Discover Sustainability

Review

More-than-human futures for decolonised digital economies: current skepticism, implementations and prospects for the post-anthropocene future

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Abstract
Existing literature predominantly focuses on the technical prospects of blockchain, particularly the possibility of digital economies built from the bottom up and self-governing. However, pressing concerns remain about the sustainability of blockchain applications. Thus, a decolonised, (meaning self-governance) critical transdisciplinary and systemic review of the current implementation of blockchain and how sustainable and supporting it would be in the future is required. The study considers the potential of its adoption and emerging development of applications focusing on social justice and civic good, including the multi-species circular economy project, 'COLife: More-Than-Human Community Codesign Century,' exploring a more-than-human value communication agenda. This review sourced articles from Clarivate and Scopus to investigate the current implementation of blockchain application areas. The review suggests a transition towards the post-Anthropocene, where blockchain presents opportunities for all beings (humans, other species, artificial intelligence, robots) to co-live and co-perform, offering sustainable alternatives to the existing unsustainable extractive and exploitative power dynamic that humans typically exert over other species and technology. For example, pollinators should be paid for their pollinations and for that they could buy a meadow. Our transdisciplinary and systemic critical review shows that some studies denigrate the merits of blockchain applications, mainly because they were written from a reductionist perspective. Our strength lies in boundary critique implementation. We argue the reductionist reviews are inconclusive, while some outcomes were subjective to practical verification and assumption validation. However, they do not consider the complexity of today's world. Lastly, we present the benefits of the drivers for future implementation, showing it outweigh the projected drawbacks and future vision of our COLife project with blockchain.

Keywords More-than-human economy · Decolonisation (self-governance) · Blockchain · Circular economy · Sustainability · Post-anthropocene · Gaia · More-than-human · Biotic and abiotic consciousness

1 Introduction

We would like to highlight the weakness to prior studies that are colonial and anthropocentric. In opposition to this, we would like to present more-than-human perspective with decolonial preview. Unfortunately, not much has been done in this sense. This review is based on 'boundary critique' [1–3], crossing across different scales, disciplines, and systems, decolonising (supporting self-governance experience) the field. The problem with the current critique is that it is based on

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Western reductionist models, not reflecting the complexity of the current world that cannot be controlled by the banking systems, enabling an extractivist approach if we want to avoid extinction and live in an equal society (human and non-human) around the world. Different conversations and communication must exist around our planet and the Gaia [4, 5].

It is essential to delineate existing themes regarding blockchain, sustainability, regenerative communities with circular economy. The advantage of blockchain is that such a token-based economy does not require banking and can be built by communities from the bottom up. It is, therefore, offering a multicentered circular economy. The first concern is the sustainability of blockchain as a technology, specifically its energy consumption. The second is to what extent blockchain—as an emerging technology—supports more sustainable behaviours or systems. Both these themes are relevant to the overarching research question, *'Can blockchain support sustainable development?'* In this section, we look at some examples to clarify this distinction, and define a clear scope of for the research questions. For example, when debating financial products, Caldecott et al. argue that "what" is defined as green or sustainable matters less than "how" those products make the world greener [6]. This study presented the transmission mechanisms available to asset managers and the potential approach to attracting funds via an analysis of five asset classes. The authors offer a template giving insight into sustainable circular finance's embryonic topic, which is tailored towards achieving environmental and climate change sustainability. However, Caldecott et al. [6] indicate this has similar applications in other impact areas. Findings showed that the greatest impact is achieved with sustainability-linked loans and bonds, with hedge fund strategies delivering the least opportunity for impact. Thus, the Caldecott et al. [6] study suggests that an empirical study is needed to affirm the viability of the findings on all the transmission mechanisms to affirm whether these weaken or reinforce real circular economies. A previous study by Uzsoki & Guerdat [7] reviewed over 200 projects in development or active sharing on the coined word '*impact token*'. The authors defined impact token as a blockchain-based solution offering a group of tokens purported precisely to unlock investment for projects that create environmental and social impact. However, the review retrospectively compared previous barriers to impact investing, which does not address the financial implications that would lead to accomplishing the Sustainable Development Goals (SDGs). In the review, impact token, which is a blockchain-based approach to address the barriers to meeting the SDGs, indicates the projects in place and the ones yet to would incentivise behaviours that foster sustainability, enhance the data collection and speed the process of monitoring, reporting and verification process, promote social and financial inclusion across the various stakeholders and strengthen the trust among these parties. Thus, impact token solutions are targeted towards engineering a new solution that draws us closer to the SDGs.

Since the release of the Nakamoto [8] White Paper, "Bitcoin: A Peer-to-Peer Electronic Cash System", its underlying concept of blockchain has become a ground-breaking tool that extends beyond the initial implementation with cryptocurrencies – Bitcoin. However, much focus is centred on cryptocurrency, mainly because of concerns that it continues to support fraud and illegal trading. It should not detract from other types of blockchain implementation, such as smart contracts, digital verification and record keeping. Blockchain, now generally referred to as a distributed ledger technology (DLT) owing to its variation in the application, operates within a decentralised peer-to-peer network in a shared, immutable ledger that supports the process of recording transactions and tracking assets in a business network [9]. Because blockchain has the potential to impact a broad range of domains and processes, it is considered an emerging technology that supports sustainability among other technologies like big data, artificial intelligence and the Internet of Things (IoT) [10].

Recent studies on sustainability have focused on how blockchain addresses sustainability owing to better security, data transparency, and information traceability in a decentralised network without any controlling centre. This approach to sustainability is increasingly preferred over classical technologies. Blockchain technologies have seen applications in other domains besides their original implementation in finance [11], agriculture, maritime transport [12, 13], healthcare [9], smart manufacturing and industry 4.0 [12, 14], energy [15], supply chain and logistics [16], to smart cities [17] and others. In these examples, blockchain results in benefits such as more efficient (faster) processes or fewer people required within the process; things are presumed more efficient by requiring fewer resources. It appears to be a common interpretation of 'sustainable' across the existing implementation.

Though many review studies have been conducted on blockchain and sustainability [15, 17–20], there remains room for further examination of the negative impact of blockchain, the most prevalent being its high energy consumption [18]. However, these assumptions demand justification for further review to affirm the sustainability of blockchain applications. The deployments done in blockchain are mainly experimental, with most lacking evidence-based proof of its application to other domains, excluding the financial domain.

According to the United Nations Environment Program (UNEP), blockchain is a significant force in the battle against climate change. According to experts, this technology is pivotal owing to its innovation. However, the United Nations

Environment Program [21] accept that little attention has been given to its potential in developing countries, mainly owing to the technology's infancy or the projected negative impact of blockchain. However, a new report from the Social Alpha Foundation (SAF) and UNEP seeks to change the narrative regarding the application of blockchain in addressing a challenge like climate change. Several successful implementations of blockchain technology address Sustainable Development Goal 7 on energy in many developed and developing countries, such as Power Ledger in India and Sun Exchange in South Africa. The report also indicates that blockchain has a higher potential in tackling the subject of energy because it addresses the challenges of lack of liquidity, high investment costs, and financing shortfalls. Blockchain can provide a secure, transparent, and firm common ground where purchasers, investors and developers of renewable energy projects can collaborate under established international standards of operation for compliance and due diligence to address this global threat [21]. This report admits the negatives of blockchain; however, it suggests that a new regulatory framework be implemented to curb the high power consumption cost. Several studies have been implemented in Jordan [22, 23] On this premise, a need arises for a critical review of how the present probe into the future of blockchain and its support for sustainability would be cognisant of the present implementation and prospects of embracing this innovation as a solution to several sustainable development goal projects. While this paper does not advocate for techno-messianism—the belief in technology as a means of salvation—it seeks to expand the discourse on blockchain by highlighting how the technology challenges dominant models of commerce and social organization rooted in capitalist and colonial ideologies. These entrenched systems are increasingly recognized as fundamental barriers to the transformative changes necessary for achieving sustainability and equity.

This study was aimed at a critical investigation of sustainable blockchain applications and an analysis of how prospective emerging technology would ensure sustainability and circular economy. Thus, our initial general research question can be refined into three specific research sub-questions as a means of addressing the problem:

Research Question 1: How can blockchain-based autonomous systems, such as distributed ledgers and smart contracts, be designed to enhance sustainability in specific sectors like agriculture and supply chain management while minimizing energy consumption and promoting social equity?

Research Question 2: What social, legal, and economic frameworks are necessary to scale blockchain technologies in developing circular economies, with a focus on regenerative communities and sustainable trade systems?

Research Question 3: How can emerging blockchain-based governance models, such as decentralized autonomous organizations (DAOs) support sustainable development goals in areas like resource management and civic participation?

The study was further sectioned into five parts. Background information is given in Sect. 2. The materials and methods used are described in Sect. 3. Section 4 presents details of the findings. Discussion on the results obtained is presented in Sect. 5, and Sect. 6 concludes the study with future studies.

2 Background

Almost one and a half decades ago, the world saw a revolutionary concept that Nakamoto [8] introduced as a decentralised currency—Bitcoin—supported by a distributed payment scheme. Blockchain technology operates on a peer-to-peer system, enabling a secure exchange or transaction without central authority. Bitcoin, an online payment system, was the first implementation of this concept. All connected nodes in the decentralised networks are called *miners and* are incentivised for their services. The highly attractive aspect of this technology, which has driven diverse implementation in several domains, was its immutability of transactions. Miners in a Bitcoin network automatically employ a cryptographic hash function to sign and validate transactions executed on a network, as these are placed into blocks. A shared public ledger manages all transactions on the Bitcoin network [24] and permits miners to add verified blocks. Although blockchain has gained much ground in the finance domain, it has other highly sought-after non-financial domains such as supply chain [16], energy [25], healthcare ([9, 26]) and e-government [27]. However, the connected network nodes require high computing power, which checks that the ledger is correct and prevents tampering. As Bitcoin has expanded in usage, so has the energy required to sustain it. As blockchain gains in popularity, the increasing energy consumption is now of significant concern, thus bringing into question the environmental sustainability credentials of blockchain as a technology.

Blockchain applications can be observed in several domains promoting social and environmental sustainability. Jiang et al. [10] assert that SDGs aim to become a model for addressing environmental sustainability, social sustainability and economic development. However, the authors admit that the challenge has been the coherence among critical stakeholders in collaborating across transnational levels by acting rationally. Additionally, uniting their diverse interests to deliver a solution for a better society remains challenging for the authors. Achieving social sustainability is heavily linked to most aspects of the SDGs, which are about identifying and managing positive and negative business impacts on people. Blockchain applications have played a crucial role at the heart of this goal. However, blockchain applications have also opened room for other challenges requiring systemic thinking. With the recent global crisis on climate change, among other activities that threaten the environment, there is a call to ensure environmental sustainability. Environmental sustainability is everyone's responsibility to ensure the conservation of natural resources while protecting the global ecosystem to support well-being and health in the present and future. Thus, with the predominant global crisis in several domains, stakeholders' quest remains to address an optimal approach that mainstreams SDGs into their policy formation.

However, the technology has matured, and according to Levis et al. [28], blockchain is destined to be part of the technological solution to social and environmental sustainability problems. Bai and Sarkis [29] shared that investing in blockchain technologies is critical to achieving sustainable development goals, and transparency is a requisite for enhancing the performance of systems. Adding sustainability dimensions further challenges technology investment decisions and evaluations [29]. Badzar [30] asserts that blockchain technology offers transparency to address sustainability challenges in the supply chain domain. A similar view is shared by Tian [31] that blockchain would afford the supply chain traceability system for food safety, which is a secure, reliable, neural, open, and transparent system. Thus, it has become imperative to fully explore blockchain applications' significant potential and influence on sustainability. Though several studies have sought to address how sustainable this technology is, the gap remains: how do we address the issues raised on a blockchain, energy consumption, and climate change challenges, among others?

This paper has provided a new decolonising (informed by self-governance), transdisciplinary and systemic perspective across boundaries on blockchain applications (and their sustainability) via a critical view of recent studies in circular economy. As observed, no single paper affirms that this technology is a radical game-changer but only touches on some negative impacts that must be reconsidered.

3 Materials and methods

This study employed a decolonised, transdisciplinary and systemic critical review to target the nonreductionist objective. It is applying boundary critique. In this context, *decolonization* refers to the dismantling of economic, social, and political systems rooted in colonial ideologies, which continue to perpetuate inequality, exploitation, and environmental degradation. It involves rethinking governance structures to prioritize local knowledge, autonomy, and sustainable practices over exploitative, top-down models imposed by historically dominant powers. *Self-governance* relates to empowering communities to manage their own resources and make decisions free from external control, particularly through decentralized systems like blockchain. These systems enable alternative modalities of transparency, participation, and autonomy in decision-making, promoting inclusive economic and social frameworks that support regenerative practices, equity, and local resilience rather than reinforcing hierarchical power dynamics.

Which facts and norms we should consider depends on how we bound the reference system and vice-versa; as soon as we modify our boundary judgments, relevant facts and norms are likely to change [3]. The 'boundary critique' deepens our understanding of what it means to reflect on boundaries in the context of intervention [1], in this case, project COLife: More-Than-Human Community Codesign [32]. This project covers transdisciplinary and more-than-human communication across the community through assigning value to more-than-humans for their ecosystemic performance, a novel approach to circular economy within a regenerative community. Here, we look at the boundary through Systems Oriented Design as a design object: a negotiation between what is seemingly relevant in the whole landscape, system environment, and the apparent system itself and what is realistic to cope with in the frames of the design process as it develops [2]. Therefore, this transdisciplinary review investigates if blockchain can be sustainable by defining a broader 'boundary' of critique.

Previous studies on blockchain applications and sustainability have only touched on the part of the subject as it relates to a specific domain of application. Others have also used a systematic or tertiary review approach to evaluate the role of blockchain applications in sustainable development. However, there are numerous approaches to review, yet they remain insufficient to address a holistic review of blockchain in ensuring social and environmental sustainability. Hence, employing systemic thinking in this critical review would be ideal as this subject is relevant and demands continuous introspection on its pros and cons since it is not a one-time event.

Systemic thinking would be relevant in such a study as it expounds the range of thinking about the solution to the problem in different and novel ways and opens only to apprehend that there are no perfect solutions to this challenge of ensuring sustainable development but only presents the alternations and the impact they would have on other parts of the global ecosystem. Thus, this would deliver ways to translate the outcome of this 'systemic review' to ensure that SDGs can be achieved using systemic systems thinking. There are several systematic and critical reviews on leveraging blockchain to achieve sustainable development of specific industries, domains or aspects. However, these do not "systemically' consider a critical introspection into the pros and cons of the adoption of blockchain in a holistic manner across different boundaries. It was crucial to prove how blockchain supports sustainability by carefully critiquing recent systematic and empirical evidence in the current literature on blockchain and sustainability.

The paper has aimed to establish the present implementations of blockchain, how they support sustainability, and how they can be adopted for sustainable applications. Hence, the two research questions stated above were used as the metrics for scrutinising the research papers tailored towards blockchain and sustainability leading to circular economy. With the search string 'blockchain AND sustainability' and 'blockchain AND sustainable' on both Scopus and Web of Science, 70 research articles were retrieved. The inclusion criteria considered studies from varying domains of blockchain implementation as a solution for ensuring sustainability, such as agriculture, construction, finance, health, and reviews that have been considered. The exclusion criteria were as follows: (i) the studies focused primarily on blockchain technology without connection with sustainable development goals. (ii) the studies that considered sustainable development with no link to blockchain as a conduit for its future implementation. After scrutinising these articles based on the criteria, 35 papers were considered relevant for the analysis of the study. All the research papers used were from the ranges of 2017 to 2022.

4 Findings

4.1 Current implementations

Our study observed that blockchain application implementation is in the pre-mature stages. However, this has been well embraced in some domains, ranging from finance, governance, supply chain (dominating most blockchain technology research), healthcare, and construction [33–35]. The present communication indicates the benefits, which could be key potentials for driving future innovation and sustainability. Though several studies have expressed several positives, these are common in most current literature [13, 36].

4.1.1 Current positive impact of blockchain implementation on sustainability

4.1.1.1 Improved security and integrity Blockchain offers numerous benefits in ensuring the sustainability of a wide range of applications, particularly for its impact on data integrity and security. In the educational sector, Bucea-Manea-Ţoniş et al. [36] targeted how one could achieve sustainable higher education using blockchain. A mixed approach of content analysis, review, case study, document analysis, and literature review was employed to evaluate how improvement could be realised in higher education. This study expressed the role of blockchain in ensuring sustainability in higher education institutions. With the implementation of blockchain on educational platforms such as Tutellus and Khan Academy, blockchain implementation, according to their student, would provide the best education as the study indicates that a more decentralised, secured system which increased transaction rate while offering data integrity capitalising on the anonymous nature of the transaction of such applications.

Security is one of the top technological factors in a systematic review to classify the sustainable factors for blockchain adoption [37]. Shoker [38] introduces a novel approach to enhancing blockchain security by introducing *proof of eXercise (PoX)* as an alternative solution to blockchain security. In this paper, the challenge with *Proof of Work (PoW)* through the heart of blockchain's maintenance, asset generation and security, yet introduces extra computational costs that further gravitate toward the high energy consumption of blockchain. Thus, based on a previous study by Shoker [38], the heart of blockchain was based on PoW, which has dramatically been criticised for contributing to high energy consumption levels for blockchain applications. However, these studies [36–38] lacked empirical proof and suffered the computational cost of implementation from the proofs [39] that touched on a sustainable payment system considering blockchain interoperability. In this regard, automatic swapping is a recent technology offering increased security compared to the cryptocurrency exchange system.

4.1.1.2 Transparency Transparency has been a known terminology when blockchain implementations are mentioned, particularly leveraging how this technology has seen massive applications in diverse domains. BitLand [40] is a blockchain implementation for land title ownership registration in Ghana. Such innovations have been employed in Georgia [41], Sweden [42], and Honduras [43].

4.1.1.3 Trust Based on our review, one predominant positive impact of blockchain application is trust in its applications in supply chain management [16, 44] and healthcare [24], among others.

Wu and Tran [45] studied an overview of blockchain and the Energy Internet. As part of their study, one of the critical impacts of blockchain technology on sustainability is how its transparency further yields a greater degree of trust among nodes in the blockchain. Trust in a blockchain system is not based on mutual trust among participating nodes but on credible mathematical algorithms. This openness and anonymity by blockchain technology offer flexibility to parties participating in that trust since there is no need to disclose identities once there are established algorithms for secured data exchange.

Jović et al. [12] explored the positive impacts of blockchain application in ensuring sustainable maritime transport. This study reviewed the challenges, barriers, and positive impacts of using blockchain in maritime transport. Issues of how blockchain ensures social and environmental sustainability were considered.

Based on Jović et al. [12] review, one significant finding indicated that blockchain applications established an effective trust for accessing resources, delegation, authentication, provision, and infrastructure. Jović et al. [12] recognised that the smoother information exchange on the peer-to-peer network realised a trustful and auditable peer interaction. Since blockchain has established a notable name in offering transparency and traceability of transactions in a blockchain network, this has been projected to increase the level of trust, enhancing sustainable performance [46].

4.1.1.4 Cost saving Li et al. [47] studied the suitability of blockchain for sustaining E-agriculture. An experiment was done by applying blockchain to five villages with equivalent development rates in China to explore the convenience of sustainable e-agriculture, and data was collected and analysed statistically to validate the suitability. Results from the study compared with traditional agriculture indicate that blockchain brought a 15% increase in convenience and another 25% increase in farmers' sales compared with conventional agriculture. Thus, all indications point to the reduction in farm maintenance costs and crop network development when blockchain is integrated with IoT to automate the management of agricultural equipment, which is the major challenge of agriculture development and extension [13].

4.1.2 Current negative impact of blockchain applications on sustainability

Despite blockchain's achievements, some authors have expressed some opposing environmental sustainability challenges to its implementation. However, it was observed that some of these were, as empirical research has yet to be conducted in some of the domains of blockchain implementation [48]. This study, therefore, analysed how these negative impacts of blockchain applications affect sustainability. A critique of blockchain technology's negative impacts and how most have not been empirically verified is provided.

4.1.2.1 Computational issues Mengelkamp et al. [49] evaluated the feasibility of blockchain as the prime information and communication technology to ensure efficiency and sustainable local energy markets with a blockchain-based smart grid. Thus, the study simulates 100 residential households in a market design and integrates a private blockchain as the primary communication channel, applying the blockchain's distributed and decentralised nature to the local energy market. An economic market evaluation was then conducted to measure the challenges and prospects for implementation. Computational complexity was one of the challenges that negatively impacted the adoption of blockchain. From their evaluation, blockchain miners of the system incur computational costs, which demands that before blockchain is accepted as the leading technology platform for communication and information, further study is necessary to affirm that efficient computational resource utilisation is necessary. This challenge was, however, attributable to the implementation of the *PoW* mechanism, which is highly computationally intensive on the resources used. Though Mengelkamp et al. [50] suggest a future study to propose a *Proof of Identification* (PoI) solution to this challenge, Nguyen et al. (2019) shared that comparatively, the introduction of *Proof-of-Stake* (PoS) has relatively reduced to a nominal state energy consumption rate while increasing the transaction confirmation speed and block generation speed with no hardware requirement. Hence, further consideration is needed to affirm the viability of these solutions in terms of computational complexity. The UNEP Nations [21] has indicated that this would also require a rework and a new governing policy. Thus, it raises the hope of blockchain applications spearheading the sustainability agenda in its widespread implementation.

4.1.2.2 Security issues Though security has been a significant proponent of adopting blockchain technology for sustainability, Caldarelli et al. [48] proposed a novel concept ensuring sustainability in blockchain's implementation in the supply chain in their paper on addressing the barriers to the pervasive adoption of blockchain. One essential context identified based on the review under technological context was the security aspect of block. Thus, security plays a crucial role in bridging the barriers to the widespread adoption of blockchain. Glavanits [51] presented an overview of the application of blockchain technology in public administration (spending). Glavanits [51] shared the security of the blockchain applications in transaction privacy, attacks on wallets (software that enables the buying and selling of cryptocurrencies such as BitCoin and Ethereum), and private keys (a code used in cryptocurrencies as a key to authorise transactions and prove ownership of a blockchain asset) Again, blockchain integration with IoT devices is also prone to security threats that are foreseeable long-term security implications. Kawaguchi [44] studied how blockchain can be deployed into the supply chain to reap the benefits of this technology. However, Kawaguchi [44] focused on how blockchain cannot record much information. Hence, we propose integrating an InterPlanetary File System (IPFS) that provides a solution that ensures all connected devices are connected to the same system and deal with a large amount of data. Thus, permanent, immutable IPFS links are connected to blockchain transactions. These operations enhance the 'transaction' security and eliminate the 'chain's load. Hence, this study affirms that blockchain indeed offers higher security, making it more sustainable and offering a much more flexible blockchain with the use of IPFS to ease the load on the blockchain, which invariably contributes to the computational efficiency of blockchain systems.

4.1.2.3 Energy issues Energy use, by some margin, dominates the discourse on blockchain. De Vries [25] and Digiconomist [52] indicated similar concerns with the high level of energy usage by blockchain. In some other studies by Truby [53], Vranken [54] and Zimmer [55], there were estimations and assumptions made on the blockchain technology, which are mainly concerned with the first implementation of Blockchain – BitCoin – owing to its highly attributable factor of the mining power of the users [56]. Ronaghi and Mosakhani [57] built a structural equation model and SmartPLS software to analyse the relationship between the model variables among four hundred and eleven SME managers. Their study indicates that blockchain technology directly impacts social sustainability, corporate governance, and business ethics. However, Ronaghi and Mosakhani [57] also reiterated the negative impact of blockchain on energy consumption. Though these two studies indicated this negative impact, further research would be required to define the precise scope of these implementations. Thus, a blockchain implementation with a globalised distributed ledger technology would incur higher energy consumption, unlike an organisational-level blockchain implementation, as [57] indicated. Again, integrating blockchain and connecting it with high energy consumption demands further empirical evidence.

Next, blockchain's controversial high energy consumption is highly debated [56]. Sedlmeir et al. [56] observed that blockchain is not homogenous; many types trade off security, permissions, and energy consumption. It challenges the overly simplified generalisation that blockchain uses significant energy. The authors also stated that such studies need to provide a more convincing argument on the negative impact of blockchain, particularly on energy consumption. Again, the study illustrated that compared with traditional centralised systems, blockchain solutions demand more energy. However, at the time of writing, one of the largest blockchain-based systems, Ethereum, had implemented the more energy-efficient proof-of-stake mechanism to replace *proof-of-work*. It suggests that the technology is not inherently energy inefficient, but efficiency can be improved in future iterations [50].

Nevertheless, since in many enterprise solutions, blockchain is integrated within traditional IT systems, only a minor part of the information is significant to the rest of the participants on the blockchain and on-chain storage, which is needed to store the core ledger data aside from the off-chain storage for the documentation and verification of the transactions as shared by IBM [58]. From the earlier analysis of the outcome of the work by Kawaguchi [44], this issue can be resolved with IPFS. Lastly, these studies [44, 56], and [50] affirm that much of the blockchain application research gathered was not empirical studies to affirm the validity of the assumed high electricity consumption.

5 Future prospects

Rejeb et al. [59] explored the significant barriers to adopting blockchain in a circular economy. Out of the eleven identified barriers to the future adoption of blockchain as an engine to drive sustainability using the fuzzy logic and best-worst approach, the authors found that the most significant barriers were technological immaturity, reluctance to change, and lack of knowledge and management support. In summary, many of the barriers being revealed in the research are archetypal for emerging technology. Barriers such as scalability issues, security risks, and investment costs are well-known barriers to adopting new technology. As such, these barriers are the least significant; history demonstrates that over time, technology will address these shortcomings—providing, of course, there is a demand. Thus, the following section explores emerging research exploring blockchain for social good and how it might offer opportunities as a tool to realise the United Nations SDGs.

6 Results and discussion of findings of future prospects

Going past the barriers and issues that may impede the adoption of blockchain for realising social and environmental sustainability, blockchain has significant potential to contribute to current implementations and other ongoing projects that promote an inclusive definition of sustainability in the economic, social, and environmental dimensions.

Distributed ledgers and smart contracts have enabled emerging autonomous systems. These technologies also offer an enhanced system to track the provenance of goods. In a study by Tallyn et al. [50], the consumption of coffee was explored via an autonomous process. Bitbarista was the project's name, and it attempted to minimise the intermediaries in the coffee trade while showing the provenance data at the time of purchase. It was tested in offices, and the various human interactions were analysed. Based on the results, the authors drew some conclusions for designing autonomous systems, drawing insight from the Bitbarista project: minimising commodification of user interactions with the system as some of the interactions with the system were incentivised for an individual. Block chain has been found to have a big potential in agriculture [61]. In other words, future autonomous systems would have to re-think the concept of rewards to offer support for other local projects or for supporting the vulnerable in society. Again, another critical lesson was increasing information on the state of the autonomous system. In the case of the coffee consumption machine, there was no predictability concerning maintenance demands that participants could mainstream in their routine. It was necessary as they empowered consumers to organise the maintenance of the system rather than the tension it created as it required service from participants without prior warning or information.

Khairuddin et al. [62] experimented with how we can provide materials and design for blockchain infrastructure. Though blockchain has existed for some time, one would hardly find mental models that explain the complexity of this technology. Thus, the authors set out to provide a '*BlocKit'* used as a test case to materialise blockchain infrastructure. Khairuddin et al. [62] engaged 15 experienced users who have worked with one of the blockchain implementations (bitcoin). Materials used to provide the mental model were backed by previous studies. Thus, in this study, an innovative approach to design for blockchain infrastructure becomes a useful knowledge tool that informs the design implications required by researchers in the human-computer interactions (HCI) domain, as this offers some level of engagement for designing infrastructure for blockchain.

Elsden et al. [63] speculate on the challenges and opportunities of designing for the future of civic with blockchain and distributed ledgers. In their speculation on civic blockchains targeted for 2030, managing multiple identities was one of the items identified as critical, and blockchain proved valuable in managing individual citizens' identities. Another speculated aspect was the self-licensing city, which was based on distributed autonomous organisations (DAOs) that operate on licensing programmes that administer permissions, rights, and payments in cryptocurrency, all based on a blockchain. Trust in governance via global and central authorities was also speculated to be eroded by 2030. Thus, a more trustworthy blockchain-based system is captioned as 'automacracy', which offers a decentralised system yielding digital governance at all scales, individual, local, or global. Thus, as cloud computing is adopted, this 'automacracy' will be envisioned as governance as a service. Lastly, managing the rising influx of tourists in Amsterdam was considered another challenge; Elsden et al. [63] speculated that tokenising tourism to have a voting system based on the blockchain allows the neighbours to vote on the kind of tourists they envision in a specific area. The tourists are then incentivised to choose a specific currency.

Murray-Rust et al. [64] annotate a couple of projects cutting around several societal domains that attempt to communicate the impact of blockchain technology. Speculations are made on the possibility of fully adopting these implementations that integrate blockchain, smart contracts, DLTs, and HCI. Public engagements, charitable giving, infrastructure delivery, and global supply chain were explored. Some projects were done in organisations, while others were installed and exposed for the general public to experiment with and experience the possible future of projects. These complexities offered a way to assist the general public in re-thinking solutions to the challenges of sustainability and new possibilities enabled by blockchain. Thus, blockchain can be seen as a critical player based on the lessons from the various blockchain projects and how they can inform the design of systems that broaden participation and address questions centred on imaginaries, social implications, and how to engage these new technologies for 'society's benefit leading towards regenerative communities and circular economy.

Pothong et al. [65] experimented with the possibilities of a fairer agricultural trade system using a distributed ledger technology, as fluctuating payment struggles predominantly change this sector. Farmers usually encounter many challenges, either devaluing the crops or delaying production payment. However, their study leveraged blockchain to address these challenges among small-scale farmers in the Caribbean. By testing the CariCrop prototype, Pothong et al. [65] devised a social context that enables the participants to co-create and negotiate an actual transaction experience, thus ensuring that the farmers would resolve their return-on-investment uncertainties. Farmers also had greater autonomy using the context provided in the prototype. The authors, however, admit that the progress of the prototype was subject to social, legal, and economic infrastructure.

In summary, blockchain energy consumption dominates the discourse, as does research into blockchain sustainability as a technology and efforts to reduce its energy consumption. However, this section has summarised a burgeoning body of parallel work exploring how blockchain might contribute to a more sustainable and equitable and circular society.

7 COLife – theoretical foundations and implications

The authors continue on this trajectory, offering our original research, which employs blockchain to support social and environmental sustainability for circular regenerative communities. The COLife: More-Than-Human Community Codesign project is critical in advancing the research on blockchain's potential for decolonization and self-governance. By enabling a *more-than-human circular economy*, where multiple species can trade through blockchain-based systems like smart contracts and digital currency, the project challenges anthropocentric and extractive models of resource management. This decentralized and autonomous approach aligns with efforts to dismantle colonial systems and support sustainable, self-governing communities. It provides a tangible example of how blockchain can be applied to foster ecological and social equity, demonstrating the transformative potential of decentralized technologies in addressing global sustainability challenges. In our project, COLife: More-Than-Human Community Codesign, which has been published elsewhere we propose a more-than-human circular economy where multiple species can trade. Which only becomes possible to explore through concepts underpinned by blockchain, such as smart contracts and digital currency. Davidová et al. [66] and Davidova and McMeel [67] have already investigated some experiments on token-based prototypes. In those prototypes, the other species are acted on behalf of people. Therefore, more-than-human communication is unsuitable, though it is transdisciplinary (i.e., a dendrologist acting on behalf of a tree). Our future vision is to use artificial intelligence to recognise the ecosystemic performance of other living and non-living beings (i.e., training image recognition for recognising the act of pollination). The agent involved will get paid within the blockchain application when the value is recognised. Afterwards, the AI would act on behalf of those beings, for instance, paying a maker to build an insect hotel for a pollinator because the pollinator earned the digital currency from the agency of pollination. The relation of blockchain technologies and AI is well discussed by Ressi at all [68]. Therefore, we will rise not just transdisciplinary but more-than-human communication, biotic and abiotic in the future. This vision is based on the argument that humans depend entirely on the ecosystem. However, the human economic models do not reflect it. Typically, we cannot harvest without pollinators; however, the pollinators do not have money to buy their habitats and edible landscapes. Therefore, we are facing Anthropocene extinction and, in some regions, starvation. Hence, the non-anthropocentric approach is the most beneficial to humans. We need to redefine recent economic models towards a more-than-human perspective. Such models can lead us towards the Post-Anthropocene era, where multiple beings (biotic and abiotic) co-perform and are in overall communication within one feedback-looping ecosystem, Gaia [5].

8 Conclusion

Our review concludes that significant research is being invested in addressing the problems of blockchain's energy consumption and credentials as a sustainable technology. In parallel, an increasing body of work explores how and where blockchain might contribute to a more sustainable society, regenerative circular communities. However, achieving the SDGs in an all-inclusive task demands stakeholder cooperation. In doing this, one must affirm without doubt the tools and philosophies implemented in realising this. Since its inception, few have embraced blockchain implementations as critical agents in this campaign, though the masses have yet to follow suit fully. COLife aims to connect 'what is with what if' [69]. It brings post-humanist concepts into the real world by prototyping within the real-life codesign 'laboratory' [70]. COLife addresses several United Nations Sustainable Development Goals, such as Zero Hunger, Good Health and Well-being, Industry, Innovation and Infrastructure, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action and Life on Land [71]. It also addresses several areas of the European Green Deal, such as Sustainable Industry, Building and Renovation, Farm-to-Fork, Pollution Elimination, Biodiversity, and Sustainable Finance [72]. The proposal is based on a broad perspective, referring to the New European Bauhaus, which aims at creating beautiful, sustainable, and inclusive living forms [73].

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Declarations

Competing interests The authors declare no competing interests.

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