VTT Technical Research Centre of Finland

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Published in:
EcoDesign2021 Conference Proceedings

Published: 03/12/2021

Document Version
Publisher's final version

Opportunities and challenges of blockchain technology in boosting sustainability

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Abstract

This paper outlines our research on the opportunities and challenges of blockchain technology applied for sustainability purposes focusing particularly on the circular economy perspective. The work is based on in-depth semi-structured interviews with Finnish blockchain professionals. The results reinforce the hypothesis that blockchain technology is in many respects a potential technology for implementing sustainability and circular economy solutions. However, the results also highlight many challenges that are often non-technical.

Keywords:

Blockchain, sustainability, circular economy, system design

1 INTRODUCTION

The European Green Deal (EGD) [1], published in December 2019, set ambitious climate targets to achieve climate neutrality in the EU by 2050. EGD is a comprehensive set of policies covering almost all sectors such as energy, transport, food, agriculture, and construction, among others. Various policy instruments will be deployed in the sectors, from regulation and coordination to economic incentives. In fact, to achieve a strong impact, EGD also includes significant investment strategies aimed at refocusing macroeconomic rules towards sustainability. Other EGD strategies are aligned with the main sustainability goals and the Circular Economy Action Plan (CEAP) [2] is directed towards decoupling economic growth from the use of resources by embracing product and material circularity. As a whole, EGD provides consistent overall guidance for climate neutrality and puts incentives in place for businesses to strive towards it.

However, the successful development of climate-wise solutions is not straightforward. It will require more and more systemic thinking, even abandoning traditional business strategies and organizational boundaries. To enable truly circular business models (e.g. transparency in supply chains), the traceability of products as well as facilitating product repairability with related services will be required.

ICT technologies can have a vitally important role in achieving climate neutrality. The EU Commission clearly emphasizes this connection of green and digital also in the CEAP. Digital technologies —such as IoT, big data, blockchain and artificial intelligence— are seen as promising in accelerating the circularity and dematerialization of the economy. Still, effectively harnessing digital tools for sustainability will also require clear rules for data sharing and more advanced data market models. In this respect, blockchain technology (BC) in particular can provide useful features by providing novel means for data management and portability as well as compensation. Generally, blockchain technology has some inherent system characteristics like decentralization, persistency, auditability, and anonymity [3] as well as security and automatic contract execution, which can in many ways be valuable in circular economy systems.

Motivated by the systemic requirements of the circular economy and the novel capabilities of decentralized technologies like BC, we have investigated how BC professionals in Finland view the use of BC to support environmental goals. The paper specifically seeks to map the opportunities and challenges of deploying BC in digital structures of applications in the field of sustainability and the circular economy.

The rest of this paper is organized as follows. First, the research method and basic concepts are introduced. In Chapter III, interview results are summarized. In Chapter IV, the results are analyzed and discussed.

2 RELATED WORK

This chapter presents the research methods and an overview of distributed ledger technologies and circular economy (CE) principles.

2.1 Research methods

In the research, we conducted in-depth semi-structured interviews to gather qualitative data on the opportunities and challenges of BC applied to sustainability and focusing in particular on the CE perspective. In total, 11 Finnish BC professionals, consultants and practitioners were interviewed from June through August 2021. The interviewees selected had previously participated in BC research projects, conducted BC experiments as part of their business, or were otherwise closely involved in the development of BC ecosystems. Most of the interviewees had no special background related to the CE. Therefore, to prepare the foundation for fruitful discussion on opportunities and synergies of BC and the CE, the interviewees were given basic background information on CE principles and business models before the actual interview. The interviews were held as Teams meetings, which were recorded, and the interview material was analyzed. A summary of the results is presented in this paper with the implications of the findings and considerations on directions for future.

2.2 Blockchain technologies

BC is a decentralized transaction and data management technology which provides a consensus of replicated, shared, and synchronized digital data. The data is confirmed by the nodes participating in a BC network and recorded in a public ledger, which is available to all nodes. Nodes typically hold a copy of the ledger or at least parts of it and any changes to the ledger are reflected to all nodes within seconds. Thus, the BC system is more transparent than centralized solutions. Decentralized approach also eliminates the need for any third-party organization in the middle and makes it practically impossible to falsify the information in the blockchain. BCs can be categorized to public, private and consortium BCs depending who can access the network and who can take part in the consensus process by validating transactions. Public BCs are highly immutable, but their transaction throughput and scalability is limited. In private BCs, transactions are validated by a single party that naturally decreases trust but has positive effects on system performance. Consortium BCs, which are typical in industrial settings, are kind of hybrid versions of public and private BCs having pre-defined parties as validators.

In summary, different BCs have distinct features and the design of BC-based system is always a trade-off between various design aspects. However, BCs have some general characteristics such as trust, immutability, traceability, security, and disintermediation. Many BCs also provide smart contract capabilities. Smart contracts are self-executing scripts stored in a BC and they can be used e.g. for automating business processes and creating tokens. BCs are one subgroup of Distributed Ledger Technologies (DLT) and these terms are often used interchangeably even though there are some basic technical differences between them. In the paper, the term BC is mainly used because it is more well-known, but it should be noted that in some cases DLT technologies might be better suited for the application.

2.3 Sustainability and Circular Economy

Geissdoerfer et al. [4] define sustainability as "the balanced and systemic integration of intra and intergenerational economic, social, and environmental performance" and the CE as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops". Despite some degree of similarity, the conceptual relationship between these two is indistinct. Often, however, the Circular Economy is regarded as one of the solutions advancing environmentally sustainable systems, but there are also cases where these two may have trade-off relation.

CE strongly emphasizes economic and financial advantages for companies combined with less resource consumption and pollution for the environment. [4] These objectives can be achieved applying CE strategies and principles which can be presented e.g. using the 9R framework: Refuse, Rethink, Reduce, Re-use, Repair, Refurbish, Remanufacture, Repurpose, and Recycle. [5] From the business perspective, Sitra's categorization [6] of CE business models can be instrumental e.g. in CE business design. Sitra distinguishes product-as-a-service, renewability, sharing platforms, product-life extension, and resource use and recycling as the main classes of CE business models. [6]

3 INTERVIEW RESULTS

3.1 Opportunities of BC in a CE and sustainability

Traceability and transparency were mentioned by all interviewees among the main benefits that can be achieved by utilizing BC in a circular economy. The protocol-level trust inherent to BC was seen to increase confidence in the origin of materials, components, and products. Also, connecting product information to BC throughout the product lifecycle could particularly facilitate end-of-life management and enhance product safety by disclosing harmful chemicals in textiles, for example. Furthermore, the reliable data on the product's use (e.g., how many times and how the product has been used) and maintenance would enable the creation of completely new services such as sharing and rental services, which could extend the life cycle of a product. In turn, transparency was related to supply chains, logistics, and their efficiency but also to the verification of corporate sustainability reporting. BC-based transparency was seen as a foundation for a chain of custody that provides all stakeholders with visibility onto the state of the possibly complex supply chain, making product recalls easier and counterfeiting more difficult.

The algorithmic trust of BCs improves data reliability and can enhance process efficiency. Interviewees emphasized the reduced transaction and contracting costs but also enabling automatic decision-making. These all can be very useful features for CE implementations. For example, a potential CE use case for BC can be a multilateral network in which one of the actors utilizes industrial by-products from numerous other actors which possibly can also change over time. To be able to plan and control the production, the actor needs relatively accurate, reliable, and real-time estimates of the by-product capacities of the network. In such a setup, BC was seen as a powerful and user-friendly database solution and co-operation platform that eases system integration by providing straightforward, secure, and scalable one-to-many integration. The security aspect of BC was especially emphasized in sharing data from closed industrial environments.

Some interviewees also brought up the emerging usage of BC-based tokens in CE. Firstly, cheap micropayments could make many novel CE business models feasible, e.g. by incentivizing the recycling of low-value products. On the other hand, BC-based tokens can represent real-world commodities such as side streams or even CO2 emissions. After successful tokenization, the commodities can be efficiently traded in marketplaces. One of the interviewees mentioned that boosting wider recycling of materials will require CE marketplaces to evolve towards commodity markets that currently mostly trade in virgin raw materials. Thus, novel commodities should also be future waste, such as concrete walls of an existing building. These kinds of waste-based commodity futures could be created using BC-based Verifiable Credentials (VC) [7], which are virtually linked and electronically signed documents based on the W3C open standard. The VCs would contain the data on the material and its lifecycle. Connecting the VCs to non-fungible tokens (NFT) could enable the pricing and trading of commodities on the exchange market. The BC-based VCs are a part of the wider concept of Self-Sovereign Identity, which has also been promoted by the European Union. [8] In summary, the cryptographically secure and privacy-respecting VCs enable portability and machine-based verification of credentials which significantly improves the reliability of data. Combined with NFTs, VCs could revolutionize traditional financing and fund management by substantially reducing the administrative burden and related costs. These effects could be especially beneficial for CE business development and project financing because an efficient scaling of local grass-root activities is needed to achieve economies of scale and products-as-a-service business models require a huge amount of capital. Proliferation of digital wallets storing VCs provides completely novel ways to build easy-to-use and reliable user interfaces for CE solutions.

3.2 Challenges of BC in a CE and sustainability

The interviewees especially raised two issues impeding BC-based system development in general -the complexity of the BC topic and building successful BC-based ecosystems. These matters largely resonate with the fundamental hindrances of achieving a sustainable circular economy, as listed in [9].

BC was mentioned as a transformative technology whose implications are still difficult to comprehend. The term BC itself was already seen as problematic. The name refers to how the data is stored, but it also refers to the huge systemic change towards distributed systems where things happen at the protocol level. Understanding what BC is all about and what it effects is difficult in itself, but successful BC system development also requires a critical number of actors to share the view of data as an ownable asset and to identify and realize the value of the data ownership. In many cases, facilitating and orchestrating these kinds of co-operative BC system development efforts calls for exceptional individuals and adequate incentives.

Building BC-based systems raise issues familiar from general ecosystem development and platform economics, such as who should build a platform or a marketplace as well as what kind of governance and pricing strategies are needed. On the other hand, in BC ecosystems, the role of a company was seen to change. Traditionally, big companies have especially been used to owning things (like their supply chain and partner networks), meaning that there is a clear decision-maker who decides how things are done. By contrast, the BC-based value network is democratized, which provides companies equally strong starting points based on shared data and activities. This transformation blurs organizational and administrative structures, forcing companies to rethink their benefits and obligations as a part of a BC network as well as in the CE value network.

However, the experienced BC system and ecosystem developers were able to recognize several ways to alleviate the afore-mentioned issues. First, the identification of hub players in industrial verticals is essential. In other words, one should be able to find a body among the actors that already serves the whole community as an ecosystem operator. The development of a BC system should then be carried out in close co-operation with that actor. Secondly, the role of third-sector and state actors was seen as crucial in the early stages of ecosystem development. Facilitating broader discussions with diverse consortia, introducing policies and regulations that enforce co-operation and secure, standardized data sharing as well as investments in the underlying digital structures were proposed as promoting measures.

Regarding technology challenges, the views of interviewees partially differed. Some thought that there are already applicable and advanced BC solutions available and the low-level challenges related to technical integrations have already been largely addressed. They regarded high start-up costs and how to get the solutions widely adopted in a globally fragmented industry as more challenging issues. Some others considered BC as an immature technology lacking standards and best practices. Therefore, many BC solutions end up being customized hindering data flows and causing rigidity.

The other challenges mentioned in the interviews were the integration of BCs and legacy and/or Internet-of-Things (IoT) systems as well as how the reliability of the information can be guaranteed and how confidential information can be distinguished. Additionally, the lack of skills and expertise in different areas of BC system development slows down the transition from testing to the production and wider use of BCs. For the last thing, the public debate regarding the huge energy consumption of BCs was generally seen as a misunderstanding that is hampering BC system development, especially for sustainability applications. The energy issue only plagues BCs having Proof-of-Work consensus algorithms such as Bitcoin and is not related to the most common industrial BC solutions. Likewise, the strong mental connection between BCs and volatile cryptocurrencies was seen troubling many discussions related to industrial BCs.

4 ANALYSIS AND DISCUSSION OF RESULTS

The interviews produced a rich set of multifaceted answers about the opportunities and challenges of using BC in sustainability and CE-related solutions. The responses also included both real-world and theoretic use cases that were mainly meant to streamline existing processes or create novel BC-based business.

One of the main findings was that the challenges were not so much related to BC technology as such but were related to wider issues of data sharing or ecosystem and platform development. For example, overcoming the companies' fear of sharing data, harmonizating data of fragmented supply chains, and getting the critical mass of stakeholders on-board to deliver network effects were often mentioned. Interestingly, the same issues seemed to plague both BC and CE solution development independently of each other.

The reliability of BCs was frequently referred to in the interviews and in many cases considered an unambigious feature of BC-based data. Only a few interviewees touched on factors that could potentially degrade the quality and reliability of BC-based data. However, the integration of the physical world with BCs, needed in many CE use cases, requires special attention to the system design. For example, the so-called oracles used for providing data about real-world events to BC-based smart contracts must be designed carefully (authentication, decentralization, security, etc.) so that the risk of a possible single point of failure or data manipulation can be minimized. As one of the interviewees pointed out, BCs do manage technical verification, but who guarantees that the issuer of a VC is reliable, and how should the reliability of actors in general be defined? Furthermore, IoT devices are often used as an interface between the BC and the physical world, which also poses data reliability issues. Many of the devices have limited memory and computational resources and possibly outdated software, making them more vulnerable to attacks. IoT devices also produce huge amounts of data requiring substantial filtering before storing them in the BC. This calls for profound trust design and deep understanding of which IoT data are relevant to the use case. On the other hand, it was suggested by some interviewees that evaluating and layering data for reliability could also be efficiently implemented using BC-based capabilities. As a data set is just as reliable as its weakest point and trust is mostly not binary, BC-based spectrum-like data reliability estimates could significantly improve data usability.

In the interviews, traceability and provenance were regarded without exception as one of the most important BC-based CE applications globally. However, in Finland, trust in products and supply chains is in many cases "built-in" with laws and regulations such as food cold chains and consequently food safety issues are mostly not considered as very acute. Also, more generally, Finland being a high-trust society [10] has probably been a reason why BC-based traceability projects have been few in number inside Finland. Anyhow, the increasing consumer awareness of sustainability and product quality are raising the value of traceability. The provenance has begun to appear as a competitive advantage, e.g., in foreign trade. It was also brought up in the interviews that even though BC-based traceability and transparency would facilitate many processes and help consumers make more informed purchase decisions, these system attributes are not necessarily beneficial for all. If an origin does not stand up to scrutiny, those on top of supply chains do not want to open data.

In the future, use cases —such as the automation of emission rights connected to payments of products or real-time calculations of emission loads for processes and products (which now are based on calculated models and estimates) —were seen possibilities that could be implemented using BC-based systems. Combining these visions with the World Economy Forum's concept of Internet-of-Materials (IoM) [11] having cryptographic anchors to underlying raw materials and the work done in digital identities and mobile wallets (e.g., in the EU [12]), we can expect several foundational BC-based enablers and use cases to emerge for boosting sustainability and CE. The BC's inherent capabilities resonate with the underlying requirements of system-wide transition towards sustainability. It can provide a more neutral and democratic platform for data sharing and business process automation across sectors, value chains, and ecosystems. Also, the BC-enabled digital identities and tokens can be the missing piece of a puzzle for empowering citizens, increasing data reliability and the degree of confidence in co-operation, as well as efficiently connecting finance and sustainability.

Lastly, steering any systemic change will need reliable indicators and statistics based on accurate and up-to-date data. The concept of the real-time economy, already introduced decades ago and comprehensively presented in [13], comprises the idea of the "digital ecosystem where transactions between diverse economic actors take place in or near real time" which helps "policy makers to take informed decisions and promptly react to the evolution of the economic situation designing effective and timelier economic and monetary policies" [14]. Similarly, CE will need these kinds of reliable global indicators, real-time monitoring, and early warning systems for its success. Based on the interviews and known capabilities of BCs, it can be assumed that many of these requirements could be filled by utilizing BC-based systems. In addition, the global interest in the development of DLT-based Central Bank issued Digital Currencies (CBDC) [15] may also simplify connecting BC-enabled systems to official financial systems and e.g., providing unbanked population with access to payment systems for widely incentivizing sustainable actions in developing countries. Furthermore, completely novel data for CE-monitoring purposes could be generated by harnessing BC-enabled prediction markets, which are interesting new tools for extracting the "wisdom of crowds". Also, BCs can provide much greater opportunities to incentivize reliable, untampered product reviews and usage information to be included in product passports, for example. Thus, BC-based solutions could essentially facilitate the materialization of a real-time *circular* economy.

ACKNOWLEDGMENT

The work is done in the Circular Design Network (CircDNet) project funded by the Academy of Finland.

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