Sustainable Smart City Using Green Blockchain Technology

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Abstract - With a large number of people living in metropolitan areas, there is greater competition for scarce commodities like food and water, as well as increased demand for infrastructure and energy. If these issues are not resolved, they have a negative influence on the country's living conditions and economic progress. An example of a technical innovation that could help solve urbanization's problems is "Smart Cities," which use innovations like Blockchain Technology, Internet of Things (IoT), etc., to improve the allocation of limited resources and more. When put together, these technologies can make everyone's lives significantly easier and more convenient. However, these technological improvements provide both possibilities and obstacles for attaining the aim of developing sustainable smart cities. The Proof of Work consensus mechanism used by the Bitcoin blockchain network is tremendously energy-intensive, rendering the blockchain technology itself unsustainable. Hence, this paper proposes the idea of "a sustainable smart city implementing blockchain with green consensus." This research employs green consensus based on a carbon score. Individuals get a carbon score based on their consumption of items with a certain carbon price, whereas companies receive a score based on the carbon price of the products they manufacture. This work is currently in the concept stage. This paper includes a discussion on green, consensus-based blockchain technology that will aid in the formation of a smart, sustainable society. In addition, we explore unresolved challenges and the future direction of our study, which includes implementation suggestions and future standards for a sustainable smart city ecosystem.

Index Terms - Blockchain Technology, Sustainable Smart City, Green Consensus, Carbon Score

I. INTRODUCTION

Smart cities used with blockchain technology can lead to improved security, transparency and efficiency. There are concerns regarding the energy usage of blockchain networks, particularly those that depend on proof-of-work consensus. Utilising conventional energy sources for powering these networks results in carbon emissions, which contradicts the objective of establishing sustainable smart cities. A sustainable smart city is often cited as an example for studying contemplating the challenges and potential remedies in constructing smart cities. Utilizing blockchain technology, the suggested eco-friendly smart urban area saves and disseminates access control information. Nonetheless, blockchain technology possesses intrinsic imperfections, which is the primary reason why it cannot be considered a long-term solution.. It's crucial that we acknowledge the obstacles we encounter.

A consensus mechanism is crucial in ensuring the validity of blocks within a blockchain network. Bitcoin, for example, uses a consensus algorithm called Proof of Work. Nevertheless, Proof of Work is extremely energy-demanding, as Bitcoin transactions require 980 kWh of energy, whereas transactions carried out via Visa and Mastercard only require 0.0006 kWh. Therefore, even basic transactions necessitate a significant amount of effort within the Proof of Work, rendering it infeasible to sustain. It's important to note that there exist various consensus algorithms such as Proof of Stake, Proof of Storage, Proof of Burn, Proof of Capacity, and more. Survey of Literature will analyze prior research on sustainable blockchain consensus techniques and investigate how they could be used in smart cities.

This research holds significant value since it investigates a critical aspect of constructing sustainable smart cities and explores the feasibility of employing blockchain technology to achieve this objective. The findings of this study could be utilized by policymakers, urban planners, and technology innovators to develop and implement smart city systems that prioritize sustainability.

The primary objective of this work is address to following questions:

What are the main challenges that must be overcome to establish a smart city that is both sustainable and utilizes blockchain technology?

Are there any suitable consensus algorithms available that are sustainable to run in the long run ?

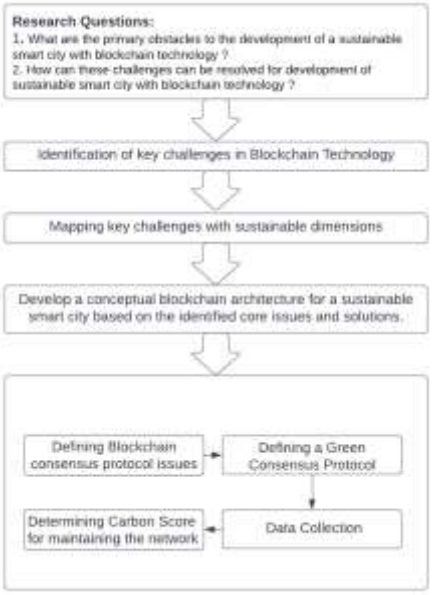

Fig.1 Process Flow

II. LITERATURE SURVEY

(1)Blockchain Technology Overview

Blockchain is a digital immutable ledger system that exploys cryptography for security and ensures authenticity of transactions. Bitcoin is the first cryptocurrency to be created, and is a classic example of blockchain technology. There are numerous use cases implementing blockchain, such as real estate, supply chain management, and voting systems. The initial mention of blockchain technology was in a whitepaper published in 2008 by an individual or group under the pseudonym Satoshi Nakamoto[1]. Using blockchain technology, the paper described a decentralized digital currency system that maintained a secure and transparent ledger of all transactions in that network. Numerous research papers and articles have been published on the use cases of blockchain and also discussing technical dimensions of a blockchain network since then. The decentralized and tamper-proof ledger generated by blockchain technology is made possible through the implementation of consensus algorithms. Consensus algorithms implemented in blockchain technology allow multiple parties to reach a consensus on the state of the ledger without requiring a central authority to oversee the process, a popular example is Proof of Work as consensus algorithm used in Bitcoin network[1]. Smart contracts are a significant feature of blockchain, allowing for contracts to be encoded directly in code, eliminating the need for intermediaries, and ensuring the execution of agreed-upon terms[2]. These smart contracts are automatically executed, depending upon the code and hence it removes the dependence on intermediaries. With all these features blockchain technology has the potential to transform various industries.

(2)Blockchain network in Sustainable Smart City overview

This field of "Blockchain network in Sustainable Smart City" is a new area of research, but there have been few studies investigating the use of blockchain networks in making the smart cities more sustainable. As an example, H. Tang[3] conducted research on the utilization of blockchain networks to develop a transparent and secure system for managing and exchanging data in intelligent cities. In a separate research conducted by Z. Liu[4], the potential of blockchain networks in creating sustainable supply chains for smart cities was examined. The study explored the possibility of creating a more efficient and transparent monitoring and management system for the movement of products and materials within urban areas[4]. The possibility of using blockchain technology to develop sustainable smart cities has been suggested due to its ability to create a tamper-proof, decentralized ledger that can effectively monitor and manage diverse data, such as energy usage, waste disposal, and transportation. Several studies have investigated the potential use of blockchain technology in smart cities. In a different research[5], a blockchain-powered waste management system for smart cities was proposed. The system would allow citizens to monitor the collection and disposal of their waste in real-time while encouraging waste reduction by providing incentives in form digital currency. Furthermore, another research[6] about smart cities put forth a blockchain-based framework for managing the sharing of electric vehicles. The proposed platform would facilitate the effective sharing of vehicles while also allowing for the monitoring of their usage and maintenance.

Consideration of the consensus method used in Blockchain technology is crucial for the sustainability of smart cities. Proof of Work (PoW) is the most popular consensus algorithm, and the Bitcoin Blockchain network uses it. But alternative consensus algorithms, such as Proof of Stake(Pos), are proposed and claim to reduce the energy consumption of PoW[7]. These studies indicate that blockchain technology has the potential to play a significant role in the development of smart cities that are more sustainable. However, the energy consumption of blockchain networks, particularly those based on proof-of-work consensus, is a major concern. The exorbitant energy utilization of traditional blockchain networks, such as those employing proof-of-work (PoW) consensus mechanisms, has been criticized. This has prompted a significant amount of research on the energy consumption of these networks, as well as the development of alternative consensus mechanisms intended to address this issue. Another study by the Cambridge Centre for Alternative Finance found that the Bitcoin network consumed approximately 7 GW of electricity in 2018 and that its energy consumption was increasing at a rate of 60% per year. They hypothesize that their PoS mechanism would require less than 1% of the energy needed by PoW mechanisms like Bitcoin. PoS enables users to validate transactions by retaining and "staking" a specified amount of the network's cryptocurrency, thereby diminishing the computational power required for validation. Moreover, consensus algorithms based on the

notion of "green mining" are the subject of ongoing research. Green mining refers to the practice of utilizing renewable energy sources to sustain blockchain mining operations, resulting in a lower carbon footprint for the network. Several studies have suggested that incorporating renewable energy sources into the mining process can significantly decrease the energy consumption of blockchain networks without compromising their security or decentralization.

To facilitate the maintenance of the blockchain network, our proposal describes a consensus protocol with an environmentally responsible approach. This protocol selects the miner accountable for generating transaction blocks and maintaining the network. The green consensus is determined on the basis of the "carbon score" of each individual or organization engaged in network maintenance. Let's investigate how the "carbon score" is calculated.

The sustainability of smart cities is dependent on the careful consideration of the consensus method employed in blockchain networks.

III. METHODOLOGY

(1)Introduction

The aim of this research was to explore potential methods for achieving consensus in the use of blockchain technology within smart cities, with a focus on sustainability. To achieve this, the study involved a comprehensive review of existing research papers related to blockchain, sustainable smart cities, and blockchain solutions for sustainable smart cities. The purpose was to identify existing gaps and opportunities for improvement in the field. Despite significant research efforts, the issue of establishing sustainable consensus mechanisms for blockchain technology in smart cities remains unresolved. Additionally, there has been limited attention given to sustainable consensus methods employed in smart cities, despite the growing interest in both smart cities and blockchain technology. This lack of information highlights the need for further investigation in this area. The primary objective of this study is to investigate sustainable methods for achieving consensus in the operation of blockchain technology within the context of a smart city. The study proposes the use of a consensus protocol for smart cities based on carbon scores to promote sustainability and address concerns regarding carbon emissions and their impact on the environment.

The carbon score estimation in the proposed architecture is based on the utilization of the carbon price. The carbon score is a quantitative measure that denotes the environmental impact of an individual or an organization in terms of their carbon emissions. The carbon price functions as a mechanism for assessing the carbon footprint by computing the quantity of carbon emissions produced by an individual or organization. The relationship between carbon score and carbon price consumption is inverse, indicating that an increase in carbon price leads to a decrease in carbon score, and conversely, a decrease in carbon price results in an increase in carbon score. The carbon score of an individual is contingent upon their utilization of carbon-derived commodities. The carbon emissions of industries are contingent upon the extent to which they reduce their carbon footprint during the production process. The utilization of the carbon score is employed by the consensus protocol to uphold the integrity of the public blockchain. There is a positive correlation between the carbon score and the probability of selection for block production. This creates a motivation for individuals and industries to decrease their carbon emissions and adopt environmentally sustainable methods. The consensus method based on carbon score guarantees the comprehensive recording of carbon emissions from both individuals and industries on the blockchain. The practice of monitoring the carbon footprint of individual entities not only facilitates the tracking of emissions but also serves as a mechanism for promoting sustainability. The proposed solution offers a novel strategy for addressing the issue of attaining a sustainable smart city by utilizing the advantages of blockchain technology and merging it with sustainable methodologies.

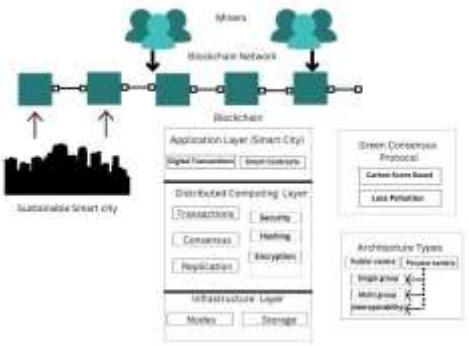

Figure 2. Depicts how the components of a smart city communicate with blockchain with a green consensus protocol.

The following figure depicts the communication between the smart city and blockchain technology using the green consensus protocol. This protocol ensures that the blockchain's high level of security is maintained while it remains viable.

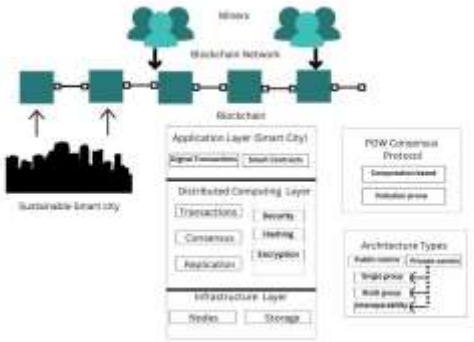

Figure 3. Depicts how the components of a smart city communicate with blockchain with POW consensus protocol.

In terms of methodology, our system architecture consists of the following components:

1. Carbon price estimation
2. Carbon score calculation module

(1)Carbon price estimation

Implementing carbon pricing has acquired global recognition as a viable policy instrument for effectively mitigating carbon emissions and addressing climate change. By requiring manufacturers and consumers to pay for every tonne of CO2 they discharge into the atmosphere, the initiative creates a financial incentive for reducing carbon emissions and transitioning to low-carbon technologies. Numerous institutions and organizations have acknowledged and supported carbon pricing, including the MIT Climate Portal[8], the International Carbon Action Partnership, the Belfer Center for Science and International Affairs at Harvard Kennedy School, and the European Commission. The aforementioned organizations view carbon pricing as a viable strategy for incentivizing the reduction of carbon emissions and mitigating the effects of climate change. It is essential to remember that a country's legislative body is ultimately responsible for determining the carbon price. Due to the fact that this is not a carbon price research paper, the precise carbon price will not receive a great deal of attention in this study. The purpose of the present study is to investigate the viability of integrating sustainable consensus mechanisms into the operation of blockchain technology in the context of a smart city, utilizing the concept of carbon pricing as an incentive for reduced carbon emissions.

(2)Carbon score estimation

The methodology proposed for the development of a sustainable smart city utilizing green blockchain technology is founded upon the implementation of carbon score-based consensus protocol. The government determines the carbon price within this system, which is utilized for the purpose of calculating the carbon score. The carbon score is a metric that quantifies the carbon footprint of an individual or an organization and is inversely correlated with carbon consumption. The calculation of the carbon score can be derived through utilization of the following formula:

Let C_i be the carbon footprint of node i, and P_i be the carbon price consumed by node i. The carbon score of node i is given by:
$S_i = 1 / (C_i * P_i)$

The carbon score of an individual is dependent upon their utilization of carbon-derived products. The carbon emissions of industries are based upon the quantity released during their production procedures. The carbon score can be further refined to take into account other factors, such as the efficiency of production processes and the use of renewable energy sources. The refined carbon score can be calculated using the following formula:

$C' = C * (1 - (R_i / T_i)) * (E_i / T_i)$
where C' is the refined carbon score, R_i is the amount of renewable energy used in the production process, T_i is the total energy used in the production process, and E_i is the efficiency of the production process.

The consensus protocol then uses the carbon score to maintain the public blockchain. The greater the carbon score, the more likely it is that the node will be selected for block production. The carbon score-based consensus method incentivizes individuals and industries to reduce their carbon footprint and promotes the adoption of sustainable practices in this manner.

IV. RESULTS

(1)Comparison between POW v/s Carbon score based consensus

Parameters	Carbon Score Based Consensus Method	POW Consensus Method
Energy consumption	Lower energy consumption as a result of encouraging users to engage in consensus who have a lower carbon score	Increased energy use as a result of the proof of work algorithm's computational complexity
Environmental impact	As the consensus mechanism encourages users to lessen their carbon footprint, lower carbon emissions will result.	Increased carbon emissions as a result of the proof of work algorithm's high energy demand
Scalability	Scalable because the consensus mechanism is not dependent on a computationally taxing proof-of-work algorithm.	As the network grows, the proof of work algorithm becomes less scalable as it becomes more computationally intensive.
Cost	Lower cost as no need of energy intensive methods	Higher cost due as high energy intensive process

The tabulated data indicate that the carbon score-based consensus approach exhibits greater efficiency in comparison to the proof of work consensus method. The method of achieving consensus based on carbon score exhibits advantages such as reduced energy consumption, enhanced security, diminished environmental impact, improved scalability, and decreased cost. The carbon score-based consensus method presents several advantages that render it a more sustainable and efficient alternative for a blockchain system in a smart city context. The utilization of the carbon score-based consensus method has been determined to offer a more sustainable and efficient approach for the maintenance of a blockchain network in a smart city, in contrast to the conventional Proof of Work (POW) consensus method. By formulating carbon score equations and scrutinizing relevant academic literature, it has been deduced that this approach offers a more ecologically sustainable solution by diminishing the network's carbon footprint and enhancing its energy efficiency.

The network employs a carbon score-based mechanism to encourage individuals and corporations to embrace eco-friendly practices, thereby resulting in a decline in their carbon footprint. The carbon score is a function of an individual's or company's carbon price consumption, and a higher carbon score increases the probability of being selected for block production. The outcome of this is a decentralized network, ensuring both security and environmental responsibility. Conversely, the conventional Proof-of-Work (POW) consensus mechanism, which involves nodes engaging in a competitive process to solve a computational puzzle and append a fresh block to the blockchain, is characterized by significant energy consumption and a substantial carbon emission. The reason for this is due to the significant computational resources required, leading to elevated levels of energy consumption and subsequent carbon emissions.

The present study concludes that the carbon score-based consensus method is a more advantageous alternative to the conventional proof-of-work (POW) consensus method. This is due to its ability to offer a more sustainable and efficient solution for the maintenance of a blockchain network in a smart city. The proposed system design can be considered as a prototype for forthcoming research and implementation of eco-friendly blockchain technology, which can pave the way for a sustainable future for smart cities.

V. CHALLENGES

To elaborate on the challenges of implementing a sustainable smart city using green blockchain technology, let's dive deeper into each of the six obstacles listed:

1.**Interoperability and Standardization**: Interoperability refers to the capacity of distinct systems to communicate and share data. Incorporating blockchain technology into conventional businesses necessitates ensuring that the data they generate pertains to the blockchain network and can be transferred between different systems without interruption. Various businesses may adhere to different technical standards and data structures, posing a significant challenge for the endeavor. To address this issue, it is essential to establish a robust integration layer that facilitates the exchange of data between businesses and their on-chain counterparts. Blockchain standardization is required to assure interoperability and promote the widespread adoption of blockchain technology in the business sector. The establishment and implementation of global technical standards to facilitate the exchange of data is essential. The standardization process should be robust and flexible enough to effectively resolve the diverse needs of various industries and businesses.

2.**Efficacy and scalability**: Blockchain technology is renowned for its security, but expanding blockchain applications can be difficult. In the real world, applications must provide minimal latency and simultaneously serve thousands of customers. As the number of users increases, the challenge is to simultaneously maintain minimal latency and ensure security. Proof of Stake (consensus mechanism for validating transactions and establishing new blocks in blockchain networks based on the number of cryptocurrency validators held as collateral) provides lower latency than the older Proof of Work mechanism, but it also presents significant security vulnerabilities. Researchers must find a method to balance security and scalability in order to address this issue. Implementation of the proposed system will be ensured by a scalable architecture. All parties, including individuals, enterprises, and government entities, must concur and have confidence in the blockchain network. To ensure that the network is secure, efficient, and capable of meeting the requirements of the smart city, extensive testing must be performed and numerous use cases must be considered.

3. **Governance and Regulations**: When implementing blockchain networks integrated with smart cities, it is crucial to consider the rules and regulations that are fundamental to modern society. These regulations must be integrated into the blockchain network and upheld. Decentralized autonomous organizations (DAOs) may be necessary to oversee the network and ensure compliance with these regulations. Currency controls are also important, according to governance and regulation principles. To introduce a digital currency in a smart city, a complex blockchain framework must be designed. This framework must ensure that the digital currency is subject to central bank control, similar to traditional currencies. However, developing a flexible and resilient system capable of supporting the complex financial transactions of the modern era presents a significant challenge.

VI. Conclusion

In conclusion, blockchain technology integration with other innovative technologies, such as AI and IoT, holds tremendous potential to revolutionize the creation and operation of sustainable smart cities. Future research in this field can explore a multitude of avenues, and it is expected that significant advances will be made in the near future. However, it is crucial to overcome the various challenges that arise with the implementation of blockchain technology in smart cities. These challenges include interoperability, standardization, effectiveness and scalability, currency control and implementation. Diligent research and development efforts can help to surmount these challenges. The concept of green consensus, which aims to make blockchain more environmentally friendly, is an important field of study that can contribute significantly to the sustainability of smart cities. The implementation of a decentralized network secured by blockchain technology in the city can reduce carbon emissions and enhance security. The creation of sustainable smart cities is attainable, but it requires a concerted effort from multiple stakeholders, including businesses, governments, and researchers. Future research should focus on identifying innovative solutions to the challenges associated with implementing sustainable smart cities using green blockchain technology. Addressing these challenges and working towards the creation of sustainable cities can contribute to a more sustainable future for generations to come.

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