Enhancing Transparency in The Coconut Supply Chain Through A Software Engineering Approach

24-25J-313

Project Proposal Report

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B.Sc. (Hons) Degree in Information Technology Specialized in Information Technology

Department of Information Technology

Sri Lanka Institute of Information Technology

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Enhancing Transparency and Efficiency in the Coco-Peat Supply Chain Through Blockchain Integration: A Focus on Energy-Efficient and Resource-Constrained Environments

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DECLARTION

We declare that this is our own work and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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The supervisor/s should certify the proposal report with the following declaration.

The above candidates are carrying out research for the undergraduate Dissertation under my supervision.

Signature of the Supervisor: Mr.Vishan Jayasinghearachchi	Date:	
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Abstract

This project focuses on enhancing transparency and efficiency in the coco-peat supply chain through the integration of blockchain technology, with a particular emphasis on addressing challenges related to energy efficiency and resource limitations. Coco-peat, a byproduct of coconut processing, plays a critical role in global horticulture due to its beneficial properties, such as high water retention and biodegradability. However, the current supply chain for coco-peat is plagued by issues of inefficiency, lack of traceability, and insufficient transparency, leading to distrust among stakeholders and potential exploitation of primary producers.

The proposed research aims to develop a blockchain-based solution that improves the traceability and transparency of coco-peat products from production to end-use. By leveraging the decentralized and immutable nature of blockchain, coupled with the real-time data collection capabilities of IoT devices and the automation potential of smart contracts, this project seeks to create a more reliable and accountable supply chain. Additionally, the research will explore energy-efficient consensus mechanisms and lightweight cryptographic protocols to ensure that the solution is viable in environments with limited computational resources.

The expected outcomes include a working prototype of the blockchain system tailored to the specific needs of the coco-peat supply chain, comprehensive testing and validation in real-world scenarios, and detailed documentation of the process. This solution is anticipated to not only enhance transparency and trust among stakeholders but also optimize supply chain operations, thereby contributing to the overall sustainability and efficiency of the coco-peat industry.

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List of Abbreviations

- RFID - Radio-Frequency Identification
- IoT - Internet of Things
- PoS - Proof of Stake
- ECC - Elliptic Curve Cryptography
- UAV - Unmanned Aerial Vehicle
- IPFS - InterPlanetary File System
- dApps - Decentralized Applications
- Geth - Go Ethereum
- DRL - Deep Reinforcement Learning
- CAGR - Compound Annual Growth Rate
- FMCG - Fast-Moving Consumer Goods
- PNG - Portable Network Graphics

Introduction

Coco-peat, also known as coir pith, is a versatile byproduct of the coconut industry, renowned for its extensive use in horticulture as a soil substitute and soil conditioner. This environmentally friendly material has gained significant traction in recent years due to its beneficial properties such as high water retention, aeration, and biodegradability. Sri Lanka, the fourth-largest producer of coconuts globally, contributes significantly to this sector, with an annual production of approximately 2.8 to 3 billion coconuts [12]. A substantial portion of these coconuts is processed into value-added products like coco-peat, positioning Sri Lanka as a key player in the global coco-peat market.

The global market for coco-peat is expanding rapidly, reflecting its growing acceptance and demand in various agricultural applications. As of 2022, the market was valued at USD 2.27 billion. Projections indicate that this market size will reach USD 3.8 billion by 2031, driven by a compound annual growth rate (CAGR) of 4.4%. This growth underscores the increasing importance of coco-peat in sustainable agriculture and its potential to support global horticultural practices [12].

Despite its promising market outlook, the coco-peat supply chain faces challenges related to transparency and traceability. Ensuring the authenticity and quality of coco-peat from production to end-use is crucial for maintaining market trust and meeting regulatory requirements. Blockchain technology offers a robust solution to these challenges by providing a decentralized, immutable, and transparent ledger for recording all transactions and processes within the supply chain.

This research proposal aims to explore the integration of blockchain technology into the coco-peat supply chain to enhance transparency and traceability. By leveraging blockchain’s core attributes, this project seeks to address current inefficiencies and build a more reliable and trustworthy supply chain. The implementation of blockchain will involve the use of IoT devices for real-time data collection and smart contracts for automating transactions, ultimately leading to a more efficient and accountable supply chain management system for coco-peat.

Background and Literature Review

Background

The global demand for coco-peat has been rising due to its applications in agriculture and horticulture. Sri Lanka, being one of the leading producers, has a significant opportunity to capitalize on this demand. However, the current supply chain system is fraught with challenges, particularly concerning transparency and traceability. suppliers and other primary producers often face challenges in ensuring fair compensation, while end consumers and international buyers seek greater visibility into the origin and quality of coco-peat products. Recent advancements in software engineering, especially in the areas of blockchain technology and supply chain management systems, offer promising solutions to these issues.

Literature Review

Blockchain technology has emerged as a transformative tool for enhancing transparency, security, and efficiency in supply chain management. By enabling decentralized, tamper-proof data sharing, blockchain addresses many of the challenges faced in traditional supply chains, such as fraud, delays, and lack of traceability. This literature review examines the role of blockchain in supply chain management, focusing on its application in various sectors, including agriculture, manufacturing, and IoT-enabled systems

Blockchain's most significant contribution to supply chain management is its ability to enhance transparency and traceability. In the context of agri-goods, blockchain technology, combined with RFID, offers a robust mechanism for ensuring product traceability from farm to fork. This integration not only mitigates the risks associated with counterfeiting and food safety but also improves consumer trust by providing verifiable proof of origin and handling conditions.

Similarly, the manufacturing sector benefits from blockchain through improved information sharing across various stakeholders. A study focusing on Sri Lankan export-led manufacturing supply chains highlighted that effective information sharing, facilitated by blockchain, can significantly reduce delays and errors, thus enhancing overall supply chain efficiency.

Blockchain's decentralized and encrypted transaction recording ensures data security and immutability, making it tamper-proof. In permissioned blockchain platforms, there is a strong focus on data protection and controlled access, which safeguards the integrity of transaction ledgers. Additionally, in IoT-enabled supply chains, blockchain provides extra security layers that protect against cyber-attacks and unauthorized access, ensuring that data from IoT devices remains accurate and unalterable.

Blockchain technology also plays a vital role in enhancing supply chain efficiency. By automating processes through smart contracts, blockchain reduces the need for intermediaries, thereby cutting down on time and costs associated with traditional supply chain operations. A review of modern blockchain platforms indicates that these smart contracts streamline operations by automatically executing agreements when predefined conditions are met, leading to faster and more efficient supply chain processes.

The energy consumption of blockchain technology, particularly in its early implementations, has been a significant concern. However, recent advancements, such as the adoption of green blockchain initiatives and energy-efficient consensus protocols, are addressing these issues. Research into green blockchain solutions emphasizes the importance of choosing the right type of blockchain and consensus mechanism to minimize environmental impact while maintaining the technology's benefits.

Moreover, the development of energy-efficient blockchain systems using programming languages like Rust showcases the potential for reducing the carbon footprint of blockchain networks. These advancements are crucial for the sustainable adoption of blockchain in supply chains, particularly as global attention shifts towards environmentally friendly practices.

Existing Solutions

Blockchain in Agricultural Supply Chains

One of the most significant applications of blockchain technology has been in agricultural supply chains, where the demand for transparency and traceability is paramount. A study on "Blockchain-Enabled Secure Agri-Goods Traceability Using RFID in Supply Chain Management [1]" explores the integration of blockchain with RFID technology to track agricultural products from farm to consumer. This integration ensures that all stakeholders, including farmers, distributors, retailers, and consumers, have access to immutable records of product history, thus enhancing trust and reducing fraud.

Similarly, another research paper titled "Revolutionizing Secure Commercialization in Agriculture Using Blockchain Technology [6]" highlights the deployment of blockchain to secure agricultural product transactions. This approach has proven effective in preventing the adulteration of goods and ensuring the authenticity of agricultural produce. By providing a tamper-proof ledger of transactions, blockchain enhances the overall security and trustworthiness of the agricultural supply chain.

Blockchain for Supply Chain Traceability

The use of blockchain in broader supply chain traceability is thoroughly explored in the paper "Role of Blockchain Technology in Supply Chain Management [2]". This paper outlines how blockchain can be leveraged to create a decentralized and transparent system for tracking goods throughout their lifecycle. By recording each transaction on a blockchain, companies can ensure that the history of a product is easily accessible and cannot be altered without consensus, thus reducing instances of fraud and counterfeiting.

Further, "Chaining Success: How Blockchain Reshapes the Landscape of Supply Chain [3]"provides a detailed analysis of various case studies where blockchain was employed to improve supply chain transparency. One notable example includes the use of blockchain in the diamond industry to prevent the circulation of conflict diamonds by maintaining a public ledger of each diamond's origin, ownership, and journey from mine to market.

Integration with IoT for Enhanced Supply Chain Management

The integration of blockchain with Internet of Things (IoT) devices is another area where significant advancements have been made. The paper "Blockchain for IoT-Enabled Supply Chain Management: A Systematic Review [5]' discusses how combining IoT sensors with blockchain allows for real-time tracking of goods, thereby providing accurate and up-to-date information on the status of products as they move through the supply chain. This system reduces inefficiencies and enhances the reliability of supply chain operations.

Moreover, ‘Blockchain-Based Resource Trading in Multi-UAV-Assisted Industrial IoT Networks [9]’ explores an innovative use case where blockchain is used to manage and secure data generated by UAVs (Unmanned Aerial Vehicles) in industrial IoT networks. This application demonstrates how blockchain can be employed to facilitate secure resource trading and data management in highly dynamic environments.

Data Protection and Blockchain

Data protection is a critical concern in any blockchain application, particularly in supply chains where sensitive information is frequently exchanged. The paper ‘Data Protection and Export for Transaction Ledgers in Permissioned Blockchain Platforms [4]’ examines the mechanisms for securing transaction ledgers in permissioned blockchain networks. It highlights how encryption and access control protocols can be used to safeguard data while still ensuring the transparency and immutability that blockchain offers.

Sustainability and Green Blockchain Adoption

The sustainability of blockchain technology is also a key consideration, particularly given the environmental concerns associated with traditional blockchain platforms. The study ‘Towards Adoption of Green Blockchain with Emphasis on Blockchain Type, Consensus Protocols, Data Sharding, and Smart Contracts [8]’ explores methods for making blockchain more environmentally friendly. The paper suggests using alternative consensus mechanisms, such as Proof of Stake (PoS), and data sharding techniques to reduce the energy consumption of blockchain networks while maintaining their efficiency and security.

With that, it is clear the various implementation of Blockchain Technology. From enhancing transparency in agricultural products to integrating with IoT for real-time tracking, blockchain offers numerous benefits. However, challenges in sustainability need to be addressed to fully realize its potential. As the technology matures, we can expect further innovative applications and improved efficiencies in supply chain operations across different industries.

Research Gap

Despite the extensive application and promising results of blockchain technology in supply chain management, several research gaps remain that need to be addressed to fully leverage its potential.

The energy consumption of blockchain technology, particularly in public blockchain networks that rely on Proof of Work (PoW) consensus mechanisms, is a significant concern. The literature reviewed highlights ongoing efforts to explore more energy-efficient consensus mechanisms, such as Proof of Stake (PoS) and data sharding. However, there is still a considerable gap in understanding how these mechanisms can be optimized for supply chain applications without compromising security and decentralization. Further research is needed to develop green blockchain solutions that minimize energy use while maintaining performance, particularly for global supply chains that require high transaction throughput.

Blockchain systems, especially when integrated with IoT for supply chain management, face challenges related to limited computational and storage resources. The integration of IoT devices, which often have limited power and processing capabilities, with blockchain technology necessitates a careful balance between data integrity, processing speed, and resource consumption. Current research has begun to address these issues, but a more comprehensive approach is needed to optimize blockchain protocols for environments with constrained resources, ensuring that these systems remain viable in practice.

Addressing these research gaps is critical for the broader adoption and optimization of blockchain technology in supply chain management.

Research Problem

The coco-peat supply chain currently suffers from a lack of transparency and traceability, leading to inefficiencies, fraud, and mistrust among stakeholders. Traditional supply chain management approaches have been unable to adequately address these issues.

How can blockchain technology be effectively integrated into the coco-peat supply chain to enhance transparency and traceability while addressing the challenges of energy efficiency and limited computational resources?

Objectives

Main Objective

To develop an effective blockchain-based solution for the coco-peat supply chain that enhances transparency and traceability while optimizing for energy efficiency and minimizing the impact of limited computational resources.

Sub-Objectives

Sub-Objective 1: To assess the current state of the coco-peat supply chain and identify key areas where blockchain technology can improve transparency and traceability.

Sub-Objective 2: To design a blockchain architecture tailored to the specific needs of the coco-peat supply chain, focusing on integrating with existing processes and overcoming industry-specific challenges.

Sub-Objective 3: To evaluate and implement energy-efficient consensus mechanisms that reduce the overall energy consumption of the blockchain solution while maintaining security and decentralization.

Sub-Objective 4: To develop strategies for optimizing blockchain performance in environments with limited computational resources, particularly in rural or resource-constrained settings.

Sub-Objective 5: To test and validate the proposed blockchain solution in real-world scenarios within the coco-peat supply chain, measuring its impact on transparency, traceability, energy efficiency, and resource utilization.5

Methodology

This research will be conducted through a systematic and phased approach to effectively address the integration of blockchain technology into the coco-peat supply chain while optimizing for energy efficiency and limited computational resources. The methodology is divided into several key phases, each focusing on a specific aspect of the research objectives.

The first phase involves a **literature review and requirement analysis**. This phase will begin with an extensive review of existing literature on blockchain applications in supply chains, with a particular focus on agricultural products and related sectors. The review will also cover energy-efficient blockchain technologies, including alternative consensus mechanisms such as Proof of Stake (PoS) and data optimization techniques like sharding. Following the literature review, a stakeholder analysis will be conducted to identify and interview key stakeholders within the coco-peat supply chain, including producers, distributors, exporters, and regulators. These interviews will help in understanding the specific needs and challenges faced by stakeholders. Based on the insights gathered, functional and non-functional requirements for the blockchain system will be defined, taking into account the constraints related to energy consumption and computational resources in the target deployment environments.

The second phase is dedicated to **blockchain system design**. In this phase, the most suitable blockchain platform will be selected based on its transaction throughput, scalability, energy consumption, and compatibility with existing supply chain management systems. Following the platform selection, an energy-efficient consensus mechanism, such as Proof of Stake (PoS) or a hybrid model, will be designed and implemented, tailored specifically to the needs of the coco-peat supply chain. Additionally, smart contracts will be developed to automate key processes within the supply chain, such as tracking product origin, processing transactions, and ensuring compliance with quality standards. These smart contracts will be optimized for minimal computational overhead and energy use. Furthermore, cryptographic techniques will be implemented to secure transactions and ensure data integrity, with a focus on using lightweight protocols suitable for environments with limited computational resources.

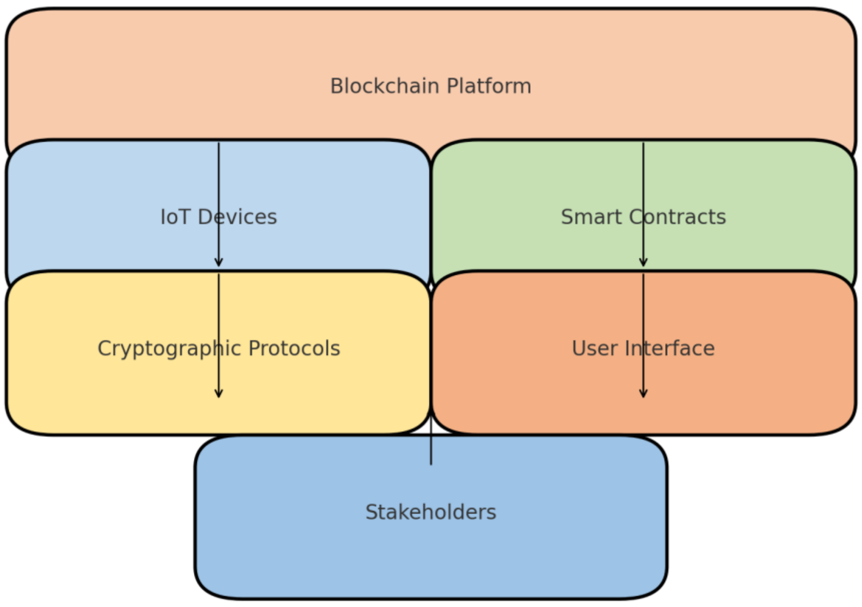

Figure 1

The architecture diagram illustrates the integration of blockchain technology into the coco-peat supply chain, focusing on key components and their interactions. At the core is the blockchain platform, which securely records and validates transactions to ensure transparency and traceability. IoT devices collect real-time data throughout the supply chain, which is then transmitted to the blockchain. Smart contracts automate processes like verifying product authenticity and managing payments. Cryptographic protocols secure the data, ensuring that only authorized stakeholders can access or modify it. The user interface provides an accessible way for stakeholders, such as manufacturers and exporters, to interact with the system, view traceability information, and manage transactions.

This architecture aims to enhance supply chain efficiency while addressing challenges related to energy efficiency and resource limitations.

The third phase focuses on **prototype development and implementation**. A working prototype of the blockchain network will be developed, integrating the designed consensus mechanism and smart contracts. This prototype will initially be deployed in a simulated environment to test its functionality, performance, and energy efficiency. Additionally, IoT devices will be integrated into the supply chain to collect real-time data on coco-peat production, processing, and distribution. The collected data will be securely transmitted and recorded on the blockchain, utilizing efficient data aggregation techniques to reduce bandwidth and storage requirements. A user-friendly interface will also be developed, allowing stakeholders to interact with the blockchain system via mobile and web applications. This interface will be designed to provide transparency and traceability information in an easily accessible format, with consideration for low energy consumption on user devices.

The fourth phase involves **testing and validation** of the prototype in real-world scenarios. Performance testing will be conducted to evaluate the system's transaction throughput, latency, and scalability under varying loads, as well as to measure energy consumption compared to traditional supply chain management systems. Security and privacy testing will assess the system's resistance to common blockchain threats, such as Sybil attacks and double-spending, while evaluating the effectiveness of privacy measures in protecting sensitive supply chain data. Usability testing will involve stakeholders from the coco-peat supply chain to ensure the system meets their needs and is user-friendly. Following these tests, the prototype will be deployed in a limited real-world setting within the coco-peat supply chain to assess its practical applicability, with performance, energy consumption, and user adoption monitored during the pilot phase.

In the fifth phase, **data analysis and optimization** will be performed based on the data collected from the pilot deployment. This analysis will identify areas for improvement in the blockchain system, particularly in terms of energy efficiency and resource optimization. The blockchain architecture, consensus mechanisms, and smart contracts will be refined based on the analysis results to further reduce energy consumption and enhance scalability and robustness. A scalability assessment will also be conducted to determine the feasibility of scaling the system for full-scale deployment across the entire coco-peat supply chain, with a roadmap developed for scaling the system while maintaining energy efficiency and managing resource constraints.

Finally, the research will conclude with **documentation and dissemination**. The entire research process, including design decisions, implementation details, and testing results, will be thoroughly documented. This will include comprehensive technical documentation for the blockchain system, such as architecture diagrams, code annotations, and user guides. The findings will be disseminated through academic publications, conference presentations, and engagement with industry stakeholders via workshops and seminars. Feedback will be collected from the academic and industry communities to refine the system further and identify areas for future research. Partnerships with industry stakeholders will be sought for ongoing development and potential commercialization of the blockchain solution.

This table provides a concise overview of the key technologies that can be integrated into the blockchain-based coco-peat supply chain, highlighting their unique features that contribute to system efficiency, security, and scalability.

Table 1

Technology	Description	Key Features
Ethereum	A decentralized blockchain platform that supports smart contracts.	• Supports smart contracts • Broad developer community • Public and private network options
Hyperledger Fabric	A permissioned blockchain platform tailored for enterprise use.	• Permissioned network • Modular architecture- • High scalability- • Privacy controls
Corda	A blockchain platform designed for complex business transactions.	• Privacy-centric design • Supports complex workflows • Scalable for enterprise use
Proof of Stake (PoS)	A consensus mechanism that selects validators based on their stake.	• Energy-efficient compared to Proof of Work • Reduces hardware requirements • Faster transactions
Elliptic Curve Cryptography (ECC)	A lightweight cryptographic protocol for securing blockchain data.	• Strong security with smaller key sizes • Suitable for resource constrained environments
IPFS (InterPlanetary File System)	A decentralized storage system for blockchain data.	• Decentralized file storage • Content-addressed storage • Efficient and scalable
IoT Sensors (e.g., RFID, GPS)	Devices for collecting real-time data in the supply chain.	• -Real-time monitoring- • Integration with blockchain • Enhances traceability
Chainlink	A decentralized oracle network for smart contracts.	• Secure data feeds for smart contracts • Cross-chain compatibility • Reliable off-chain data access
Metamask	A browser extension and mobile app for interacting with blockchain networks.	• User-friendly interface • Wallet functionality • Integration with decentralized applications (dApps)
Geth (Go Ethereum)	A Go implementation of Ethereum, allowing for running nodes and interacting with the blockchain.	• Full-node support • Smart contract deployment • Ethereum blockchain interaction
Raiden Network	A layer-2 scaling solution for Ethereum to facilitate fast and low-cost payments.	• Off-chain transactions • High throughput • Micro-payments capability

Workload Gantt chart

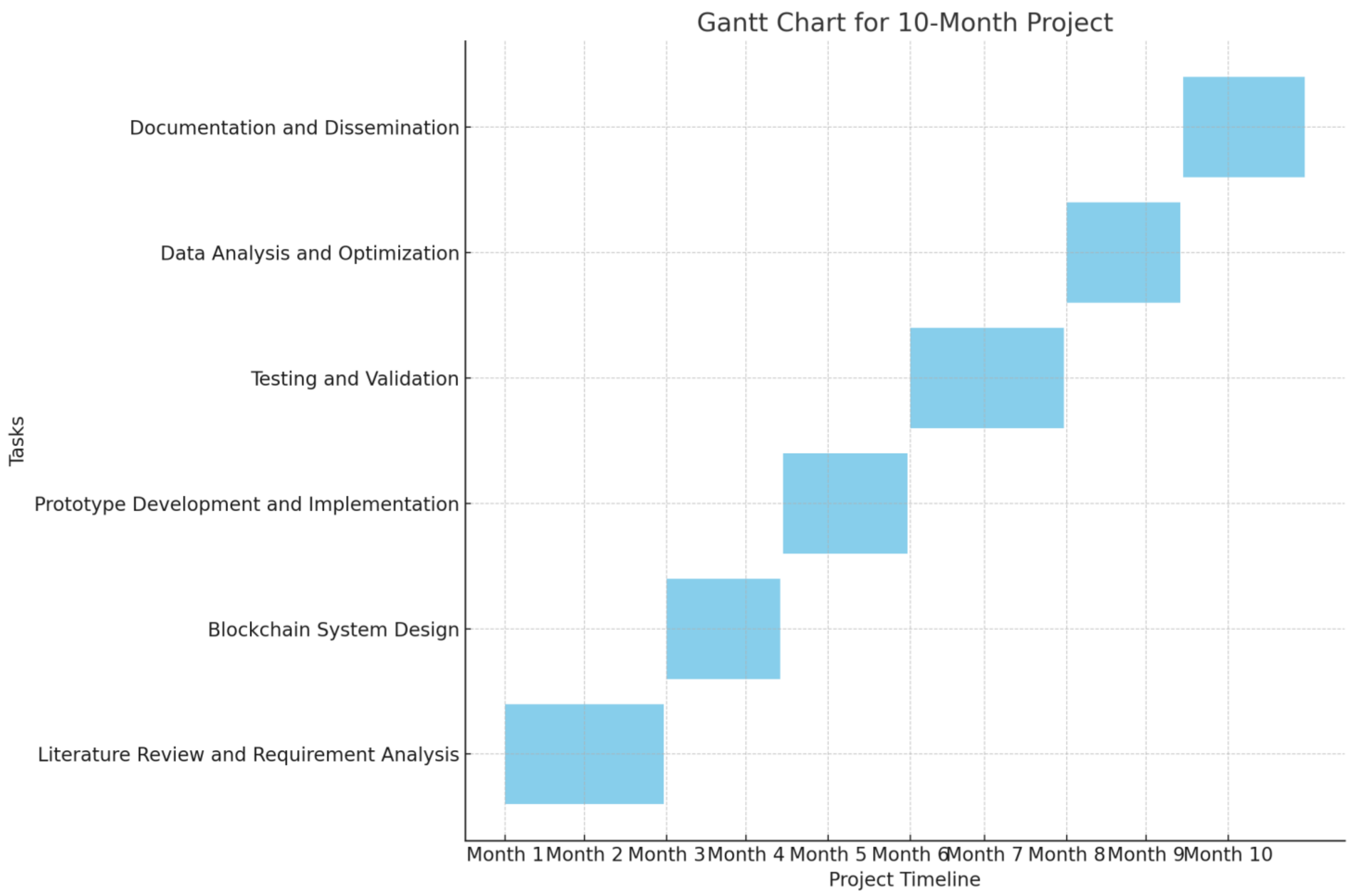

Figure 2

Project Requirements

Functional Requirements

1. Traceability of Coco-Peat Products:
   - The system must track coco-peat products from the point of origin to the final destination, recording every transaction on the blockchain.
2. Smart Contract Execution:
   - The system should automatically execute smart contracts for transactions, such as payments or quality checks, when predefined conditions are met.
3. Data Collection via IoT Devices:
   - The system must integrate with IoT devices to collect real-time data on the production, processing, and distribution stages of the coco-peat supply chain.
4. User Authentication and Access Control:
   - The system must authenticate users and provide role-based access control to ensure that only authorized personnel can view or alter blockchain data.
5. Product Verification:
   - The system should allow users to verify the authenticity and quality of coco-peat products by querying the blockchain.
6. Transaction Logging:
   - The system must log all transactions related to coco-peat products, including production, processing, and distribution, in an immutable ledger.
7. Data Query and Reporting:
   - The system should provide users with the ability to query blockchain data and generate reports on product history, transaction details, and supply chain efficiency.

User Requirements

1. Easy-to-Use Interface:
   - Users should be able to interact with the blockchain system through a user-friendly interface that is accessible via mobile and web platforms.
2. Real-Time Data Access:
   - Users require real-time access to data regarding the status and location of coco-peat products within the supply chain.
3. Product Verification:
   - Users, including customers and regulators, should be able to verify the origin and quality of coco-peat products quickly and easily.
4. Transaction Transparency:
   - Users require transparency in all transactions, with the ability to track each step in the supply chain.
5. Secure Access:
   - Users need secure access to the system, with robust authentication mechanisms to protect their data and transactions.

System Requirements

1. Blockchain Platform:
   - The system must use a robust blockchain platform (e.g., Ethereum, Hyperledger Fabric) to handle transactions, smart contracts, and data storage.
2. IoT Device Integration:
   - The system should support the integration of IoT devices for data collection, including RFID tags, GPS devices, and environmental sensors.
3. Cryptographic Security:
   - The system must implement strong cryptographic protocols (e.g., ECC) to secure data transactions and user information.
4. Consensus Mechanism:
   - The system should use an energy-efficient consensus mechanism, such as Proof of Stake (PoS), to validate transactions.
5. Scalability:

- The system must be scalable to accommodate growing data volumes and an increasing number of users and transactions.

Non-Functional Requirements

1. Performance:
   - The system should process transactions within a few seconds to ensure efficiency in the supply chain.
2. Scalability:
   - The system must scale to support thousands of transactions per second as the supply chain grows.
3. Security:
   - The system must ensure data confidentiality, integrity, and availability through strong cryptographic methods and secure access controls.
4. Reliability:
   - The system should have a high uptime, with minimal downtime, ensuring continuous availability for users.
5. Energy Efficiency:
   - The system should be optimized for low energy consumption, especially in environments with limited resources.
6. Compliance:
   - The system must comply with relevant industry standards and regulations for data protection and supply chain management.

Use Cases

1. Use Case 1: Product Traceability
   - Actors: Farmer, Distributor, Retailer, Customer
   - Description: A farmer enters product data into the system, which is recorded on the blockchain. As the product moves through the supply chain, each transaction is logged, allowing stakeholders to trace the product's journey.
   - Preconditions: The user is authenticated and authorized.
   - Postconditions: The product's history is updated on the blockchain, and stakeholders can access the traceability information.
2. Use Case 2: Smart Contract Execution
   - Actors: Distributor, Retailer
   - Description: A smart contract is triggered when the retailer receives a shipment, automatically transferring payment to the distributor.
   - Preconditions: A smart contract has been set up with predefined conditions.
   - Postconditions: The payment is processed, and the transaction is recorded on the blockchain.
3. Use Case 3: Product Verification
   - Actors: Customer, Regulator
   - Description: A customer scans a QR code on a product, which queries the blockchain to verify the product's authenticity and quality.
   - Preconditions: The product data has been recorded on the blockchain.
   - Postconditions: The customer receives verification information, and the query is logged.
4. Use Case 4: Data Reporting
   - Actors: Supply Chain Manager
   - Description: The manager generates a report on the performance and efficiency of the supply chain using data recorded on the blockchain.
   - Preconditions: The manager has access to the system and the necessary permissions.
   - Postconditions: A detailed report is generated and available for review.

Test Cases

1. Test Case 1: Product Traceability
   - Objective: To verify that the system correctly tracks and logs product movement through the supply chain.
   - Steps:
     1. Enter product data at the production stage.
     2. Record the product's movement through various stages of the supply chain.
     3. Query the blockchain to trace the product's history.

    - Expected Result: The system should display a complete, immutable record of the product's journey.
2. Test Case 2: Smart Contract Execution
    - Objective: To ensure that smart contracts execute automatically when predefined conditions are met.
    - Steps:
        1. Set up a smart contract between a distributor and a retailer.
        2. Trigger the condition (e.g., receipt of shipment).
        3. Verify that the payment is processed and logged on the blockchain.
    - Expected Result: The smart contract should execute as intended, with the transaction recorded on the blockchain.
3. Test Case 3: Product Verification
    - Objective: To test the ability of customers and regulators to verify product authenticity via the blockchain.
    - Steps:
        1. Record a product on the blockchain with its associated data.
        2. Use a QR code or other identifier to query the blockchain.
        3. Verify that the correct product information is returned.
    - Expected Result: The system should return accurate and complete product verification details.
4. Test Case 4: Data Reporting
    - Objective: To confirm that the system can generate accurate reports based on blockchain data.
    - Steps:
        1. Access the reporting tool as a supply chain manager.
        2. Generate a report on specific supply chain metrics (e.g., efficiency, transaction history).
        3. Review the report for accuracy and completeness.
    - Expected Result: The report should reflect the correct data as recorded on the blockchain.

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Appendix