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HARNESSING BLOCKCHAIN FOR SUSTAINABLE PROCUREMENT: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

The integration of blockchain technology into sustainable procurement processes has garnered significant attention in recent years, promising a transformative shift in ensuring transparency, traceability, and adherence to sustainability standards. This study embarked on a comprehensive exploration of the potential, effectiveness, challenges, and future implications of blockchain in the realm of sustainable procurement. Utilizing a rigorous methodology, the research delved into decentralized ledgers, smart contracts, and the inherent transparency offered by blockchain. Key findings highlighted the unparalleled potential of blockchain in enhancing trust and accountability

among stakeholders, while also emphasizing the barriers to its widespread adoption, such as high implementation costs and the need for a paradigm shift in organizational culture. The study concludes with a forward-looking perspective, emphasizing the profound benefits organizations stand to gain by proactively embracing blockchain in their procurement processes. Recommendations underscore the importance of stakeholder education, pilot projects, and collaboration with regulatory bodies. As the landscape of sustainable procurement evolves, blockchain emerges as a pivotal tool in shaping its future.

Keywords: Blockchain, Sustainable Procurement, Decentralized Ledgers, Smart Contracts, Transparency.

INTRODUCTION

Overview of Sustainable Procurement Practices

Sustainable procurement (SP) has emerged as a pivotal agenda in the aftermath of the Sustainable Development World Summit. Governments globally are increasingly emphasizing sustainable procurement as a testament to their commitment to sustainable development (Islam et al., 2017). Such practices have the potential to revolutionize markets, conserve resources, foster job creation, and contribute significantly to sustainable development. The strategic importance of purchasing and supplying as a mechanism for sustainable development has been accentuated in recent times.

The increasing societal and political awareness has made environmental and social considerations paramount in business management. This heightened consciousness has spurred the adoption of sustainable procurement practices, now viewed as an integral component of corporate management, enabling organizations to realize their stated objectives (Islam et al., 2017). This global trend has seen a surge in interest in various facets of procurement, including ethical, green, and e-procurement. Researchers and industry professionals are keenly exploring the impact of organizations and their suppliers on the environment, society, and the economy.

However, a gap exists in understanding the tangible organizational performance outcomes from the implementation of SP practices, especially in regions like the Middle East. Notably, Saudi Arabia's unique cultural fabric, deeply embedded in religious and traditional values, offers a distinct backdrop for examining the interplay between SP practices and organizational performance (Islam et al., 2017).

In essence, sustainable procurement practices are not merely a contemporary trend but an essential paradigm in today's interconnected world. As organizations navigate their sustainability trajectories, comprehending the intricacies and ramifications of these practices is crucial. In regions like the Middle East, where age-old traditions intersect with modernity, sustainable procurement can be a linchpin for organizational success and broader sustainable development aspirations.

Introduction to Blockchain Technology

Blockchain technology, often referred to as a distributed ledger, has garnered significant attention across various sectors, including healthcare. This innovative technology promises to revolutionize the way data is managed, stored, and shared, offering solutions to challenges that have plagued

traditional systems for years. At its core, blockchain is a decentralized system where data is stored across a network of computers, ensuring transparency, security, and immutability. Every transaction or data entry is recorded as a 'block' and linked to the previous one, forming a 'chain'. This structure ensures that once data is added to the blockchain, it cannot be altered without altering all subsequent blocks, which would require the consensus of the majority of the network (Engelhardt, 2017).

The healthcare sector, like many others, is inundated with vast amounts of data. From patient medical records to research data, the need for secure, transparent, and easily accessible data storage and management systems is paramount. Traditional systems often operate in silos, leading to fragmented data, limited access, and potential security breaches. The advent of technologies like genome sequencing and the Internet of Things has further increased the volume of data, emphasizing the need for efficient data management solutions. Blockchain technology addresses several challenges faced by the healthcare sector. One of the primary focuses of modern healthcare is to place the patient at the center of care. This means ensuring that patients have access to their medical data, can share it with healthcare providers of their choice, and can actively participate in their care decisions. Blockchain, with its decentralized nature, can ensure that medical data is accessible to patients, giving them control over who can access it and for what purpose. Medical data is sensitive and requires the highest level of security. At the same time, it needs to be easily accessible to authorized personnel for timely and effective care. Blockchain, with its cryptographic security measures, ensures that data is secure. Its decentralized nature ensures that data is available to authorized personnel whenever and wherever required, without the need for intermediaries. Fragmented data can lead to incomplete medical histories, potentially affecting patient care. Blockchain ensures that all patient data is stored in a single, immutable ledger, ensuring that healthcare providers have access to complete patient histories, leading to better care outcomes (Engelhardt, 2017).

While blockchain holds immense promise, its adoption in sectors like healthcare requires careful consideration of various factors, including regulatory compliance, interoperability with existing systems, and the need for standardization.

Basic Principles and Mechanisms of Blockchain

Blockchain technology has emerged as a transformative force in various sectors, offering innovative solutions to longstanding challenges. At its core, blockchain is a decentralized ledger system that promises enhanced security, transparency, and efficiency. Its application in diverse fields, from finance to logistics, underscores its versatility and potential to reshape traditional operational paradigms.

One of the defining characteristics of blockchain is its decentralized nature. Unlike centralized systems, where a single entity holds authority, blockchain operates on a network of computers. Each transaction or data entry is recorded as a 'block' and linked to the preceding one, forming a 'chain'. This structure ensures data integrity, as once information is added to the blockchain, altering it would necessitate changes to all subsequent blocks, requiring network consensus. Such a

mechanism ensures data immutability, making blockchain a trusted and reliable system (Fu & Zhu, 2019).

Another fundamental attribute of blockchain is traceability. Every transaction is recorded transparently, allowing for easy tracking and verification. This feature is particularly valuable in sectors like logistics, where tracking goods, ensuring their authenticity, and verifying transactions are paramount. For instance, in intelligent logistics systems, blockchain can address challenges like security threats, privacy leaks, and lack of system supervision. By leveraging blockchain's traceability, these systems can enhance their efficiency, security, and reliability. Furthermore, blockchain's ability to provide a transparent and immutable record can significantly improve the supervision of intelligent logistics operations (Fu & Zhu, 2019).

The consensus mechanism is a cornerstone of blockchain technology, ensuring that all participants in the network agree on the validity of transactions. Various consensus algorithms have been developed, each with its strengths and application scenarios. These algorithms play a pivotal role in maintaining the safety and efficiency of the blockchain. For instance, the consensus authentication mechanism is integral to the operation of intelligent logistics systems based on blockchain. By constructing algorithm models and realizing the principles of consensus authentication, blockchain can offer enhanced efficiency and supervision in logistics operations (Mingxiao et al., 2017).

Blockchain technology, with its foundational principles of decentralization, traceability, and consensus, offers a robust solution to many challenges modern industries face. Its potential to revolutionize operations, ensure data integrity, and foster trust makes it a promising tool for the future.

Economic and Societal Implications of Blockchain Integration

Blockchain technology, initially conceived as the underlying mechanism for cryptocurrencies, has evolved to become a transformative tool with profound economic, environmental, and societal implications. As the global community grapples with paradigm shifts, such as the transition from a linear to a circular economy, the need for innovative and radical technologies to facilitate these changes becomes paramount. Blockchain, with its decentralization, distributiveness, and smart contract capabilities, emerges as a pivotal technology to support these transitions (Corsini, Gusmerotti & Frey, 2023).

The circular economy (CE) represents a departure from the traditional linear economic model, emphasizing the sustainable use of resources, waste minimization, and the creation of closed-loop systems. This model is driven by global challenges, including resource scarcity, environmental concerns, and the need for sustainable economic growth. The integration of blockchain technology into the CE framework can address several of these challenges. For instance, blockchain's inherent transparency can satisfy the growing demand from consumers and governments for brands and manufacturers to provide clear insights into their supply chains, ensuring ethical and sustainable practices (Corsini, Gusmerotti & Frey, 2023).

Moreover, blockchain's decentralized nature aligns well with the principles of the CE. Decentralization eliminates the need for intermediaries, reducing inefficiencies and ensuring that

value is retained within the system. This is particularly relevant in sectors like supply chain management, where blockchain can provide real-time tracking, verify the authenticity of products, and ensure that goods are produced and distributed sustainably. Furthermore, the integration of blockchain with other emerging technologies, such as 3D printing and the Internet of Things (IoT), can further enhance the transition towards a circular economy. For instance, blockchain can provide a secure platform for sharing information and know-how, facilitating collaborative efforts towards sustainability (Corsini, Gusmerotti & Frey, 2023).

The societal implications of blockchain integration are equally profound. By promoting transparency and trust, blockchain can empower consumers to make informed choices, aligning their purchasing decisions with their values. This, in turn, can drive businesses to adopt more sustainable practices, knowing that their operations are under scrutiny. Additionally, blockchain's potential to democratize access to information and resources can lead to more inclusive economic systems, reducing inequalities and promoting social welfare.

The integration of blockchain technology into economic and societal frameworks holds the promise of a more sustainable, transparent, and inclusive future. As research and development in this domain continue to evolve, it is crucial for stakeholders across sectors to collaborate, ensuring that the full potential of blockchain is realized for the betterment of society.

Blockchain's Role in Modern Supply Chain Management

The advent of blockchain technology has ushered in a new era of possibilities across various industrial domains, with the logistics and supply chain sectors standing out prominently. As supply chains have become increasingly complex, the need for transparent, secure, and efficient mechanisms to track and manage assets throughout their lifecycle has become paramount. Blockchain, with its decentralized ledger system, offers a robust solution to many of the challenges inherent in modern supply chain management (Litke, Anagnostopoulos & Varvarigou, 2019).

Central to the appeal of blockchain in supply chain management is its ability to record every single asset as it progresses through the supply chain. From the production phase to consumption, every step in a product's lifecycle generates data. This data, when documented as transactions on a blockchain, creates a permanent, immutable history of the product. Such a feature is invaluable in ensuring transparency, traceability, and accountability in supply chains. For instance, blockchain can effectively track orders, receipts, invoices, payments, and other official documents. Additionally, it can monitor digital assets such as warranties, certifications, copyrights, licenses, serial numbers, and barcodes in tandem with physical assets. This dual tracking ensures that every aspect of a product, both tangible and intangible, is accounted for (Litke, Anagnostopoulos & Varvarigou, 2019).

Furthermore, the decentralized nature of blockchain brings forth new modalities of collaboration in complex assembly lines. By sharing information about the production process, delivery, maintenance, and wear-off of products between suppliers and vendors, blockchain fosters a more collaborative and transparent environment. This is especially crucial in today's globalized world, where products often pass through multiple countries and jurisdictions before reaching the end

consumer. A decentralized ledger that offers real-time tracking and verification can significantly reduce inefficiencies, fraud, and mismanagement in such intricate supply chains.

Moreover, the integration of blockchain with other emerging technologies can further amplify its benefits. For instance, when combined with the Internet of Things (IoT), blockchain can provide enhanced real-time tracking capabilities, ensuring that goods are not only produced sustainably but also distributed in the most efficient manner possible.

In essence, blockchain technology holds the potential to revolutionize supply chain management. By providing a transparent, secure, and efficient mechanism for tracking assets, it addresses many of the challenges that have plagued traditional supply chain systems. As industries continue to evolve and adapt to the demands of the 21st century, technologies like blockchain will undoubtedly play a pivotal role in shaping the future of supply chain management.

Historical Evolution of Blockchain in Procurement

The inception of blockchain technology has been a transformative force across various sectors, with procurement being no exception. As the world becomes increasingly interconnected, the complexities of procurement processes have grown, necessitating innovative solutions to ensure transparency, efficiency, and trustworthiness. Blockchain, with its decentralized and immutable nature, has emerged as a potential game-changer in this context, especially in the realm of public sector e-procurement and project management.

Historically, successful project implementations have been a significant challenge for many organizations. The essence of a successful project lies in its ability to deliver all aspects of the project plan within the stipulated time and budget, ensuring stakeholder satisfaction and sustainability (Ofori, 2013). However, in developing countries, sustainable development problems often inhibit the levels of usage required to facilitate successful implementations. These challenges are further exacerbated by issues such as poor project management, lack of transparency, and inefficient procurement management practices (Khalfan et al., 2022).

In countries like Bangladesh, the challenges are particularly pronounced. For instance, in the fiscal year 2016-17, out of 49 projects completed under the Road Transport and Highway Division, 41 experienced both cost overruns and schedule delays. Some projects even reported a staggering 400% time-overrun and 250% cost-overrun. Such discrepancies highlight the pressing need for accountability and trust in project implementation, especially in the public sector (Khalfan et al., 2022).

Enter blockchain technology. With its ability to provide a transparent, tamper-proof ledger, blockchain offers a promising solution to many of the challenges plaguing public sector projects. The technology's inherent features, such as decentralization and immutability, ensure that every transaction is recorded and verified, fostering an environment of trust and accountability. This is especially crucial in procurement processes, where transparency and traceability are paramount.

One of the notable applications of blockchain in procurement is its integration with e-procurement platforms. For instance, the Oracle platform, built on blockchain technology, has emerged as a prominent e-procurement platform. By offering both the blockchain platform and cloud-based applications, Oracle provides a holistic solution that addresses many of the challenges associated

with traditional procurement processes. Through blockchain, the platform can effectively resolve issues related to transparency, traceability, and accountability, ensuring that procurement processes are streamlined and efficient (Khalfan et al., 2022).

The evolution of blockchain in procurement signifies a paradigm shift in how organizations approach procurement processes. By leveraging the transformative potential of blockchain, organizations can address many of the challenges inherent in traditional procurement practices, paving the way for more transparent, efficient, and trustworthy processes.

Current Trends and Technological Advancements in Blockchain for Procurement

The digital transformation era has ushered in a myriad of technological advancements, reshaping traditional systems and processes across various sectors. One such transformative technology is blockchain, which has shown immense potential in revolutionizing procurement systems. As organizations grapple with the complexities of global supply chains, the need for transparent, secure, and efficient procurement processes has never been more pronounced. Blockchain, with its decentralized nature and immutable ledger, offers a promising solution to many of these challenges.

In recent years, the application of blockchain in procurement has moved beyond mere conceptual discussions to practical implementations. One such implementation is the integrated platform based on blockchain technology designed to serve the procurement system. This platform, as described by Divyabharathi et al. (2022), involves multiple stakeholders, including vendors, industries, customers, and delivery executives. The system, built as a web application, leverages blockchain frameworks and operates on smart contracts. A notable feature of this system is its ability to replace conventional procurement systems, eliminating the need for third-party intermediaries or payment gateways. The use of public frameworks like Ethereum ensures that all procurement processes are transparent, secure, and efficient, addressing challenges related to data manipulation and capacity overbooking (Divyabharathi et al., 2022).

Another significant trend in blockchain for procurement is the dematerialization of government processes, particularly in public procurement. Governments worldwide are recognizing the potential of blockchain in ensuring transparency, integrity, traceability, and immutability of data. Diadia et al. (2022) explored the combination of blockchain technology and the OCDS format to standardize public procurement data through smart contracts. Their proposed system, built on Hyperledger Fabric, defines chain codes for every step of the public procurement process, from planning and tendering to awarding and contracting. This approach not only streamlines the procurement process but also ensures the confidentiality of offers in the blockchain using secret shared keys and private data collection (Diadia et al., 2022).

Furthermore, the integration of blockchain in healthcare supply chains has emerged as a pivotal trend. The healthcare sector, with its intricate supply chains, faces challenges related to product recalls, supply shortages, and counterfeiting. Rashid et al. (2022) proposed a blockchain-based approach that combines distributed storage to enhance transparency and improve stakeholder communication. Their framework, which connects all parties in the healthcare supply chain, from manufacturers to healthcare providers, leverages the Ethereum network and uses smart contracts to

streamline operations. The integration of decentralized storage systems like IPFS and Hyperledger Fabric further bolsters the system's efficiency and security (Rashid et al., 2022).

In essence, the current trends and technological advancements in blockchain for procurement underscore the technology's transformative potential. As organizations continue to explore and implement blockchain-based solutions, the future of procurement is poised to be more transparent, secure, and efficient.

Aim and Objectives

The aim of this literature is to assess the potential of blockchain technology in enhancing sustainable procurement practices.

Objectives

1. Critically evaluate the current state of sustainable procurement practices and identify areas where blockchain technology can offer improvements.
2. Explore the latest technological advancements in blockchain related to procurement and determine their applicability and effectiveness in promoting sustainability.
3. Identify potential challenges and barriers in integrating blockchain technology into sustainable procurement processes and propose solutions to overcome these challenges.
4. Engage with key stakeholders in the procurement process, including suppliers, buyers, and regulatory bodies, to gather insights and feedback on the practical implications of blockchain integration.

Scope of the Review

This review is centered on the integration of blockchain technology into sustainable procurement practices. The primary emphasis is on understanding how blockchain can enhance transparency, efficiency, and sustainability in procurement processes. We begin with a detailed exploration of the foundational principles of blockchain technology and its relevance to procurement. This is followed by examining the current state of sustainable procurement practices and the challenges organisations face in this domain. Further, the review delves into the technological advancements in blockchain that are pertinent to procurement, highlighting their potential benefits and limitations. To ensure a holistic understanding, we engage with both primary and secondary literature, encompassing case studies, empirical research, and theoretical discussions related to blockchain and procurement. Additionally, insights from key stakeholders in the procurement process are considered, capturing their perspectives on the feasibility and implications of blockchain integration. It's important to note that while the review is comprehensive in its approach to blockchain and sustainable procurement, it does not explore the broader applications of blockchain outside of this context or delve into wider issues of supply chain management unrelated to procurement.

Identified Research Gaps in Blockchain and Sustainable Procurement

Blockchain technology, with its decentralized nature and features like enhanced security, transparency, and traceability, has been heralded as a potential game-changer for various industries. The construction industry, often seen as a late adopter of technological advancements, is now exploring the potential benefits of integrating blockchain into its operations

(Hirusheekesan, Kulatunga, & Wijayasiri, 2023). However, despite the growing interest, there are discernible gaps in the research landscape that need to be addressed.

One of the primary gaps is the intersection of Industry 4.0 technologies and circular procurement. While there have been strides in understanding how Industry 4.0 technologies can enhance various supply chain functions, the specific implications of these technologies in circular procurement remain underexplored. Rejeb and Appolloni (2022) emphasized the need for a systematic review of the applications of Industry 4.0 technologies in circular procurement. Their study highlighted the potential opportunities that these technologies, including blockchain, can offer in accelerating the shift to a circular economy.

Another area that warrants attention is the halal supply chain. The halal industry, with its unique requirements and standards, presents a set of challenges that can potentially be addressed through blockchain. Rusydiana et al. (2023) conducted a bibliometric analysis of the halal supply chain and identified several research gaps. Topics such as halal procurement and the halal value chain were highlighted as areas that need further exploration. The study also pointed out the potential of emerging trends like halal blockchains and sustainability in halal supply chains, indicating a rich avenue for future research.

Furthermore, while there is growing literature on the adoption of blockchain in the construction industry, a holistic evaluation considering not just the technological aspects but also the sustainability, resilience, and productivity of the industry is lacking (Hirusheekesan, Kulatunga, & Wijayasiri, 2023). This underscores the need for research that goes beyond the technical implementation of blockchain and delves into its broader implications for the industry.

While blockchain's potential in enhancing sustainable procurement practices is evident, there is a clear need for more nuanced and comprehensive research. Addressing the identified gaps will not only contribute to the academic discourse but also provide practical insights for industries aiming to harness the benefits of blockchain.

METHODOLOGY

Research Design: Combining Qualitative and Quantitative Approaches

The exploration of blockchain technology's potential in sustainable procurement necessitates a robust research design that can capture the multifaceted nature of this emerging field. A combined qualitative and quantitative approach offers a comprehensive methodology to delve deep into the intricacies of blockchain while also providing empirical evidence of its impact on procurement practices.

Qualitative research, as emphasized by Van Hilten, Ongena, & Ravesteijn (2020), is instrumental in understanding the drivers and challenges of blockchain for organic food traceability. Through case studies, interviews, and focus group discussions, qualitative research can unearth the nuanced experiences of stakeholders, capturing their perceptions, challenges, and aspirations related to blockchain integration in procurement. This approach is particularly valuable in understanding the human and organizational aspects, such as the cultural and behavioral changes required for successful blockchain adoption.

On the other hand, quantitative research provides the empirical backbone to the study. By leveraging statistical tools and methodologies, quantitative research can measure the tangible impacts of blockchain on procurement efficiency, transparency, and sustainability. For instance, the study by Rahardja et al. (2021) employed a quantitative approach to assess the immutability of the distributed hash model on blockchain node storage. Such studies provide quantifiable evidence of blockchain's benefits, offering a compelling case for its broader adoption in procurement.

Criteria for Data Collection and Source Selection

Data collection is critical to any research endeavor, and its quality and relevance can significantly influence the study's outcomes. In the realm of blockchain and sustainable procurement, the rapidly evolving landscape necessitates a careful selection of data sources to ensure accuracy and relevance.

As highlighted by Yuneline (2019), primary data can be sourced through surveys, interviews, and direct observations. For instance, professionals in the telecom sector can provide firsthand insights into the practical challenges and benefits of integrating blockchain into procurement processes. Such primary data offers a real-world perspective, capturing the ground realities of blockchain adoption.

Secondary data, on the other hand, can be sourced from peer-reviewed journal articles, conference papers, and reports. The study by Rahardja et al. (2021) is an example of secondary data that provides a deep dive into the technical aspects of blockchain, such as the distributed hash model. Such secondary sources offer a theoretical foundation, complementing the primary data's practical insights.

Analytical Framework for Evaluating Blockchain's Impact on Sustainable Procurement

The integration of blockchain technology into sustainable procurement practices promises transformative changes in supply chain management. As industries grapple with the challenges of ensuring sustainability, transparency, and traceability, blockchain emerges as a potential solution. However, to harness its full potential, there is a need for a robust analytical framework that can evaluate the impact of blockchain on sustainable procurement.

Yousefi and Mohamadpour Tosarkani (2022) proposed an analytical approach to assess the performance improvement arising from blockchain implementation in sustainable supply chains. Their study emphasized the importance of identifying blockchain technology adoption enablers and analyzing their impact on supply chain performance. The research highlighted the potential of blockchain in promoting environmental sustainability, traceability, and transparency, especially in the mineral supply chain. The use of smart contracts was identified as a significant factor in enhancing these aspects.

Similarly, Varriale et al. (2021) explored the digital transformation of supply chains, focusing on adopting emerging technologies such as IoT, RFID, and blockchain. Their study, based on a simulation of order management in the cheese supply chain, demonstrated the time performance improvements achieved through the integration of these technologies. The research underscored the potential of blockchain in enhancing sustainability aspects, especially when combined with other emerging technologies.

While these studies provide valuable insights into the potential benefits of blockchain in sustainable procurement, there is also a need to consider the broader implications of this technology. Ahmed et al. (2022) introduced a smart IoT framework for sustainable cities, emphasizing the convergence of blockchain and artificial intelligence. Their research highlighted the advantages of blockchain in promoting the advancement and development of sustainable IoT applications. The study proposed a layer-based architecture that leverages cloud computing, IoT devices, and artificial intelligence to process and obtain necessary information, with results saved in decentralized cloud repositories through blockchain technology.

Drawing from these studies, it is evident that the evaluation of blockchain's impact on sustainable procurement requires a multi-faceted approach. While the technical benefits of blockchain, such as enhanced traceability and transparency, are well-documented, there is a need to consider its broader implications, especially in the context of sustainable cities and IoT applications. The integration of blockchain with other emerging technologies, such as IoT and artificial intelligence, can further amplify its benefits, leading to more sustainable and efficient procurement practices.

In essence, the analytical framework for evaluating blockchain's impact on sustainable procurement should encompass both its technical and broader implications. The framework can provide a comprehensive understanding of blockchain's transformative potential in procurement by considering factors such as technology adoption enablers, integration with other emerging technologies, and its role in promoting sustainable cities.

FINDINGS

Current Landscape of Blockchain in Sustainable Procurement

Blockchain technology, with its decentralized nature and inherent security features, has been gaining traction across various sectors, including education, energy, and infrastructure. Its potential to revolutionize sustainable procurement practices is becoming increasingly evident, as organizations seek more transparent, efficient, and secure methods to manage their supply chains.

In the realm of education, the traditional centralized model of awarding and validating qualifications is being challenged by the advent of blockchain technology. Williams (2019) envisions a landscape where universities might have to outsource parts of their course delivery and assessment to remain competitive. The study suggests that blockchain, by offering automated secure credentialing of students' activities and achievements, could significantly erode existing systems of assessment. This shift would not only challenge the current monopoly of educational institutions in awarding degrees but also necessitate a broader transformation in the way education is delivered and validated.

The energy sector, particularly smart grids, is another area where blockchain is making significant inroads. Moradi et al. (2019) highlight the need for a sustainable solution for cybersecurity in smart grids, especially concerning financial transactions. The study underscores the potential of blockchain as a decentralized platform that can handle myriad microtransactions without the need for supervisory authority. With the proliferation of small-scale distributed generation and the increasing penetration of electric vehicles, the future power systems will witness a surge in

microtransactions. Blockchain, with its capability to provide a secure and transparent platform for these transactions, emerges as a viable solution.

Infrastructure, as a critical component of sustainable development, is also witnessing the transformative potential of blockchain. The Organisation for Economic Co-operation and Development (OECD) 2019 report emphasizes the role of blockchain technologies as a digital enabler for sustainable infrastructure. The transition to a low-carbon future necessitates a visionary reassessment of infrastructure systems and services. Blockchain, as an emerging distributed ledger technology, can act as a digital catalyst across the infrastructure value chain, from planning and procurement to financing, construction, and operations.

In the context of sustainable procurement, the current landscape suggests a growing inclination towards leveraging blockchain technology to address challenges related to transparency, efficiency, and security. Whether it's the validation of qualifications in education, financial transactions in smart grids, or the planning and procurement of sustainable infrastructure, blockchain is poised to play a pivotal role.

The integration of blockchain in these sectors underscores its potential to bring about a paradigm shift in sustainable procurement practices. By providing a decentralized, transparent, and secure platform, blockchain can address some of the longstanding challenges in procurement, such as lack of transparency, inefficiencies, and security concerns. As organizations across sectors continue to explore and adopt blockchain, its role in shaping the future of sustainable procurement becomes increasingly evident.

Mechanisms and Protocols in Blockchain for Procurement

The transformative potential of blockchain technology in sustainable procurement is underpinned by its unique mechanisms and protocols. These foundational elements ensure transparency, security, and efficiency, making blockchain a promising tool for modern procurement practices.

One of the primary mechanisms that blockchain introduces is the decentralized ledger system. This system ensures that every transaction is recorded across multiple nodes, eliminating the need for a central authority and reducing the chances of fraud or manipulation (Kim et al., 2019). In the context of sustainable procurement, this decentralized approach ensures that every transaction, whether it's the sourcing of raw materials or the final delivery of products, is transparently recorded. This transparency is crucial for stakeholders who demand accountability in the supply chain, ensuring that sustainability standards are met at every stage.

Another pivotal mechanism is the use of smart contracts. These are self-executing contracts with the terms of the agreement directly written into code. Smart contracts automatically enforce and execute contractual clauses when predefined conditions are met, reducing the need for intermediaries and ensuring faster, more efficient transactions (Chen et al., 2019). In sustainable procurement, smart contracts can be used to automate compliance checks, ensuring that suppliers adhere to sustainability standards. For instance, a smart contract could automatically release payments to a supplier only when they provide evidence of sustainable practices, such as using renewable energy in their operations.

The propagation of transactions on the blockchain is another critical aspect that ensures the system's robustness. Ersoy et al. (2017) delve into the challenges and solutions related to transaction propagation on permissionless blockchains. Their research highlights the need for incentivizing nodes for transaction propagation, ensuring that the decentralized nature of the blockchain is maintained. By providing incentives for nodes to propagate transactions, the blockchain remains secure and efficient, even as the number of transactions increases.

In the realm of sustainable procurement, the mechanisms and protocols of blockchain offer a new paradigm. The decentralized ledger ensures transparency and traceability, allowing stakeholders to track products from source to shelf. Smart contracts automate and streamline compliance checks, ensuring that sustainability standards are consistently met. And the propagation mechanisms ensure that the blockchain remains robust and efficient, even as the volume of sustainable procurement transactions grows.

The mechanisms and protocols inherent in blockchain technology offer a transformative approach to sustainable procurement. By ensuring transparency, efficiency, and security, blockchain holds the promise of revolutionizing how organizations source, procure, and deliver products, aligning with the global push towards sustainability.

Smart Contracts and Automated Compliance

The advent of blockchain technology has brought forth a myriad of innovations, with smart contracts emerging as one of the most transformative. These self-executing contracts, with the terms of the agreement directly written into lines of code, have the potential to revolutionize various sectors, including sustainable procurement. The inherent properties of smart contracts, such as transparency, immutability, and automation, make them particularly suited for ensuring protocol compliance and data transparency in diverse applications.

In the realm of clinical trials, ensuring protocol compliance and data transparency is of paramount importance. Omar et al. (2020) explored the potential of blockchain smart contracts in this context. Their research highlighted the challenges faced in clinical trials, such as data management issues related to protocol compliance, patient enrollment, transparency, traceability, data integrity, and selective reporting. By integrating blockchain technology, the study proposed a framework that promotes transparency, streamlines communication among stakeholders, and minimizes the timeline of the procurement process. The use of Ethereum smart contracts in this framework ensures that trial protocols are strictly adhered to, and functions are executed only by authorized stakeholders. This not only ensures data integrity but also fosters transparency and traceability of information among stakeholders.

The healthcare supply chain, another critical sector, also stands to benefit immensely from the integration of blockchain smart contracts. Omar et al. (2021) delved into the challenges faced in the healthcare supply chain, particularly in the context of Group Purchasing Organizations (GPOs). Despite the advantages offered by GPOs, such as cost savings, volume discounts, and vendor selection, the current contract process is riddled with inefficiencies. The study proposed a blockchain solution using Ethereum smart contracts to automate the GPO contract process. By connecting all stakeholders, including manufacturers, GPOs, distributors, and providers, on the

Ethereum network, the solution ensures a seamless, transparent, and efficient contract process. The automation brought about by smart contracts not only streamlines the procurement process but also ensures that pricing discrepancies and inaccuracies are avoided.

In the context of sustainable procurement, the integration of smart contracts offers a plethora of advantages. By automating compliance checks, organizations can ensure that suppliers adhere to sustainability standards without manual intervention. For instance, payments to suppliers can be automatically released only when evidence of sustainable practices is provided. This not only streamlines the procurement process but also ensures that sustainability standards are consistently met.

Furthermore, the decentralized nature of blockchain ensures that all transactions are transparently recorded, fostering trust among stakeholders. This is particularly crucial in sustainable procurement, where stakeholders demand accountability and transparency in the supply chain. By providing a transparent, immutable, and automated platform, blockchain smart contracts are poised to play a pivotal role in shaping the future of sustainable procurement.

Decentralized Ledgers and Transparency in Supply Chains

Blockchain technology, characterized by its decentralized, distributed database, has emerged as a transformative force in various sectors, including supply chain management. This technology's core feature is its ability to record transaction information across multiple nodes, ensuring transparency and reducing the need for centralized intermediaries (Francisco & Swanson, 2018). In the context of sustainable procurement, this decentralized approach ensures that every transaction, from sourcing raw materials to the final delivery of products, is transparently recorded, fostering trust and accountability among stakeholders.

The potential of blockchain to enhance supply chain transparency is vast. Every product, from its inception to its final destination, has a detailed history. However, much of this history remains obscured in traditional supply chain systems. Blockchain's decentralized ledgers can illuminate this history, ensuring that stakeholders have access to comprehensive and transparent data about products at every stage of their journey. This is particularly crucial in situations where unethical practices, such as the use of child labor or the unsustainable extraction of resources, can quickly escalate into significant scandals with financial and reputational repercussions (Francisco & Swanson, 2018).

The sustainability performance of supply chains can also be significantly enhanced through the integration of blockchain technology. Park and Li (2021) emphasized the potential of blockchain to reshape supply chain management, particularly in terms of environmental protection, social equity, and governance efficiency. The decentralized database of transactions that blockchain offers ensures transparency, reliability, and traceability, key attributes that are essential for sustainable procurement. By recording every transaction on a transparent and immutable ledger, blockchain ensures that sustainability standards are met and verified at every stage of the supply chain.

Furthermore, the healthcare sector provides a compelling case for the integration of blockchain in supply chain management. Omar et al. (2021) highlighted the challenges faced in the healthcare

supply chain, particularly in terms of Group Purchasing Organizations (GPOs). Despite the advantages offered by GPOs, the current contract process is inefficient and time-consuming. By integrating blockchain technology, the study proposed a solution that promotes transparency, streamlines communication among stakeholders, and minimizes the procurement timeline. The use of Ethereum smart contracts in this framework ensures that contracts are transparently and efficiently executed, fostering trust and efficiency in the healthcare supply chain.

In essence, the decentralized ledgers offered by blockchain technology hold the promise of revolutionizing supply chain management, particularly in the context of sustainable procurement. By ensuring transparency, traceability, and efficiency, blockchain can address many of the challenges faced in traditional supply chain systems, paving the way for more sustainable and ethical procurement practices.

Dispute Resolution and Trust Building in Blockchain Networks

Blockchain technology, with its decentralized and immutable nature, has the potential to revolutionize various sectors, including the realm of dispute resolution and trust-building. The inherent properties of blockchain, such as transparency, immutability, and decentralization, make it particularly suited for ensuring protocol compliance and data transparency in diverse applications.

In the context of clinical trials, ensuring protocol compliance and data transparency is of paramount importance. Omar et al. (2020) explored the potential of blockchain smart contracts in this domain. Their research highlighted the challenges faced in clinical trials, such as data management issues related to protocol compliance, patient enrollment, transparency, traceability, data integrity, and selective reporting. By integrating blockchain technology, the study proposed a framework that promotes transparency, streamlines communication among stakeholders, and minimizes the timeline of the procurement process. The use of Ethereum smart contracts in this framework ensures that trial protocols are strictly adhered to, and functions are executed only by authorized stakeholders. This not only ensures data integrity but also fosters transparency and traceability of information among stakeholders.

Furthermore, as the Internet of Things (IoT) continues to expand, trust-building becomes a critical concern, especially in decentralized marketplaces. A study by Michalopoulos, Singh & Veneris (2023) delved into inducing trust in blockchain-enabled IoT marketplaces through reputation and dispute resolution mechanisms. The research emphasized the feasibility of the proposed reputation system and provided insights into its behavior concerning its parameters. A dispute resolution scheme was presented that acts as a fail-safe mechanism to further establish trust in this system. By leveraging blockchain's inherent properties, the study showcased how trust can be induced in decentralized IoT marketplaces, ensuring secure and transparent transactions.

In essence, blockchain technology offers a transformative approach to dispute resolution and trust-building. By ensuring transparency, immutability, and decentralization, blockchain holds the promise of revolutionizing how disputes are resolved and trust is built in various sectors. Whether it's ensuring protocol compliance in clinical trials or building trust in decentralized IoT marketplaces, blockchain's potential in these domains is vast and continues to grow.

Opportunities Presented by Blockchain in Sustainable Procurement

Blockchain technology, with its decentralized and immutable characteristics, is increasingly being recognized as a transformative force in the realm of sustainable procurement. This digital ledger system offers a myriad of opportunities that can significantly enhance the transparency, efficiency, and reliability of procurement processes, particularly in the context of sustainability.

One of the most prominent opportunities lies in the realm of traceability. Ensuring the origin and journey of products and services is a cornerstone of sustainable procurement. With the increasing complexity of global supply chains, verifying the authenticity and sustainability credentials of products has become a daunting task. Blockchain technology can address this challenge head-on. For instance, in industries like timber, where the provenance of the product is crucial to ascertain its sustainability, blockchain can provide an unalterable record of the product's journey from its source to the end consumer. This not only ensures that the product is sourced sustainably but also instills confidence in consumers and stakeholders about its authenticity (Komdeur & Ingenbleek, 2021).

Beyond traceability, blockchain offers the opportunity to automate and streamline various procurement processes through smart contracts. These self-executing contracts, with the terms of the agreement directly written into lines of code, can automate compliance checks, ensuring that suppliers adhere to sustainability standards. This not only reduces the administrative burden but also ensures that sustainability standards are consistently met throughout the supply chain. Such automation can be particularly beneficial in complex supply chains, where ensuring compliance at every step can be resource-intensive (Krings & Schwab, 2021).

In essence, the integration of blockchain technology into sustainable procurement processes presents a plethora of opportunities. From enhancing traceability and transparency to automating compliance checks, blockchain can revolutionize the way organizations approach sustainability in their procurement processes. As the global emphasis on sustainability continues to grow, leveraging technologies like blockchain will be pivotal in ensuring that procurement processes are not only efficient but also sustainable.

Real-time Tracking and Traceability

The advent of blockchain technology has ushered in a new era of real-time tracking and traceability across various sectors. The decentralized and immutable nature of blockchain ensures that every transaction is transparently recorded, fostering trust and confidence among stakeholders (Kshetri, 2018).

In the realm of supply chain management, the importance of real-time monitoring and tracking cannot be overstated. A global supply chain involves numerous stakeholders, and ensuring transparency among them is paramount. Blockchain-based platforms have been developed to secure all transactions, ensuring that data related to various supply chain stakeholders, such as producers, retailers, and distributors, remains secure and private. Furthermore, the integration of smart contracts in these platforms has been instrumental in automating and streamlining various processes, ensuring that all stakeholders adhere to the predefined protocols (Sabeti et al., 2019).

Collaboration with Stakeholders for Enhanced Transparency

Collaboration among stakeholders is pivotal for achieving enhanced transparency in any system. Blockchain, with its decentralized nature, offers a platform where multiple stakeholders can collaborate without the need for intermediaries. The decentralized nature of blockchain ensures that every transaction is transparently recorded, fostering trust and confidence among stakeholders. This transparency is particularly crucial in sectors like finance, where trust is paramount. Blockchain offers a solution to challenges like inefficient lending practices, lack of monitoring, and fraudulent activities by providing a platform where real-time execution, fund deployment, and project monitoring can be achieved (Kshetri, 2018).

In essence, blockchain technology, with its inherent features of transparency, traceability, and immutability, offers a robust platform for real-time tracking and collaboration among stakeholders. Its application in supply chain management and the finance sector has showcased its potential in addressing challenges and ensuring enhanced transparency and trust among stakeholders.

Engagement with Regulatory and Standardization Bodies

The rapid evolution of blockchain technology has necessitated a parallel evolution in the regulatory and standardization landscape. As blockchain finds its way into various sectors, the need for a standardized approach becomes paramount to ensure its seamless integration and to harness its full potential (Enwerem & Chukwudebe, 2021).

Regulatory bodies worldwide are grappling with the challenges posed by blockchain technology. Its decentralized nature, which is one of its core strengths, also presents unique challenges from a regulatory perspective. Traditional regulatory frameworks are often ill-equipped to handle the nuances of decentralized systems, leading to a pressing need for new regulatory paradigms (Bylinkina, 2020).

Standardization, on the other hand, is crucial for ensuring that blockchain technology is interoperable across different platforms and sectors. As organizations and industries begin to adopt blockchain, the lack of standardization can lead to fragmented systems that cannot communicate or interact with each other. This defeats one of the primary advantages of blockchain: the creation of a unified, transparent, and immutable ledger (Enwerem & Chukwudebe, 2021).

Engaging with regulatory and standardization bodies is not just about compliance. It's about actively shaping the future of blockchain technology. By working closely with these bodies, stakeholders can ensure that the regulations and standards developed are in line with the ground realities of the technology and its applications. This proactive engagement can help in avoiding overly restrictive regulations that stifle innovation or lax standards that compromise security (Bylinkina, 2020).

Furthermore, as blockchain technology continues to evolve, so will its applications and use cases. This dynamic nature of the technology means that regulatory and standardization efforts need to be agile and adaptive. A one-size-fits-all approach will not suffice. Instead, a more nuanced, sector-specific approach may be required. For instance, the regulatory needs of a blockchain-based financial system might differ significantly from a blockchain-based supply chain system (Enwerem & Chukwudebe, 2021).

Another critical aspect of this engagement is the need for global collaboration. Blockchain, by its very nature, is a global technology. Transactions on a blockchain can involve participants from multiple jurisdictions. Hence, for blockchain to realize its full potential, regulatory and standardization efforts need to be harmonized across borders. This requires international regulatory and standardization bodies to work in close collaboration, sharing best practices, and learning from each other's experiences (Bylinkina, 2020).

As blockchain technology continues its march towards mainstream adoption, the importance of engaging with regulatory and standardization bodies cannot be overstated. Only through active engagement and collaboration can we ensure that blockchain technology is harnessed safely, efficiently, and to its fullest potential.

ANALYSIS

Evaluating the Potential and Effectiveness of Blockchain in Sustainable Procurement

Blockchain technology, with its decentralized architecture and immutable record-keeping, has been heralded as a transformative force across various industries. In the realm of sustainable procurement, blockchain's potential is particularly pronounced, promising to address many of the longstanding challenges faced by organizations. This section delves into the potential and effectiveness of blockchain in sustainable procurement, drawing insights from recent academic research.

Sustainable procurement, at its core, is about ensuring that products and services are sourced and produced in a manner that minimizes negative environmental, social, and economic impacts. This requires a high degree of transparency and traceability across the supply chain, ensuring that every stakeholder, from raw material suppliers to end consumers, adheres to sustainability standards (Kim et al., 2019). Traditional procurement processes, with their centralized databases and reliance on intermediaries, often fall short in ensuring this transparency. Blockchain, with its decentralized ledgers and smart contracts, offers a solution.

Kim et al. (2019) explored the potential of blockchain in the procurement of sustainable timber products. The study highlighted the challenges faced by timber procurement officers, such as verifying the authenticity of sustainability certifications and tracing the origin of timber products. Blockchain's decentralized nature ensures that every transaction, from the felling of a tree to its transformation into a finished product, is recorded transparently. Moreover, smart contracts can automate compliance checks, ensuring that timber is sourced sustainably. The study found that blockchain significantly enhanced purchaser trust, especially when combined with other factors like certification schemes and long-standing supplier relationships.

In the broader context of public sector e-procurement, Khalfan et al. (2022) identified numerous challenges, from inefficient procurement management to lack of transparency. The study proposed blockchain as a solution, emphasizing its potential to address 25 out of the 38 identified challenges. Particularly noteworthy was blockchain's ability to ensure data integrity, reduce fraudulent activities, and streamline procurement processes through the use of smart contracts.

However, while the potential benefits are evident, the effectiveness of blockchain in sustainable procurement also depends on various factors. Both studies emphasized the importance of

understanding the technology and its implications. For instance, while blockchain can enhance transparency, it requires a significant shift in organizational culture and behavior. Stakeholders across the supply chain need to be educated about the technology, its benefits, and potential challenges. Moreover, the high implementation costs and the nascent stage of the technology mean that its widespread adoption might be gradual.

In essence, while blockchain holds significant promise for revolutionizing sustainable procurement, its effectiveness is contingent on various factors. As the technology matures and more sectors realize its potential, there is a need for comprehensive research and pilot projects to understand its implications fully. Only then can organizations harness the full potential of blockchain, ensuring that sustainable procurement becomes the norm rather than the exception.

Challenges and Barriers to Blockchain Adoption in Procurement

Blockchain technology, with its decentralized and immutable characteristics, has been recognized as a potential game-changer in various industries, including supply chain management and healthcare. However, despite its transformative capabilities, the adoption of blockchain faces several challenges that need to be addressed for its successful integration into procurement processes.

One of the primary sectors that have shown interest in blockchain's capabilities is the construction industry. Singh et al. (2023) highlighted the potential of blockchain in enhancing supply chain transparency and sustainability within the construction realm. The decentralized nature of blockchain ensures transparent recording of every transaction, from sourcing materials to the final product delivery. However, the study identified several barriers to its adoption. Among the most significant challenges were the "transparency range" and the "security environment". The former pertains to the extent to which transactions are made transparent on the blockchain, while the latter emphasizes the need for a secure environment to protect sensitive data. Another barrier identified was the "inadequate access to institutional finance", suggesting that financial constraints could hinder the adoption of blockchain in the construction sector (Singh et al., 2023).

In the healthcare sector, blockchain has been proposed as a solution to enhance the management and security of patient information. Joshi and Sharma (2023) explored the barriers to implementing blockchain technology in public healthcare systems of developing countries. Their study emphasized the sociological, economical, and infrastructural challenges that these nations face. Among the barriers identified were the lack of technical expertise, regulatory hurdles, and the absence of a standardized approach to blockchain adoption. The study underscored the need for a multi-level analysis to understand and address these challenges, emphasizing the importance of considering the unique socio-economic contexts of developing nations (Joshi & Sharma, 2023).

Furthermore, Kafeel et al. (2023) conducted a bibliometric analysis to understand the barriers and enablers of blockchain adoption in supply chain management. Their study synthesized the challenges into the Political, Economic, Social, Technological, Legal, and Environment (PESTLE) framework. Interestingly, the study found an absence of political barriers or enablers, suggesting that while blockchain challenges the status quo, it does not necessarily face political resistance. However, the environmental implications of blockchain, both as barriers and enablers, were

scarcely discussed, indicating a potential area for further research. The study also highlighted the need for a more manager-friendly framework, suggesting that the academic models used in literature might be too complex for practical implementation (Kafeel et al., 2023).

While blockchain technology offers transformative potential for procurement processes across various sectors, its adoption is not without challenges. From technical and financial constraints to regulatory hurdles and the need for standardized approaches, these barriers need to be addressed for blockchain to realize its full potential in sustainable procurement. Collaborative efforts between academia, industry stakeholders, and policymakers are essential to navigate these challenges and harness the benefits of blockchain for a more transparent and sustainable future.

Implications for the Future of Sustainable Procurement Practices

The advent of blockchain technology has ushered in a new era of possibilities across various sectors, including sustainable procurement. As organizations increasingly recognize the transformative potential of blockchain, it becomes imperative to understand the broader implications of this technology on the future of sustainable procurement practices.

One of the most significant implications of blockchain technology lies in its ability to revolutionize freight transportation in the digital era. Dong et al. (2021) provide a comprehensive overview of the impact of emerging and disruptive technologies on freight transportation. Their research identifies blockchain as a pivotal technology that can address various challenges in logistics management. The decentralized nature of blockchain ensures transparency and traceability across the supply chain, fostering trust among stakeholders. This transparency is particularly crucial in sectors like freight transportation, where the provenance and journey of goods need to be ascertained to ensure sustainability. By leveraging blockchain, organizations can achieve a higher degree of transparency, thereby enhancing stakeholder trust and paving the way for more sustainable freight transportation practices (Dong et al., 2021).

In the realm of auditing, blockchain's implications are equally profound. Lombardi et al. (2022) conducted a systematic literature review to understand the disruption of blockchain in auditing. Their findings reveal that blockchain can address numerous challenges in the auditing sector, from ensuring data integrity to reducing fraudulent activities. The decentralized nature of blockchain ensures that every transaction is transparently recorded, fostering trust among stakeholders. This transparency is particularly crucial in sectors like auditing, where trust and data integrity are paramount. By integrating blockchain, auditing processes can be streamlined, ensuring transparency and reducing the potential for fraud. Furthermore, the use of smart contracts can automate various auditing processes, enhancing efficiency and ensuring compliance with sustainability standards (Lombardi et al., 2022).

The broader implications of blockchain for sustainable supply chain management have also been explored in recent research. Sahoo et al. (2022) conducted a comprehensive review of the trends and future directions of blockchain for sustainable supply chain management. Their research underscores the transformative potential of blockchain in ensuring sustainability across supply chains. By leveraging blockchain, organizations can achieve a higher degree of traceability, ensuring that products are sourced and produced sustainably. Furthermore, the integration of smart

contracts can automate various supply chain processes, ensuring compliance with sustainability standards and reducing the administrative burden. Such automation is particularly beneficial in complex supply chains, where ensuring compliance at every step can be resource-intensive. By harnessing the power of blockchain, organizations can revolutionize their supply chain processes, ensuring sustainability and enhancing stakeholder trust (Sahoo et al., 2022).

The implications of blockchain for the future of sustainable procurement practices are vast. Whether it is revolutionizing freight transportation, streamlining auditing processes, or ensuring sustainability across supply chains, blockchain's potential is undeniable. As organizations increasingly recognize the transformative power of this technology, it becomes imperative to understand its broader implications and harness its potential to pave the way for a more sustainable future.

Pathways to Overcome Identified Challenges

The rapid evolution of the Internet of Medical Things (IoMT) has brought forth a plethora of opportunities, particularly in enhancing patient care and streamlining medical processes. However, with these advancements come significant challenges, especially concerning security and sustainability (Bhushan et al., 2023). Addressing these challenges requires a multifaceted approach, encompassing technological, organizational, and regulatory strategies.

One of the primary concerns in IoMT is ensuring data privacy and security. Kamalov et al. (2023) emphasize the importance of blockchain technology in addressing these concerns. The decentralized nature of blockchain ensures data integrity and authentication, making it a robust solution for securing IoMT systems. By leveraging blockchain, healthcare providers can ensure that patient data remains confidential, tamper-proof, and accessible only to authorized personnel. Furthermore, smart contracts, a feature of blockchain, can automate various processes, ensuring compliance with data protection regulations and reducing the risk of human error (Kamalov et al., 2023).

In addition to technological solutions, organizational strategies play a crucial role in overcoming IoMT challenges. Bhushan et al. (2023) highlight the importance of fostering a culture of security awareness within healthcare institutions. This involves regular training sessions for medical staff, ensuring they are well-versed with the latest security protocols and understand the implications of data breaches. Furthermore, healthcare providers should adopt a proactive approach, continuously monitoring their IoMT systems for potential vulnerabilities and addressing them promptly.

Regulatory frameworks also play a pivotal role in ensuring the secure and sustainable adoption of IoMT. Villegas-Ch. et al. (2023) emphasize the need for clear guidelines that outline the responsibilities of various stakeholders in the IoMT ecosystem. These guidelines should be flexible enough to accommodate the rapid advancements in technology while ensuring that patient safety and data security remain paramount. Collaborative efforts between regulatory bodies, technology providers, and healthcare institutions are crucial in developing these frameworks, ensuring that they are grounded in practical realities while upholding the highest standards of care.

Future Innovations and Trends in Blockchain for Procurement

The integration of blockchain technology into various sectors, including healthcare, has opened up new avenues for innovation. As the technology matures, several trends are emerging that promise to revolutionize procurement processes further.

One such trend is the convergence of blockchain with other emerging technologies, such as the Metaverse. Alsamhi et al. (2023) discuss the potential of Semantic Communication (SemCom) in the Metaverse, emphasizing its role in facilitating efficient communication between humans and intelligent agents. The decentralized nature of blockchain, combined with the immersive experiences offered by the Metaverse, can significantly enhance procurement processes, ensuring transparency, efficiency, and user engagement.

Another promising trend is the increasing emphasis on sustainability in blockchain-based systems. Villegas-Ch. et al. (2023) highlight the potential of blockchain in ensuring sustainable procurement in the medical sector. By providing a transparent and immutable record of medical transactions, blockchain can ensure that medical devices and treatments adhere to sustainability standards. This not only enhances patient trust but also paves the way for eco-friendly medical practices.

Furthermore, as the global emphasis on sustainability continues to grow, blockchain's role in promoting green procurement practices is becoming increasingly evident. Bhushan et al. (2023) discuss the potential of blockchain in ensuring energy-efficient medical processes, emphasizing its role in automating compliance checks and reducing the carbon footprint of medical institutions.

The future of blockchain in procurement looks promising, with numerous innovations on the horizon. As technology continues to evolve, it will undoubtedly play a pivotal role in shaping the future of sustainable and efficient procurement processes across various sectors.

CONCLUSION

The transformative potential of blockchain technology in the realm of sustainable procurement has been the focal point of this study. With its decentralized architecture and immutable record-keeping capabilities, blockchain promises to address many of the longstanding challenges faced by organizations in ensuring transparency, traceability, and adherence to sustainability standards across supply chains. The primary aim of this research was to delve deep into the potential, effectiveness, challenges, and future implications of blockchain in sustainable procurement.

Adopting a comprehensive approach, the study explored the myriad ways in which blockchain can revolutionize procurement processes. The decentralized ledgers and smart contracts inherent to blockchain offer unparalleled transparency, ensuring that every transaction, from sourcing raw materials to the final delivery of products, is recorded with utmost clarity. This transparency fosters trust and accountability among stakeholders, a cornerstone of sustainable procurement. Furthermore, the integration of blockchain technology promises to automate and streamline various procurement processes, ensuring consistent adherence to sustainability standards.

However, like any transformative technology, the road to widespread adoption of blockchain in procurement is fraught with challenges. From high implementation costs to the need for a paradigm shift in organizational culture, the barriers are significant but not insurmountable. The

study highlighted potential pathways to overcome these challenges, emphasizing the importance of stakeholder education, pilot projects, and collaboration with regulatory and standardization bodies. Looking ahead, the future of sustainable procurement practices is intrinsically linked with innovations in blockchain technology. As the technology matures, its applications in procurement are set to expand, paving the way for more efficient, transparent, and sustainable procurement processes.

In conclusion, while the journey of integrating blockchain into sustainable procurement is still in its nascent stages, the potential benefits are profound. Organizations that proactively embrace this technology, understanding its implications and addressing its challenges, will be at the forefront of a new era in sustainable procurement. The recommendations from this study serve as a roadmap for these organizations, guiding them towards a future where sustainable procurement is not just an aspiration but a reality.

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