SAVITRIBAI PHULE PUNE UNIVERSITY

A PROJECT REPORT ON

Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized carbon Economy

SUBMITTED TOWARDS THE PARTIAL FULFILLMENT OF THE REQUIREMENTS OF

BACHELOR OF ENGINEERING (Computer Engineering)

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CERTIFICATE

This is to certify that the Project Entitled

Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized Carbon Economy

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is a bonafide work carried out by Students under the supervision of Dr. S. P. Bendale and it is submitted towards the partial fulfillment of the requirement of Bachelor of Engineering (Computer Engineering).

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PROJECT APPROVAL SHEET

Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized Carbon Economy

(Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized Carbon Economy)

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ACADEMIC YEAR 2024-2025

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Abstract

This report presents the design and development of a decentralized carbon offsetting platform that leverages IoT and blockchain technologies to improve transparency, reliability, and efficiency in carbon markets. The platform integrates IoT devices for real-time data collection on carbon emissions and energy production, directly linked to renewable energy projects.These devices continuously capture environmental impact data, which is then securely stored and validated on a blockchain. Through the use of tokenization,

verified carbon credits are created as tradable tokens within a decentralized marketplace. This blockchain-driven system ensures tamper-proof tracking of carbon offsets, addressing key issues such as data integrity, trust, and scalability in carbon credit verification. The Hedera Hashgraph consensus and token services facilitate transparent token creation and trading, while smart contracts enable automated transactions and verifications. Key advantages include automated data validation, real-time monitoring, and immutable record-keeping, offering a trusted solution for companies and individuals aiming to offset their carbon footprints. By combining IoT-based en-

vironmental tracking with blockchain validation, this platform demonstrates a robust model for transforming the carbon offset market, contributing to a sustainable, decentralized carbon economy.

Acknowledgments

It gives us great pleasure in presenting the preliminary project report on ***'Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized Carbon Economy'****.*

I would like to take this opportunity to thank my internal guide ***Dr. S. P. Bendale*** *for giving me all the help and guidance I needed. I am really grateful to them for their kind support. Their valuable suggestions were very helpful.*

I am also grateful to ***Dr. S. P. Bendale****, Head of Computer Engineering Department, NBN Sinhgad School Of Engineering for his indispensable support, suggestions.*

In the end our special thanks to ***Dr. S. P. Patil****, Principal of NBN Sinhgad School Of Engineering for providing various resources such as laboratory with all needed software platforms, continuous Internet connection, for Our Project.*

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Contents

List of Figures

List of Tables

Chapter a

Synopsis

a Project Title

Trust Based Carbon Offsetting using IOT and Blockchain for a Decentralized Carbon Economy

b Project Option

This carbon credit management system is an internal project, designed to explore the use of blockchain and IoT for real-time, verifiable carbon tracking. It enhances transparency and security in carbon markets and supports decentralized trading.

c Internal Guide

Dr. S. P. Bendale

d Sponsorship and External Guide

Sponsorhip from Rudra Tech Solutions

e Technical Keywords

Carbon Trading, C++, Node JS, Jotai State Management, ESP32, Smart Meter

f Problem Statement

Contemporary carbon offsetting frameworks exhibit significant operational limitations that hamper their effectiveness. The current system's opacity creates barriers in tracking and validating carbon credits, raising questions about their legitimacy and impact. Ad-ditionally, the complex administrative structures result in substantial operational costs, creating entry barriers for smaller participants and reducing market accessibility. These systemic inefficiencies necessitate a transformative approach that addresses transparency

g Abstract

- as climate trade intensifies the constraints of conventional carbon offsetting systems including restricted transparency high prices and scalability issues have become increasingly more apparent this studies introduces a decentralised framework the use of blockchain and iot to allow a transparent comfy and scalable technique to carbon offsetting and buying and selling iot sensors capture actual-time statistics on co emissions thats then recorded on a blockchain for tamper-proof monitoring and verification by leveraging clever contracts the framework enables a peer-to-peer marketplace for carbon credit lowering dependency on intermediaries and improving transaction performance a case examine within the production and logistics sectors demonstrates the frameworks ability for wide application suggesting it may support stakeholder engagement and foster worldwide sustainable practices the take a look at concludes with a discussion on regulatory challenges and destiny studies pathways to extend the frameworks impact across industries.

h Goals and Objectives

- The primary goal of this project is to bring transparency and trust to carbon credit markets through blockchain technology, which allows for immutable and traceable records of carbon transactions. This integration helps address the challenges of data accuracy, as well as the need for auditable and secure records that build stakeholder confidence. By creating a system where carbon credits can be tokenized and verified on the blockchain, we aim to streamline the process of trading and tracking carbon credits, making it more efficient and accessible.
- Additionally, the project leverages IoT devices to monitor emissions in

real-time, ensuring accurate data collection for carbon tracking. This continuous data flow reduces the need for manual intervention, minimizing errors and decreasing administrative costs. Combined, these elements create an innovative approach to managing carbon credits, enabling a transparent and accountable system that supports sustainable practices and fosters wider participation in carbon offsetting efforts.

i Names of Conferences / Journals where papers can be published

- IEEE/ACM Conference/Journal 1
- Conferences/workshops in IITs
- Central Universities or SPPU Conferences
- IRJMETS

j Review of Conference/Journal Papers Supporting Project Idea

- Blockchain enhances transparency and traceability in carbon markets, preventing fraud and ensuring the integrity of carbon credits (Mezquita et al., 2020).
- IoT devices like smart meters provide real-time emissions and energy data, improving accuracy and timeliness in carbon offset reporting (Saraji Borowczak, 2021).
- Decentralized platforms automate carbon credit validation and trading, reducing delays and costs, and expanding market reach (Patel et al., 2020).

Chapter b

Technical Keywords

a Area of Project

The project "Trust-Based Carbon Offsetting using IoT and Blockchain for a Decentralized Carbon Economy" focuses on creating a reliable and transparent system for carbon offsetting by integrating IoT and blockchain technologies. IoT sensors enable accurate, real-time monitoring of carbon emissions, while blockchain provides a decentralized ledger for secure, traceable, and transparent carbon credit transactions. By using smart contracts to automate offset agreements, the project reduces transaction costs and promotes efficiency. This decentralized approach fosters a peer-to-peer carbon economy, enhancing trust and accessibility in offsetting efforts, and ultimately contributes to global climate change mitigation.

b Technical Keywords

1. Carbon Offsetting
2. Blockchain Ledger
3. Smart Contracts
4. IoT Sensors
5. Trustless System
6. Climate Change Mitigation

Chapter 3

Introduction

3.1 Project Idea

The project "Trust-Based Carbon Offsetting using IoT and Blockchain for a Decentralized Carbon Economy" aims to revolutionize carbon offsetting by creating a secure, transparent, and decentralized system for tracking and trading carbon credits. Using IoT sensors, the project enables real-time monitoring of carbon emissions, ensuring accurate and reliable data collection. Blockchain technology provides a transparent, tamper-proof ledger for managing carbon credits, making transactions traceable and secure. By incorporating smart contracts, the system automates offset agreements, reducing transaction costs and increasing efficiency. This decentralized approach empowers organizations and individuals to trade carbon credits in a peer-to-peer marketplace, fostering greater accessibility and trust in the carbon economy. Through this project, we aim to make carbon offsetting more transparent, accessible, and impactful in the global fight against climate change.

3.2 Motivation of the Project

The motivation behind "Trust-Based Carbon Offsetting using IoT and Blockchain for a Decentralized Carbon Economy" is to address the urgent need for reliable and accessible carbon offset solutions in the face of escalating climate change. Traditional carbon offset systems are often hindered by a lack of transparency, high transaction costs, and centralized control, leading to inefficiencies and mistrust among participants. By leveraging IoT for real-time emissions monitoring and blockchain for secure, decentralized tracking of carbon credits, this project seeks to create a more transparent, trustworthy, and accessible carbon offset marketplace. The project is driven by the vision of empowering individuals and organizations to actively contribute to climate change mitigation, reduce their carbon footprints, and promote sustainability through a decentralized, peer-to-peer platform that ensures accountability, lowers barriers to participation, and facilitates meaningful environmental impact.

3.3 Literature Survey

- **Blockchain-Based Platforms for Carbon Offsetting: A Survey:**
  This paper explores the use of blockchain for creating more transparent and efficient carbon offset markets, discussing its potential to improve verification processes and scalability. It focuses on the importance of decentralizing carbon markets using blockchain and Web3 technologies for regenerative finance.

- **A Blockchain-Based Carbon Credit Ecosystem:**
  This study proposes a blockchain-based system for managing carbon credits. It introduces smart contracts and decentralized token trading to improve transparency, reduce transaction costs, and combat double-spending in carbon markets

- **Blockchain of Carbon Trading for UN Sustainable Development Goals**
  The paper explores how blockchain can support carbon trading aligned with the United Nations' sustainable development goals, enhancing the integrity and security of the carbon trading system.

- **Using Blockchain for Environmental Governance: Power and Offsets**
  This paper looks at the role of blockchain in governance models for carbon offsets and environmental sustainability, focusing on decentralizing governance to make carbon offset projects more accessible and accountable.

- **Harnessing Web3 on the Carbon Offset Market**
  This research delves into how Web3, combined with blockchain and IoT, can be used to revamp the carbon offset market. It discusses the potential of blockchain to provide transparency in energy generation and carbon trading.

Chapter 4

Problem Definition and scope

4.1 Problem Statement

Contemporary carbon offsetting frameworks exhibit significant operational limitations that hamper their effectiveness. The current system's opacity creates barriers in tracking and validating carbon credits, raising questions about their legitimacy and impact. Additionally, the complex administrative structures result in substantial operational costs, creating entry barriers for smaller participants and reducing market accessibility. These systemic inefficiencies necessitate a transformative approach that addresses transparency concerns while promoting broader market participation.

4.1.1 Goals and objectives

This study aims to develop an advanced framework that combines blockchain and IoT technologies to transform carbon offsetting processes. The proposed system employs IoT sensors for continuous emission monitoring across various sources, from industrial facilities to transportation networks. This real-time data collection system interfaces with blockchain networks, creating permanent, verifiable records of emission data. The integration of smart contracts enables automated carbon credit issuance and trading within a decentralized marketplace, significantly reducing dependency on traditional intermediaries. To achieve this goal, several key objectives have been set. Our platform integrates IoT devices with blockchain technology to automate and decentralize the carbon tokenization process. By recording energy generation data directly from power plants through IoT devices and processing it on the Hedera blockchain, we create verifiable and tradeable carbon tokens. This transforms traditional carbon accounting into a seamless, automated process.

4.2 Major Constraints

- Technical Constraints:

  Platform Limitations: The application is developed using a cross-platform framework (e.g., React and TypeScript), which may introduce limitations in accessing some device-specific features compared to native applications. Some advanced functionalities, such as certain IoT device integrations or custom hardware interfacing, may require additional APIs, custom configurations, or workarounds, potentially increasing development complexity. Firebase Limitations: Using Hedera Hashgraph for blockchain-based transactions comes with certain restrictions, such as transaction speed limits, network congestion, or API rate limits for smart contract interactions. These limitations could affect the performance of token minting and carbon credit trading during high demand periods

- Network Dependency: he system heavily depends on a stable internet connection for key functionalities like real-time data collection from IoT devices, token minting, and blockchain synchronization. Poor network conditions could disrupt data transmission between IoT devices and the Hedera blockchain, leading to delays in tokenization, unreliable data validation, or failure in transactions.

- User Privacy and Data Security:

  The platform collects sensitive environmental and energy data, which must be securely stored and processed. Ensuring compliance with data protection regulations (e.g., GDPR, CCPA) is necessary to protect user and environmental data. Securing data storage and transmission while maintaining user privacy can add complexity to development and require additional layers of encryption and user consent management.

- Battery Consumption:

  Continuous operation of IoT devices (such as smart meters and environmental sensors) and data collection may lead to increased energy consumption, especially for remote or mobile installations. This could impact the operational efficiency of energy systems or user experience, requiring optimizations in device power management and communication protocols to reduce battery drain.

- Scalability:

Continuous operation of IoT devices (such as smart meters and environmental sensors) and data collection may lead to increased energy consumption, especially for remote or mobile installations. This could impact the operational efficiency of energy systems or user experience, requiring optimizations in device power management and communication protocols to reduce battery drain.

- Regulatory Compliance:

  The platform must comply with local, national, and international regulations concerning blockchain usage, carbon credit trading, and environmental data handling. Adhering to various legal frameworks across jurisdictions can be complex, as different countries may have distinct carbon offset standards, reporting requirements, or blockchain regulations, potentially limiting certain functionalities or requiring ongoing adjustments to the platform.

- User Adoption and Behavior:

  Encouraging widespread adoption of blockchain-based carbon credits and ensuring users' trust in the accuracy and transparency of the system can be challenging. Companies and individuals must be convinced of the platform's reliability, security, and the validity of the carbon credits being traded. Overcoming skepticism towards blockchain technologies and decentralized carbon markets is crucial for the platform's success.

- Development Timeline:

  The integration of multiple technologies, including IoT devices, blockchain smart contracts, and a user-friendly frontend, may require significant time and effort. The timeline may be constrained by the complexity of hardware and software integration, rigorous testing, and addressing potential delays related to blockchain transaction speeds, regulatory compliance, or unforeseen technical challenges.

4.3 Methodologies

- IoT Device Integration for Real-Time Data Collection: Develop a custom fork of Tasmota firmware to integrate IoT devices (e.g., Elite smart meters and Sonoff Pow 320D devices). This firmware allows the devices to capture real-time energy production and carbon emission data and communicate with the backend system.Use smart meters and environmental sensors to continuously monitor energy production (e.g., from solar plants) and carbon emissions in real-time. These devices are configured to transmit data to the system securely.

- Hedera Blockchain Integration: Set up a Hedera Offset Node, a TypeScript-based backend system, to facilitate communication between the IoT devices and the Hedera blockchain. The node is responsible for verifying data authenticity and managing the data flow between the devices and blockchain.
- Data Tokenization: Once the data from IoT devices is validated, it is tokenized into carbon credits in the form of Non-Fungible Tokens (NFTs), which can be traded and tracked on the Hedera blockchain. These NFTs represent a unit of verified carbon reduction or renewable energy production.
- Carbon Credit Marketplace and Trading Platform: Develop a decentralized platform where businesses and individuals can trade carbon credits represented by NFTs. This marketplace ensures transparency and traceability of carbon credits, enabling secure transactions between parties.

4.4 Outcome

- Efficient Carbon Credit Verification and Minting: The system efficiently tracks real-time energy production and carbon emission reductions from renewable energy sources through IoT devices. This data is automatically verified and tokenized into carbon credits using Hedera's blockchain. These carbon credits are represented as Non-Fungible Tokens (NFTs), ensuring that each credit is backed by verified environmental data. This significantly reduces fraud and enhances the trustworthiness of the carbon offset process.
- Real-Time Monitoring and Transparency: The integration of IoT devices allows for real-time monitoring of energy production and carbon emissions. This data is continuously updated and stored on the Hedera blockchain, providing full transparency for all transactions and carbon credit validations. Users can confidently verify the authenticity of carbon credits and trace their origin, ensuring the credibility of the offsets they purchase or sell.

- Scalable Architecture: The app will be built to efficiently handle increasing user traffic, ensuring consistent performance and service quality as the user base grows.

- Automated Carbon Offset Process: By automating the entire process—from data collection by IoT devices to the minting and trading of carbon credits— the project reduces human error and administrative overhead. The use of blockchain technology ensures that data is immutable and tamper-proof, promoting accuracy in carbon offset reporting and eliminating delays associated with traditional manual processes.

- Scalability for Global Adoption: The decentralized nature of the platform, powered by Hedera Hashgraph, allows the system to scale efficiently as the user base and the volume of carbon credits increase. The architecture can support a wide range of industries and sectors, including renewable energy, transportation, agriculture, and beyond, to create a truly global carbon offset marketplace.

- Regulatory Compliance: The platform adheres to international standards and regulations for carbon offsetting, such as ISO 14064 and UNFCCC protocols. By ensuring that all tokenized carbon credits meet legal requirements for verification and trading, the system helps businesses comply with their sustainability goals and legal obligations while supporting global carbon reduction efforts.

4.5 Applications

- Carbon Credit Trading Platforms: The Hedera Offset system provides the infrastructure for decentralized carbon credit marketplaces where companies and individuals can buy, sell, and trade verified carbon credits. This marketplace eliminates intermediaries, reducing transaction costs and improving transparency in the trading process. The platform's integration with smart contracts ensures that all trades are secure, automated, and tamper-proof.

- Renewable Energy Projects: Renewable energy producers, such as solar, wind, and hydropower projects, can integrate IoT sensors to track energy production and carbon emissions reduction in real-time. The Hedera Offset platform then tokenizes this data into carbon credits, which can be traded to offset emissions from other sectors. This creates an automated and verifiable process for companies involved in renewable energy production to participate in carbon offset markets.

- Sustainability Reporting for Corporations: Large corporations and businesses looking to meet their environmental, social, and governance (ESG) goals can use the Hedera Offset system to track their carbon footprint in real-time.

- Carbon Offset for the Transportation Industry: he transportation sector, which is a significant contributor to carbon emissions, can benefit from the Hedera Offset system by tracking and offsetting emissions generated by vehicles. Electric vehicle (EV) fleet operators, for example, can use the platform to monitor and verify reductions in emissions compared to traditional fuel-based vehicles.

- Government and Regulatory Compliance: overnments and regulatory bodies can leverage the Hedera Offset system to create carbon offset programs that help nations or regions meet international carbon reduction targets.

- Private and Public Sector Partnerships: The Hedera Offset system can foster collaboration between the private and public sectors. Governments can incentivize businesses to adopt carbon offset programs by offering tax credits or subsidies, while companies can use the Hedera Offset platform to directly engage in sustainable practices.

4.6 Hardware Resources Required

4.7 Software Resources Required

1. Operating System: Windows/ Mac/ Linux
2. IDE: VS code/ Android Studio
3. Programming Language: C++ and Node JS
4. Blockchain Platform: Hedera Blockchain

Sr. No.	Parameter	Minimum Requirement
1	Processor	i3
2	RAM	4 GB
3	Micro Controller	ESP32
4	Meter	Sonoff POW320D
5	Power Generator	Solar Pannel

Table 4.1: Hardware Requirements

Chapter 5

Project Plan

5.1 Project Estimates

This project aims to create a blockchain and IoT-driven platform that automates carbon credit tracking, tokenization, and trading to address key issues in the carbon offset market. By leveraging custom IoT firmware on smart meters, we will collect real-time data on CO emissions and renewable energy production, ensuring accurate and up-to-date environmental data. This data will then be transmitted to our Hedera Offset Nodes, which use blockchain to securely notarize emissions data, creating a tamper-proof, decentralized record. The system will mint tokenized carbon credits as NFTs based on verified data, ensuring each carbon credit's transparency and trustworthiness for use in decentralized markets.

The platform architecture integrates a custom Tasmota firmware, which is compatible with devices like the Elite smart meter and Sonoff Pow 320D, and a Hedera-based backend built in TypeScript. This backend will facilitate seamless communication between the IoT devices and the blockchain, automating data verification and token minting processes. Additionally, a user-friendly React frontend will allow companies to register devices, monitor emissions data, and view their generated carbon credits. Companies can connect their Hedera HashPack wallets to manage and trade carbon credits within the platform, enabling a streamlined experience for environmental data validation and credit trading.

To further enhance usability and impact, we will create a decentralized marketplace for tokenized carbon credits, enabling transparent and traceable transactions. Businesses can offset their emissions by purchasing these tokens, with each transaction recorded immutably on the blockchain. By integrating blockchain, IoT, and decentralized trading, this project not only simplifies carbon credit validation but also broadens access to trusted carbon markets, providing a scalable solution for sustainable environmental impact.

5.2 Risk Management

Effective risk management is crucial for the successful execution of the car-sharing application project. Identifying potential risks early on allows the project team to implement strategies to mitigate them and ensure the project stays on track.

- Data Accuracy and Device Integrity: Ensuring that IoT devices collect accurate and reliable data is crucial. Regular device maintenance, secure firmware updates, and validation protocols will be implemented to mitigate risks of data inaccuracies or device malfunction.

- Blockchain Security and Data Tampering: Blockchain technology is inherently secure, but to further safeguard data integrity, cryptographic methods and robust consensus mechanisms will be used. These will prevent unauthorized access and tampering, ensuring that all recorded data remains immutable and trustworthy.

- Regulatory Compliance: Carbon markets are subject to evolving regulations, and non-compliance could disrupt operations. The project will integrate compliance checks within smart contracts, and we will monitor relevant legal requirements to ensure alignment with regional and international standards.

- Scalability and System Performance: As more devices and users join the platform, scalability may impact performance. We will optimize system architecture, use efficient data handling protocols, and plan for cloud-based scaling to maintain smooth operations as the platform expands.

Chapter 6

Software requirement specification

6.1 Introduction

The purpose of this Software Requirements Specification (SRS) document is to define the functional and non-functional requirements for a blockchain and IoT-driven platform designed for automated carbon offset tracking, tokenization, and trading. The platform addresses key challenges within the carbon offset market, including lack of transparency, data tampering, and limited accessibility. By integrating IoT data collection with blockchain technology, this system aims to create a trusted, scalable solution for verifying and trading carbon credits globally. This document outlines the requirements necessary to achieve these objectives, ensuring a clear, consistent development path.

Carbon offsetting is a critical mechanism in combating climate change, allowing organizations to counterbalance their emissions by investing in projects that reduce or sequester carbon dioxide. However, current carbon offset systems often face issues of reliability, inefficiency, and fraud, as they depend on centralized intermediaries for verification and management. The proposed platform provides a decentralized alternative by using IoT devices to collect real-time emissions and energy data from renewable sources, which is then securely notarized on a blockchain. This approach enables accurate, verifiable carbon credits that are accessible for trading within decentralized markets.

The platform's core components include custom IoT firmware, blockchain integration via Hedera Hashgraph, and a web-based frontend for user interaction. IoT devices equipped with custom Tasmota firmware continuously monitor CO emissions and energy production, sending data to a Hedera Offset Node for notarization and tokenization. The blockchain layer ensures that all data is immutable and transparent, addressing trust issues within the carbon offset market. Through a user-friendly interface, companies can register their IoT-enabled devices, manage carbon credits, and participate in a decentralized marketplace for trading verified credits.

6.2 Usage Scenario

- Real-Time Emissions Monitoring

  A renewable energy company installs IoT-enabled smart meters and environmental sensors at their solar power plant. These devices continuously collect data on CO emissions reduction and energy output, which is sent to the blockchain for real-time notarization. The company can view this data on the platform's dashboard, ensuring transparency and immediate access to verified emissions data.

- Carbon Credit Tokenization

  After verifying emissions data from IoT devices, the system automatically tokenizes this data into carbon credits as NFTs on the blockchain. Each carbon credit token is backed by verified environmental data, providing a traceable record that ensures its authenticity. These tokens are now ready for trading or retirement to offset emissions.

- Carbon Credit Trading

  A manufacturing company aiming to offset its emissions accesses the platform's decentralized marketplace to purchase carbon credits. By connecting their Hedera HashPack wallet, they can securely buy carbon credits and review their origins and impact. Each transaction is immutably recorded, enabling the company to publicly demonstrate its commitment to reducing its carbon footprint.

- Device Registration and Management

  An organization registers multiple IoT devices through the platform's frontend interface, assigning each device a unique ID and configuration. Administrators can monitor each device's location, operational status, and emissions data in real-time, allowing for efficient device management and ensuring the integrity of data collected across various locations.

6.3 Data Model and Description

The data model for this blockchain and IoT-driven carbon offset platform is designed to capture, validate, and represent emissions data in a way that is transparent, immutable, and traceable. At its core, the data model is built around the IoT devices and their data outputs, which include metrics such as CO emissions, energy production, and timestamps. Each IoT device is uniquely identifiable and registered within the system, and its data feeds into a blockchain ledger via a Hedera Offset Node. This data is then validated, ensuring that only accurate and secure information is recorded on the blockchain for tokenization.

Once the emissions data is verified, it is used to generate tokenized carbon credits on the blockchain. These carbon credits are represented as NFTs (Non-Fungible Tokens) using the Hedera Token Service (HTS), and each token contains metadata detailing the source of the emission data, including device ID, location, data timestamps, and metrics on carbon reduction. This structure enables every tokenized carbon credit to have a fully traceable lineage, providing buyers and regulatory bodies with confidence in the authenticity and origin of each credit. Additionally, the blockchain ledger offers a decentralized, permanent record that helps prevent data tampering and enables transparent, auditable transactions.

The platform's data model also includes tables and schemas for user profiles, device management, and marketplace transactions. User profiles store information on registered companies, roles, permissions, and associated devices, while device management tables hold details on device status, configuration, and data history. The marketplace transactions schema includes records of token purchases, sales, and retirements, linking each transaction back to the originating IoT data and associated carbon credits. This comprehensive data structure supports seamless integration, clear data relationships, and efficient querying, allowing users to access accurate information about emissions reductions and participate confidently in the carbon trading ecosystem.

6.4 Functional Model and Description

The functional model of this blockchain and IoT-driven carbon offset platform is designed to streamline the process of carbon emissions monitoring, verification, tokenization, and trading within a decentralized marketplace. The platform's core functions revolve around data collection from

IoT-enabled devices, blockchain-based validation, and the creation of tokenized carbon credits. IoT devices, such as smart meters and environmental sensors, capture real-time data on CO emissions and renewable energy output. This data is then sent to the backend Hedera Offset Node, which processes and notarizes the information on the Hedera blockchain, ensuring data integrity and preventing tampering.

The platform's functional model further includes an automated tokenization process that turns verified emissions data into tradeable carbon credits. Each data point validated by the blockchain triggers the generation of a Non-Fungible Token (NFT) through Hedera's Token Service (HTS). These NFTs serve as carbon credits, each linked to specific emissions data, device ID, and timestamp information. This function not only creates a digital asset for carbon trading but also embeds transparency and traceability within the token, making it easy for buyers and regulatory authorities to verify the source and impact of each credit. The tokenized credits can then be listed on the platform's marketplace, where companies or individuals interested in offsetting their carbon footprint can buy, hold, or retire these credits as part of their sustainability efforts.

Additionally, the platform provides a user-friendly frontend interface for managing devices, tracking emissions data, and interacting with the marketplace. Through this interface, registered companies can add new IoT devices, configure device settings, and monitor emissions data in real time. The marketplace function allows users to connect their Hedera HashPack wallet, view available carbon credits, and securely complete transactions using smart contracts that govern each trade's terms. This marketplace feature not only simplifies carbon credit trading but also ensures that all transactions are securely recorded on the blockchain, offering a transparent and trusted ecosystem for all stakeholders.

Chapter 7

Detailed Design Document

7.1 Introduction

The global urgency to combat climate change has led to increased reliance on carbon offsetting as a critical strategy for reducing greenhouse gas emissions. Traditional carbon offset mechanisms, however, often suffer from inefficiencies, lack of transparency, and data inaccuracies, which undermine their effectiveness and trustworthiness. To address these challenges, this project proposes an innovative approach combining Internet of Things (IoT) and blockchain technology to create a decentralized carbon offset platform. By utilizing real-time data collection through IoT sensors and leveraging the security and transparency of blockchain, the system aims to enhance the traceability, automation, and scalability of carbon credit generation and trading. This platform not only ensures a more efficient and trustworthy carbon offset process but also empowers businesses and individuals to participate in global efforts to mitigate climate change through a transparent, decentralized marketplace for carbon credits.

7.2 Architectural Design

The platform follows a layered architecture, separating data collection, blockchain processing, and user interaction for better maintainability. The Device layer collects emissions data, the Blockchain layer notarizes and tokenizes it on Hedera, and the Database layer ensures efficient data access. This modular design enhances scalability and ease of management.
LAYERS:

- Device and Firmware Layer: This layer includes ESP32 devices with custom firmware that connects to Elite Power Smart Meters via Mod-

BUS. The firmware collects real-time emissions data from the meter and sends it to the Hedera Offset Node for logging and verification.

- Blockchain and Data Processing Layer: The Hedera Offset Node, built in Node.js, processes data from IoT devices and notarizes it on the Hedera blockchain using the Consensus Service (HCS). Verified data points trigger the creation of tokenized carbon credits as NFTs through Hedera's Token Service (HTS), ensuring traceable, immutable records.

- Database and Indexing Layer: A PostgreSQL database, connected through Prisma, indexes the blockchain data for efficient querying and storage. This layer allows seamless data retrieval and management, supporting both real-time monitoring and historical data access within the platform.

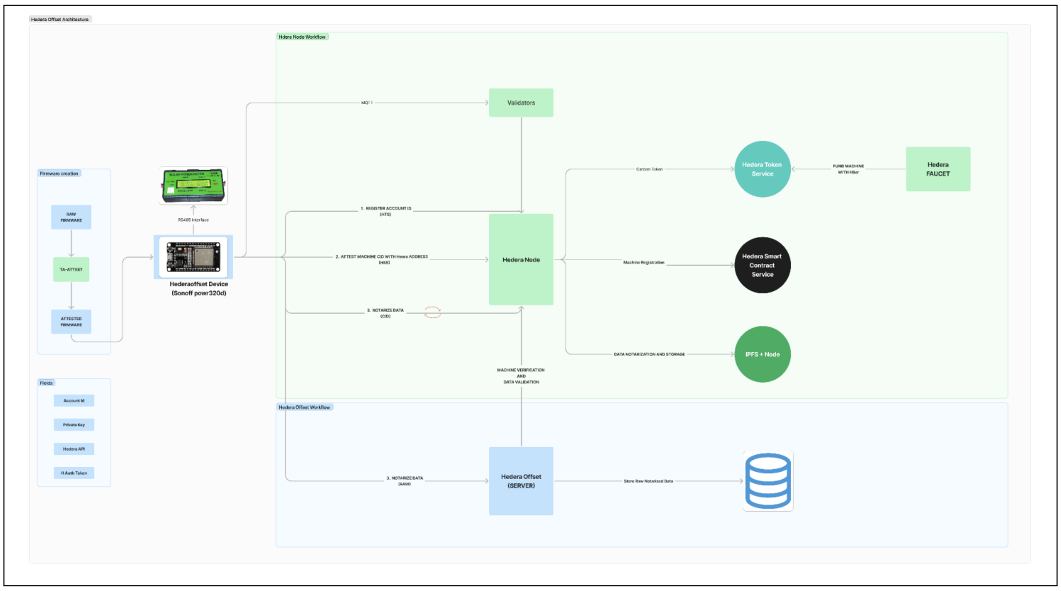

Figure 7.1: Architecture diagram

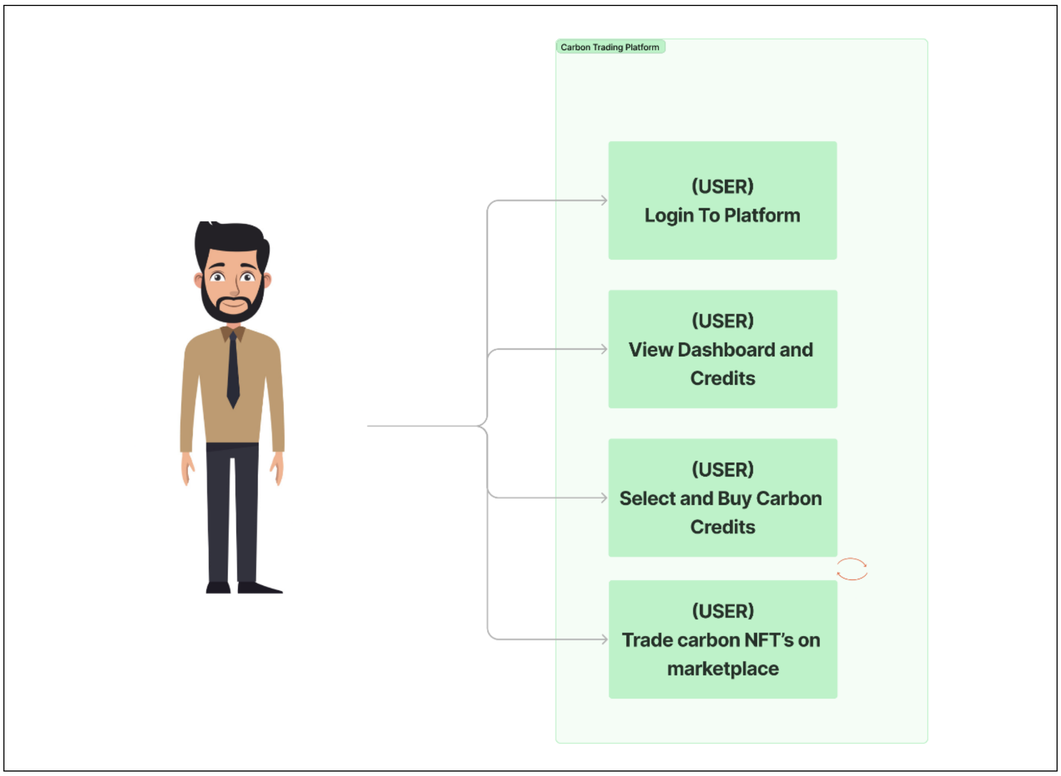

Figure 7.2: UML diagram

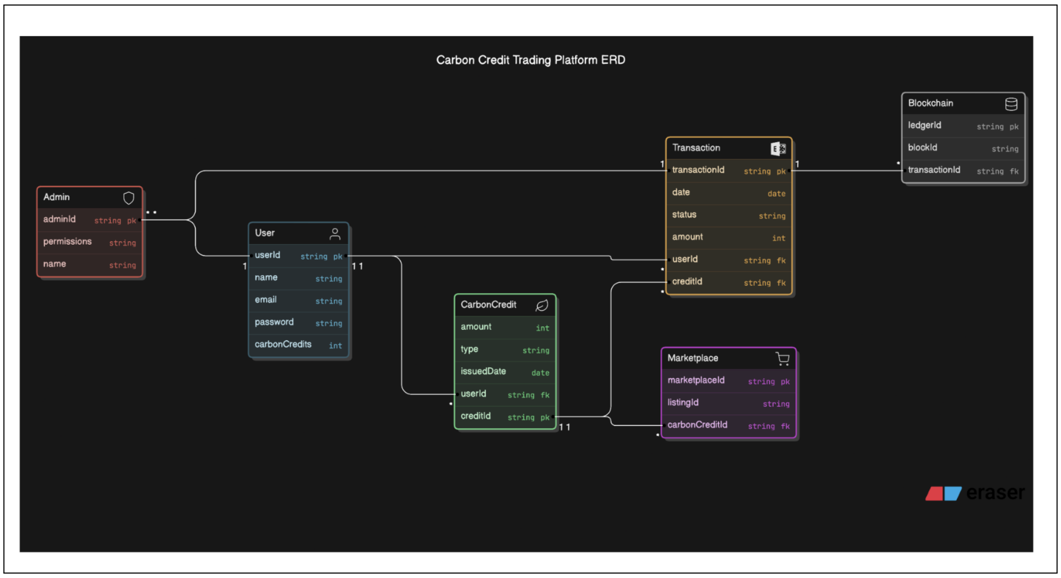

Figure 7.3: Class Diagram

Chapter 8

Project Implementation

8.1 Introduction

In recent years, the demand for transparent and reliable carbon offset solutions has grown as organizations prioritize environmental responsibility and carbon reduction. Blockchain-based systems have emerged as a promising approach, offering verifiable, decentralized, and tamper-proof platforms for carbon credit management. By leveraging blockchain, carbon credits can be tokenized, ensuring that each offset is traceable and credible.

This report presents the design and implementation of a decentralized carbon offset platform utilizing Hedera Hashgraph, which integrates with a web-based dashboard and supports tokenization via the Hedera Token Service. The platform also connects with Hedera's HashPack wallet, providing secure and seamless management of carbon credits. The technical groundwork, including web and Web3 implementation with Hedera, is complete, with only the hardware coding phase remaining to establish IoT connectivity.

The purpose of this report is to outline the project's objectives, technical approach, and architecture, as well as to detail the functionalities and user interface design of the web dashboard. By enhancing traceability and transparency in carbon offsetting, this platform aims to build trust and scalability in the carbon economy, supporting the global push for sustainable practices.

8.2 Tools and Technologies Used

1. Hedera Hashgraph: Hedera Hashgraph is a public distributed ledger technology that offers fast, secure, and fair consensus, making it suitable

for applications requiring transparency and trust. This project uses Hedera's Consensus Service for notarizing data and the Hedera Token Service for tokenizing carbon credits.
2. HashPack Wallet: HashPack is a Hedera-compatible wallet that facilitates secure storage and transaction of Hedera tokens. In this project, HashPack enables users to manage and trade tokenized carbon credits with ease, supporting user-friendly interactions with the platform.
3. Prisma: Prisma is an ORM for Node.js and TypeScript that simplifies database management. It connects our Node.js backend to a PostgreSQL database, streamlining data access and indexing for efficient blockchain data retrieval.
4. PostgreSQL: PostgreSQL is a powerful, open-source relational database system. It is used here to store and index carbon offset data, ensuring that information is easily accessible for verification and reporting within the platform.
5. Google Maps API: The Google Maps API was integrated into the app to provide mapping and navigation functionalities. This allows users to view available rides, track their journey in real time, and enhance the overall usability of the application.
6. Version Control (Git): Git was employed for version control throughout the development process. This tool enabled collaborative coding, version tracking, and efficient management of the project codebase, facilitating seamless teamwork and reducing conflicts.
7. Integrated Development Environment (IDE): Visual Studio Code: This lightweight IDE was used for Flutter development, providing a robust set of tools, extensions, and features that streamline the coding process and enhance productivity.
Android Studio: Used primarily for testing and debugging the app on Android devices, Android Studio offers a rich suite of tools tailored for mobile app development.

8.3 Methodologies/Algorithm Details

The development of the Car Sharing App employed Agile methodologies, allowing for iterative progress and flexibility in responding to user feedback. By organizing the project into short development cycles known as sprints, the team focused on specific features and regularly assessed progress. Daily stand-up meetings fostered collaboration among team members, ensuring everyone remained aligned on tasks and quickly addressed any challenges. User stories were crafted to encapsulate functional requirements from the end user's perspective, guiding the prioritization of features and enhancements throughout the project lifecycle.

To achieve a clean separation of concerns and promote maintainability, the app was designed using the Model-View-ViewModel (MVVM) architecture. In this structure, the Model represents the data entities, such as user profiles and ride details, while the View is composed of Flutter widgets that provide the user interface. The ViewModel serves as an intermediary, managing application state and business logic while keeping the View updated with real-time changes. This approach not only enhances code readability but also simplifies testing and debugging.

State management was effectively handled using the Provider package, which enables a reactive programming model within Flutter applications. By creating dedicated state classes for different aspects of the app—such as user authentication and ride requests—developers ensured that changes in the application state automatically reflected in the UI. Each state class extended ChangeNotifier, allowing for seamless communication between the state and the views, thus enhancing the overall user experience.

Real-time data handling was facilitated through Firebase Firestore, a NoSQL database that provides dynamic synchronization between the client and server. The app's data models were designed to represent various entities and efficiently manage storage and retrieval of user and ride information. Firestore's powerful querying capabilities allowed the app to present available rides based on user location and preferences quickly. Additionally, to enhance user safety, the app integrated specific security features, including an SOS alert system that sends the user's location to predefined contacts during emergencies and an audio tracking feature that records audio during rides.

Comprehensive testing methodologies were implemented throughout the development process to ensure the application's reliability and quality. Unit testing was performed on individual components using Flutter's built-in framework, while integration testing evaluated the interactions between the frontend and the Firebase backend. User Acceptance Testing (UAT) involved potential users providing feedback on usability and features, guiding refinements and improvements before the final release. This rigorous approach to testing ensured a robust and user-friendly application that meets the demands of its users.

8.4 Verification and Validation for Acceptance

Verification Verification focuses on ensuring that the software meets its design specifications and requirements before it is delivered to users. Throughout the development of the Car Sharing App, various verification activities were conducted:

- Requirements Review: All project requirements were thoroughly reviewed and analyzed to ensure clarity and feasibility. This step involved cross-checking user stories and functional specifications against the design to confirm alignment.
- Design Review: The architecture and design of the application were subjected to detailed reviews, ensuring that the MVVM structure, data models, and security features were correctly implemented according to best practices.
- Code Review: Regular code reviews were conducted to assess code quality, adherence to coding standards, and the implementation of desired features. Peer reviews helped identify potential issues early in the development process.
- Unit Testing: Automated unit tests were created to verify the functionality of individual components of the app. This process ensured that each module performed as expected in isolation, reducing the likelihood of defects in the final product.
- Integration Testing: Integration tests were executed to verify that different modules of the application work together seamlessly. This included testing interactions between the frontend interface and the Firebase backend, ensuring data was correctly retrieved and displayed.

Validation Validation is the process of evaluating the software against user needs and requirements, confirming that it meets the expectations of its intended users. For the Car Sharing App, validation activities included:

- User Acceptance Testing (UAT): A group of potential users was involved in testing the app to validate its functionality and usability. Feedback was collected regarding the user interface, features, and overall experience, allowing the development team to make necessary adjustments before final deployment.
- Performance Testing: The app underwent performance testing to assess its responsiveness, speed, and stability under varying loads. This

included stress testing to ensure the app could handle multiple simultaneous users without degradation in performance.

- Security Testing: Security features, such as the SOS alert system and audio tracking, were rigorously tested to ensure they functioned correctly and provided the necessary level of user safety. This validation process included evaluating data protection measures and verifying compliance with relevant security standards.
- Documentation Review: All user documentation and help guides were reviewed to ensure they accurately reflected the app's functionalities and provided clear instructions for users.

Chapter 9

Software Testing

Software testing is a crucial phase in the development of the Hedera Offset system, ensuring the platform meets quality standards and performs as expected. The testing process encompasses multiple methodologies to address different aspects of the system, from data collection to tokenization and marketplace transactions.

Unit Testing Unit testing verifies the functionality of individual components within the system. For the Hedera Offset platform, each module—such as the IoT sensor data collection, blockchain interaction, tokenization process, and user registration—was subjected to comprehensive unit testing. These tests were designed to ensure that each function, including the secure data notarization and carbon credit minting, works as expected in isolation.

Integration Testing Integration testing assesses how well different components of the Hedera Offset system interact with each other. The platform's frontend (React app), backend (TypeScript Node), and blockchain integration (Hedera Hashgraph) were thoroughly tested to confirm seamless communication between modules. Scenarios such as data from IoT devices being correctly logged onto the blockchain, carbon credit tokens being minted, and users interacting with the marketplace were validated.

User Acceptance Testing (UAT) User Acceptance Testing (UAT) is performed to ensure the Hedera Offset system meets user needs and expectations. Potential users, including businesses and organizations, participated in testing real-world scenarios such as adding IoT devices, verifying data, and purchasing or retiring carbon credits on the marketplace. Feedback collected from these users helped refine the user interface, improve user workflows, and address usability concerns. This phase ensured that the platform was intuitive, easy to navigate, and met the core objectives of carbon offsetting.

Performance Testing PPerformance testing is critical for evaluating the scalability and responsiveness of the Hedera Offset system, especially under heavy traffic. Load testing was conducted to simulate a high volume of users interacting with the marketplace simultaneously. Stress testing was also performed to determine the system's breaking point and its ability to recover from high-demand scenarios.

Security Testing Security testing focused on identifying potential vulnerabilities within the Hedera Offset system and ensuring the protection of sensitive data. Key security components, such as the blockchain ledger, IoT data transmission, and user authentication, underwent rigorous testing. Security audits were performed to check for common vulnerabilities, including unauthorized access to data, fraudulent carbon credit creation, and token tampering. This testing phase confirmed that the system adheres to industry standards for data security, providing users with a safe and trusted platform for carbon offset transactions.

Chapter 10

Results

10.1 Screen shots

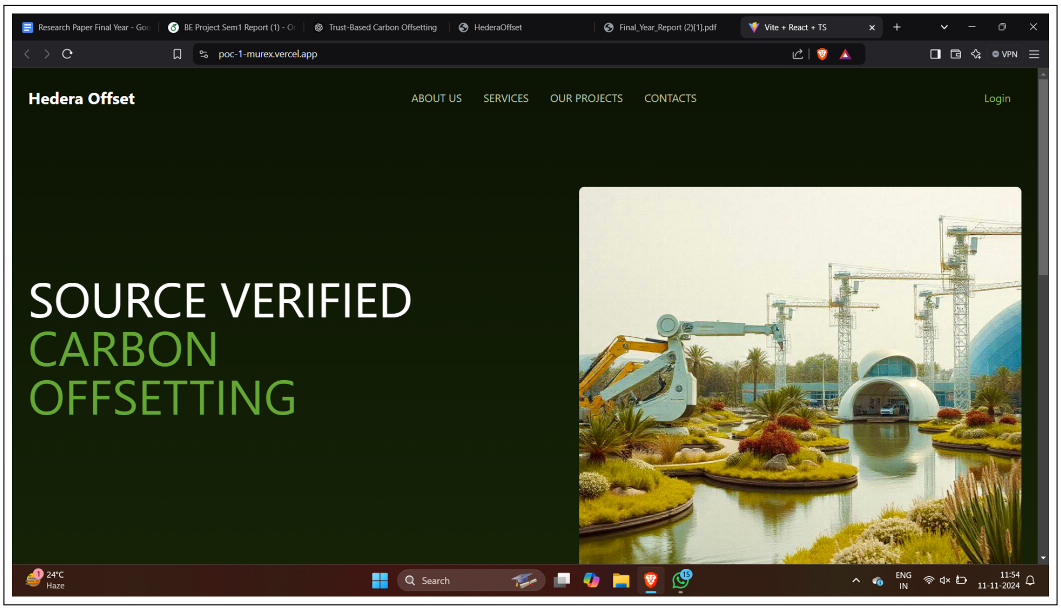

Figure 10.1: Landing Page

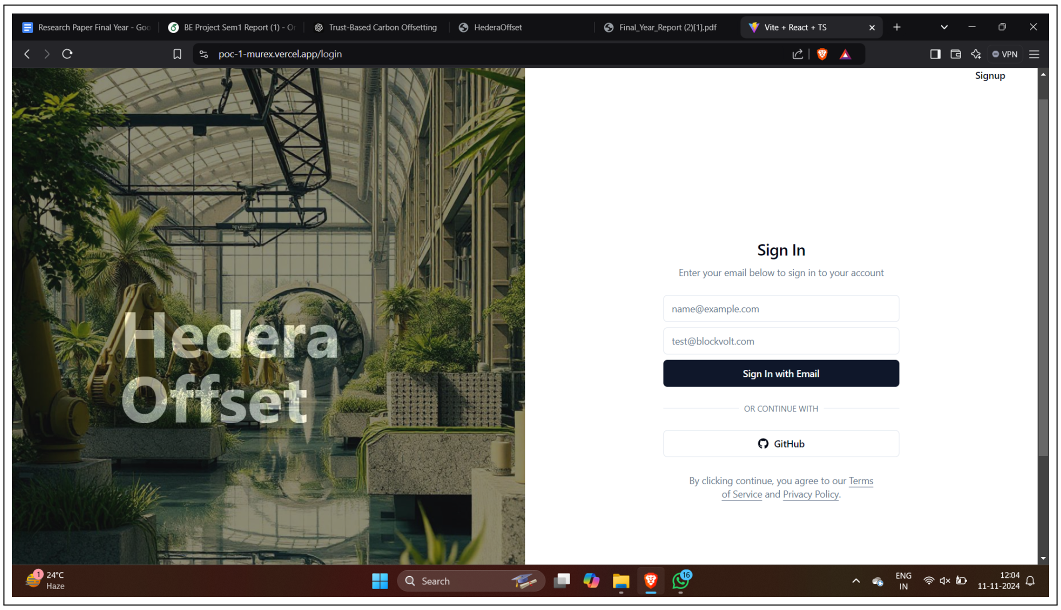

Figure 10.2: Login Page

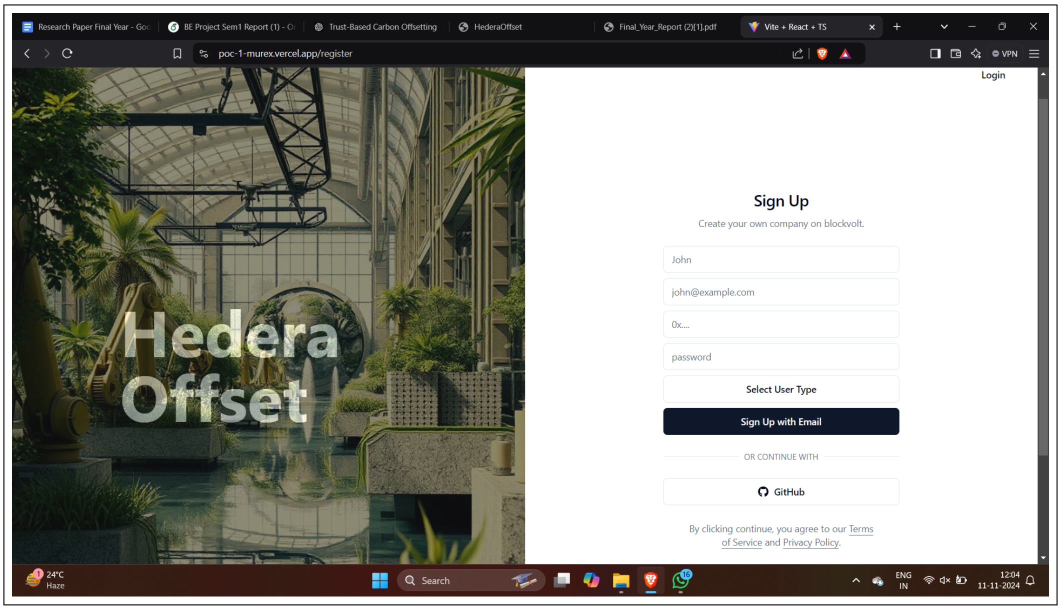

Figure 10.3: SignUp Page

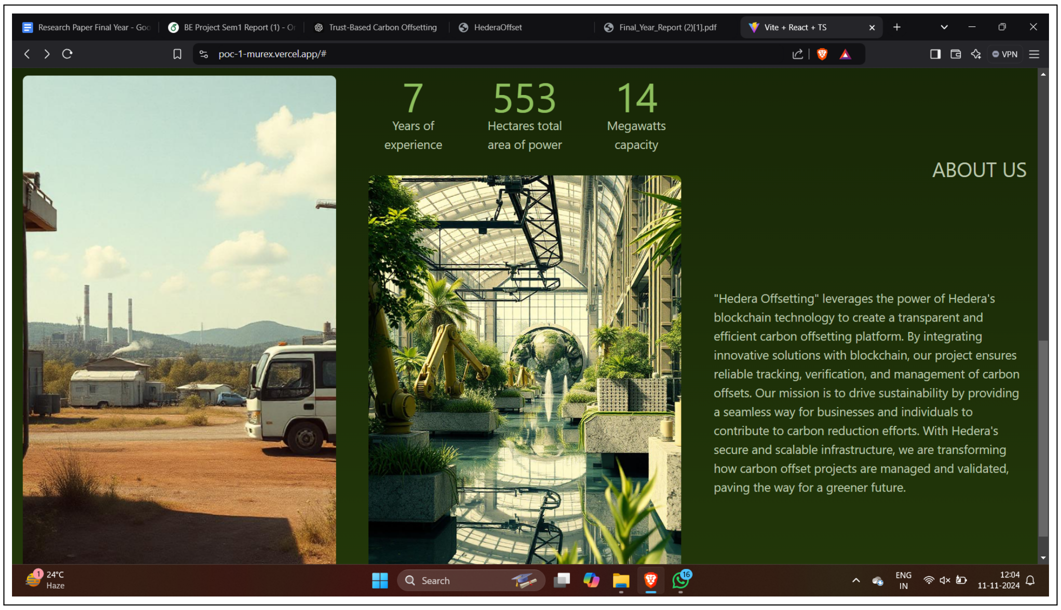

Figure 10.4: About Us

Chapter 11

Conclusion and Future Scope

CONCLUSION

This study pioneers a unique fusion of IoT and blockchain to revolutionize carbon offsetting. By harnessing the strength of IoT devices to capture real-time emissions data and blockchain's unwavering security, we propose a system that not only enhances transparency and security but also streamlines carbon credit trading. Our innovative solution addresses the persistent challenges of data integrity and trust, providing an ironclad, auditable record of carbon emissions and offsetting endeavors. A real-world application of our system is showcased through a solar power plant case study. By generating and verifying carbon credits on the blockchain, we highlight the potential to incentivize sustainable practices and accelerate carbon reduction projects. While technical and regulatory hurdles may exist, the synergy of IoT and blockchain offers a beacon of hope for a sustainable and equitable future. Through weaving together these technologies, we aspire to build a robust and scalable carbon market that empowers stakeholders to make informed decisions and contribute to global climate action.

FUTURE SCOPE

One promising avenue for future research is the integration of machine learning (ML) algorithms into the platform. Predictive models powered by ML could enhance the accuracy and efficiency of the carbon credit system. For instance, algorithms could forecast future energy production based on historical data from IoT devices, weather patterns, and other relevant factors, thereby improving the accuracy of carbon savings predictions. This predictive capability could optimize the allocation and pricing of carbon credits in the market, ensuring that credits are issued in a more dynamic and responsive way. Machine learning could also be used to enhance anomaly detection in data, ensuring that any irregularities or potential inaccuracies are identi-

fied and addressed promptly. Additionally, predictive analytics could assist organizations and industries in planning for future emissions reductions, supporting long-term sustainability planning. .
The current system, which focuses primarily on renewable energy projects, has the potential to be expanded to other sectors such as agriculture, transportation, and industrial manufacturing. These sectors represent significant sources of global carbon emissions and offer numerous opportunities for carbon offsetting. In agriculture, for example, IoT sensors could monitor soil conditions, water usage, and emissions from farming practices, contributing to the generation of carbon credits based on sustainable farming methods. Similarly, IoT-enabled tracking of vehicle emissions in transportation or real-time data from industrial processes could provide new avenues for carbon credit generation. Expanding the system to include a broader range of industries could diversify the carbon credit market and offer additional revenue streams for offset projects. This expansion could help create a more inclusive carbon trading environment, involving a wider range of sectors, regions, and participants.

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