***Blockchain and Sustainable Development: Where Are We Heading for Future Business Practices?***

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*Abstract*

Blockchain, an evolving technology in information recording and management, is believed to revolutionize modern business as it advances functionality and operational value of data usage to ensure programmability, security, anonymity, unanimity, timestamping, immutability, and distribution, while it simultaneously increases data processing transparency and efficiency. This study is important as it aims to offer an inclusive view and strategic reference to field practitioners and cross-sectoral decision makers when the feasibility or adoption of blockchain is considered. It provides fundamental and qualitative analysis covering the main concept of the technology, its theoretical structure and architectural design, the associated costs and perceived benefits, its application across the business field, and blockchain’s potential impact and implication upon sustainable development.

**Introduction**

Blockchain, an emerging technology, is said to create plenteous potential in information management across businesses. Like all industries in their infancies, while receiving growing awareness, skepticism on blockchain along with the accolade has also risen due to the unknowns and uncertainties in its development. Chronically, blockchain technology was originated with the inception of Bitcoin, the first cryptocurrency, in 2008 whilst its fast headway and possibly wide sectoral application instigate business interest and investment. As of today, numerous studies suggest the adoption of blockchain to be extensive across the fields from the hard science such as computing and engineering to the soft or social science covering broad business disciplines, public services, and the health and medical sciences.

From the architectural perspective, blockchain is created under the infrastructure of Distributed Ledger Technology (DLT) which heavily utilizes the cryptography to record and manage all information in a transaction or exchange. It is a system of decentralized database management enabling data access, distribution, validation, and instant update while the trace of data processing is encrypted with the merits of programmability, security, anonymity, unanimity, timestamping, and immutability. The technique of blockchain under DLT therefore organizes the data into ‘blocks’ cryptographically and chronologically in the decentralized network in its main goal of reaching transparency and efficiency.

Given the ongoing development of blockchain technology, this analysis is qualitative aiming to unveil its concept and structure, its costs and benefits, and its sectoral application centered on the business world. It is contributory as facing the pressing call of sustainable development in the 21st-century world economy, the potential impact and implication of blockchain upon sustainability are also explored which has not been discussed elsewhere. The analytical framework is set as follows, Section (I): Introduction; Section (II): Literature Review, followed by Theoretical Architecture of Blockchain in Section (III). Section (IV) synopsizes Blockchain Application in Business. Section (V) delineates Blockchain and Sustainable Development. Section (VI) offers Future Studies and Thoughts, while Conclusion is given in the last section (VII).

**Literature Review**

Blockchain, a novel concept and technology derived from the creation of the first cryptocurrency, Bitcoin, in 2008 has gradually gained business attention and research interest due to its functionality and possibly broad industrial application. Leible et al. (2019), summarizing the primitive design of blockchain outlined by Haber and Stornetta (1991) in early 1990s, suggested it an innovative framework aiming to elevate security, transparency, and efficiency for data organization, processing, storage, and management, while its application in *open science* was claimed to foster intellectual creation, exchange, and dissemination. Chondrogiannis et al. (2022), Shetty et al. (2022), Dimitrov (2019), and Przhedetskiy et al. (2019) analyzed the blockchain application in the healthcare system alleging both blockchains and the smart contracts to be useful and trustworthy which fortify time-efficiency and security in the process of healthcare insurance policy making between the insured and the insurer. Reviewing the existing literature of blockchain used in insurance industry, Kar and Navin (2021) likewise asserted the immutability and cryptography of such technology to be innovative to upgrade the insurance system; nonetheless, the diffusion and adoption of blockchain are presently sluggish given its emerging and somewhat premature industrial status posing likely skepticism. In the study of Stallone et al. (2022), blockchain technology was employed in e-business to enhance targeted digital marketing, securitize digital transactions, improve customer relationship, and increase customer data safety. Asuncion et al. (2021) affirmed that the blockchain system used by the U.S. Department of Defense (DoD) enabled full transparency with necessary privacy protection across the military and its supplier networks, as it also improved institutional efficiency in the military supply-chain planning and management. In business application, blockchain is alleged to “*greatly improve supply chains by enabling faster and more cost-efficient delivery of products, enhancing products’ traceability, improving coordination between partners, and aiding access to financing*” (Gaur and Gaiha, 2020). Equally, Javaid et al. (2021) stressed the potential contribution of blockchain applied in the environment of ‘*Industry 4.0*’, where rapid advancement driving digital transformation in technology and industries changes how we live thanks to increasing interconnectivity, data-driven manufacturing, and smart automation (also see Dhanabalan and Sathish, 2018; Dursun, et al., 2022).

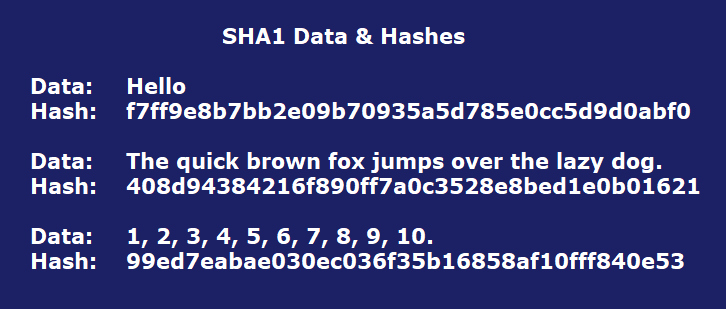
Along with the advent of ‘*Industry 4.0*’, the application of blockchain in financial technology, or popularly known as ‘FinTech’, is believed to be the 21st-century breakthrough in global finance which centers on data science and artificial intelligence (AI). Chang et al. (2020) claimed that wide-range of financial services can potentially be advanced through the use of blockchain to increase financial data security, immutability, and transparency while reaching time-efficiency and strengthening risk management for suspicious financial activities. However, blockchain is neither cheap nor for everyone; of the hardware, it requires substantial capital investment in the system, complex mathematics with high computational power which consumes massive energy covered by extensive electrical supplies. Of the software, it demands a well-trained team to operate the blockchain system so as to ensure financial security and privacy and to serve and provide the clients with well-functioned analytics and user interfaces. Its ultimate goal is to promote product development and quality assurance for financial stakeholders and create a better and trustworthy financial environment (also see Ali, et al., 2019; Wamba and Queiroz, 2020; Nelaturu, et al., 2022)

**Theoretical Architecture of Blockchain**

The Concept of Blockchain

Blockchain is “*a system of recording information in a way that makes it difficult or impossible to change, hack, or cheat the system*”, and “*a shared, [and] immutable ledger that facilitates the process of recording transactions and tracking assets in a business network*” (Euromoney Learning at <https://www.euromoney.com/learning/blockchain-explained/the-risks-with-public-blockchains>; IBM at <https://www.ibm.com/topics/what-is-blockchain>). Technically, all of the transactions (data) on a blockchain are managed by Distributed Ledger Technology (DLT) through an immutable cryptographic signature known as ‘hash’. DLT is a technological infrastructure, or a decentralized database management system, containing protocols for records or data to be simultaneously accessed, shared, validated, and updated across a network of multiple entities or locations (or, the ledgers). The first use of DLT is its application in blockchain following the launch of Bitcoin in 2008 as it then evolves and gains momentous attention in the business world due to its design which allows and endorses programmability, security, anonymity, unanimity, timestamping, immutability, and distribution (Kakavand, et al., 2017; Geroni, 2020; Cryptoticker at <https://cryptoticker.io/en/seven-properties-of-a-distributed-ledger-technology-dlt/>).

Briefly, to describe the ‘hashing’ process, an example of blockchain hashing on Bitcoin is illustrated. Bitcoin uses the ‘Secure Hashing Algorithm 256’ (or, known as SHA-256) which implies a total of 2^256 (that is, 2 to the exponential power of 256 or 1.1 x 10^77) possible hashes (combinations) in the cryptocurrency transaction, making any attempt of attack merely impossible and infeasible. Technically, in the function of cryptographic hash, transactions or data in various lengths are mathematically generated and operated through hashing algorithm with an output, or ‘hash’, under a fixed length. Or, simply put, in the image below, it displays the data and hashes under the structure of SHA1 (or, SHA-1). The complexity of its counterpart at the level of SHA-256 should then be imaginable (see Ray, 2018; Online Hash Crack at <https://www.onlinehashcrack.com/how-to-hashing-in-blockchain-explained.php#:~:text=A%20good%20example%20is%20Bitcoin's,the%20output%20is%2032%20bytes>).



Source: Ray, 2018 at <https://towardsdatascience.com/mechanisms-securing-blockchain-data-9e762513ae28>

In sum, blockchain built on DLT contains the following properties: (1) it is programmable using the ‘smart contract’. A smart contract comprises a transaction protocol (i.e. computer programming) following the contract agreement to legally self-execute, control, record and authenticate a transaction or business event to be trackable and irreversible (IBM at <https://www.ibm.com/topics/smart-contracts>). (2) It is secure as every record or transaction is individually encrypted. (3) The user of blockchain is either kept confidential or pseudonymous unless it is the user’s decision to reveal the identity. (4) It is unanimous as all of the blockchain users agree to the validity of an action or each of the records. (5) Every transaction with respective timestamp is recorded on a block permitting the computing algorithm to check for data validation and verification. (6) It is immutable as any validated transaction made in blockchain cannot be reverted or changed (without leaving a record). (7) It is distributed, as given in the name of DLT, when all users are able to retrieve and see all information in a record (i.e. ledger) for equal info-sharing and complete transparency (Euromoney Learning at <https://www.euromoney.com/learning/blockchain-explained/the-risks-with-public-blockchains>; Cryptoticker at <https://cryptoticker.io/en/seven-properties-of-a-distributed-ledger-technology-dlt/>).

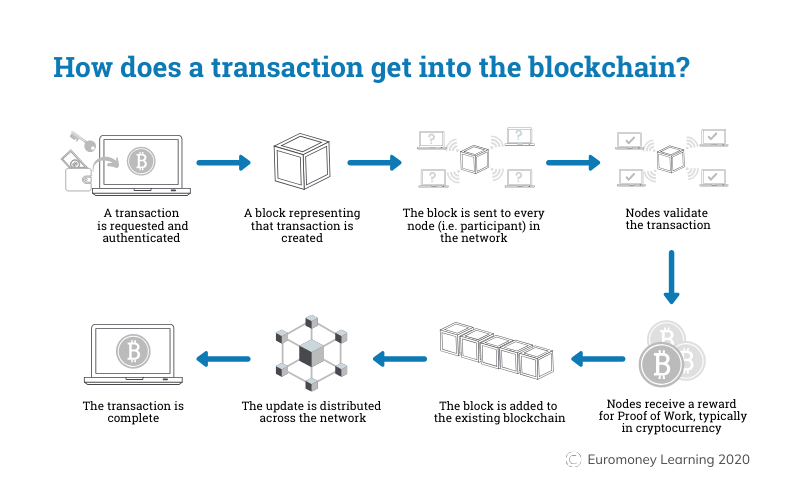
The Rise of Blockchain and Its Establishing Goal

Published in a White Paper titled “*Bitcoin: A Peer-to-Peer Electronic Cash System*” (Nakamoto, 2008), Bitcoin was first introduced in 2008 by Satoshi Nakamoto, a believed pseudonym behind it no one really knows the creator’s true identity. As the best-known cryptocurrency, Bitcoin is a new digital medium of exchange using the encryption techniques with which blockchain technology is invented to process digital transactions securely without the presence or involvement of a central clearing authority. Based on the structure of decentralized ledger (or DLT described above), blockchain enables all transactions of the participants across a peer-to-peer network to transfer funds, settle deals, engage trades, and manage and deliver other digital businesses. Blockchain is therefore considered a novel but key technology to empower modern operation in the digital economy to achieve security, transparency, accuracy, cost and time efficiency, and neutrality of central monetary controls.

In principle, the primary goal of blockchain technology is to reduce risks and cut transaction costs, while staying away from the conventional authoritative controls. Typically, in transaction of a common currency (e.g., U.S. Dollar), almost every monetary activity through the international banking system would leave a trace subject to costly fees and the regulatory governance. The invention of Bitcoin under blockchain instead would permit the person-to-person digital transfer transparently and efficiently with fractional or no fees, while government censorship routed through the banking system could also be evaded (Gladstein, 2018). That is, anything of value including tangible assets like a house or a car and intangible property like patents and copyrights, besides financial instruments, can be traded through blockchain. Hence, facing soaring business potential and gaining awareness and popularity in its application, blockchain presents a fundamental and possibly significant breakthrough to advance modern business operation.

The Process of Blockchain over Transactions – The Flowchart

For a transaction to be conducted via blockchain, ordinarily eight steps are involved. As illustrated in the flowchart below, Step 1 and Step 2 start with the request of a transaction such as trading of a cryptocurrency; a transaction ‘block’ is instantly created. Step 3 follows that the newly created block is sent to the peer-to-peer network consisting of computers called ‘nodes’ across the trade participants. Step 4 contains the process for transaction authentications by the networked nodes. Step 5 continues with the nodes receiving ‘proof of work’ or the ‘consensus mechanism’ to verify the transaction including all relevant transaction information. In Step 6, once verified, the transaction in the block is added to the existing blockchain into the ledger, of which data in the chain are permanent and immutable. Step 7 contains all updates of the transaction to be distributed across the network. Finally, Step 8 completes the transaction (Euromoney Learning at <https://www.euromoney.com/learning/blockchain-explained/how-transactions-get-into-the-blockchain>; PWC at <https://www.pwc.com/us/en/industries/financial-services/fintech/bitcoin-blockchain-cryptocurrency.html#:~:text=Blockchain%20is%20the%20technology%20that,which%20blockchain%20technology%20was%20invented>).



Source: Euromoney Learning, at <https://www.euromoney.com/learning/blockchain-explained/how-transactions-get-into-the-blockchain>

Blockchain’s Benefits and Costs

With respect to key benefits, the merits of data usage under blockchain ensure programmability, security, anonymity, unanimity, timestamping, immutability, and distribution, while simultaneously increasing data processing transparency and efficiency are summarized in the sections above. Normally, blockchain is structured using the member-only network, of which only the subscribed members can access the platform for data activities and transactions. Thus, blockchain is expected to increase the user trust under a protected network. Meanwhile, thanks to the features of record immutability and the process of data validation, blockchain would assume greater security over all transactions. Blockchain technology is believed to increase operational efficiencies. Its distributed ledger sharing records across its members is to assure the transparency and cutting time for unnecessary record reconciliation, while the use of ‘smart contracts’ is also efficient, transparent, and time-saving as all the transactions can be automatically executed and documented without the need of manual processing and logistics. Cost-saving innovation in distributed ledger system of blockchain is deemed to critically restructure the practices of world business especially in markets like finance and insurance potentially and substantially reducing the infrastructure cost between US$15 and $20 billion per year (PWC at <https://www.pwc.com/m1/en/media-centre/articles/blockchain-new-tool-to-cut-costs.html>; Panuparb, 2019).

Nonetheless, no lunch is free. The costs of blockchain are at least twofold, one in the cost of block building and maintenance while the other in the cost of control (attack). First, as blockchain technology is relatively novel and emerging since the early 2010s, its building cost remains rather unclear and somewhat difficult to be estimated. Since its first use in the Bitcoin transaction with the Bitcoin mining, its basic cost has involved both hardware equipment and software applications. Bitcoin mining is a process during which a powerful computing system in a computer is needed to solve complex mathematical problems known as ‘hash’ (the backbone of the blockchain network; the above-described output with a fixed length encrypted over the data inputs). Typically, it requires an individual Bitcoin miner to invest in specialized graphics processing units (GPUs) and other computing tools which can cost $10,000 or more, in consort with costs of electricity and energy running the computation and the cost of broadband Internet. The mining software associated with the cryptocurrency ‘wallet’ for sending and receiving Bitcoin is normally provided by the Bitcoin mine for mostly free of download and use. Since Bitcoin and other cryptocurrencies recently gain their popularities in global financial investment and trade, accompanied by increasing digital-currency market entries by many financial conglomerates, the cryptocurrency mining seems getting more competitive which could induce mining costs to be prohibitively expensive (Duggan, 2022).

The second cost of blockchain is associated with the risk of monopolistically malicious control and attack, especially in the case of public blockchains. In the market of cryptocurrency where public blockchains are used, nefarious coin-miners can act as a group to collectively control mining computing power (or hashes) to influence the validation, addition, or omission of transactions in the chain. Typically, the architecture and protocol of Bitcoin blockchain is designed to have all participants follow the longest chain. If the immoral mining control with fraudulent transactions is substantial or more than 50%, of which its chain length is longer than the genuine one, the so-called ‘51% attack’ would occur. Such scenario realistically happened in 2018 when Bitcoin Gold, the ‘hard fork’ or derived cryptocurrency of Bitcoin, was hacked by iniquitous miners, leading the Bitcoinists to follow the fraudulent chain for their transactions ending up with the loss of over $18 million worth of Bitcoin Gold (Sharma, 2018).

An equally detrimental by-risk resulting from the ‘51% attack’ is called ‘Proof of Stake (PoS)’. In the blockchain technology, a validation process known as ‘consensus mechanism’ is used to keep the distributed database secure and to add new blocks. PoS is the decentralized consensus mechanism evolved from ‘Proof of Work (PoW)’, the original mechanism under the creation of Bitcoin. PoS is deemed to be vulnerable in transaction security due to the blockchain forking (or, the ‘hard fork’), which means a radical change in the blockchain’s protocol making the original block split into two branches. As a result, the validation of transaction becomes hard and indefensible (Euromoney Learning at <https://www.euromoney.com/learning/blockchain-explained/the-risks-with-public-blockchains>; Chandler, 2021).

Lastly, public blockchains are also subject to the risk of ‘double spending’, a situation when a currency is simultaneously spent twice. That is, when a customer spends his/her money to buy one product, he/she concurrently uses the same money to buy another product. In traditional and physical marketplace, double spending is unlikely due to physical verification of the transaction between the buyer and the seller. However, in the digital currency market, double spending may unethically occur when dishonest participants who are familiar with blockchain protocols manipulate fraudulent transactions using the same cryptocurrency for malicious gains (Euromoney Learning at <https://www.euromoney.com/learning/blockchain-explained/the-risks-with-public-blockchains>)

**Blockchain Application in Business**

Given the increasing interest and popularity of cryptocurrency and the widespread electronic (or, e-) and mobile (or, m-) global commerce, blockchain is assumed to facilitate domestic and international finance and business under higher and better security, accuracy, and efficiency, while it faces enormous potential to be applied beyond the world of finance thanks to the continuous advancement in information highway and the Internet technology. Especially under ongoing development and uncertainty of COVID-19, various degrees of computerized or tech-nested activities across all sectors have become essential and preponderated changing the ways how people live, work, and interact. With such unpredictable global challenge somewhat prompting to a ‘new norm’, the development of blockchain opportunely offers an alternative and novel system which complements the traditional ways of life potentially allowing us to move for an advancing future.

Blockchain application to advancing the financial technology, or known as the ‘FinTech’, is deemed feasible and timely in the revolutionary digital economy. Since 1990s, the rise of e- and m-, or known as the web-, commerce has expanded and accelerated the global business into a whole new level. Headed by China while modestly followed by its advanced counterparts such as the U.S., U.K., Germany, and Japan, digital economy centered on the e-payment (known as the ‘digital or e-wallet’) and e-banking systems for exchange of goods and services or the digital currency and financial trading has evolved as a trend, especially among the tech-savvy new millennium generations. Globally, digital economy also excites many privately-held business start-ups valued at US$1 billion or over, known as the ‘unicorns’, to develop and use the electronic system for digital corporate finance and digital equity management, leading a new movement in world business (McKinsey & Company, 2017). In general, from a small scale of personal and household e-finance to a large extent of business and market capitalization, the application of blockchain technology is reckoned to facilitate all kinds of business processes thanks to its recognized levels of security, confidentiality, unanimity, time-efficiency, transparency, and immutability.

In addition to the blockchain-embedded fintech, private industry as a whole also could be beneficiary of blockchain technology. From the logistics of business payment and receipt in international trade and finance, business or homeowner financing in real estate, insured’s submission of claims in insurance, corporate accounting and auditing for regulatory compliance, to capital-raising and asset trading for corporate expansion, or even combating illicit money laundering, blockchain in data management and analytics over these activities is believed to help consolidate transactions and settle deals, expediate trading and clearing processes, reduce man-made errors, and increase transaction transparency, or provide solid evidence for unlawful acts. Alternatively, in other business sectors dealing with supply-chain management, healthcare, transportation, entertaining and media, and energy and utility, blockchain adoption could improve goods’ and services’ distributive logistics and tracking, increase record-safety in one’s medical information and health history, protect user data in transportation, ownership of vessel or vehicle, store and secure intellectual properties, and verify energy and utility consumption (Insider Intelligence, 2022).

Beyond broad business practices, blockchain infrastructure is believed to be widely applicable in both public and private sectors. In the public sector, blockchain can be utilized in education for student data recording and storage. In political election, blockchain can be used to make voting process an easier access with higher security and the resulted vote-counting more accurate and efficient, as the attempt of hacking is presumed improbably achievable when the ‘nodes’, once created, are impossible to be altered. On the other hand, governmental authority can use blockchain to improve identity and record management for its citizens. For example, in the state-controlled tax system, the key advantage of blockchain in data encryption, storage, and privacy-protection would reduce cumbersome tax-filing procedure and ensure tax payers’ tax and public records for cybersecurity.

**Blockchain and Sustainable Development**

With the multifaceted applications of blockchain across businesses in public and private sectors, how can it be used to empower and achieve sustainable development of an economy? First, stated as an overarching goal of United Nations, the concept of sustainable development was defined by the 1987 Bruntland Commission Report as “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*” (<https://en.unesco.org/themes/education-sustainable-development/what-is-esd/sd#:~:text=The%20concept%20of%20sustainable%20development,to%20meet%20their%20own%20needs.%E2%80%9D>). It implies that global resources are scarce, so for any spendthrift and destructive action taken by a generation upon its living environment, it would most likely exhaust and crowd out what should belong to its offspring consequently leaving them worse off. That is, sustainable development needs prompt attention and integrated effort by trans-generations. Only is such joint endeavor endorsed by the mankind of all ages and all races, viability in all lives can be made possible. Over the last few decades, scientific claims of climate change, global warming, food depletion, animal extinction, among others, and the unprecedented COVID-19 pandemic are threats to the global sustainability. They warn us that sustainable development should not be a jargon; as it is not just a mission, it needs an action.

Technically, in the micro-level, distinct business entity and corporation, relatively small organization, and the individual peer-to-peer trader can adopt blockchain to save resources and use or co-share them more strategically and efficiently in production and conducting business. Since such technology uses electronic computation and automation to reduce the reliance on human labor, the processed data and activities could be precise, transparent, and secure avoiding manual errors, while the saved wage and labor costs can be reinvested in physical capitals for production expansion, or to accumulate and advance human capitals to support research and development in blockchain and its relevant technology to foster sustainable development.

Conversely, in the macro-level, large institutions with bountiful resource endowment should lead the initiative in developing sustainable economy under collective structure and effort applied to blockchain technology. For example, governmental leadership in developing blockchain infrastructure providing its citizens with viable identity and record protection is assumed to help reduce information crimes. Continuous development in human resources and talents in data science could promote ‘smart use’ of technology such as blockchain leading to ‘smart-living’ across communities. Alternatively, state-led investment in cyber- and data-security would presumably allow businesses of all kinds to manage their productions and services effectively and cut down operational logistics to reach efficiency in time and costs.

Conventionally, the ideal of sustainability establishes on the pillars of environment, society, and economy. For sustainable development to be feasible, an economy needs to practice sustainable living embracing schemes such as ‘5*r*s’ – resource *r*ecycling, *r*euse, *r*enewal, and *r*ecovery, and wastes *r*eduction. When the economy becomes sustainable, it would most likely encourage and support favorable societal living under the same principles. Then, as both economy and society are viable, the natural environment should be made better off with long-term sustainability. Since blockchain technology is believed to be widely applicable, it should be employed into the three pillars based on the specific needs and its best fit to bring about the collective sustainable development.

**Further Studies and Thoughts**

Although sustainable development is an ultimate goal when it could be achievable with the use of blockchain, it is imperative, yet, to understand that we are living in an imperfect world where nothing comes free. As also revealed in the ‘natural law’ of such imperfection, the opportunity cost of an action would alert us to conduct cost-and-benefit analysis for an optimal outcome. Presently, the blockchain technology has been claimed to produce large and increasing carbon footprint in the case of cryptocurrency, such as Bitcoin, mining (i.e. consuming substantial electricity), which hypothetically hinders the progress of sustainability. Therefore, even if blockchain remains novel in its concept and implementation while its applications across various fields are to be defined and suited. Like all other sciences of which many follow the spirit of Schumpeter’s Gale in ‘*creative destruction*’, further studies and advancement in blockchain will therefore be essential and needed for the goal of sustainability.

**Conclusion**

When innovation becomes a norm in modern business, the ‘*creative destruction*’ known as Schumpeter’s Gale revolutionizes the world of production and consumption with new ideas and applications aiming at productivity growth, increasing consumer welfare, and higher efficiency. Amidst such innovative change, blockchain is an evolving concept on information recording and management attempting to bring the supply and demand a breakthrough, ever since its inception with the birth of Bitcoin, and soon broad attention from industrial and business sectors thanks to its potentially wide applications across fields of the hard and soft sciences. Given its architectural design, blockchain is said to advance the functionality and operational value of data ensuring programmability, security, anonymity, unanimity, timestamping, immutability, and distribution, while it encounters momentous opportunity costs requiring the investment of physical (e.g. blockchain infrastructure) and human (e.g. knowhow and training) capitals as well as facing the consequence of vast energy consumption (e.g. electricity) leading to carbon-footprint hazard to the environment.

Blockchain is believed to be widely applicable across industries. Its business adoption can elongate from production such as smart-manufacturing and supply-chain networking to consumption reflected in business marketing, trade and finance, and other services, along with the use in governmental activity such as election. Although its incessant development seems provoking, it is important for the users to know the capacity and limitation of blockchain in application, its resulted costs and benefits, and the unknows and uncertainties in the course of its development. Thorough understanding of blockchain technology should most likely promote its sectoral use possibly reaching higher productivity and efficiency to attain long-term sustainable development.

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