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Carbonchain: Web3-Based Carbon Emission Monitoring System

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Abstract: Industrial carbon emissions play a major role in environmental pollution and climate change. Because of this, industries are required to continuously monitor their emissions and ensure they follow environmental regulations. Traditional emission monitoring systems generally rely on centralized databases, which can sometimes lead to problems such as delayed reporting, lack of transparency, and the possibility of data being altered. To overcome these issues, this paper introduces CarbonChain, a decentralized carbon emission monitoring system that combines Internet of Things (IoT) sensing technologies with blockchain verification. Environmental parameters such as gas concentration and particulate matter are collected in real time using sensors connected to microcontroller units. The sensor readings are then transmitted to a backend server where the data is validated and categorized. After validation, the emission records are stored on the blockchain through smart contracts, generating secure transaction hashes that ensure the integrity of the data. A web-based dashboard allows regulators and industry stakeholders to monitor emission levels, check compliance status, and verify blockchain records in real time. By combining IoT-based sensing with blockchain technology, CarbonChain creates a transparent and tamper-resistant monitoring platform that can support environmental auditing and carbon credit verification.
Keywords: Blockchain, Carbon Monitoring, IoT Sensors, Smart Contracts, Carbon Credits, Sustainability

I. INTRODUCTION

The rapid growth of industrial activities and large-scale manufacturing has led to a significant increase in carbon emissions worldwide. These emissions contribute heavily to climate change and environmental degradation. As a result, governments and environmental agencies have introduced strict regulations that require industries to monitor their emissions and maintain transparent environmental records.

However, most conventional emission monitoring systems rely on centralized reporting infrastructures. In these systems, environmental data is stored in a single database controlled by a particular organization. Although this approach simplifies data management, it also introduces several problems. For example, emission data can sometimes be submitted late, auditing processes may lack transparency, and there is always a risk that stored data might be altered intentionally or unintentionally. These limitations can reduce trust among industries, regulatory bodies, and independent auditors.

Recent advancements in Internet of Things (IoT) technologies have significantly improved environmental monitoring capabilities. IoT sensors can collect environmental data continuously and transmit it in real time to monitoring systems. These sensors are capable of measuring parameters such as gas concentration, air quality, temperature, and particulate matter levels. Today, IoT monitoring infrastructures are widely used in smart factories, power plants, wastewater treatment facilities, and other industrial environments to track operational conditions and environmental impact [16]–[19].

Wireless sensor networks have further enhanced pollution monitoring by allowing sensors to be deployed across large industrial areas. For example, real-time carbon monoxide monitoring systems based on wireless sensor networks have been successfully used to detect hazardous emissions in industrial settings [23]. Similarly, portable air-quality sensors provide cost-effective solutions for monitoring pollution exposure across urban and industrial regions [24].

Environmental monitoring systems depend heavily on reliable sensing technologies. Advances in gas sensor materials and particulate matter detection systems have improved measurement accuracy and response time. These improvements allow monitoring infrastructures to detect pollutants with greater sensitivity and reliability [25]–[28].

Although IoT-based monitoring systems provide continuous data collection, they do not automatically guarantee data integrity. Since sensor data is usually stored in centralized databases, there is always a possibility that the data could be modified or tampered with. This limitation makes it difficult to ensure that environmental records remain trustworthy during regulatory audits.

Blockchain technology offers a promising solution to this challenge. Blockchain is a decentralized ledger system that stores data in a series of interconnected blocks secured using cryptographic techniques.

Once data is recorded on the blockchain, it cannot be altered without consensus from the network participants. These characteristics provide key advantages such as immutability, timestamping, and traceability of stored records [3].

Blockchain platforms have been widely studied for their ability to support secure data storage, collaborative databases, and decentralized applications. Research on blockchain technologies highlights their potential for building secure transaction systems and distributed record management infrastructures [5]. In these systems, consensus mechanisms ensure that all participating nodes agree on the validity of transactions before they are added to the ledger [4].

The combination of blockchain and IoT technologies has attracted growing attention from researchers. Blockchain can help secure IoT networks by providing trusted data storage and enabling secure communication between devices and stakeholders [6], [8]. Blockchain-based database architectures also allow distributed systems to maintain secure records without relying on centralized control [11].

Hybrid architectures that combine blockchain with traditional databases have been proposed to improve system performance and scalability while maintaining data integrity [13]. In addition, embedded blockchain frameworks have been explored to enhance the security of IoT systems operating in distributed environments [12].

Another important feature of blockchain systems is the use of smart contracts. Smart contracts are self-executing programs stored on the blockchain that automatically enforce predefined rules. These contracts can be used to validate environmental data, record emission events, and automate compliance verification. Research on Ethereum smart contract development has also identified security best practices that ensure reliable decentralized applications [2].

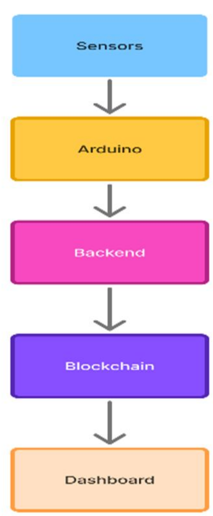
Modern industrial sustainability systems increasingly integrate IoT monitoring, cloud computing, and decentralized infrastructures to support environmental management and carbon accounting [22]. These systems demonstrate the potential for combining sensor technologies with secure data governance frameworks.

Motivated by these developments, this paper proposes CarbonChain, a decentralized carbon emission monitoring system that integrates IoT sensing, backend analytics, and blockchain verification. The goal of this system is to provide transparent emission monitoring while ensuring that environmental data remains secure, verifiable, and tamper-proof.

II. PROPOSED SYSTEM

The CarbonChain system is designed to create a reliable and transparent way of monitoring industrial carbon emissions. Instead of depending entirely on centralized databases, the system integrates IoT sensors with blockchain technology to ensure that emission data remains secure and verifiable.

The overall architecture consists of four main layers: the sensing layer, the data processing layer, the blockchain layer, and the visualization layer.



At the sensing layer, environmental parameters such as gas concentration and particulate matter levels are captured using gas sensors and dust detection modules. These sensors are capable of detecting pollutants commonly found in industrial environments. Recent research in environmental sensing technologies has shown that modern gas sensors provide improved sensitivity and faster response times, making them suitable for real-time monitoring applications [25], [27]. Micro-dust detection systems further enable accurate monitoring of airborne particles in industrial facilities [26].

The sensors are connected to microcontroller units that convert the analog sensor signals into digital values. These microcontrollers act as edge devices that collect environmental data and transmit it to the backend system for further processing.

In the data processing layer, the received sensor data is analyzed and validated. Industrial monitoring systems require reliable communication and data processing to ensure that monitoring information is transmitted without interruption [20]. The backend server filters the incoming data, removes noise or irregular readings, and classifies emission levels based on predefined environmental thresholds.

Once the emission data has been validated, it is forwarded to the blockchain layer. Blockchain technology ensures that emission records are stored in a decentralized and tamper-resistant manner. Distributed ledger systems provide immutable data storage and timestamped transaction records, which are important for regulatory monitoring and auditing processes [3].

Smart contracts are used to automate the recording of emission data on the blockchain. These contracts verify incoming data and generate cryptographic hashes representing each recorded transaction. Consensus mechanisms ensure that all participating nodes agree on the validity of transactions before they are permanently added to the blockchain ledger [4].

Finally, the visualization layer provides a web-based dashboard that allows users to observe emission data in real time. Industrial monitoring systems often use dashboards to present operational data and environmental indicators in a clear and accessible format [16], [18]. The CarbonChain dashboard displays emission levels, historical trends, compliance status, and blockchain transaction records, enabling stakeholders to verify environmental monitoring results easily.

III. METHODOLOGY

The CarbonChain system follows a multi-stage process designed to ensure reliable environmental monitoring and secure data storage.

A. Environmental Data Collection

The monitoring process begins with the collection of environmental data using gas sensors and particulate matter detection devices. These sensors detect pollutants such as carbon monoxide and airborne dust particles. Advances in sensing technologies have significantly improved pollutant detection accuracy and system reliability [25]–[27].

Wireless sensor networks can also support large-scale environmental monitoring by enabling sensors to communicate across industrial zones [23].

B. Data Transmission

The sensor readings are transmitted to the backend system using communication protocols supported by industrial IoT infrastructures. Reliable communication technologies are essential for ensuring that environmental data reaches the monitoring system without delays or interruptions [20].

C. Data Validation

After transmission, the data is validated to ensure accuracy and consistency. The backend server filters anomalies and categorizes emission levels into different environmental categories such as safe, warning, or critical levels. Automated classification systems are commonly used in industrial monitoring platforms to support regulatory compliance [17].

D. Blockchain Storage

Once the data has been validated, it is stored on the blockchain. Each emission record becomes a blockchain transaction that includes a timestamp and a cryptographic hash. Blockchain technology ensures that these records remain immutable and cannot be modified after they are stored [3].

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E. Secure Data Sharing

Blockchain integration allows monitoring data to be securely shared among multiple stakeholders. Secure storage frameworks prevent unauthorized changes while maintaining transparent access records [15].

F. Visualization and Monitoring

The final stage involves presenting monitoring data through a dashboard interface. Visualization tools allow stakeholders to observe emission trends and verify monitoring results in real time. Such dashboards are widely used in industrial monitoring environments to provide operational insights [16], [18].

IV. RESULTS AND DISCUSSION

A prototype version of the CarbonChain system was developed to evaluate how effectively IoT monitoring could be combined with blockchain verification. The experimental setup included gas sensors and particulate matter detectors connected to microcontroller units that collected environmental data continuously.

The monitoring system successfully captured real-time variations in gas concentration and dust levels. These readings were transmitted to the backend server, where they were processed and displayed through the monitoring dashboard.

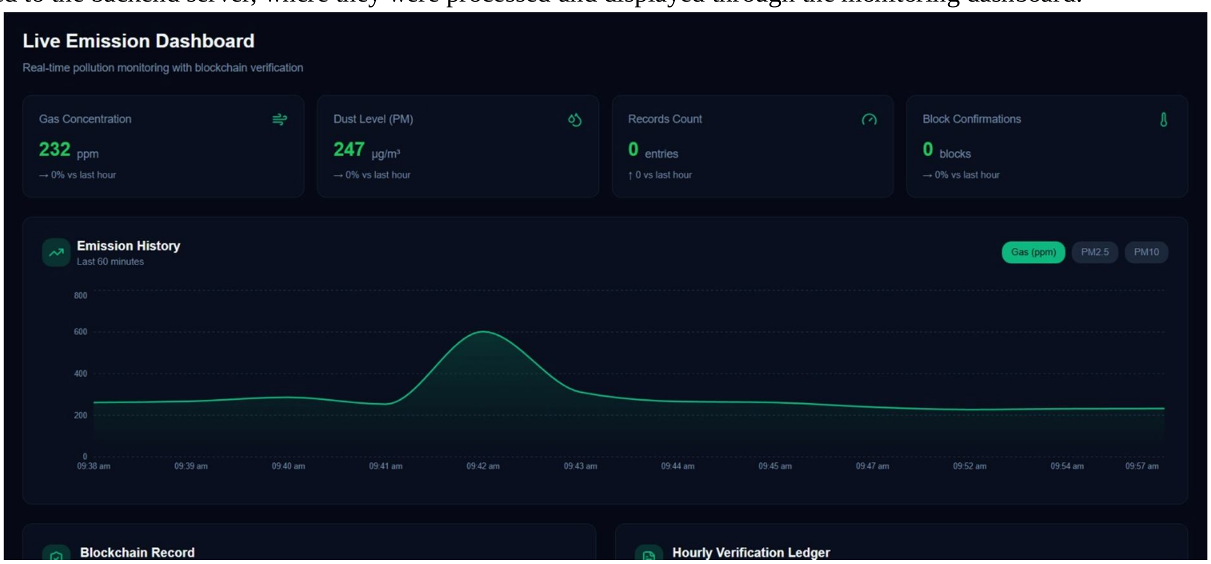

Fig. 5. Real-time emission monitoring dashboard displaying live sensor telemetry.

Previous research on wireless sensor networks has demonstrated that distributed sensing infrastructures can effectively monitor pollutant concentrations in industrial environments [23]. Similarly, portable air-quality monitoring sensors have been shown to provide reliable pollution tracking across urban areas [24].

The backend system maintained stable communication with sensor devices and processed incoming data without significant delays. Reliable data transmission is essential for industrial IoT monitoring systems, which must operate continuously to provide accurate environmental information [20].

When emission records were stored on the blockchain, each record generated a unique transaction hash. This ensured that the data remained immutable and could be verified at any time. Blockchain infrastructures have previously been used in enterprise monitoring systems to provide scalable and secure data management [1].

The monitoring dashboard also displayed blockchain verification logs alongside emission data, allowing stakeholders to confirm that environmental records had not been modified. Visualization dashboards are commonly used in industrial monitoring environments to present operational and environmental analytics [16], [18].

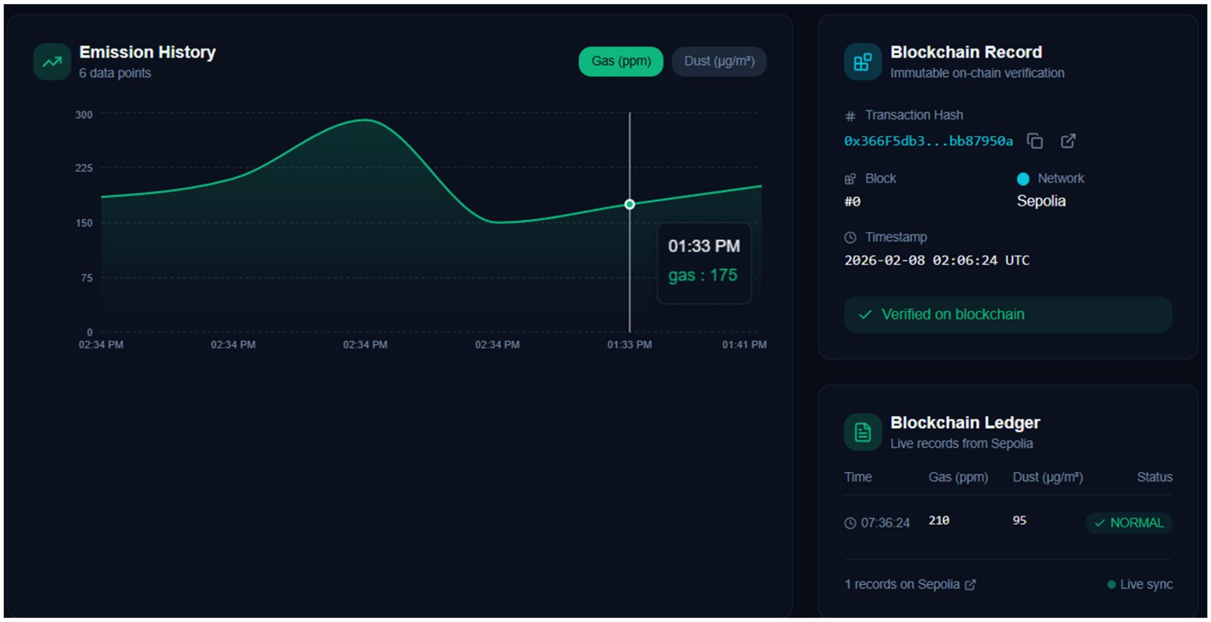

Fig. 6. Blockchain transaction record showing immutable emission logging.

Overall, the prototype demonstrated that integrating IoT sensors with blockchain technology can significantly improve transparency and reliability in environmental monitoring systems.

V. CONCLUSION

This paper presented CarbonChain, a decentralized carbon emission monitoring system that integrates IoT sensing technologies with blockchain-based data verification. The proposed framework addresses key challenges associated with traditional monitoring infrastructures, particularly issues related to data manipulation, centralized control, and limited transparency.

The prototype implementation demonstrated that environmental data can be collected in real time using distributed sensor networks. Gas sensors and particulate monitoring devices enabled continuous measurement of industrial emissions, while the backend processing system ensured accurate validation and classification of sensor data.

By storing emission records on the blockchain, the system introduced immutable data storage and transparent audit trails. This approach improves trust among regulatory authorities, industries, and environmental auditors by ensuring that monitoring records cannot be altered after they are recorded.

The web-based monitoring dashboard further enhanced system usability by providing real-time emission analytics and blockchain verification logs. This interface enables stakeholders to track emission levels and verify compliance records efficiently.

Overall, the CarbonChain system demonstrates how the integration of IoT and blockchain technologies can create a secure, transparent, and scalable environmental monitoring ecosystem. The proposed architecture also lays the foundation for future developments such as automated carbon credit management systems and decentralized sustainability reporting platforms.

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