also crucial in this layer, as the proposed system aims to outperform existing conventional systems.
3. **Information Systems**: This layer provides users with data to make informed decisions. It includes an embedded email and SMS notification system, along with access to the electronic trading platform for allocating and monitoring emission rates, ensuring effective emission management.

4. Implementation Methodology

The designed system framework was implemented using the Hedera Blockchain Network, and the payment was powered by the Solana payment gateway system, which is also a decentralised technology. Hedera is an open-source, decentralised, proof-of-stake ledger powered by an asynchronous Byzantine Fault Tolerance hashgraph consensus algorithm. In its decentralised collusion-resistant platform, council, leading enterprises, universities, and Web3 projects are represented. Using Hedera's Ethereum Virtual Machine smart contracts, a real-time Web3 application and ecosystem can be created. It also provides cryptocurrency, file storage, smart contracts, and consensus services. Hedera differs from other blockchains in several ways. Through a robust codebase, high throughput, fast finality, low fees, predictable charges, and fair transaction ordering are ensured at every layer of the network infrastructure. For the purpose of preventing collusion, Hedera is governed by internationally recognised organisations. For writing smart contract programs, Hedera employs "Solidity.". This is an object-oriented and high-level programming language. It is also the core language used for the implementation of smart contracts on the network [20].

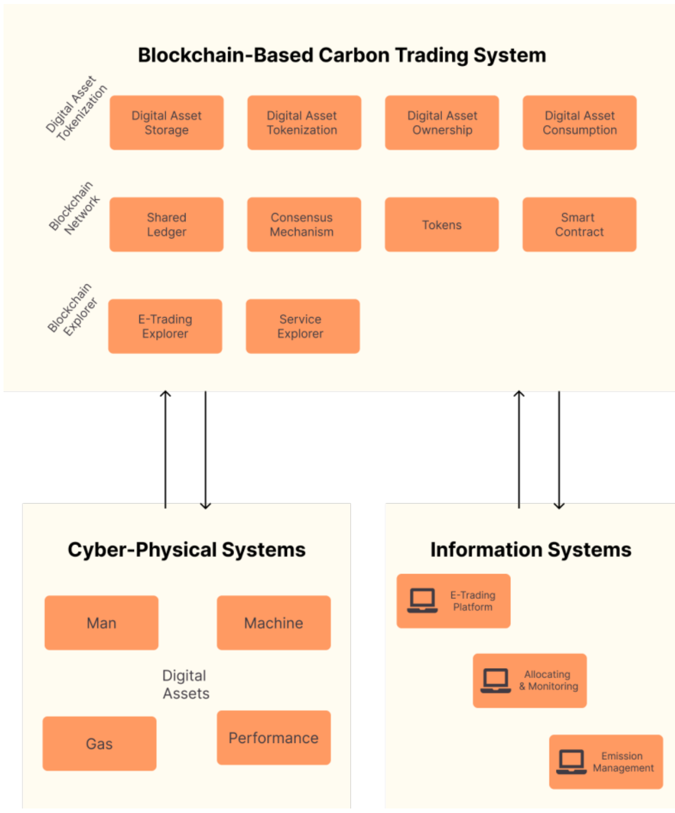

Figure 1. Architectural Design of the Carbon Trading System (Inspired by [19])

Furthermore, checking the execution of each of the transactions performed is done with the aid of Hashscan, which is an open-source tool used for the exploration of the performed operations on the chain. Among the other available tools, Hashscan was selected because it provides essential real-time analysis information of the Hedera blockchain simulation network, which includes details of the node and the prize of the transactions' used units. By the way, there is no need to register or make payments before assessing and using the platform. The only constraint of using it is that it enlists all the transactions performed on the Hedera network. So, to filter the transactions to the ones related to our smart contract, the account identification number (ID) of the smart contract test network deployment is connected [21].

To ensure a seamless experience for our "non-technical" system users while navigating the system, a UI connected to the Smart Contract was built. This UI was built using a popular programming language understood by the browser, which is known as JavaScript.

The data used for testing the system was randomly generated in the background using the Redis in-memory database. This was done to simulate carbon emission data that is generated in real time using an IoT-powered emission sensor. The development of the logic and the coding of the emission trading system powered by blockchain was implemented by following the following steps:

- First, samples of carbon emission data were checked using sources like ourworldindata.org/co2-dataset-sources, epa.gov/ghgreporting/data-sets, and cdp.net/en/investor/ghg-emissions-dataset. This helped us to get familiar with the format of a typical carbon footprint record. This knowledge was then leveraged to generate random emissions records in real time to reduce the carbon quota allocated to the emitting entities automatically.
- Second, the logic of the blockchain was developed. This step paid attention to the roles of each system actor and ensured that all the roles played by each of the entities involved in the system were strictly adhered to; that is, the system was made to work on an authorisation and authentication basis.
- Moving forward, the logic developed was then written using the Smart contract programs.
- The output obtained from the simulation of the system was then used to further enhance the system implementation to make it more effective.

After all the necessary checks have been done, the smart contracts will be moved from the Hedera blockchain's testing environment to the blockchain's main network.

4.1 System Operation Flow

An acceptable deliverable of the first version of the system was achieved when all use cases of the system were addressed, and it conformed to the following predefined conditions and workflow:

Based on the targeted annual emission volume, the system enables the government to allocate a carbon emission quota to each company or large emitting entity, considering their size and the taxes paid. During this allocation process, the government or environmental institutions ensure that a surplus quota is retained for contingency purposes.

Each company can monitor its emissions via a dashboard featuring user-friendly charts that compare its emissions against the allocated carbon quota. This is accomplished by using precomputed carbon records to generate random carbon footprints for each company on the system, which simulate real-time carbon footprints obtained through IoT carbon sensors.

Moreover, the system facilitates the trading of excess carbon quotas. Companies with surplus CO_2e quotas can offer them in the market. These offers can be updated at the company's discretion. However, once a buyer agrees to purchase an offer, the transaction becomes irrevocable. Similarly, a company nearing its allocated carbon quota and requiring additional emissions can bid for available offers in the marketplace.

If no offers are available for the bidder, the issue will be escalated to the authorities or government. If the government has a reserved quota, it will be sold to the company at a price slightly higher than the current market value but lower than the penalty fee. If the government does not have a reserved quota, the company must cease emissions for that month, even if it means stopping production. This scenario encourages the company to devise creative methods to continue production while reducing emissions. Alternatively, the company might choose to exceed its allocated quota without regard for the limitations. Exceeding the quota will result in imposing a high penalty fee corresponding to the excess emissions. Repeated violations of the emission rules by exceeding the quota without purchasing additional allocation will lead to the shutdown of the emitting entity's operations after three warnings.

The implementation methodology is illustrated in the flowchart shown in Figure 2.

5. Results

A decentralised ledger facilitates real-world trading conditions within the designed system. Additionally, the system was engineered to store, manage, and retrieve data to support users' decision-making processes. The operation of the blockchain-powered carbon trading system necessitates the use of a decentralised network, a server-side web programming language, and a client-side programming language.

The system was developed using six significant tools. The PostgreSQL database (version 15) is utilised for data recording, while Hedera blockchain technology stores the buy and sell orders. To develop the core application, Django (version 4.2.8), built on Python (3.12.1), was employed. Instead of generating real-time CO_2 emissions from IoT devices, random emission data is collected and entered into the system using Redis command line interface (CLI) powered by an Ubuntu runtime server/virtual machine. JavaScript was used for the front end.

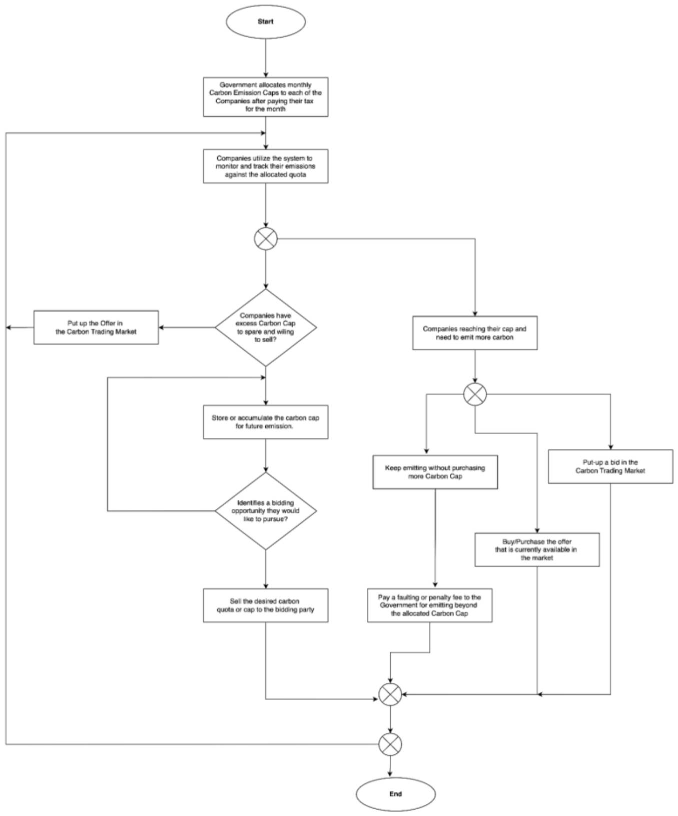

Figure 2. Carbon Cap Trading Process

5.1 Final Implementation Output

The designed framework was developed with a government-centric approach, implying that the government has full control over the system. The administrator interface makes it possible for the government to oversee the entire system process. From the point of creating large emitting entities, reducing payment through a decentralised approach, and allocating the genesis emitting block to the created emitting entities. The government or environmental institutions' authorities that are acting as the government delegate also reserve the right to maintain fair usage of the system, as they are the only system actors that can delete a sell order of a carbon quota that has been created if the seller desires to delete it or make a reverse on the move before any buyer shows interest of making the purchase.

Furthermore, after the emitting entities have been created, made payments, and allocated carbon quotas, they will then have full access to the system's functionalities. Despite granting full access to the system. At any time when the user wants to access the system, there is an authentication step that the emitter must pass through to access the system; this authentication step can be either through email and password, Google authentication, or Meta (formerly Facebook) authentication. Once the user has been authenticated, the emission dashboard will come up.

As shown in Figure 3, the emission below showcases the emission records of all participating companies instead of just showing the record of only the logged-in entity. This points to the fact that the emission reduction target is a collaborative effort of all companies in the region. This method fosters transparency, openness, and trust within the system. Moreover, it creates an environment where companies can compete to keep their emissions within the specified target.

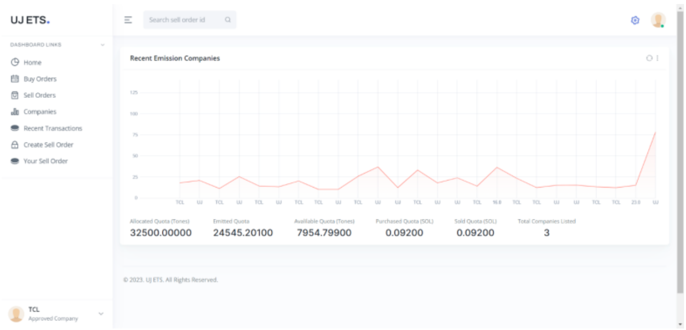

Figure 3. Emission Dashboard

The core functionality of the system is the exchange of excess carbon quota for monetary reward. This is only possible when entities are able to creatively limit the rate at which they emit and stay significantly below the allocated quota. Once a carbon quota has been listed for sale, a barcode will be generated and displayed at both the seller's and buyer's end of the system, as seen in Figure 4. This enhances the payment for the carbon quota by the buyer using the Solana wallet token storage known as Solflare. The payment process for the desired carbon quota sell order is illustrated in Figure 5. Upon successful and validated payment, the quota is transferred from the seller's allocation to the buyer's allocation.

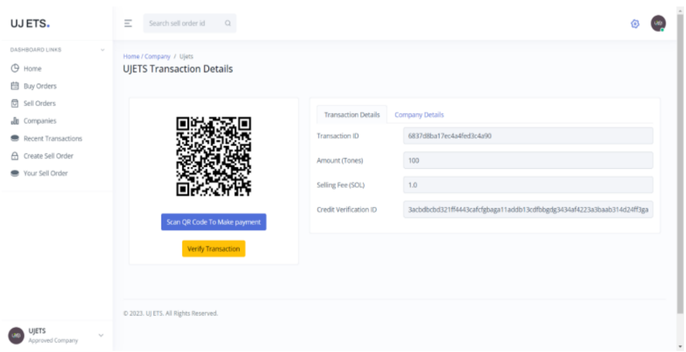

Figure 4. Carbon Quota Sell Order Creation

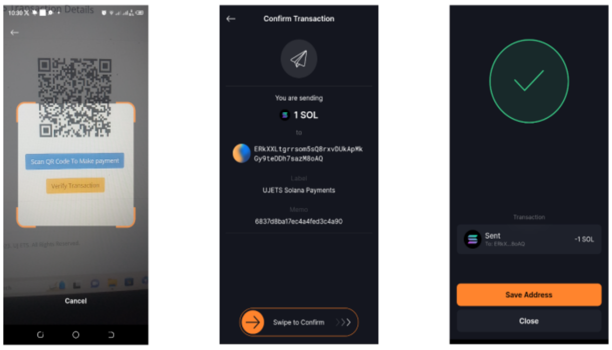

Figure 5. Payment Process using Solflare. https://solflare.com/

Moreover, the system uses smart contracts instead of conventional agreements. We used the Hedera Blockchain platform to power these smart contracts. Hashscan was utilised to monitor network transactions. By the way, Hashscan normally displays all transactions carried out on the Hedera Blockchain network; however, in this instance, the account ID number of our contract was linked to Hashscan, allowing the tool to display only transactions related to the contract.

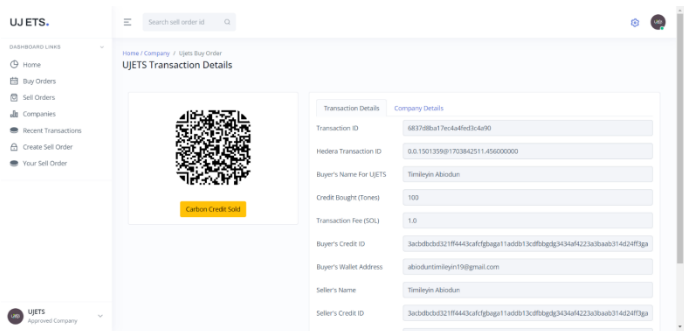

Figure 6. Successfully Bought Carbon Quota Showing the Details of the Buyer and Seller

5.2 System Performance Evaluation

The evaluation of the smart contract powering the system was conducted using Maian, a tool that uses an interprocedural symbolic implementation to identify contracts that are greedy, prodigal, and suicidal [22], as well as Semgrep [23], a code review tool that assesses the smart contract against standard practices. The findings of this evaluation are illustrated in Figure 8 and Table 1, which indicate that the smart contract is highly robust and does not exhibit any prodigal, suicidal, or greedy tendencies. The results obtained from Semgrep also reveal that the smart contract complies with 47 out of 48 Solidity rules, with the only violation being that the constructor is not payable. However, this has been further established by Praitheeshan et al. [24] to pose a security risk if made payable.

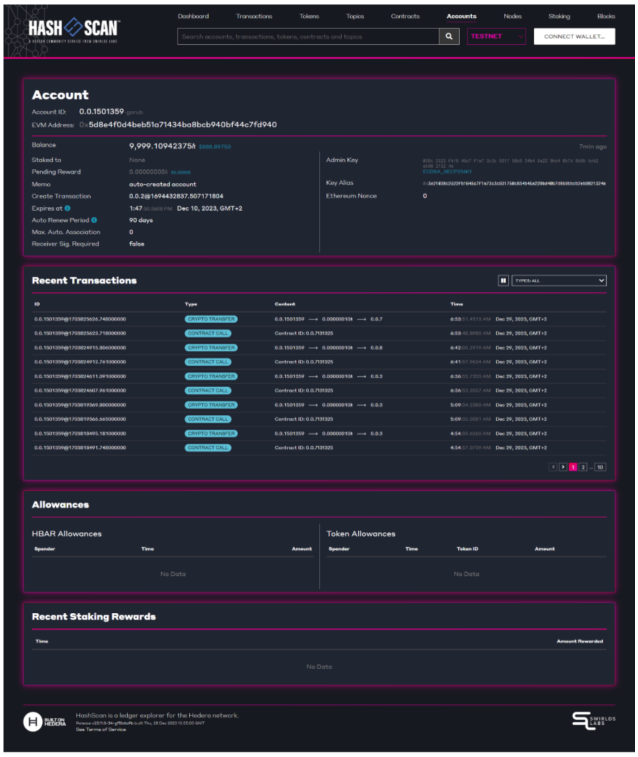

Figure 7. Tracking Smart Contracts Using Hashscan, https://hashscan.io/testnet/dashboard

Table 1. Analysis of the Smart Contract with Maian

Test	Result
Check if contract is SUICIDAL.	The code does not contain SUICIDE instructions; hence, it is not vulnerable.
Check if contract is PRODIGAL.	The code does not have CALL/SUICIDE; hence, it is not prodigal.
Check if contract is GREEDY.	No lock vulnerability was found because the contract cannot receive Ether.

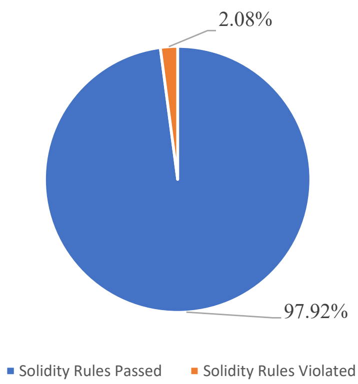

Figure 8. Analysis of the Smart Contract with Semgrep

Additionally, the system's source code was assessed using Bandit [25], generating a report that demonstrates a high confidence level and a low severity level for the code.

Table 2. Result of the Source Code Severity Analysis with Bandit

Low Severity	Medium Severity	High Severity
3,189 lines of code	551 lines of code	627 lines of code

Table 3. Result of the Source Code Confidence Analysis with Bandit

Low Confidence	Medium Confidence	High Confidence
233 lines of code	383 lines of code	3,751 lines of code

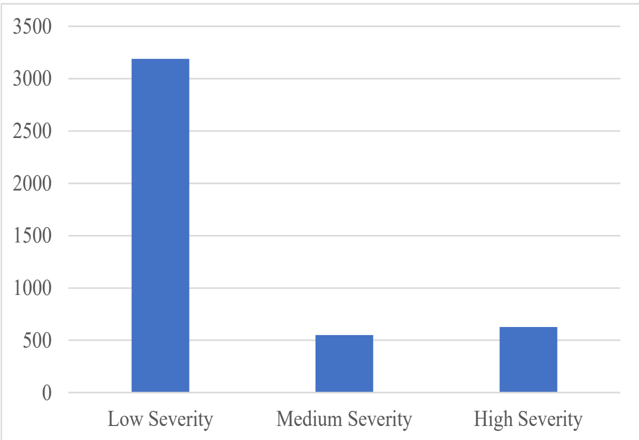

Figure 9. Result of the Source Code Severity Analysis with Bandit

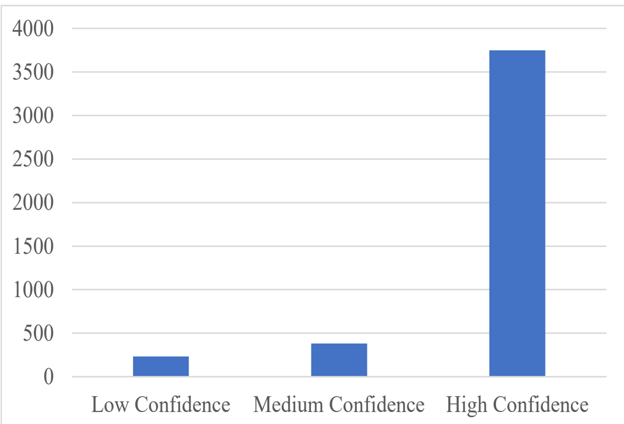

Figure 10. Result of the Source Code Confidence Analysis with Bandit

6. Discussion

6.1 Comparison of the Study with Related Works

Previous studies have explored the implementation of carbon trading systems using BCT. For instance, a study by Zhang et al. [26] demonstrated the potential of fostering a digital economy while reducing carbon emission intensity, highlighting BCT as an effective tool for this purpose. Similarly, research by T. Jiang et al. [17] established that BCT can intelligently automate carbon quota certification and payment, thereby reducing transaction costs and emissions through enhanced monitoring. Furthermore, the interoperability of the carbon trading market with other energy markets, such as the photovoltaic power market, has been validated through a decentralised architectural design [16].

This implementation, however, differs from the existing applications of BCT in the carbon trading domain in its focus and scope. First, it is fully automated, eliminating human interference from data capture to emission reduction within the allocated carbon quota based on proportional emissions. Additionally, the practical application to the African context has been considered, addressing the lack of such systems across the continent. The architectural design employed in developing this system is a decentralised architectural framework.

6.2 Limitations of the Current Study

These limitations are in place to encourage future research endeavours. First, the IoT data-capturing process of the system is simulated using random data that operates in the background through an in-memory database known as Redis CLI, running on an Ubuntu runtime environment. Second, the results are strictly focused on the emission trading system; future studies could explore the integration of a renewable energy trading mechanism into the system. Third, to enhance the system's alignment with the technological demands of the Fourth Industrial Revolution, machine learning and artificial intelligence could be incorporated to enable predictive analytics functionality. This would allow the system to utilise data to forecast carbon market behaviour and strategically plan methods to reduce emissions.

6.2 Conclusion

South Africa is the largest GHG emitter in Africa and one of the top 20 emitters globally. Recognising the adverse effects of these emissions, environmental experts in South Africa have set a goal of achieving zero emissions by 2050. One of the strategies to achieve this goal is the implementation of a carbon trading mechanism and carbon taxation, introduced in June 2019. However, the system's flaws soon became apparent. In 2022, the fee levied on the GHG-emitting system was R134 per ton of CO_2e, yet the returns amounted to only R7 per ton of CO_2e. This discrepancy is likely due to manipulation in the reported emission rates.

The scalability of the carbon market necessitates robust safeguards against any form of human or machine-induced manipulation, especially as the government plans to increase the value of CO_2e per ton to \$30 by 2030 and to \$120 per ton beyond 2050. This exponential increase demands 100% integrity and transparency within the system.

In this study, a framework is designed wherein BCT will be utilised to power the carbon trading and taxation system. BCT was chosen due to its ability to transfer authority from a centralised system to a decentralised network of stakeholders. This not only eliminates a single point of failure but also integrates trust and transparency into the system, owing to the security and immutability of data provided by the blockchain ecosystem.

Competing Interests:
None declared.

Ethical Approval:
Not applicable.

Author's Contribution:
Conceptualisation, NN; methodology, TA, NN, and PO; software, TA; validation, TA, NN, and PO; writing – original draft preparation, TA; writing – review and editing, NN and PO; visualisation, TA.

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