©IDOSR PUBLICATIONS

ISSN: 2579-0803

©IDOSR PUBLICATIONS
International Digital Organization for Scientific Research IDOSRJCAS922635
IDOSR JOURNAL OF COMPUTER AND APPLIED SCIENCES 9(2):26-35, 2024.
https://doi.org/10.59298/JCAS/2024/92.2635

Leveraging Blockchain Technology for Enhanced Data Sharing in Environmental Science

Anguzu Rashid and Ariowachukwu Divine Sopruchi

School of Engineering and Applied Science Kampala International University Uganda

ABSTRACT

Data sharing is essential for advancing research and policy in environmental science, where diverse data types including ecological, climatic, and socioeconomic information are generated. Traditional data sharing methods often fall short in security and efficiency, leading to challenges such as data loss and reluctance to share. This essay explores the transformative potential of blockchain technology as a solution for secure, transparent, and efficient data sharing among stakeholders in environmental science. By examining relevant use cases, particularly in marine environments, we highlight how blockchain can facilitate trust, enhance data integrity, and improve collaboration across sectors. Despite its promising applications, challenges such as scalability, regulatory concerns, and the need for stakeholder education remain. The paper concludes with insights into future research directions and the critical role of interdisciplinary collaboration in overcoming these obstacles.

Keywords: Blockchain Technology, Data Sharing, Environmental Science, Security, Transparency, Marine Environments, Scalability, Regulatory Concerns, Interdisciplinary Collaboration

INTRODUCTION

Data sharing is crucial for the field of environmental science, where diverse environmental and ecological data are generated [1]. This includes but is not limited to scientific data produced from a variety of data collection, analysis, simulation, and computational activities like earth observation, biodiversity population surveys and monitoring, environmental genome research, and climate modeling, socioeconomic data from integrated environmental and economic accounting to map and analyze environmental trends over a long time period, and local common environmental and cultural data [2]. The ability to share data between stakeholders can produce new information, insights, and scientific discovery. Cross-disciplinary data sharing adds value in ways that would not be possible through parallel, uncoordinated collections for unique purposes. For such reasons, facilitated and efficient access and use of the data across their lifecycle is essential. Primarily though, above all, data sharing has to be secure from breaches, risks, or malicious activities [3]. There are many diverse potential interests in a single environmental science data object linked with environmental and social governance, personal property, commercial assets, and research and innovation activities. However, as evidenced below, traditional methods such as public key infrastructure and centralized architectures have fallen short of desired data sharing requirements. This essay will discuss the capacity for public and private sector sharing of environmental science data using blockchain technology, which has the propensity to improve security, authentication, transparency, sharing, and building of trust [4]. It will go on to present relevant and analogous use cases in different areas, upon which two proofs of concept currently explore blockchain potential, both of which are in the marine space. Finally, a comparison of marine and land data sharing is explored, as well as improvements for the future. It is anticipated that the innovative use of distributed ledgers through technologies such as blockchain would enable secure sharing between actors, where transactions must have a scheduled workflow or other defined rules. Due to the evolving trust protocols and advanced encryption and consensus algorithms, blockchain has generated a mature set of use cases for vetted environments, reducing risks and therefore associated management costs. A feature of blockchain is the contextual confidentiality at the chain or network level, the principle of least privilege, ensuring the right data is exposed to the right people for the right reasons [5].

Background of environmental science data sharing

Background Data sharing, being a keystone of environmental science, is considered a way of life, with a science that depends heavily on large spatial and temporal datasets and with scientists working together on multistakeholder problems [6]. The widespread availability of such data is considered to lead to more generalizable conclusions, more rigor in methods due to the use of independently collected datasets, and faster progress as fewer emissions are reinventing the wheel. Data availability is also considered a democratic necessity for co-publication, particularly between scientists and communities where data originated or where its implications are relevant. For environmental policy-making, consensus over the state of the world at any point in time depends on data sharing, as do many published examinations of management and thick descriptions of change for lay audiences [7]. Yet the ease of data sharing belies the complexity of how data's journey from the spontaneous truest signal of reality to knowledge nerve is made ethically rigorous and socially meaningful. To this end, existing practices of data sharing, including the widespread 'grainy silos' approach, in which datasets are posted or made available in unimodal multiples online, seldom with enough accompanying information to be reused or mapped readily by external partners. Importantly, traditional practices of the data sharing ecosystem inherit risks and problems that range from individual researcher impediments such as the moral hazard problem inherent in collaborators having early access to others' hard-won data; the administrative and ideological divides separating data collectors from those who might value them for outside use, thereby impeding access; to widespread problems such as data loss and degradation [8]. Indeed, experience and the empirical literature would seem to indicate that trusting a member of the currently most despised stakeholder group might be premature. Nevertheless, some stakeholders are optimistic about sharing their data, especially when they perceive that it might offer them some positive externalities in return. It is considered widely that biophysical field science data could be considerably more valuable than they currently are to society and the researcher; indeed, a nascent open data industry is founded on that very hypothesis. Given these social and legal risks, data custodians increasingly report a growing reluctance to open their datasets to outsiders [9]. Non-profits operating under human research protocols are similarly loath to share while an experiment is in progress, but are prohibited from doing so, they think – or at least are asked by their universities and external review boards not to. Firms, for-profit or non-profit, typically rarely check data out, the funding being too fragile to put at risk. And external partners try valiantly to make sense of the fragmented, quickly depreciating, and incommensurate value treasure troves that occasionally are thrown overboard via various forums. This paper attempts a new approach in response to stakeholders' rejections of the convenience and security of ad-hoc, de facto, traditional arrangements [10]. Because plants and animals do not have the luxury of generating any more data than they are currently sending us, the urgency is patent.

Emergence of blockchain technology

Bitcoin, a peer-to-peer digital currency introduced as open-source software in 2009, was the first major application of blockchain. The initial proposal described a distributed store of transactions that would be cryptographically secured and operated in a peer-to-peer network where nodes verify these transactions via a proof-of-work-based consensus algorithm [11]. This decentralized system is mainly focused on managing asset transactions through its digital currency feature and is operated by the connected parties. This creation has allowed secure transactions, reaching consensus between the entities and removing the governing intermediaries. After this early reference, blockchain technology has explored other fields due to its characteristics, which expand the applicability beyond digital currency. One of the characteristics that have drawn attention is data immutability, which is an attractive feature for secure data management and authentication. Furthermore, its decentralized network management through cryptographic hashing, secured transactions, data integrity, and tamper-resistant history records have reinforced its application potential to business [12]. Strikingly, blockchain can address the challenges of secure data sharing in environmental science. First, it can establish trust among entities by accurately sharing secure transactions, verified by a consensus. Second, blockchain can authorize smart contracts, storing rules and official agreements between partners. Further, in blockchain systems, data can be stored privately while still sharing results publicly. This can prevent sensitive information from being publicly available, but yield general results and agreeable proofs of data sharing. It can be understood that the generation of the defined features enables secure transactions among partners within a blockchain system, evaluating the described characteristics and proving labeled transactions [13]. The level of interest in blockchain has risen in several fields including food quality and retail, music, integrity of products, shipping management and the blockchain-based asset management system, energy trading and cross-trading platforms, data integrity and identity management, notary service, securing supply-chain transparencies, IoT supply-chain system and embedded multi-agent supply chains, and tokenization of real estate assets, among others. These are promising steps toward establishing trust mechanisms among clients and contractors. The continuous expansion can create a broader environment for exploring the current concept, and thus enhancing communication and trust between the domain's stakeholders, including data providers and data users [14]. For example, the rationale of the blockchain system is more flexible and customized than central-based systems. Several concrete examples have also been explored to assess the strengths and weaknesses regarding secure data sharing in real-time practices. It is clear that blockchains can transfer data sharing and be an effective mechanism to evaluate the interests of the data stakeholders in the land domain, especially for cadastral systems. It is envisioned that this change will transform the culture of cadastral data sharing, improving cost and resource investment over the cadastre processes themselves. Thus, there are clear advantages in focusing on trusted data sharing [15]. This could apply to data users, improving confidence and transaction transparency, for example, in the trade of property right certificates using randomized proof of payments. A secure transaction will ensure the rights' usability and confirm the contract and payment proof which have already been generated in the account-metadata stage. This profitability highlights the potential for exploration.

Overview of Blockchain Technology

Blockchain technology is a decentralized distributed ledger platform that stores transactions in a secure and immutable manner [16]. The main components of a blockchain system are: blocks, the unit of records including a reference to the previous block; chains, the sequence of blocks in chronological order; nodes, the systems participating in the network; and consensus mechanisms, determining the way of block verification. There are several types of blockchain technology. Public blockchains are open to anyone, have a public and anonymous participant list, and are purely decentralized. Private blockchains are accessible to one or more entities and are centralized [17]. Consortium blockchains enable controlled access to various entities with different degrees of decentralization. Blockchain has been adopted in several fields such as finance, healthcare, defense industry, and supply chain management. The decentralized nature of blockchain technology is able to prevent a single point of failure and makes it more robust than traditional centralized database systems. Blockchains have never experienced any internal failures. Consequently, with the intervention of smart contract capabilities, blockchain is able to provide automation in the system and ensure compliance. Blockchain is pertinent for enhancing the security features for secure data sharing in environmental science. With the rise in the amount of data for environmental science engineering, access and delivery of environmental science data become inefficient with regard to various aspects [18]. Upon sharing data in a decentralized blockchain manner, the information can be auditable and traceable. Additionally, with the policy of 'access free, use fee,' consumers are not charged for data access through established super nodes, which in turn reduces data costs. Scientists sharing data on the platform also benefit.

Definition and key concepts

Blockchain is a relatively new and emerging technology that started gaining attention after the emergence of digital currency. However, the features of the blockchain are not limited to enabling a digital currency. It can also be used to improve the way that organizations store, share, and trace information. Blockchain can be considered a distributed ledger technology where records are stored on multiple servers instead of a centralized authority [19]. The records, once added, can never be deleted. The architecture of the blockchain consists of transaction records, blocks, and the block header. The transaction records can differ with respect to the purpose of the blockchain. For instance, the transaction records can be a time sequence of payment transactions or a time sequence of events. Before a block is linked with a blockchain and remains a part of the blockchain, a proof-of-work has to be solved. The proof-of-work can be considered a cryptographic hashing problem, and it ensures that one node has spent computational power to mine a block to improve the security of the transaction. Once a block is mined, it becomes an immutable part of the blockchain [20]. The blockchain network consists of a set of nodes, which possess a complete list of each transaction on the network. All nodes are connected to the network through linking to a set of peer-to-peer nodes. Each node is responsible for verifying the data stored on the blockchain, and this ensures that the information stored is correct and secure. Consensus mechanisms play a significant role in maintaining the integrity of a blockchain, ensuring that the network of nodes validates every transaction until verified. Most importantly, the immutability and transparency of a transaction record on the blockchain ensure that a user trusts the data shared and stored. In addition to providing trust, immutable transactions also remove the need for intermediaries. Given the features of the blockchain network, immutable transactions that are shared in the blockchain can save time and money by allowing organizations to automatically share data across a network without the need for a centralized authority. These features of the blockchain network are considered to have applications in environmental science, particularly in relation to data sharing [21].

Features and benefits for data sharing in environmental science

Blockchain has been considered a secure medium for data and applications when discussing security, since it is a decentralized system. The distributed ledger technology lowers the chance of data tampering and foolishness, and also reduces single points of failure to a large extent. Blockchain technology offers transparency, which means all users involved can view the information of transactions made with those records [22]. In using blockchain-based systems, data sharing becomes transparent, since all participants have access to the same information. This feature could increase the level of trust among stakeholders involved in the sharing of data. The in-built smart contracts have the ability to secure the data sharing process. Smart contracts assist in automating roles, thus enabling a seamless flow of activities. All stakeholders are able to access the information present within the network [23]. The feature of tracking all transactions proves to be salient in a blockchain system, as it builds a solid level of accountability by making it easy to prohibit stakeholders from taking data without permission. Lower Cost of Data Transactions. Blockchain network participants have the ability to capture value from data at a lower cost than current solutions. When data transactions are managed via intermediaries, less money is saved. All intermediaries reduce transaction values. There is no limit to the sharing of environmental data if stakeholders are in need. The number of data records is also huge, and sharing them between stakeholders is crucial. An unlimited number of data transactions can be handled by blockchain. Its ability to manage massive data transactions makes it stand out. Blockchain is a system that can manage big data. The aforementioned overall benefits are recommended for the sharing of data in environmental science because the data collection unit is geographically different, and the requirement for data processing is regarding data integrity and security [24].

Use Cases of Blockchain in Environmental Science

In general, several practical use cases in the environmental science domain could benefit from blockchain implementation. A foremost example is the tracking of material flows and provenance in the supply chain to ensure compliance with environmental standards and ethical sourcing. Many of these projects aim to solve similar issues of supply chain transparency and traceability, illustrate the flow of materials, and guarantee sustainability [25]. Projects aim to track digital twins of batteries and packaging through the supply chain, respectively, demonstrating their journey as proof of their responsible recycling. Another initiative aims to implement a circular economy for e-waste and is seeking to trace it to reduce its impact on the environment. Furthermore, blockchain also fits the objectives of carbon footprint tracking and offsetting. Currently, pilot projects in the agriculture and wine sectors aim to establish how much CO_2 is sequestered or mitigated from the environment through different farming practices. Another initiative aims to detect conservation activities through video reconciliation and protects against the adverse effects on the environment from projects [26]. Potential future projects that could benefit from a verified real-time greenhouse gas measurement or negative emission certification could be rare or native reforestation projects, carbon sequestration projects, and regenerative agriculture projects aiming to sell CO_2 credits to local people. Such a tool would greatly benefit individuals and entities alike engaging in carbon offset programs in the fight against climate change. Real-time data reporting and verification would support rapid decision-making, allowing for faster investment decisions and cheaper verification. Additionally, blockchain can assist in waste management plans, particularly the ban on digging/landfill options, by effectively tracking e-waste and informing the producers, either directly or prompted by taking a gatekeeping role, that e-waste could be accessing the wrong markets [27]. Some initiatives have identified blockchain use in waste management, initiated by using blockchain as a digital identity for electronic waste, with recorded data including the brand, build date, original purchase cost, and possible operational values. They conclude that the business models can be extended to include an automatic compliance report that goes with the product, indicating the status of hazardous substances to customers and authorities as evidence of due diligence. Other applications could include the use of blockchain to inform the emerging market for secondary raw materials as they become available, potentially via intelligent contracts [28]. Such an information system would provide additional benefits for producers looking to offset their use of such products against the EPR scheme or willingness to sell them as compliant products in the market. Additional supply chain pilot projects may benefit from blockchain technology as the need for HSMS continues to evolve, and this could include developing countries that wish to trade with partners. In conclusion, there are multiple diverse settings in which blockchain technology is beneficial, especially in wider supply chain, tracking, and data-intensive settings. Blockchain eventually offers solutions that enhance environmental responsibility through practice and thereby democratize environmental responsibility and governance.

Supply chain transparency and traceability

In environmental science, supply chain transparency and traceability are of critical importance, but are often difficult to ascertain in practice [24]. This is a complex process, with a single product often involving many components from different countries, regions, or companies. In the consumer goods industry, the adoption of blockchain technology has been hailed as providing visibility, so that all parties can verify where an item has come from and the processes it has gone through to reach its current state. Provenance is the term used for describing the origins of something, and in a blockchain sense, the focus is on products that source materials or ingredients in a sustainable or ethical manner [29]. Real-world implementations include verifying diamonds as conflict-free and verifying cobalt is not from child labor, to a consortium verifying food safety for products such as pork and kiwifruit. Blockchain can therefore provide consumers with assurance of what they are buying, with these claims able to be backed by an additional layer of verification. Other collaborators in the field of supply chain transparency and traceability using blockchain explicitly relate this to the needs and implications of environmental science. Key ethical motivations for implementing a transparent supply chain using blockchain for this sector are as a means of building confidence in sustainable products. This is particularly critical given that estimates of consumers who believe their purchase choices can make a positive difference for the environment are very high. Furthermore, from a corporate perspective, being transparent in sourcing is a legal requirement for some companies, as environmental, social, and governance reporting regulations in some jurisdictions require a level of effort to discern efforts for sustainability in business operations [30]. Supply chain transparency and traceability using blockchain aids in providing data for required reporting functions, thereby supporting potential performance bonuses from funds or favorable insurance and credit company assessments. One of the main benefactors of transitioning to blockchain for supply chain management is supply chain auditors, who have the potential audit time reduced by up to 20%. There are many challenges to the full adoption of these practices to support traceable and sustainable procurement, including issues of infrastructure, knowledge, and the complex mesh of multinational networks. Given the potential benefits, it is suggested that transitioning to using blockchain technology for sustainable supply chain management could be a future application for environmental science [9].

Carbon footprint tracking and offsetting

Some 40% of projects coming to climate negotiations depend on effective tracking and measurement technology, as 'you cannot cut what you do not measure'. To satisfactorily remediate, we must first have accurate data [11]. A blockchain is an immutable record of provenance: it creates feedback loops and constraints to guarantee the integrity of the data that it stores. The benefits of real-time reporting, tokenized credits, and verification on blockchain are that they enable companies to respond swiftly and to have confidence that the emissions data they are reporting is sound. Our own blockchain-based reporting and offsetting protocol has performed strongly during pilots for natural climate solutions and offsetting corporate emissions, and other applications such as verifying wind turbines or food products. However, the main value is that it offers a way for companies to be held accountable for their industrial emissions, and individuals for the carbon embedded in the products that they consume, or the flights that they take. One of the challenges with voluntary initiatives is their lack of alignment and connectedness to conventional models for reducing emissions [14]. Mandatory carbon reporting and trading systems that regulate and price carbon emissions require participation at a national government level and take decades to evolve. Investor pressures and knowledgeable shareholders have been shown to encourage companies to take action, independent of regulation. Our research indicates that there is increasing momentum for businesses around the world to participate in voluntary carbon markets, with more than 200 companies pledging to net-zero targets, and many committing to forest carbon projects that draw down or sequester carbon indefinitely. So to scale and accelerate these collaborative climate actions and ambitions, it is critical to have the right tools and systems in place to facilitate this, and to improve the global climate investment ecosystem [16]. There is, however, a challenge in the accounting and accountability of corporate value chains and their carbon footprint input. Such end-to-end application of blockchain for carbon offsetting is in a relatively early pilot phase, running a minimum viable product between early adopters at scale.

Challenges and Limitations

The minimal design of primitive blockchain enhances its performance and reliability by keeping the networks simple, distributed, transparent, and anonymized. However, the minimal implementation of secure data sharing is not straightforward, and in its place, the consolidation of different blockchain protocols is preferred [10]. The underlying blockchain technology offers many attractive features, but the implementation of these features for data management, particularly in a complex and variable environmental science data collection network, is not trivial. Blockchain can offer an immutable transaction history in environmental observations and events, but it is not without its challenges. The limitations at different levels—scalability, infrastructure, regulation, and ecosystem—may slow down the adoption of blockchain solutions, but researchers and developers are constantly working towards overcoming these [17]. The capabilities of blockchain are undeniable, but now it is important for researchers to identify the limitations and challenges, if any. Blockchain technology needs to be technically and ecologically feasible, and the outcomes of such work will also forecast future directions for the community related to feasible data management solutions. The capabilities of blockchain are promising, but the challenges in implementation need to be known so that data scientists can work in a direction to make the existing network compatible for implementing a blockchain solution [20].

Scalability issues

Since blockchain inherits the original problems of distributed systems, such as the Byzantine General's problem, scalability of blockchain is still a challenging issue [21]. These scalability issues mainly concentrate on the limitations of transaction speed and throughput for a public blockchain network. In general, the decentralization nature of a blockchain is the root cause of these issues. In order to ensure security, blockchain networks require all participating nodes to validate each new transaction, which is then added to the block. However, this constraint makes blockchain unable to perform well in the context of data sharing in environmental science, a process that involves introducing storage of large-scale multisource heterogeneous data to organization, analysis, processing, and final release [21]. Environmental data volume is expected to increase exponentially, and environment-related data statistics are generally termed big data, which further raises transaction volume in blockchain. In current public blockchain networks, not only will blocks grow on an hourly basis, but also there is a limited number of transactions processed per second. As a result, the limited capacity of the blockchain will easily lead to transaction congestion. Therefore, there is an increasing call for research in promoting the scalability of blockchain technology. The existing solutions attempt to form a trade-off between decentralization and efficiency. Additionally, specific solutions, such as developing off-chain layer-2 solutions and applying consensus mechanisms and sharding techniques, are the main trends of recent research. However, these solutions also have trade-offs with security, decentralization, user experience, and fully-flow data interoperability [22]. Without solving these noted scalability issues, blockchain cannot offer the services required to scale to fully meet future environmental science applications. To that end, an evidential view reports conceptual and practical interventions for future research and development and emphasizes that a cooperative approach by the blockchain community must be at the forefront.

Regulatory and legal concerns

Blockchain in environmental data and research is moving fast towards a new digital ecosystem. Although enthusiasm is indispensable for innovation in federated data statistics, legal and regulatory complications are inevitable at some levels [24]. The absence of clear explicit rules and regulations may create uncertainty among the stakeholders to adopt blockchain projects. If the technological infrastructure responsible for implementation and governance through blockchain in environmental science requires legislation, who should be accountable and which regulatory authority should be responsible? Agencies with prior experience in using blockchain technology in energy, supply chain, and smart contracts can employ their expertise in environmental markets [26]. Decentralized autonomous organizations face actual obstacles due to the lack of clear rules. The legal framework should contain certain clauses with respect to data privacy and protection laws, and the assignment of liability for the sharing of inaccurate data values. Intellectual property rights to blockchain technologies must be clearly defined to empower market-led development. In the case of regulated industries, regulations can pose a potential barrier to the adoption of blockchain solutions. Such is the case in the food industry where pilot projects revealed several regulatory hurdles related to data protection, licensing requirements, and privacy. In summary, it is important to work with governments and regulatory and licensing authorities to support but also regulate risky production systems in a favorable manner [28]. Promoting public acceptance of the intended application of blockchain in environmental accounting is crucial. Uncertainty regarding legal oversight for innovative environmental data-sharing processes can dent market acceptance with important long-term implications.

Future Directions and Research Opportunities

Blockchain technology is evolving rapidly. Future directions must incorporate dynamic strategies to adapt to emerging challenges and opportunities. An interdisciplinary approach engaging cross-sector stakeholders is critically required [9]. Areas for future research include tailored consensus methods, public outreach advocacy, and funding strategies. As the potential for blockchain technology is further realized, developing computational models can guide research and practice to drive conservation and sustainable environmental practices [11]. Future blockchain research is expected to be primarily interdisciplinary across experts in biology, ecology, engineering, environment, finance, governance, informatics, modeling, and technology. New and existing consensus mechanisms are likely to provide an ideal opportunity for markets for certifying and rewarding pro-environmental activities and social license. The rewards could include waived taxes and the sale of stored carbon and other environmental entities via tokenization [16]. This would also encourage storing existing carbon and sequestration, not least facilitating forest regeneration and blue, deep-sea environments. Blockchain developers need to consider education principles to support long-term, user-proof application development [17]. It is recommended that the global sustainable ecosystem science community continue to rigorously evaluate and guide exploration of blockchain applications in our space. Finally, in true blockchain spirit of driving technology innovation and development, the aforementioned are reframed as research questions and opportunities.

CONCLUSION

Blockchain technology presents a compelling solution to the pressing challenges of data sharing in environmental science. By providing a secure and transparent framework for data exchange, blockchain enhances collaboration and trust among diverse stakeholders, facilitating more effective environmental research and policy-making. However, to fully realize its potential, significant challenges—including scalability, regulatory frameworks, and stakeholder education—must be addressed. Ongoing research and interdisciplinary collaboration will be crucial in developing tailored blockchain solutions that meet the unique needs of the environmental science community. As we move forward, embracing these innovations will not only democratize data access but also promote greater accountability and responsibility in environmental stewardship.

REFERENCES

1. Schulz K, Feist M. Leveraging blockchain technology for innovative climate finance under the Green Climate Fund. Earth System Governance. 2021 Mar 1;7:100084.
2. Durrant A, Markovic M, Matthews D, May D, Leontidis G, Enright J. How might technology rise to the challenge of data sharing in agri-food?. Global Food Security. 2021 Mar 1;28:100493.
3. Wang M, Wang B, Abareshi A. Blockchain technology and its role in enhancing supply chain integration capability and reducing carbon emission: A conceptual framework. Sustainability. 2020 Dec 17;12(24):10550.
4. Chin T, Shi Y, Singh SK, Agbanyo GK, Ferraris A. Leveraging blockchain technology for green innovation in ecosystem-based business models: a dynamic capability of values appropriation. Technological Forecasting and Social Change. 2022 Oct 1;183:121908.
5. Wang Z, Zheng Z, Jiang W, Tang S. Blockchain-enabled data sharing in supply chains: Model, operationalization, and tutorial. Production and Operations Management. 2021 Jul;30(7):1965-85.
6. Ma X, Yuan H, Du W. Blockchain-Enabled Construction and Demolition Waste Management: Advancing Information Management for Enhanced Sustainability and Efficiency. Sustainability. 2024 Jan 14;16(2):721.
7. Bhubalan K, Tamothran AM, Kee SH, Foong SY, Lam SS, Ganeson K, Vigneswari S, Amirul AA, Ramakrishna S. Leveraging blockchain concepts as watermarkers of plastics for sustainable waste management in progressing circular economy. Environmental Research. 2022 Oct 1;213:113631.
8. Gómez-Goiri A, Gutierrez-Aguero I, Garcia-Estevez D. Leveraging Blockchain Usage to Enhance Slag Exchange. Applied Sciences. 2024 Jul 18;14(14):6243.
9. Yadav A, Shivani S, Manda VK, Sangwan V, Demkiv A. Blockchain technology for ecological and environmental applications. Ecological Questions. 2024 Jul 22;35(4):1-20.
10. Kumar NM, Chopra SS. Leveraging blockchain and smart contract technologies to overcome circular economy implementation challenges. Sustainability. 2022 Aug 2;14(15):9492.
11. Mohamed SK, Haddad S, Barakat M, Rosi B. Blockchain technology adoption for improved environmental supply chain performance: The mediation effect of supply chain resilience, customer integration, and green customer information sharing. Sustainability. 2023 May 11;15(10):7909.
12. Erri Pradeep AS, Yiu TW, Amor R. Leveraging blockchain technology in a BIM workflow: A literature review. InInternational Conference on Smart Infrastructure and Construction 2019

(ICSIC) Driving data-informed decision-making 2019 (pp. 371-380). ICE Publishing.
13. Rejeb A, Keogh JG, Simske SJ, Stafford T, Treiblmaier H. Potentials of blockchain technologies for supply chain collaboration: a conceptual framework. The International Journal of Logistics Management. 2021 Jul 22;32(3):973-94.
14. Balcerzak AP, Nica E, Rogalska E, Poliak M, Kliještik T, Sabie OM. Blockchain technology and smart contracts in decentralized governance systems. Administrative Sciences. 2022 Aug 4;12(3):96.
15. Kouhizadeh M, Sarkis J, Zhu Q. At the nexus of blockchain technology, the circular economy, and product deletion. Applied Sciences. 2019 Apr 25;9(8):1712.
16. Tawiah V, Zakari A, Li G, Kyiu A. Blockchain technology and environmental efficiency: Evidence from US-listed firms. Business Strategy and the Environment. 2022 Dec;31(8):3757-68.
17. Njualem LA. Leveraging blockchain technology in supply chain sustainability: a provenance perspective. Sustainability. 2022 Aug 24;14(17):10533.
18. Capossele A, Gaglione A, Nati M, Conti M, Lazzeretti R, Missier P. Leveraging blockchain to enable smart-health applications. In2018 IEEE 4th International Forum on Research and Technology for Society and Industry (RTSI) 2018 Sep 10 (pp. 1-6). IEEE.
19. Tsolakis N, Schumacher R, Dora M, Kumar M. Artificial intelligence and blockchain implementation in supply chains: a pathway to sustainability and data monetisation?. Annals of Operations Research. 2023 Aug;327(1):157-210.
20. Boumaiza A, Maher K. Leveraging blockchain technology to enhance transparency and efficiency in carbon trading markets. International Journal of Electrical Power & Energy Systems. 2024 Nov 1;162:110225.
21. Guggenberger T, Schweizer A, Urbach N. Improving interorganizational information sharing for vendor managed inventory: Toward a decentralized information hub using blockchain technology. IEEE Transactions on Engineering Management. 2020 Apr 22;67(4):1074-85.
22. Hong Z, Xiao K. Digital economy structuring for sustainable development: the role of blockchain and artificial intelligence in improving supply chain and reducing negative environmental impacts. Scientific Reports. 2024 Feb 16;14(1):3912.
23. Hakak S, Khan WZ, Gilkar GA, Haider N, Imran M, Alkatheiri MS. Industrial wastewater management using blockchain technology: Architecture, requirements, and future directions. IEEE Internet of Things Magazine. 2020 Jun 25;3(2):38-43.
24. Lal A, You F. Climate concerns and the future of nonfungible tokens: Leveraging environmental benefits of the Ethereum Merge. Proceedings of the National Academy of Sciences. 2023 Jul 18;120(29):e2303109120.
25. Shen M, Duan J, Zhu L, Zhang J, Du X, Guizani M. Blockchain-based incentives for secure and collaborative data sharing in multiple clouds. IEEE Journal on Selected Areas in Communications. 2020 Apr 17;38(6):1229-41.
26. Shen M, Duan J, Zhu L, Zhang J, Du X, Guizani M. Blockchain-based incentives for secure and collaborative data sharing in multiple clouds. IEEE Journal on Selected Areas in Communications. 2020 Apr 17;38(6):1229-41.
27. M. Bublitz F, Oetomo A, S. Sahu K, Kuang A, X. Fadrique L, E. Velmovitsky P, M. Nobrega R, P. Morita P. Disruptive technologies for environment and health research: an overview of artificial intelligence, blockchain, and internet of things. International journal of environmental research and public health. 2019 Oct;16(20):3847.
28. Uddin MA, Stranieri A, Gondal I, Balasubramanian V. Blockchain leveraged decentralized IoT eHealth framework. Internet of Things. 2020 Mar 1;9:100159.
29. Nawari NO, Ravindran S. Blockchain and the built environment: Potentials

and limitations. Journal of Building Engineering. 2019 Sep 1;25:100832.
30. Alsamhi SH, Myrzashova R, Hawbani A, Kumar S, Srivastava S, Zhao L, Wei X, Guizan M, Curry E. Federated learning meets blockchain in decentralized data-sharing: Healthcare use case. IEEE Internet of Things Journal. 2024 Feb 19.

CITE AS: Anguzu Rashid and Ariowachukwu Divine Sopruchi (2024). Leveraging Blockchain Technology for Enhanced Data Sharing in Environmental Science. IDOSR JOURNAL OF COMPUTER AND APPLIED SCIENCES 9(2):26-35. https://doi.org/10.59298/JCAS/2024/92.2635