Edited by Hamed Taherdoost,
Mohsen Saeedi and Aydin Shishegaran

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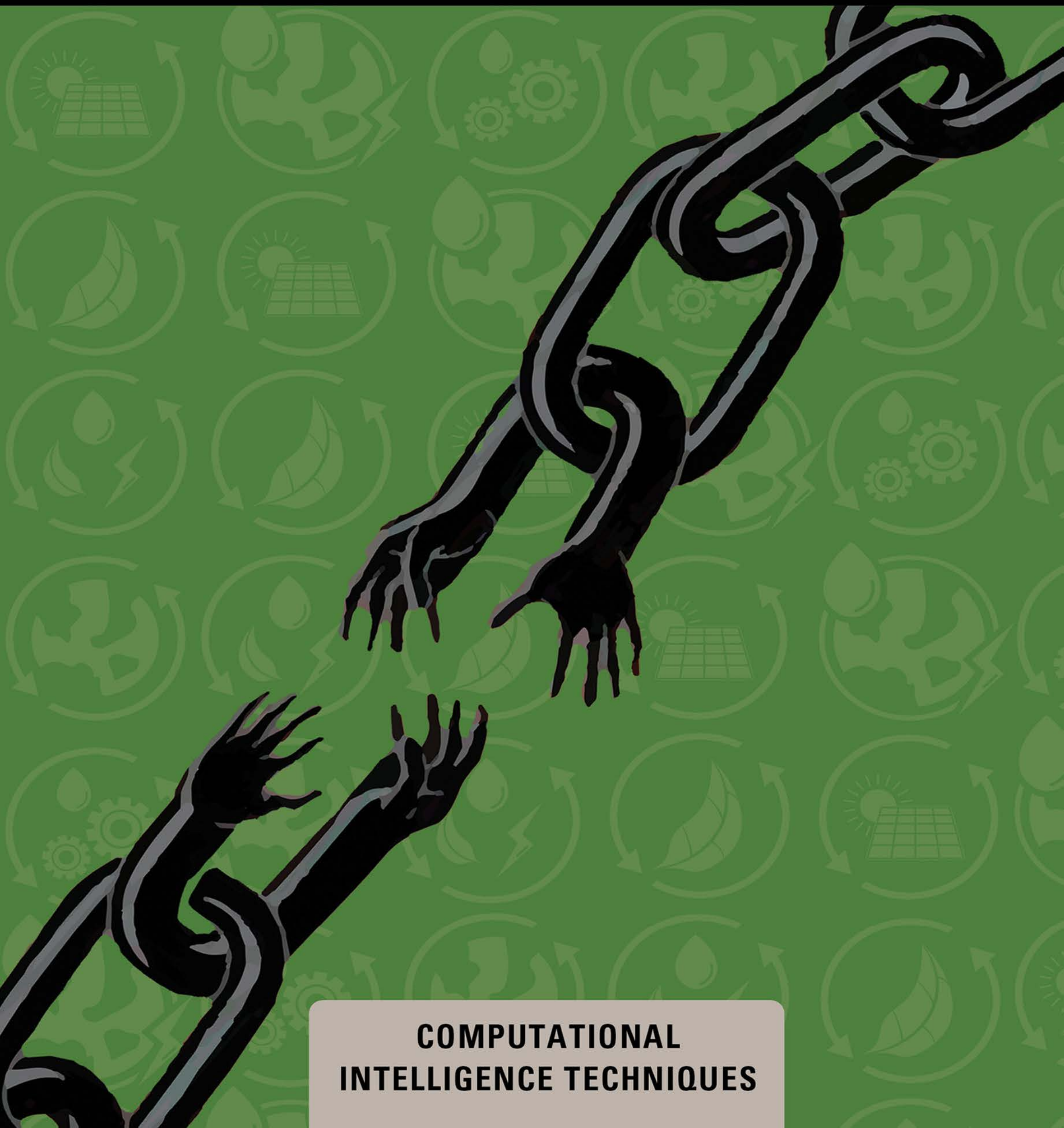
Applications of Blockchain and Computational Intelligence in Environmental Sustainability



COMPUTATIONAL INTELLIGENCE TECHNIQUES

Applications of Blockchain and Computational Intelligence in Environmental Sustainability

The book explores the complex correlation between blockchain technology and sustainability, demonstrating the potential of cutting-edge computational intelligence methods to address critical environmental and societal challenges. It provides a comprehensive analysis of the most recent developments in research, innovative approaches to design, and real-world implementations, establishing a strategic plan for the incorporation of blockchain technology into environmentally friendly solutions.

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Preface

In a world increasingly driven by technology and a pressing need for sustainable solutions, the intersection of blockchain technology and sustainability represents a beacon of hope and innovation. This book delves into this dynamic interplay, offering a comprehensive exploration of how blockchain technology can be and is being leveraged to foster sustainable practices across various sectors.

PURPOSE AND SCOPE

The primary aim of this book is to provide readers with an in-depth understanding of the potential and practical applications of blockchain technology in promoting sustainability. Through detailed chapters, we explore a range of topics from the foundational principles of blockchain and smart contracts to their applications in renewable energy, agriculture, and circular economies. Each chapter is meticulously structured to cover theoretical aspects, real-world applications, challenges, and future outlooks.

STRUCTURE OF THE BOOK

The book is organized into nine chapters, each focusing on a distinct aspect of blockchain technology and its relevance to sustainability:

1. **Introduction to Blockchain and Sustainability**: This chapter sets the stage with an overview of blockchain technology, its key features, and its potential to enhance sustainability through transparency, traceability, and security.
2. **Blockchain in Environmental Conservation:** This chapter discusses how blockchain technology, known for underpinning cryptocurrencies like Bitcoin, is revolutionizing environmental conservation. By providing decentralized, transparent ledgers, blockchain enhances sustainable practices, carbon trading, resource management, wildlife protection, and renewable energy initiatives. As the technology develops, its applications in environmental conservation and broader industrial and societal changes are expected to grow, offering innovative solutions to significant environmental challenges.
3. **Smart Contracts and Sustainable Business Models**: This chapter examines how smart contracts can revolutionize business models by embedding sustainability into their core operations, highlighting the challenges and opportunities for innovation.
4. **Blockchain Integration in Renewable Energy**: This chapter explores the applications of blockchain in the renewable energy sector, emphasizing the benefits and hurdles in integrating these technologies to foster a sustainable energy future.

5. **Sustainable Agriculture and Food Supply Chains**: This chapter explores the critical issues facing food supply chains and how blockchain can address these challenges, from resource optimization to minimizing emissions.
6. **Blockchain Applications in Sustainable Agriculture and Food Systems**: Building on the previous chapter, this chapter provides case studies from various countries, showcasing the practical use of blockchain in enhancing agricultural sustainability.
7. **Blockchain and Circular Economy**: This chapter discusses the principles of a circular economy and the transformative role blockchain can play in facilitating sustainable economic practices.
8. **Sustainability Reporting and Transparency**: The focus here is on how blockchain can enhance transparency and accountability in sustainability reporting, offering a foundation for future advancements in this area.
9. **Blockchain for Carbon Credits and Emissions Reduction**: This chapter addresses the integration of blockchain in the carbon credit market, exploring how this technology can streamline carbon trading and support global emissions reduction efforts.

AUDIENCE

This book is intended for a diverse audience including scholars, industry professionals, policymakers, and anyone interested in the potential of blockchain technology to drive sustainable development. Whether you are a technologist seeking to understand sustainability applications, a business leader looking to integrate blockchain into sustainable practices, or a researcher exploring new frontiers, this book offers valuable insights and practical knowledge.

ACKNOWLEDGMENTS

The creation of this book has been a collaborative effort, drawing on the expertise and contributions of numerous individuals. We extend our gratitude to the researchers, practitioners, and experts who have provided their insights and to the academic and professional communities that continue to push the boundaries of what is possible in the realms of blockchain and sustainability.

We hope this book serves as a valuable resource and inspiration for all who read it, fostering a deeper understanding and appreciation of the profound impact that blockchain technology can have on our journey toward a more sustainable future.

About the Editors

Dr. Hamed Taherdoost is an award-winning leader in research and development, recognized for his significant contributions across industry and academia. He is the founder of Hamta Business Corporation, Associate Professor and Chair of RSAC at University Canada West, and Director of R&D at Q Minded. With over 20 years of experience, Dr. Taherdoost has worked in global companies based in Cyprus, the UK, Malta, Iran, Malaysia, and Canada, and has been instrumental in various industry projects across healthcare, transportation, residential, oil and gas, and IT sectors. Additionally, he has served as a technical and technology consultant for numerous companies, providing expert guidance and mentorship.

In academia, Dr. Hamed Taherdoost has held teaching roles across Southeast Asia, the Middle East, Europe, and North America since 2009. Actively engaged in academic publishing and advisory roles, he serves on the editorial boards of prestigious journals from leading publishers. His academic leadership extends to organizing and chairing numerous workshops and conferences, as well as contributing to scientific and technical committees for over 300 international conferences worldwide.

Dr. Taherdoost has a prolific publishing record, with over 300 scientific articles in top-tier journals and conference proceedings. His work is widely recognized, with a strong citation impact reflecting in a high h-index, and his contributions span book chapters, edited volumes, and authored books focusing on technology and research methodology. His research accomplishments have earned him a place among the top 10 SSRN Business Authors from 2022 to 2024, as well as repeated listings on the Stanford-Elsevier compilation of the world's top 2% scientists from 2021 to 2024.

He currently serves as Editor for the Routledge (Taylor & Francis Group) Book Series *Mastering Academic Excellence: Research, Teaching, Learning, and Publishing* and is Editor of several prominent journals, including the *International Journal of Information Technology Project Management* (IGI), *EAI Endorsed Transactions on Scalable Information Systems*, *Journal of Blockchain* (MDPI), and *International Journal of Data Mining, Modelling, and Management* (Inderscience). Dr. Taherdoost is also an Associate Editor of *Frontiers in Research Metrics and Analytics*. Dr. Taherdoost is a GUS Fellow at the GUS Institute | Global University Systems and holds senior memberships in IEEE and Working Group Member of the International Federation for Information Processing (IFIP) TC 11.

Dr. Mohsen Saeedi is Professor of Sustainability at the University of Canada West. With over 20 years of experience in academia, he specializes in sustainability, environmental management, and technology, having contributed to both research and curriculum development in Canada and Iran. He has served in prominent roles, including Dean of the School of Civil Engineering at the Iran University of Science and Technology. His research spans sustainable development and environmental pollution, environmental management, and management systems, with numerous publications in peer-reviewed journals. He also serves as an associate editor for international sustainability-focused journals. As an editor of this book, he brings his expertise to the intersection of blockchain technology and sustainable practices.

Aydin Shishegaran is Lecturer at IU International University of Applied Sciences and another institute in Germany. He got his first PhD in 2022 from Iran University of Science and Technology and his second PhD accepted in 2024 at Bauhaus University Weimar. However, he has published over pre-reviewed papers in high-ranked journals and has 798 citations and has also reviewed 265 manuscripts for high-ranked journals. He is an editor in *Journal of Mechatronics and Artificial Intelligence in Engineering* since 2020. Furthermore, in 2021, he is a guest editor in Sustainability at MDPI. In 2020, he published a new MCDA method for sustainable evaluation. In 2023, 2023, and 2024, he published four new ML methods in high-ranked journal, in which one of them is the most cited paper in computers and structures.

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1 Introduction to Blockchain and Sustainability

Hamed Taherdoost and Mohsen Saeedi

1.1 INTRODUCTION

In November 2022, the world's population reached eight billion people. Assuming that the population growth rate will continue to decline, according to the medium scenario, the global population is still expected to reach 8.5 billion by 2030, 9.7 billion by 2050, and 10 billion to 12.5 billion by 2100 (Nationen, 2022). This growth has been and will remain the main driver for our unsustainable present and future because the population drives consumption. The amount of consumption per person is also growing.

Several long-term environmental problems are now showing up on a global scale, including pollution of the environment, climate change, loss of biodiversity, deforestation, etc. (Maximillian et al., 2019; Singh & Singh, 2017). The fast growth and dissemination of information and communication technologies have exacerbated the so-called Great Acceleration, which began in the 1950s (Brauch, 2021; Rosa, 2013; Steffen et al., 2015).

In 2012, at the World Conference on Sustainable Development in Rio, the UN member states developed a new set of goals called Sustainable Development Goals (SDGs) to be achieved over 15 years from 2015 to 2030. The SDGs were launched in 2015 after getting inputs, feedback, and views from citizens, civil society organizations, scientists, academics, and the private sector from around the globe. Among 17 SDGs, there are social, economic, and environmental goals. There are a few targets under each goal and some indicators for evaluation.

In 2023, the statistics division of UN DESA (United Nations Department of Economics and Social Affairs) conducted and published a progress assessment. The SDG progress evaluation showed significant challenges. Data analysis from the latest global-level data and custodian agencies revealed concerning results. Among the assessable targets, only 15% were on track to be achieved by 2030. Forty-eight percent of the targets showed moderate or severe deviations from the desired trajectory. Moreover, over 37% of these targets have experienced no progress or regressed below the 2015 baseline values (United Nations Economic and Social Council, 2020).

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1.1.1 Sustainable Development and Blockchain

In recent years, "sustainable development" has emerged as a buzzword in the international development sector, with different players applying it in various ways (Horner, 2020; Ogbuoji & Yamey, 2019; Salifu & Salifu, 2024). Beyond environmental sustainability, sustainable development encompasses a multifaceted notion. It also includes aspects of institutions, society, and the economy (Guerrero et al., 2023; Koch et al., 2021). According to Shepherd et al. (2016) and Scopelliti et al. (2018), the concept is likely to remain the dominant development paradigm for a considerable amount of time because it has garnered the kind of widespread attention that other development concepts have not.

Some societal domains highlight the relevance of sustainability in scholarly works. For example, according to the Brundtland Report, sustainability is achieving a state where current and future needs are met through investments, resource exploitation, technological development, and institutional changes (Hariram et al., 2023). This definition highlights the importance of looking at sustainability from a long-term perspective. The necessity for sustainable practices in economic activities is further emphasized by the Cambridge Institute for Sustainability, which emphasizes the creation of "Competitive Sustainability" as a means to a robust recovery and dynamic growth (Javanmardi et al., 2023).

To promote sustainability, individual actions are crucial. People can help lessen their impact on the environment and promote a culture of sustainability by making small changes in their everyday routines. Eating a plant-based diet, reducing water consumption, and switching to more environmentally friendly modes of transportation like biking or public transportation are all examples of what can be done to help the environment (Böhme et al., 2022; Seyfang, 2013).

Societal norms and values also impact sustainable practices. By encouraging a worldview that treats the universe as a machine and places a premium on prediction and control rather than comprehending complicated interactions and relationships, the prevailing social paradigm – also known as the mechanistic paradigm – can impede sustainable lifestyles. In contrast, a relational paradigm can aid in developing sustainable lifestyles by investigating and organizing relational patterns, emphasizing the interdependence of ecological and human systems (Böhme et al., 2022). Sustainable development in all its forms is essential to combating global issues like poverty, inequality, climate change, and environmental degradation, and the SDGs give a blueprint for doing just that (Laininen, 2019).

Innovative technology abounds, giving businesses a leg up in the marketplace (Kamble et al., 2021). The rapid pace of technological development has far-reaching consequences for businesses' environmental consciousness and long-term viability in society (Kouhizadeh & Sarkis, 2018). Blockchain, a distributed ledger technology, is one of the most recent innovations that has a major impact on sustainability (Kouhizadeh & Sarkis, 2018; Taherdoost & Madanchian, 2023).

A distributed ledger system that links data in chronological order within blocks is known as blockchain technology. It has undergone substantial evolution over the years and guarantees data anonymity. Since its introduction by "Satoshi Nakamoto" in a paper about a decentralized Bitcoin system, blockchain technology has expanded to accommodate many more uses. It is currently focusing on applications that need high performance and reliability on a large scale (Dong et al., 2023; Habib et al., 2022; Liu et al., 2023).

One-way blockchain technology works are by eliminating the need for a middleman by enabling numerous nodes to validate transactions in real time. Several industries, including energy, logistics, and education, have begun to use this technology, demonstrating its adaptability and the breadth of its possible influence (Chen et al., 2018; Habib et al., 2022).

Blockchain technology's key features are decentralization, immutability, transparency, and security. This could cause a sea change in many sectors and turn the Internet we know today into an "Internet of Value." There are far-reaching consequences for 21st-century education, corporate operations, and governance due to blockchain's immutable distributed ledger system, which guarantees the authenticity of transactions (Chen et al., 2018; Dong et al., 2023; Kimani et al., 2020).

1.2 BLOCKCHAIN TECHNOLOGY

Blockchain is a distributed ledger that keeps track of transactions across multiple computers in an immutable, decentralized manner. Fifth, computational logic, transparency with pseudonymity, irreversibility of records, peer-to-peer transmission, and distributed databases form its basis (Treiblmaier, 2020).

A distributed ledger system, or blockchain, is a shared database that keeps track of every transaction made by any user and ensures that every user has a copy of the ledger, thanks to replication. A blockchain or hash chain is formed when each block includes a hash value of the header from the block before it, and each block contains a transaction. You can distinguish permissioned blockchains from permissionless ones by looking at how each member's identity is defined in the network (Justinia, 2019).

Blockchain technology's decentralized design ensures that no one entity controls the data and that everyone can independently verify transactions (Namasudra et al., 2021). Everyone with access to the blockchain can see all transactions, thanks to the transparency with pseudonymity principle, and users can choose to be identified by a unique 30-plus character alphanumeric address or by providing proof of identity to others. Every block in a blockchain stores the hash value of the header from the block before it, ensuring that records cannot be changed after a transaction has been entered, according to the principle of irreversibility of records. Blockchain transactions can be effectively programmed using the computational logic principle (Treiblmaier, 2020).

Several industries stand to benefit from blockchain technology's revolutionary potential (Wijesekara & Gunawardena, 2023). These include education, healthcare and biomedical sciences, and knowledge-defined networking. It can be utilized to establish a fair system for evaluating the learning process and its results, guaranteeing their authenticity and offering a reliable method for investing in talent. Concerns about privacy and security and the system's inherent complexity are possible downsides of using blockchain technology in the classroom (Chen et al., 2018).

1.3 KEY FEATURES AND COMPONENTS OF BLOCKCHAIN SYSTEMS

1.3.1 Decentralization

Distributed ledger technology underpins blockchain's decentralization efforts (Howell & Potgieter, 2019). This technology also underpins data verification, storage, maintenance, and transmission. The foundation of this system is a network of linked nodes, each of which verifies the integrity of the data stored, thereby maintaining a full record of all transactions that have occurred (Paik et al., 2019; Xu et al., 2019).

Instead of relying on centralized organizations, mathematical methods are used to build trust between distributed nodes. All nodes in the network contribute to the upkeep of consensus algorithms, which allow it to happen. To validate transactions and solve mathematical problems, Bitcoin, for instance, employs a verification mechanism known as PoW. Miners compete with one another. However, the certifier on Ethereum must demonstrate ownership of a specific amount of cryptocurrency using PoS (Hoffman et al., 2020).

Among the many advantages of decentralization are transaction trustworthiness, transparency, and security improvements. It also makes it possible to build DApps and DAOs, autonomous applications, and organizations without a central authority to function (Singh & Kim, 2019). Scalability, energy consumption, interoperability, and regulatory concerns are some challenges that decentralization can bring (Hoffman et al., 2020).

The promise of blockchain technology for decentralization in several domains, such as the Internet of Things (IoT), edge networks, and the IoV, has been the subject of multiple studies (Gadekallu et al., 2021; Prabadevi et al., 2021; Taherdoost, 2023). Chowdhury et al. (2020) offered a broad overview of blockchain technology for Internet decentralization without going into specifics.

1.3.2 Immutable Ledger

The immutable ledger is a crucial component of blockchain technology that guarantees data cannot be deleted or altered once recorded. Each transaction is validated and verified before being added to the blockchain, achieving this feature through a consensus mechanism (Yadav et al., 2022). Cryptographic hash functions generate a distinct digital fingerprint for every data block in the blockchain, making the ledger immutable (Rahardja et al., 2021). The hash function connects each block in the blockchain to the one before it, ensuring no changes can be made to the chain without changing the hash value of each block that follows it (Komalavalli et al., 2020; Politou et al., 2019). Because of this, the data recorded on the blockchain cannot be altered, and it is completely secure.

Blockchain technology can revolutionize the financial industry by making transactions more efficient and less fraud-prone (Khadka, 2020; Kimani et al., 2020). Blockchain technology can improve data security and patient privacy in healthcare by building a decentralized and secure system for storing and sharing electronic health records. To improve supply chain efficiency and decrease the likelihood of fraud, supply chain managers can employ blockchain technology to build a transparent and immutable system for monitoring the flow of products and goods (Dutta et al., 2020; Shahnaz et al., 2019). The immutability of blockchain data makes it an ideal system for recording transactions and other events. Industries like healthcare, government, and finance, where the security and integrity of data are paramount, can benefit greatly from this (Dutta et al., 2020).

1.3.3 Consensus Mechanisms

Consensus mechanisms ensure that every node in a distributed network agrees on the current ledger (Lashkari & Musilek, 2021). They allow for decentralized decision-making and secure the network, making them the backbone of blockchain systems. This text will outline blockchain consensus mechanisms, discussing their uses, classification, and significance.

Crash fault tolerance (CFT) and byzantine fault tolerance (BFT) are two general categories into which consensus mechanisms fall (Yao et al., 2021; Zhou et al., 2023), as classified in Figure 1.1. While BFT mechanisms deal with more complicated malicious activities like purposefully delaying messages and misleading other nodes, CFT mechanisms handle non-malicious faults like delays and losses.

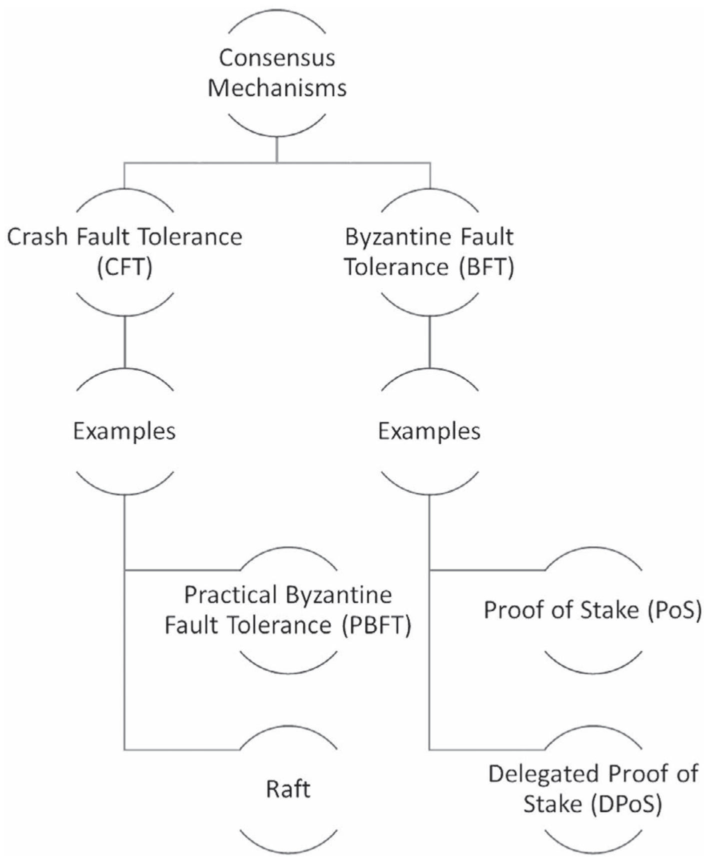

FIGURE 1.1 Consensus mechanisms.

1.3.4 How CFTs Reach Consensus

Non-Byzantine faults are the most prevalent and fundamental distributed system failure, and CFT consensus mechanisms are built to handle them. Some examples of CFT consensus mechanisms include the state machine replication algorithm Practical Byzantine Fault Tolerance (PBFT) (Khan et al., 2022; Zhou et al., 2023), which fixes the original Byzantine Fault-Tolerant algorithm's inefficiency, and the simplicity and reliability-focused consensus algorithm Raft (Zhou et al., 2023).

1.3.5 The Mechanisms for BFT Consensus

Deliberate delays and deceit are examples of more sophisticated malicious actions that BFT consensus mechanisms tackle. Proof of stake (PoS) (Dong et al., 2023; Sayeed & Marco-Gisbert, 2019; Zhou et al., 2023) is one example of a BFT consensus mechanism; it uses stakeholders' stake in the network to select validators; another variation of PoS, delegated proof of stake (DPoS) (Sayeed & Marco-Gisbert, 2019), uses stakeholders' election of delegates to validate transactions; and both use consensus mechanisms.

1.4 SMART CONTRACTS

To facilitate the verification and enforcement of contract negotiations and execution, a digital protocol called a "smart contract" has been developed. Without intermediaries, smart contracts allow for the execution of trustworthy transactions (Wang et al., 2019; Zheng et al., 2020). These deals cannot be undone and can be tracked. A "smart contract is a set of promises specified in digital form, including the protocols within which the parties execute those promises" (Szabo, 1997).

Reduced transaction costs, enhanced security, and increased efficiency are just a few benefits of smart contracts over conventional contracts. Smart contracts automate the execution of contract terms, reducing transaction costs by eliminating intermediaries. Further, a decentralized blockchain network is used to store smart contracts, which makes them more secure and less susceptible to fraud or manipulation. On top of that, smart contracts can cut down on processing and enforcement time and effort, which greatly improves contract execution efficiency (Cheng et al., 2024).

Several problems with smart contracts must be resolved before they can be used, including security, privacy, legal, and performance concerns. Due to a re-entrance vulnerability, the Decentralized Autonomous Organization (DAO) smart contract was the victim of a notoriously malicious attack in 2016 that caused a loss of US$50 million. Another major concern is privacy since smart contracts are published on a blockchain network, which could expose sensitive information. There is a great deal of worry about smart contract legality since this concept still needs to be better defined in many jurisdictions. Smart contracts must be widely adopted, but their performance has significant challenges, such as gas costs and scalability (Khan et al., 2021).

Several exciting developments may soon be coming for smart contracts, which bodes well for their future. Data science smart contracts, which use AI and ML, are believed to greatly enhance smart contracts' functionality and efficiency (Badruddoja et al., 2021). More complicated and dynamic contract structures should be possible once game theory is integrated into smart contracts. Energy management and operations, renewable energy exchange, and peer-to-peer energy trading are some of the possible uses of smart contracts in the energy sector, which is anticipated to experience substantial growth shortly. To enable decentralized and automated processes, several blockchain platforms use smart contracts. A groundbreaking platform, Ethereum, introduced smart contracts, which allowed for the transparent and trustless execution of code in a variety of contexts, including decentralized finance (DeFi) and non-fungible tokens (NFTs) (Vionis & Kotsilieris, 2023).

1.5 CRYPTOGRAPHIC SECURITY

The safety and efficiency of blockchain systems rely heavily on cryptographic methods. Digital encryption, the backbone of blockchain technology, guarantees user data and transaction records' authenticity, integrity, and secrecy. Blockchain systems primarily employ cryptographic methods such as digital signatures, asymmetric cryptosystems, and hash functions. Secure data blocks and a tamper-evident chain are created using hash functions, and secure communication and trust between network participants are enabled by asymmetric cryptosystems (Zhai et al., 2019). Digital signatures are utilized to authenticate transactions and guarantee non-repudiation. The data, network, and consensus layers are just a few of the blockchain infrastructure layers that use these cryptographic techniques to guarantee the system's overall security and integrity (Hardjono & Smith, 2019; Paik et al., 2019; Zhai et al., 2019). Blockchain systems that use these cryptographic techniques have enabled it to build decentralized, secure, and transparent platforms for various uses, such as healthcare data management, supply chain management, and financial transactions (Justinia, 2019).

Using a public key and a private key that corresponds to it, public–private key cryptography is essential for securing transactions. The encryption and decryption procedures made possible by this cryptographic system ensure the privacy and authenticity of data transmitted over the internet, allowing for safe and secure communication. A publicly distributed public key allows anybody to encrypt messages in this architecture, but only individuals with the matching private key can decrypt them and view the original content. By utilizing digital signatures, where the sender signs a message with their private key and the receiver verifies its authenticity with the sender's public key, this asymmetric encryption method secures message content and provides authentication. Data privacy and integrity in digital communications can be assured through public–private key cryptography, which allows for secure transactions (Astorga et al., 2022; Kumar & Tripathi, 2020).

Secure and effective data protection is possible with cryptographic methods like searchable encryption and encryption. The rising use of cloud services has made data storage protection in cloud computing an increasingly pressing issue, necessitating the application of these techniques (Hassan et al., 2022). One of the most basic human rights that cryptography helps to safeguard is the right to privacy, which is jeopardized when cloud providers have unfettered access to user data (Limniotis, 2021). To keep people's and businesses' private information safe, it is essential to use cryptographic security measures to safeguard data and stop unauthorized access.

1.6 TRANSPARENCY AND TRACEABILITY

Thanks to blockchain technology, all transactions are recorded on a public ledger, a decentralized and immutable database that anyone in the network can access, which provides transparency (Sedlmeir et al., 2022). Supply chain management, the fashion and textile industry, and food traceability are just a few of the many sectors interested in blockchain technology for its transparency and traceability features (Azevedo et al., 2023; Badhwar et al., 2023; Ellahi et al., 2023; Sedlmeir et al., 2022). While traceability entails knowing where a product came from, how it was processed, and where it is now after delivery, transparency provides relevant, timely, and trustworthy information in both written and verbal forms (Badhwar et al., 2023; Ellahi et al., 2023; Sedlmeir et al., 2022).

To combat problems like product recalls, fraud, gray markets, stolen goods, and counterfeiting, blockchain technology has become an attractive option for supplying secure traceability and control in supply chains (Ellahi et al., 2023; Jabbar et al., 2021). Supply chain trust and traceability can be improved with blockchain technology because of its immutability, transparency, security, and fault tolerance. Some examples of real-world applications of blockchain technology include the mango traceability pilot project that Walmart ran successfully, the food supply chain transparency initiative that IBM spearheaded with Walmart, the diamond provenance tracking system Everledger, and the integration of blockchain technology for free-range chickens and other foods by Carrefour. In addition to automating the management of outstanding invoices in supply chains, smart contracts powered by blockchain technology can handle sales outstanding amounts that exceed the usual credit contract limit (Jabbar et al., 2021). Nevertheless, scalability and interoperability are two of the most important remaining technical and non-technical obstacles to overcome before blockchain technology is widely used in supply chains (Ellahi et al., 2023; Jabbar et al., 2021; Kouhizadeh et al., 2021).

1.7 INTEGRATING COMPUTATIONAL INTELLIGENCE INTO SUSTAINABLE BLOCKCHAIN SOLUTIONS

An area of artificial intelligence known as computational intelligence centers on creating models and algorithms that mimic biological processes. Examples of such systems include fuzzy logic, neural networks, and evolutionary algorithms (Wagner et al., 2022). Complex problems in many fields, such as engineering, healthcare, and education, can be solved using these methods (Hsieh et al., 2022). Computational intelligence can shape blockchain consensus mechanisms, smart contracts, data privacy, and scalability solutions to promote SDGs (Figure 1.2).

Some examples of how computational intelligence is helping out in the classroom include automating tutoring duties for teachers, identifying instances of conflict in collaborative learning, and providing individualized support to students taking online courses. For example, eTeacher is a system that tracks how students are doing in class and creates a profile for each. Based on that profile, the system can tailor its recommendations for readings and exercises to each individual's needs. By developing smart tutoring systems that can adjust to each student's unique requirements and offer constructive criticism, computational intelligence can elevate the standard of education. These systems can bolster group learning by enabling collaborative writing and employing academically productive speech patterns (Zawacki-Richter et al., 2019).

There are several ways in which computational intelligence, specifically AI and ML, can improve blockchain's sustainability. More efficient and environmentally friendly supply chains are possible with the help of AI and blockchain technology, which can increase supply chain visibility, transparency, and product tracing (Charles et al., 2023). Overcoming scalability issues, AI-ML applications can also aid in managing network traffic and completing a high volume of blockchain transactions. Blockchain technology's immaturity, security, and privacy concerns can be addressed through AI, which improves the technology's architecture and overall performance (Olaniyi et al., 2022).

When applied to the setting of smart cities, AI and blockchain have the potential to enhance social, environmental, and economic sustainability. For example, blockchain technology and Internet of Things (IoT) sensors powered by artificial intelligence can facilitate waste collection, disposal, and recycling. To further a nation's pledge to achieve sustainable development goals, blockchain can supply civil engineers with trustworthy big data to enhance urban resources and services (Rejeb et al., 2021).

FIGURE 1.2 Data science for long-term blockchain sustainability.

1.8 SUMMARY

This chapter examines the convergence of blockchain technology and sustainability within the context of global population growth and escalating environmental challenges. The world population reached eight billion in 2022 and is projected to continue increasing, driving greater consumption and exacerbating sustainability issues such as pollution, climate change, and biodiversity loss. The United Nations' Sustainable Development Goals (SDGs), established in 2015, aim to address these challenges through social, economic, and environmental targets set for 2030. However, recent assessments show significant gaps in achieving these goals, with many targets off track or regressing. The chapter explores the broad concept of sustainable development, which includes environmental, institutional, societal, and economic dimensions, emphasizing the importance of long-term planning and individual actions in fostering sustainability. It also highlights the potential of blockchain technology to enhance transparency, accountability, and efficiency in sustainability efforts. By leveraging blockchain's unique features, the chapter suggests innovative solutions to support the SDGs and address complex global challenges effectively.

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