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DECENTRALIZED CARBON EMISSION MANAGEMENT USING BLOCKCHAIN AND SMART CONTRACTS

Dr. E. Shailaja
Associate Professor, Department of Computer Science and Engineering,
Vasavi College of Engineering, Hyderabad,
e.shailaja@staff.vce.ac.in

Daram Charan Teja
Post Graduate Student, M. TECH (CSE), Department of Computer Science and Engineering,
Vasavi College of Engineering, Hyderabad,
Charantej1005@gmail.com

ABSTRACT
In carbon trading, blockchain technology offers an alternative mechanism of managing carbon emissions, a decentralized and unalterable, open system, as opposed to the traditional centralized approaches. Due to increased digitalization and the use of more smart devices there has been an increased carbon emission. This is the reason why international treaties such as the Kyoto Protocol establish a restriction on the emissions and establish systems to pay the same. The existing centralized systems can be edited or hacked without authorization and the outcome is incorrect tax calculations and reduced accountability. In order to avoid these issues, a blockchain-based carbon emission management system is proposed that applies Ethereum and Smart Contracts. This would provide the opportunity to have a safe and permanent storage of taxation and emission records. Smart contracts developed on SOLIDITY ensure that the data is verified and implemented automatically, without the assistance of a third party, which guarantees privacy. The system consists of components of entering into the carbon department, customer registration, recording emission data, calculating the taxes, and monitoring the use. To make it more effective, an AI algorithm makes the required guess of the quantity of emissions (High, Medium, and Low) and instructs users on what to do. It also incorporates a data compression extension that reduces storage costs and emission that accompany it. This blockchain approach ensures that the emission of carbon is properly monitored and taxed instantly. It also contributes to the efforts of the world in minimizing the carbon emissions and enhancing security and openness.

Keywords:
Blockchain, carbon emission, smart contract, Kyoto Protocol, decentralized system, data compression, AI prediction, tamper-proof.

INTRODUCTION
Increase in the emission of carbon dioxide (CO2) and other GHG in transportation, factories, deforestation and energy production is the primary reason why the world temperatures have been rapidly increasing. Such anthropogenic emissions trap heat in the atmosphere of the earth and lead to serious climate issues such as global warming, melting glaciers, summation of sea level and extensive destruction of ecosystems [1]. With the worsening and increasingly frequent extreme weather events, minimization of carbon emission has become a worldwide issue of concern.

In 1997, the Kyoto protocol was formulated by the United Nations, one of the most significant international agreements that required developed nations to cut on their emission of GHG. This was done following increasing threat of climate change. Establishing a CTS was one of the aspects of the protocol. It aimed at reducing the overall carbon production through market-based schemes. Certain number of carbon credits or allowance to businesses is given by states under this system that enables them to emit a specific quantity of CO2 or other GHG. Carbon markets can be used to make money as people, businesses, and other organizations are permitted to sell surplus credits of carbon. Alternatively, it is the violation of the limit, which is punishable by fines, so people are encouraged to be more cautious of emissions [2, 3].

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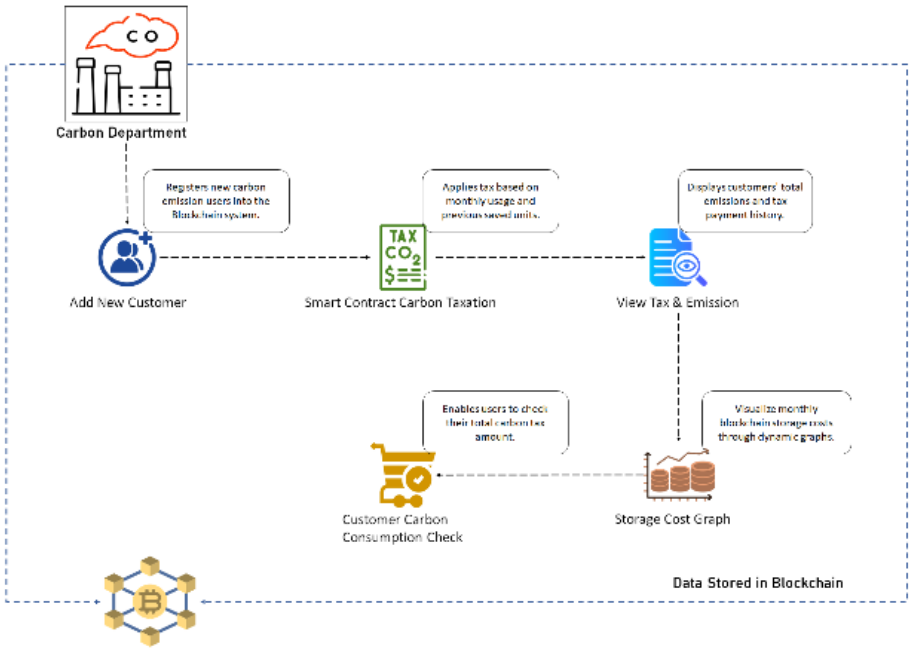
This system evolved to be known as ETS all over the world. One of the most significant is the EU ETS that was initiated in 2005 and remains the largest carbon market on the planet [4]. Programs such as the RGGI in US and national programs in New Zealand, Japan, South Korea and most recently in China started the largest national ETS in 2021 instituted this type of system [5, 6]. Carbon credits are now regarded as a market value thus Carbon companies have a monetary incentive to develop new products that consume less carbon.

By 2023, the carbon market in the world had expanded significantly and earned over $95 billion. This was due to the fact that the environmental laws were becoming stiffer and the companies were becoming more responsible [7]. This demonstrates the significance of carbon markets not only in reducing the emission levels but also in utilizing money to help in protecting the environment. Thus, CTS have a significant role in the strategies to curb climate change as it aids in the development of the environment as well as economy [8].

OBJECTIVES

The primary objective of this project is to develop a secure, transparent, and decentralized carbon emission management system using blockchain technology. By leveraging Ethereum and Smart Contracts written in Solidity, the system aims to eliminate data tampering, automate emission tax computations, and ensure immutable logging of emission records. It introduces modules for user and department access, real-time emission data monitoring, and AI-based emission level prediction to promote environmentally responsible behavior. Additionally, a data compression mechanism is implemented to reduce storage overhead and digital carbon footprint. The system ultimately seeks to support global carbon reduction goals through secure, automated, and accountable carbon trading operations.

SYSTEM ARCHITECTURE



METHODOLOGY

The proposed system with Ethereum smart contracts involves an open, automated, and safe carbon emission taxing framework using blockchain. It eliminates the necessity of central databases, which store data about carbon utilized on a decentralized record. This allows automatic calculation of taxes where users exceed their monthly emission limits. The system has an AI module that categorizes amounts of consumption into three categories which include High, Medium, and Low. This provides data on the reduction of emissions. There is a data compression scheme that is in-built to reduce the size of storage required in blockchain, which indirectly reduces the energy consumed. Carbon module registers the user, tracks, and tax under the Python interface

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connected with Solidity smart contracts. This ensures that actions are not modifiable and cannot be verified [12, 13, 20]. This system design of a blockchain-based carbon taxation system is operated by the Carbon Department. The first step is to add a new customer. Secondly, carbon taxes are automated using smart contracts. The users are able to view graphs of their storage expenses and view their tax and carbon information. Then the quantity of carbon consumed by individual customers is calculated and placed in groups. The block chain tracks all transactions and records the information in a secure manner, which guarantees that all information is transparent, cannot be modified, and is distributed among a large number of computers. It is a structure that eliminates the manual work and simplifies monitoring and policing carbon emission policies.

a) Modules:

1) Carbon Department Login: Gives access to the system after the carbon department logs in with already established credentials. The module ensures that the administrators are able to access safely the customer data, blockchain records, and system activities of taxing and tracking carbon emissions.

2) Add New Customer: It allows the administrator to add new customers to the system in order to track down carbon emissions. The information on the customer is gathered and secured on the blockchain. Each user is assigned a unique ID in order to be able to trace the carbon usage and see the records by all.

3) Smart Contract Carbon Taxation: Enables the administrator to add monthly data concerning the amount of carbon per customer used. The smart contract calculates the tax regarding the use amount, the saved units, and the limit should not be violated. It further secures all the calculations and transactions on the blockchain securely to be used later.

4) View Tax & Emission: Provides the administrator with the comprehensive picture of the past carbon emission of all the customers, as well as their tax payments. The records of the consumption and the relevant tax amounts are reflected on this module and stored in the blockchain. This assists in decision making and enforcement of rules.

5) Customer Carbon Consumption Check: Customers have an option to view their exclusive ID and identify the amount of carbon they utilize every month, the amount of units remaining and any form of tax due. This aspect makes it easy to understand and it assists users to monitor their carbon footprint to evade penalties in future.

b) Methods/Technologies:

Ethereum: Ethernet is a decentralized blockchain platform that allows the construction and execution of smart contracts and DApps [17]. Ethernet has EVM which allows Ethereum to be programmed, unlike Bitcoin. This allows the developers to create secure, free and non-modifiable apps that function without any downtime or interruption by an outsider which makes it ideal with systems that stress carbon.

Solidity: Solidity is a high-level computer language based on contracts and can be used to write smart contracts on the Ethereum blockchain. It allows authors to establish regulations on how to operate transactions, calculate and track assets and conduct decentralized operations. A project based on solidity is executed to store data on carbon emissions, calculate the taxes, and leave the handling of the blockchain to computers in a safe and automated manner.

Web3.py: The Web3.py Python tool provides Python with the ability to interact with the Ethereum blockchain. It also allows Python applications to communicate with smart contracts, make transactions in the blockchain, and access information in decentralized registries. To have the carbon tax managed in real time, the front-end application is connected to a Solidity smart contract that is executed in this system with the help of Web3.py.

Ganache: Ganache is a personal Ethereum blockchain and it is utilized to create and test smart contracts. It is user-friendly, already funded accounts and mining controls and time travel. To test, release [18], and debug smart contracts, Ganache is employed to produce a simulated local blockchain environment in which developers can test their Smart contracts.

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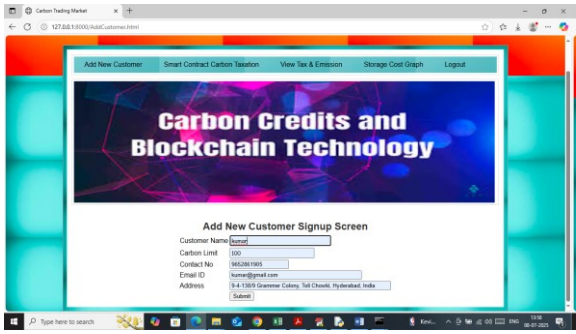
RESULTS AND DISCUSSION

The proposed system is executed by first installing Python 3.7.2 along with all the required libraries specified in the requirements.txt file. After launching the application using the run.bat file, the Python web server starts, and the system can be accessed through a web browser using the local host URL. The administrator logs into the Carbon Department portal to manage all carbon emission activities within the platform.

The admin can register new customers, and their details are securely stored on the blockchain. Each transaction is recorded with blockchain information such as block number, timestamp, and hash value, ensuring secure and tamper-resistant data storage. The Smart Contract Carbon Taxation module enables the administrator to enter monthly carbon consumption values for each customer. Based on the predefined emission limit, the smart contract automatically determines whether tax should be applied. Customers consuming within the limit are not charged, while users exceeding the limit are taxed after considering any previously saved balance units.

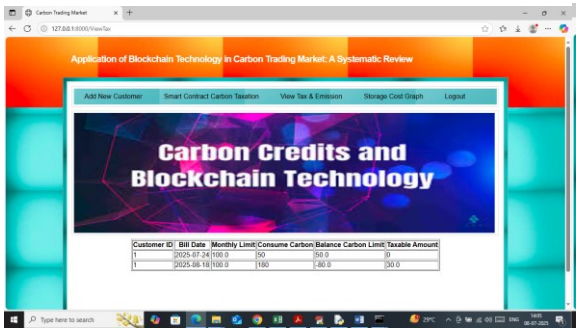
The platform also provides a View Tax & Emission feature that allows administrators to monitor customer consumption records and corresponding tax amounts. A Storage Cost Graph is included to demonstrate how the integrated compression technique minimizes blockchain storage requirements, thereby reducing storage expenses and indirectly lowering carbon emissions associated with digital infrastructure. Customers can independently access their carbon usage information through the Customer Carbon Consumption Check module by entering their unique ID. In addition, the AI-enabled prediction module analyses usage patterns and categorizes emission levels as High, Medium, or Low, helping users better understand and control their carbon footprint. Overall, the system delivers a transparent, automated, and secure blockchain-based solution for efficient carbon emission taxation and monitoring.

a. Admin is adding customer details

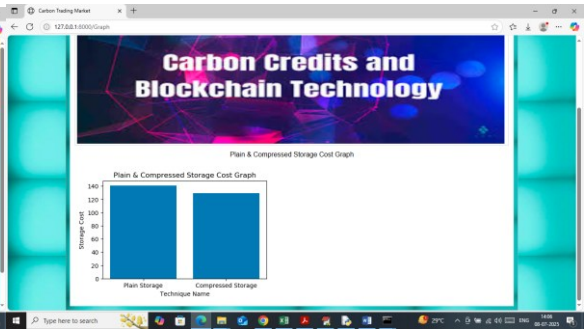


b. Admin can select customer id and enter current consumption with bill date

c. Admin can view each month consumption



d. Storage cost graph



e. Bill details and AI-enabled prediction module

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S. No	Research Insight with Existing System Limitation	Proposed System	Improvement Achieved
1	Traditional ETS platforms are centralized, making them less transparent and more vulnerable to data alteration.	Ethereum-based decentralized blockchain platform.	Enhances transparency, trust, and data security.
2	Present carbon markets experience issues such as fraud, low trust, and slow processing.	Automated blockchain-based taxation mechanism.	Reduces manual dependency and improves efficiency.
3	Conventional systems lack intelligent technologies for emission prediction and monitoring.	AI-based emission classification module.	Enables smart analysis and user guidance.
4	Existing systems depend on third parties for validation and tax management.	Smart contracts handle taxation and data processing automatically.	Eliminates intermediaries and automates operations.
5	Existing platforms require higher storage resources and operational costs.	Integrated data compression mechanism.	Reduces storage overhead and infrastructure cost.
6	Traditional carbon management processes are partially manual and inefficient.	Complete digital platform using Django, Web3.py, and Ethereum.	Supports automated real-time monitoring.
7	Existing infrastructure still depends heavily on centralized architectures.	Blockchain deployment tested using Ethereum and Ganache.	Validates practical feasibility of decentralized taxation systems.

CONCLUSION

This work successfully demonstrates a secure, transparent, and efficient approach to managing carbon emission taxation using blockchain technology. By integrating Ethereum-based smart contracts, the system ensures decentralized storage, automated tax calculation, and immutable record-keeping of carbon emissions. The shift from a centralized database to a tamper-proof blockchain structure eliminates risks associated with data manipulation and unauthorized access, thereby enhancing trust and accountability in carbon trading systems. Smart contracts accurately assess carbon usage against predefined limits and automatically compute applicable taxes, streamlining the administrative process while ensuring fairness. The addition of a data compression module significantly reduces storage size, which helps lower associated costs and environmental impact, aligning with the objective of reducing emissions. Moreover, the AI-driven module provides real-time categorization of user consumption behavior—High, Medium, or Low—enabling users to make informed decisions to minimize their carbon footprint. This intelligent feedback mechanism promotes sustainable practices among users. Overall, the system provides a scalable, tamper-resistant, and cost-effective solution for carbon emission management that aligns with global climate action goals.

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