

# Blockchain Based Carbon Footprint Verification and Management

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**Abstract**—The goal of the "Blockchain Based Carbon Footprint Verification and Management" project is to use blockchain technology to manage corporate CO<sub>2</sub> emissions data in an open, safe, and unchangeable manner. Data security, verifiability, and reliability are problems with traditional carbon tracking and reporting methods. This project tackles these issues by integrating blockchain technology into carbon footprint management. It does this by making sure that all emissions data—more especially, Scope 1 (direct emissions), Scope 2 (indirect emissions from electricity purchased), and Scope 3 (other indirect emissions throughout the supply chain)—is safely stored and cannot be changed or tampered with after verification. This system removes the need for self-reported data, which is frequently unreliable, by directly collecting and entering verified emissions data. Since each entry is given a distinct cryptographic hash and kept on a blockchain, data is guaranteed to be unchangeable once it is logged. Blockchain technology improves transparency and adds a layer of security, enabling businesses, regulators, and stakeholders to view CO<sub>2</sub> emissions records with assurance that they are authentic. Based on their emissions data, the project also uses a machine learning model to give businesses practical insights and suggestions for lowering their carbon footprint. This creative strategy promotes more sustainable practices across industries and corporate accountability. This platform offers a useful framework that can be modified for wider industrial applications by first concentrating on high-emission industries, like the cement sector. The project provides a complete solution to address the pressing need for verified, transparent carbon footprint management in the quest for a greener future by integrating blockchain and IPFS (for decentralized file storage).

**Index Terms**—Sustainability, Blockchain, Carbon Emissions, Transparent Carbon Emission, Carbon Footprint

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## INTRODUCTION

Reducing carbon emissions has become a crucial global goal as climate change continues to pose serious threats to ecosystems, economies, and communities around the world. Governments, investors, and consumers are putting more and more pressure on industries that produce a large amount of greenhouse gas emissions to implement sustainable practices. The requirement for efficient systems to monitor, control, and reduce carbon emissions at different stages of production and supply chains is one of the most pressing issues. Demand for safe, dependable platforms that give businesses and regulators a clear picture of corporate carbon footprints has increased as a result of the realization that accurate and transparent emissions data is essential to attaining significant reductions.

Three scopes are commonly used to classify a company's carbon emissions. Direct emissions from resources owned by the company, such as fuel combustion during heating or manufacturing processes, are referred to as scope 1 emissions. Indirect emissions from the use of purchased electricity, steam, heat, or cooling are referred to as scope 2 emissions. Lastly, all other indirect emissions from upstream and downstream operations in a business's value chain, such as the procurement of raw materials, transportation, and waste disposal, are included in Scope 3. To obtain a complete picture of the environmental impact, comprehensive carbon management necessitates tracking across all three scopes.

Despite the importance of such tracking, conventional carbon footprint management systems often suffer from several critical issues:

- **Data Integrity:** It is possible for self-reported data to be inaccurate, manipulated, or inconsistent between reporting periods.
- **Transparency:** Stakeholders who depend on precise carbon data to make educated decisions lose faith in traditional systems when there is a lack of transparency.
- **Security:** Data loss or unauthorized changes may result from storing emissions data in centralized systems, which may present security risks.

These problems make it more difficult to verify emissions data, which hinders attempts to accurately measure, cut, and offset carbon footprints. A revolutionary solution to these problems is provided by the incorporation of blockchain technology, which raises the bar for security, transparency, and reliability.

#### *A. Motivation for Using Blockchain in Carbon Footprint Management*

A distributed ledger system called blockchain technology offers a safe and impenetrable method of managing and storing data. Blockchain technology allows for an unchangeable record of emissions data in the context of tracking carbon footprints, guaranteeing that once an entry is made, it cannot be changed. A comprehensive and irreversible historical record of a company's carbon footprint can be obtained, for example, by securely logging emissions data from Scope 1, Scope 2, and Scope 3 sources on the blockchain. Because every data point is cryptographically secured and time stamped, stakeholders can be sure that the information is reliable and accurate.

Data transparency is further improved by blockchain's decentralized structure. Blockchain data is dispersed throughout a network of nodes, making it publicly accessible and verifiable in contrast to traditional databases where data is controlled by a central authority. This feature of blockchain is especially helpful in the field of carbon management, where understanding a business's environmental impact is crucial for competitive advantage, consumer trust, and regulatory compliance. Businesses can demonstrate their dedication to sustainable practices and corporate responsibility by transparently sharing emissions data with stakeholders through the use of blockchain technology.

Blockchain offers accountability by requiring verification prior to data being added to the ledger, in addition to improved data security and transparency. In order to avoid depending solely on self-reported data, this project will record verified CO emissions data from Scope 1, Scope 2, and Scope 3 sources on a blockchain. Because any attempts to alter historical data would be immediately apparent, this verifiable ledger approach not only guarantees data accuracy but also increases stakeholder confidence in the reported numbers.

The importance of implementing blockchain for carbon footprint management can be summarized in the following key benefits:

- **Immutability and Data Integrity:** The integrity of historical records is guaranteed since emissions data cannot be changed or tampered with once it has been validated and entered onto the blockchain.
- **Enhanced Transparency:** Access to and verification of emissions data by all parties involved fosters accountability and trust in carbon reporting.
- **Improved Traceability:** The traceability features built into the blockchain make it simple to audit and validate emissions data throughout the supply chain.
- **Decentralized Verification:** Fraudulent reporting is less likely when emissions data is validated by multiple nodes prior to being added to the blockchain.
- **Elimination of Intermediaries:** The reporting process is streamlined when emissions data is directly verified and recorded, eliminating the need for middlemen.

## **REVIEW OF LITERATURE**

### *A. Carbon Capture and Storage Technologies*

Carbon capture and storage (CCS) is one of the important projects that is widely used across many industries in order to reduce atmospheric carbon emissions—a critical environmental target outlined in Sustainable Development Goal 13 (SDG 13) in 2015. In an effort to lower carbon emissions, CCS gathers (i.e., captures and compresses) and stores CO from industrial by-products rather than releasing it directly into the atmosphere. With CCS, the captured CO can be used immediately or stored at nearby facilities for later use in a variety of industrial processes. [2].

Aristia and Salehin (2024) have looked more closely at how distributed ledger systems can improve the transparency and verification of carbon capture, as well as how blockchain technology can be integrated with carbon capture and storage procedures. Their study highlights how blockchain technology could develop a more dependable carbon capture credit tracking system, enabling businesses to more successfully profit from their carbon reduction initiatives. [2].

### *B. Carbon Emissions Portfolio Management*

The purpose of this paper is to analyze the performance of carbon-based portfolios when all emission scopes are taken into account. We define low-carbon mean-variance portfolio methods by incorporating a carbon penalty into a limited mean-variance optimization framework. Scopes 1-2 and Scope 3 comprise the direct and indirect emissions that we use. We make use of geographic zones (Europe and the US) and data from Refinitiv and Carbon4 Finance. Our results show that emission intensities can be cut in half with virtually no loss in Sharpe ratio at suitable carbon constraint levels. [7].

Anquetin et al. (2022) expand on this study by examining the effects of varying carbon emission scopes on the performance of investment portfolios. According to their research, portfolios that are optimized for all three emission scopes can

significantly reduce carbon intensity while having little effect on financial returns. This study emphasizes how crucial thorough emissions monitoring at every scale is to efficient carbon management. [5].

### **C. Challenges in Measuring Device-Level Emissions**

Information technology (IT) uses more than 10% of commercial electricity, and energy is responsible for 35% of global greenhouse gas (GHG) emissions. Desktops and notebooks that are used for end-user computing (EUC) account for 0.37GtCO<sub>2</sub>e of greenhouse gas emissions. According to the UN, lowering GHG emissions can be achieved by combining behavioral and technological changes. Finding mobile devices that use less energy can help companies make the switch from desktops to notebooks. However, logistical and scale challenges make it difficult to measure energy use and emissions accurately. Existing techniques use benchmark data to estimate emissions, but studies reveal that these techniques can result in errors ranging from -48% to +107%, underestimating GHG emissions by 30%, and missing abatement opportunities by up to 55%. [3].

The difficulties in precisely measuring Scope 2 GHG emissions from computing devices are further examined by Kelly et al. (2021). Their study emphasizes the need for more accurate measurement techniques by demonstrating the notable variation in energy consumption across various device types and usage patterns. This study highlights how difficult it is to track emissions at the device level and offers potential blockchain-based solutions to increase data accuracy. [3].

### **D. Financial Implications of Carbon Exposure**

The financial sector and the economy are both at serious risk from climate change, so it is necessary to assess and control these risks (TCFD, 2017). Assessing supply chains' and products' carbon exposure is one method of doing this (Economist, 2020). This risk might be internalized by a universal carbon tax, but political obstacles make this unlikely (Cullenward Victor, 2020). In any case, calculating carbon exposure is essential to evaluating transition risks (Baker, 2020). Stakeholders are putting more and more pressure on businesses to lower their carbon footprints because doing otherwise will hurt their financial performance and reputation (GS, 2019). Scope 1, 2, and 3 emissions are used by businesses to calculate their carbon exposure (WRI, 2017). [4].

The financial ramifications of carbon exposure across supply chains were highlighted by the Stanford Sustainable Finance Initiative's (2021) extensive study on the measurement and management of Scope 3 emissions. Their results highlight the increasing significance of Scope 3 emissions in risk management frameworks and corporate sustainability strategies. This study offers insightful information about the potential effects of blockchain-based verification systems on corporate valuations as well as the financial materiality of carbon emissions. [4].

### **E. Sustainable Development in Cement Industry**

The 17 Sustainable Development Goals (SDGs) were adopted by countries due to global concerns about sustainability; SDG 13 (Climate Action) is centered on lowering carbon emissions. Global warming was largely caused by CO<sub>2</sub> emissions in 2019, and India aims to reduce these emissions from 2005 levels by 33–35% by 2030. Seven percent of the world's CO<sub>2</sub> emissions are caused by the cement and concrete industries. Increasing concrete durability, optimizing cement content, and utilizing supplementary cementing materials (SCM) present difficulties for these industries. Portland-limestone cement (PLC), which is being developed in India, uses less clinker in the production of cement, saving energy, fuel, and natural resources. The advantages and difficulties of using limestone in cement are discussed in this review, along with how it can support a green economy. [8].

With an emphasis on its potential to lessen the cement industry's carbon footprint, Gupta et al. (2020) offer a thorough analysis of Portland limestone cement development in India. Their study investigates how adding limestone to cement can reduce the amount of clinker, which in turn lowers CO<sub>2</sub> emissions and energy use. Because it emphasizes how crucial it is to focus carbon footprint reduction efforts on high-emission industries like cement production, this work is especially pertinent to our project. [8].

## **PROPOSED METHODOLOGY**

### **A. Drawbacks of Existing System**

Effective efforts to reduce the carbon footprint are hampered by a number of flaws in the current carbon emissions tracking and management systems. The following list of disadvantages emphasizes the need for a more reliable, open, and secure blockchain-based system.

1) **Inadequate Data Integrity and Security:** Traditional carbon emissions monitoring systems mainly rely on manually entered data or centralized databases, both of which are susceptible to manipulation, unauthorized access, and security

breaches. Because emissions data is stored in different places, these systems are frequently vulnerable to counterattacks or attacks on their internal data structures. Security flaws undermine the data’s accuracy and dependability, making it hard for stake- holders—like investors and regulators—to trust reported emissions figures. Furthermore, conventional systems’ emphasis on centralizing information leads to a single point of failure, meaning that any disruption to the system could cause crucial emissions data to be lost or altered.

2) **Deficient transparency and accessibility:** The lack of transparency in current emissions management systems makes it challenging for external parties, including investors, regulators, prosecutors, and the general public, to access or validate emissions data. Companies that lack transparency are less accountable because stake- holders lack a reliable means of assessing the veracity of the information they are providing. Emissions data are frequently too heavily aggregated, inaccessible, or generated by a single central authority, which breeds skepticism and mistrust of the system. It is difficult for regulators and consumers to assess whether regulated companies are making truthful environmental claims when there is no clear and easily accessible platform for examining emissions reports.

3) **Abilities in handling intricate, multi-scope data:** Target 3: Intractable values across the value chain, Scope 2: Indirect emissions from energy consumption, and Scope 1: Direct emissions are the three main categories into which carbon emissions data is usually divided. Due to the use of disparate data sources, reporting standards, and verification procedures, traditional systems might not be as successful in tracking emissions across all three scopes, despite their similarities. Since many legacy systems do not typically have this level of complexity, emissions calculations are frequently imprecise, disjointed,

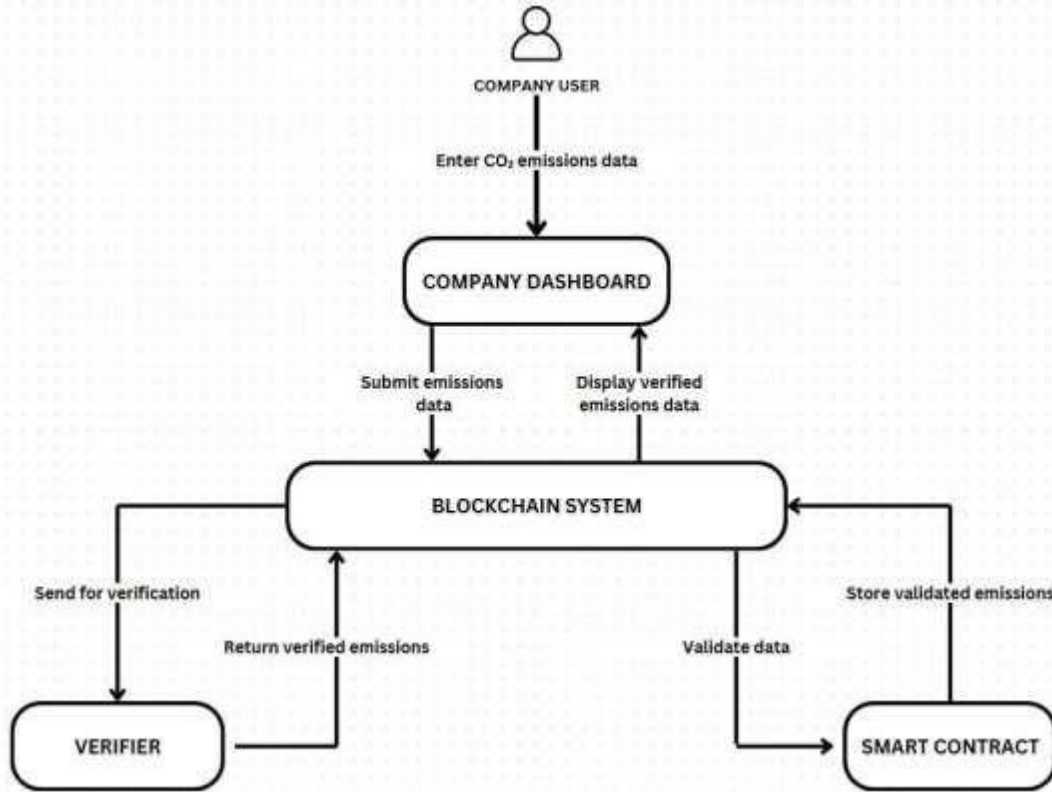


Fig. 1. Block Diagram of the Blockchain-Based Carbon Credit Management System. This diagram represents the flow of CO emissions data from company users to the blockchain system, including verification and storage through smart contracts.

incomplete. Because of their wide supply chain sources, Scope 3 emissions—which account for a sizable amount of businesses’ carbon footprint—are difficult to monitor. This might be an issue. Consequently, businesses might not reveal or take into consideration a significant portion of their environmental impact, which could result in an inaccurate understanding of the carbon footprint.

4) **Self-Reported Data:** Companies’ self-reporting is a major drawback of the carbon tracking systems in place today. Why? Because companies may be enticed to present their emissions data in a positive light when regulatory requirements or corporate image are at risk, this practice carries the risk of partiality, distortion, or purposeful underreporting. Without a third-party verification system, it is nearly impossible to ensure the veracity and accuracy of self-reported emissions data. To avoid fines or scrutiny, some companies might report only specific emissions or make changes. Subjective control weakens efforts to reduce carbon emissions and damages the credibility of emissions reporting.

5) **Unable to collect and analyse real-time data:** Emissions reports must frequently be submitted by current systems on a quarterly, annual, or irregular basis. The delay in reporting prevents stakeholders and regulators from having instant access to real-time emissions data.

As a result, companies use carbon-based trading strategies for a long time before assessing and addressing their carbon footprint. Efforts to quickly reduce emissions and stop needless environmental harm are hampered by this delayed feedback loop. It also limits businesses’ ability to make data-driven, well-informed decisions to optimize their operations for sustainability in real time.

6) Different industries, geographical areas, and businesses may use different metrics, accounting procedures, or definitions of emissions categories, making it difficult to aggregate or measure emissions. Governments, regulators, and other stakeholders find it challenging to consistently assess emissions reductions due to the fragmented and non-parallel data, even in the face of widely recognized standards. Additionally, the infrequency makes it more difficult to enforce rules and policies.

7) Businesses can keep an eye on their emissions without linking carbon data to other ESG goals. A hierarchical approach to sustainability causes businesses to be unable to assess their overall environmental impact or align emissions reductions with other important corporate objectives, like waste reduction, energy efficiency, and water conservation.

8) The verification processes, which are laborious and prone to human error, may include physical audits, printed documents, and manual inspections. Additionally, it could be difficult for small businesses to defend the costs of hiring outside

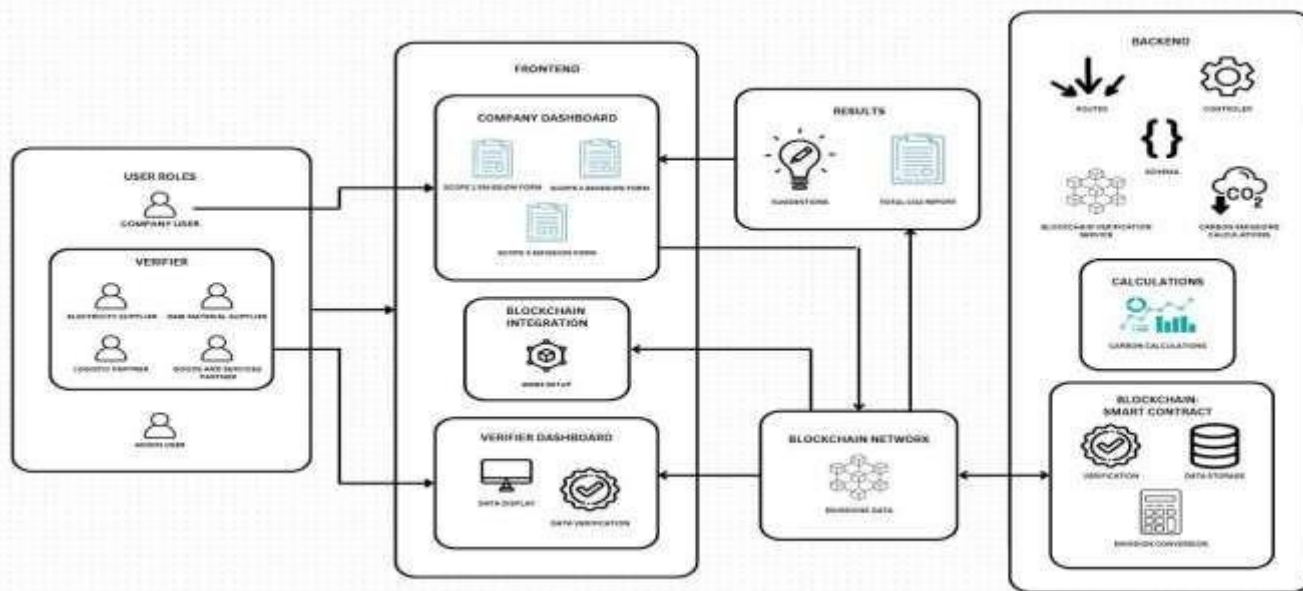


Fig. 2. System Architecture of the Blockchain-Based Carbon Footprint Verification and Management System. This diagram shows the interaction between Frontend, Backend, and Blockchain components, highlighting the data flow from submission to verification and user and storage on the blockchain.

auditors or using third-party verification services. Delays or even non-verification may result from this, which could compromise the reliability and correctness of emissions data.

9) Because multiple suppliers, logistics providers, and other third parties are involved, tracking upstream and downstream emissions (Scope 3 emissions) is especially difficult. A company’s overall carbon footprint may be hampered or diverged from by fragmented data sources. Furthermore, there is no simple way to ensure that all parties involved in this chain are giving the system accurate and consistent information if there is no uniform emission management system across all supply chains and related components.

10) **High Cost of Implementation and Maintenance:** The implementation and upkeep of many of the current carbon emissions tracking systems are costly. Businesses frequently have to hire professionals, purchase specialized software, and expend a lot of money to set up tracking systems that might not be very functional. Smaller businesses may be discouraged from implementing emissions tracking systems or find it difficult to expand their efforts over time due to the high initial and continuing maintenance costs. The overall effectiveness of carbon reduction initiatives may be limited as a result of these financial obstacles, which may lead to a wider adoption of emissions tracking technologies, especially among small and medium-sized businesses (SMEs).

*B. Architecture*

1) *System Architecture Overview:* The system architecture comprises three main components: Frontend, Backend (facing the blockchain), and Blockchain Network. Figure 2 illustrates the overall architecture of our proposed system.

1) **User Roles:**

- Through the Company Dashboard, Company Users can provide their emissions data on Scope 1, 2, and 3.
- The data is inspected by Verifiers, such as electricity suppliers, logistics partners, and raw material suppliers before it is processed.
- The verification is managed by Admin Users.

2) **Frontend:**

- The Company Dashboard permits users to input emissions data.
- For review and validation purposes, The Verifier Dashboard presents emissions data.
- Blockchain Integration enables the recording of data through Web3.

3) **Backend Processing:**

- MongoDB temporarily stores Emissions data before validation.
- A Carbon Emissions Calculator processes and evaluates the confirmed information.
- Smart Contracts on the Blockchain system manage verification, data storage, and emission conversion.

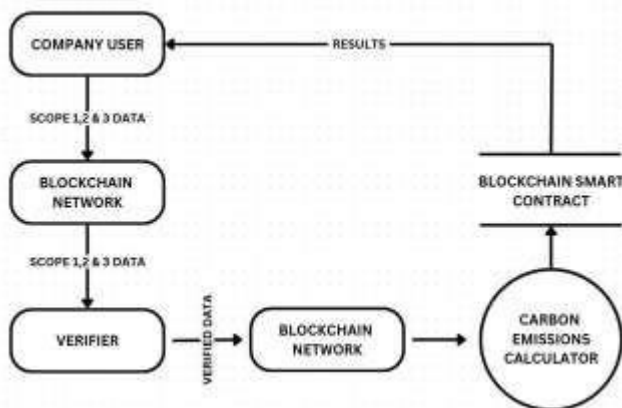


Fig. 3. Key Components of the Prototype Design. This figure illustrates the three main components of our approach: (1) Carbon Emissions Verification System, (2) Carbon Credit Management in Smart Contracts, and (3) Cryptographic Data Integrity Model.

4) **Blockchain Network:**

- The store’s emissions are verified in an Emissions Ledger to maintain transparency.
- Final reports are produced, detailing the total CO output and suggesting ways to decrease emissions.

This architecture guarantees the management of carbon emissions is secure, transparent, and tamper-proof, with the help

of blockchain technology.

C. *Prototype Design*

Our strategy consists of three primary components: a blockchain-based carbon emissions verification system, carbon credit management through "smart contracts," and an underlying cryptographic data integrity model. To ensure the accuracy, safety, and accountability of carbon emissions reporting or credit distribution, each element is required.

Companies that report their Scope 1, 2, and 3 emissions must submit data as our first step. A MongoDB database contains the data for these emissions, which are then processed further. The data is then sent to the Carbon Emissions Calculator, which uses preset formulas to determine the company's carbon footprint, after being reviewed and verified for emissions by a verifier.

A smart contract is then used to safely record the validated emissions data onto a blockchain network, guaranteeing transparency and immutability. Lastly, businesses get their results, which include credit eligibility and carbon scores.

D. *Smart Contract Implementation*

Our system's smart contracts, which manage, store, and verify emissions data on the blockchain, are an essential part. To handle various facets of the carbon footprint verification and credit management procedure, we have put in place a number of smart contracts.

Businesses can apply for carbon credits based on their eligibility once emissions data has been validated and saved on the blockchain. Only businesses with a carbon credit deficit are able to apply because the smart contract verifies the legitimacy of requests.

*Process Flow:* Our carbon emissions verification and credit management system's entire process flow is described below and shown in Figure 3.

- **Data Submission:** The business uses a web interface to submit emissions data. This data includes supporting documentation and comprehensive information about Scope 1, 2, and 3 emissions.
- **Verification:** After verifying emissions data, the verifier either accepts or rejects it. To guarantee the correctness and completeness of the data submitted, this step combines automated checks with manual reviews.
- **Blockchain Storage:** A smart contract logs verified data onto the blockchain. The integrity of the historical record is guaranteed since the emissions data is tamper-proof and unchangeable once it is stored on the blockchain.
- **Carbon Credit Request:** Businesses use the platform to apply for credits. Through a specialized interface, businesses can request carbon credits based on their verified emissions data and accomplishments in reducing their carbon footprint.
- **Approval & Issuance:** The smart contract handles the transaction and verifies the company's eligibility. By ensuring that only qualified businesses obtain carbon credits, this automated procedure removes the chance of fraudulent allocations.
- **Dashboard Update:** Businesses can see their available credits and emissions reports. The user dashboard offers a thorough summary of the carbon credit balance, verification status, and emissions history.

This system guarantees a fraud-proof carbon credit allocation by leveraging blockchain's tamper-resistant properties.

This structure allows easy verification of emissions data integrity.

**IMPLEMENTATION**

A stack of technologies that guarantee security, scalability, and usability was used to implement the blockchain-based carbon emissions verification and management system. Developing smart contracts, integrating with IPFS for decentralization, file



Fig. 4. User Interface for Company Dashboard. This screenshot displays the main dashboard where companies can view their emissions data, verification status, and carbon credit balance.

storage, and designing an intuitive web interface were all part of the implementation process.

#### A. User Interface

The user interface was designed to provide a seamless experience for different user roles within the system. Figure 4 shows the main dashboard for company users.

The interface includes the following key features:

- ✓ **Emissions Data Submission Form:** enables businesses to upload supporting documentation and enter comprehensive Scope 1, 2, and 3 emissions data.
- ✓ **Verification Status Tracker:** Gives current information on the status of the emissions data submission verification.
- ✓ **Carbon Footprint Visualization:** Shows emissions data in graphical form for various reporting periods and scopes.
- ✓ **Carbon Credit Management:** Permits businesses to monitor their carbon credit balance and submit applications for carbon credits.
- ✓ **Verifier Dashboard:** Gives verifiers the resources they need to examine, confirm, and authorize emissions data.

#### B. Integration with IPFS

The system was integrated with the InterPlanetary File System (IPFS) to guarantee the decentralized storage of supporting documentation for emissions data. This integration makes it possible for:

- ✓ **Decentralized Storage:** By distributing the storage of supporting documents, single points of failure are avoided.
- ✓ **Content Addressing:** Data integrity is ensured by retrieving documents based on their content rather than their location.
- ✓ **Permanent Storage:** Documents stored on IPFS are immutable records that cannot be changed or removed.

#### C. Integration with Gemini API

The system was integrated with the Gemini API to improve decision-making and offer useful insights. Following the creation of an emissions report, the API examines the information and offers tactical suggestions to assist companies in efficiently reducing their carbon footprint. This integration makes it easier to:

- ✓ **AI-Driven Insights:** The Gemini API assesses trends in emissions and makes recommendations for actions to strengthen sustainability initiatives.
- ✓ **Emissions Reduction Strategies:** Tailored advice on carbon credit offsets, greener supply chain adoption, and energy efficiency.
- ✓ **Predictive Analytics:** Helps businesses plan for future reductions by forecasting possible emissions based on historical data and industry benchmarks.
- ✓ **Regulatory Compliance Guidance:** Keeps companies in line with international environmental standards by pointing out areas that might need remedial action.

## RESULTS

The efficacy of the suggested blockchain-based carbon emissions verification and credit management system in safely storing, validating, and processing emissions data was evaluated through extensive testing. Simulated data submissions from 100 distinct businesses in a range of industries, each reporting Scope 1, 2, and 3 emissions, were used to assess the system.

#### A. Testing Environment

Testing was conducted in a controlled environment:

- **Controlled Testing:** The accuracy of blockchain recording and verification was assessed using a predefined dataset with known emissions values. This method made it possible to evaluate the accuracy of the system by comparing recorded values with ground truth data.

#### B. Security and Transparency Benefits of Blockchain

Data integrity and transparency in emission tracking are greatly improved by blockchain technology. Once emission data is recorded, it cannot be changed or tampered with thanks to immutable records.

## TABLE I

### COMPARISON OF TRADITIONAL VS. BLOCKCHAIN-BASED EMISSION TRACKING SYSTEMS

Feature	Traditional System	Blockchain-Based System
Transparency	Limited visibility, controlled by central authority	Full transparency with real-time tracking
Data Verification	Centralized, prone to manipulation	Decentralized, immutable records
Storage Cost	Variable, dependent on third-party servers	Predictable costs with on-chain storage
Security	Vulnerable to unauthorized changes	Cryptographically secured, tamper-proof

The system guarantees a higher degree of security and dependability in emission tracking by utilizing blockchain. This decentralized strategy improves accountability across industries and reduces fraudulent reporting.

C. Performance Metrics

Key performance metrics, including data integrity, smart contract execution time, transaction latency, and verification accuracy, were analyzed to determine the system’s reliability.

- 1) *Data Integrity:* All Merkle Root hashes successfully confirmed the original emissions data, demonstrating 100% data integrity. During the testing stage, no signs of data corruption or tampering were found.
- 2) *Smart Contract Execution Time:* PLACEHOLDER
- 3) *Transaction Latency:* PLACEHOLDER
- 4) *Verification Accuracy:* PLACEHOLDER

D. Blockchain Transaction Cost Analysis

Key transaction parameters were examined in order to assess the viability of storing emission data on the blockchain. Gas consumption, transaction speed, and storage expenses for data recording are shown in the table below.

TABLE II ETHEREUM NETWORK PARAMETERS

Parameter	Value
Gas per Transaction	21,000 units
Transaction Speed	12.05 seconds per block
Storage Cost	Approximately 0.000083 ETH per kilobyte

Approximately 21,000 units of gas were used on average to record emission data, costing 0.001743 ETH per transaction (assuming a gas price of 83 gwei). While the storage cost of about 0.000083 ETH per kilobyte keeps long-term data retention feasible, the transaction speed of 12.05 seconds per block guarantees timely data recording. These elements suggest that the blockchain-based emission tracking solution is still commercially feasible.

E. User Experience

Twenty industry experts who tested the system provided input that was used to assess the user experience. The system’s user-friendly interface, clear emissions data visualization, and transparent verification process were cited by users as its main advantages in the overwhelmingly positive feedback.

F. System Advantages

The testing results demonstrated several key advantages of the blockchain-based approach over traditional carbon emissions tracking systems:

- ✓ **Enhanced Data Security:** Once verified and recorded, emissions data cannot be changed thanks to the blockchain’s immutable ledger.
- ✓ **Increased Transparency:** Access to and verification of emissions data by all parties involved fosters accountability and trust.
- ✓ **Efficient Verification:** Validating emissions data takes less time and money thanks to the automated verification process.
- ✓ **Decentralized Architecture:** System resilience is increased and single points of failure are eliminated when there is no

central authority.

## CONCLUSION

Transparency, security, and efficiency in emissions tracking and credit distribution are effectively improved by the suggested blockchain-based carbon emissions verification and credit management system. The system addresses important issues in carbon credit markets by utilizing smart contracts and cryptographic verification to guarantee tamper-proof data storage and fraud prevention. This system's deployment has a number of significant ramifications for managing carbon footprints. A solid basis for carbon reduction initiatives is provided by the blockchain-based verification process, which guarantees that emissions data is accurate and unchangeable. All stakeholders can validate emissions data thanks to the blockchain's transparency, which holds businesses responsible for their environmental impact. Furthermore, using smart contracts to automate carbon credit requests and approvals lowers administrative costs and guards against false claims. Additionally, by tracking Scope 1, 2, and 3 emissions, the system offers a comprehensive view of a business's carbon footprint, facilitating more successful reduction tactics.

Integration with Internet of Things (IoT) devices may be one of the system's future developments, allowing for the collection and verification of emissions data in real time. By putting machine learning algorithms into practice, it would be possible to analyze emissions trends and give businesses useful information for reduction plans. To increase adoption and flexibility, cross-chain interoperability could be implemented to allow the system to function across several blockchain networks. Additionally, creating regulatory compliance tools would help businesses adhere to changing standards and regulations for carbon reporting. Overall, this blockchain-based strategy offers a reliable, decentralized, and effective way to manage credits and report carbon emissions, opening the door for increased sustainability and accountability in business environmental initiatives.

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