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Blockchain: An Assessment of its Potential and Challenges in Addressing Sustainability Issues

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Abstract: Blockchain, the technology behind the worldwide-known cryptocurrency Bitcoin, offers a new set of potential advantages and opportunities that various industries and institutions could use to enhance their processes. Although most research and development on blockchain has focused on applications for cryptocurrencies and the finance industry, relatively few analyses and assessments have been conducted on how it could provide tools to address social and environmental issues. This research, using interviews, literature review and examples of blockchain applications, explores how this technology can be employed to address sustainability issues under the framework of three UN Sustainable Development Goals: 2. Zero Hunger, 7. Affordable and Clean Energy, and 14. Life Below Water. The analysis shows that blockchain has the potential to support solutions to sustainability problems that need efficient traceability, trust, a unique ID, transparency, or a highly secure payment system. However, the technology should not be mistaken for a panacea for addressing sustainability issues in its current state because it is not yet mature and has not been sufficiently tested. Expansion of blockchain as an effective tool for helping solve sustainability challenges will require a greater understanding of the governance of blockchain, its scalability and its potential unintended consequences for the technology to become properly integrated into the decision-making progress.

Keywords: sustainability; blockchain; SDGs; Bitcoin; commonalities; challenges

1. Introduction

Blockchain refers to the algorithm created to support a digital currency called Bitcoin which offers a way to trade without needing banks as an intermediary [1]. There is some consensus that one of the reasons behind the creation of Bitcoin and its decentralized nature, was the financial crisis of 2008 and the consequent distrust in banks as institutions [2,3]. Nevertheless, reducing the use of blockchain to Bitcoin's origin and incentives hinders society's capacity to assess the technology and propose new uses for it. As the first of Melvin Kranzberg's "laws of technology" proposes, "Technology is neither good nor bad; nor is it neutral"[4]. Even though primary motives to develop a technology vary in every case, the innovation itself is morally and ethically instantiated [5]. And blockchain is no exception. Beyond the initial reasons for the development of blockchain, the technology is being developed for use in a range of industries around the world [6,7], opening the window to look at it from different perspectives. Reijers and Coeckelbergh [8] go even further and suggest that "[e]merging blockchain-based decentralized applications have the potential to transform our financial system, our bureaucracies and models of governance."

When Satoshi Nakamoto developed blockchain technology to create the cryptocurrency known as Bitcoin [9,10], probably he- she or they- didn't anticipate the worldwide attention it would get almost a decade later. The purpose of blockchain, at its origin, was to support the operation of the cryptocurrency Bitcoin without the presence of an intermediary [11]. Even though during its early years, the existence of Bitcoin was mostly known by cryptographic enthusiasts, the cryptocurrency has more recently caught a wider audience [12]. This increase in the popularity of Bitcoin has opened the space to analyze its different challenges and opportunities [13–15]. Among the principal discussion topics around Bitcoin are the significant carbon footprint of its operation [16], its association with illegal activities [17], and its real potential to become an accepted payment method [18,19].

Certainly, technology will play a crucial role in making progress toward addressing several of the sustainability issues we are currently facing. Even though Bitcoin, and other cryptocurrencies, have the potential to provide tools to address some social or environmental issues [20,21], they are just one of the different applications of blockchain [22,23]. Thus, research focused on blockchain could identify a more extensive set of advantages that could be used to face sustainability issues. In order to explore the characteristics of blockchain that can provide novel alternatives to address sustainability challenges, first, it is necessary to understand how it works.

1.1 Blockchain's operation

In straightforward terms, blockchain is a new technology that enables users to handle information securely. The technology is based on a distributed network (Figure 1) to increase its safety. This represents a shift from regular ways of a centralized style of information storage, which usually relies on a single server -with backup copies in some cases. Blockchain stores information not on just a single, centralized server but, instead, on every computer participating in the network [24]. With this move from traditional methods of storing data, the likelihood of successful tampering or hacking of information decreases [13].

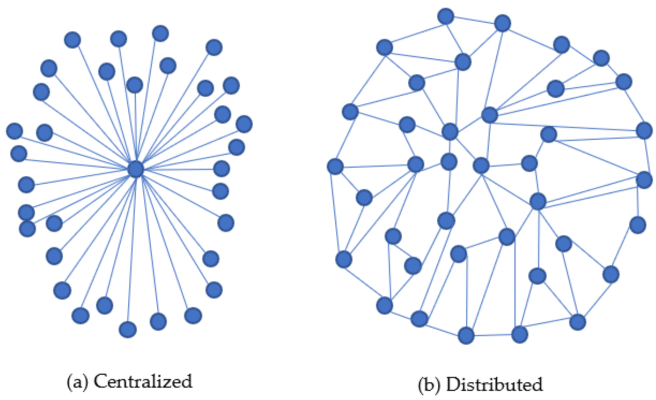

Figure 1. A graphic description of the differences between a centralized, and a distributed network.

Once a piece of information is written in the blockchain, it is almost impossible to change [25]. All the information is saved in blocks and the number of records stored in every block varies among blockchains. For example, let's assume that only one record is stored in a block. Then, if we want to save a new record, we will create a new block that is linked to the previous one. If we want to repeat the process, a new block will be born, being connected to the last. Thus, we start to build a chain of blocks, or in other words, a blockchain. But how are those blocks connected? Figure 2, which represent a simplified version of blockchain, shows that every block will have the data inputted, a timestamp, a unique code called hash, and the code of the previous block [9,25]. The hash is a cryptographic code generated in function of the previous hash and all the data of the new block. For example, in the case of Bitcoin, the data stored in the blocks are the transactions of the cryptocurrency that have happened on the network. This structure adds a new layer of security to the technology. Any attempt to change the data of "Block # 1" of Figure 2 would affect its hash and the hash of "Block #2" and every block after it since they are all interconnected.

Figure 2. Creation of blocks of information: Every new block will have a timestamp, the data stored, the previous and a new hash. The new hash is a function of all the information in the block.

The process to determine the creation of a new block, and its respective hash, is through the consensus mechanism of the network. But reaching that consensus is not easy. Zheng, Xie, Dai, Chen, and Wang [26] present several common approaches of consensus mechanism dealing with the Byzantine General Problem [27] which addresses the challenge of reaching consensus in a distributed network. While in a centralized ecosystem there is always a central participant who validates the information and could add a new block to the chain, the Byzantine General Problem states that in a distributed version, the lack of the aforementioned actor hampers this process. For example, the blockchain version of Bitcoin uses a consensus method called "Proof of Work" [9] which relies on a race based on computing power among all the participants of the network to calculate the new hash. The first participant that calculates the correct hash, -which is validated by the rest of the network-, earns Bitcoins as a reward, and a new block is created. This method, currently known as "mining", requires the consumption of a considerable amount of energy which impacts on the carbon footprint of this cryptocurrency [16]. But, other versions of consensus protocols used by different cryptocurrencies don't rely on this mining process. This can considerably reduce their energy consumption and, hence, their environmental impact as is the case of the cryptocurrencies Ripple and Stellar.

Finally, it is interesting to highlight that there is no official definition of what blockchain is. Different sources define the technology in different ways, highlighting or excluding features of blockchain [28]. For example, there is an ongoing debate about the possibility of developing private blockchains. While Bitcoin's version of blockchain is public, meaning it is open to everyone who wants to participate in it, a private, or permissioned, blockchain has an access control layer that manages who can join the network, add blocks, request information, and who can participate in the consensus process. Some argue that a private application of the technology is just a shared database, thus, losing the characteristics of blockchain, while others support the idea that a private version of the technology is still considered a blockchain [29]. While most of the cryptocurrencies use public versions of blockchain allowing anyone to participate in the operation, the rest of the applications usually relies on some version of permissioned platform to protect the information contained.

Despite the lack of a formal definition, the principal attributes of blockchain technology are its high-security levels based on the encryption of the information, the distributed nature of the database, and the trust around the systems due to the almost full immutability of the information registered in the ledgers. And, as some have argued before, it is the blockchain's ability to operate when normal trust architectures are not enough that makes it an interesting tool to analyze.

The concept of "trust" is a very important aspect of blockchain technology, one that has garnered increasing attention. Werbach identifies four types of trust architectures [30]. The first one, called peer-to-peer trust, is the one operating between people when they trust each other. The second one, Leviathan or institutional trust, exists when an institution allows trust among parties due to the government system's capacity to resolve any dispute. The third one, named intermediary trust, operates when the parties do not trust each other, but they do trust an intermediary organization – as is the case of the credit cards. Finally, Werbach states that there is a new trust architecture called distributed trust, which works when the users trust a decentralized system such as blockchain, without needing to trust neither an intermediary nor the other parties.

Because of these features, the technology can be applied to achieve outcomes on a wide variety of topics and systems. Even so, most blockchain applications have mainly focused on finance and cryptocurrencies [31], recent new developments and research have started to evaluate the use of blockchain to introduce novel solutions to existing areas. For instance, Chen, Xu, Lu, and Chen [32] explored potential applications of blockchain to solve diverse education challenges. Dagher, Mohler, Milojkovic, and Marella [33], in the health area, proposed a blockchain-based framework that preserves the privacy of patients' sensitive information while offering secure, interoperable, and efficient access to medical records by patients, providers, and third parties. Marsal-Llacuna [34] analyzed, using the UN's New Urban Agenda, the advantages blockchain could provide to the urbanization field.

1.3 Sustainability and Blockchain Research

While there are many definitions of the concept of sustainability, the objective proposed by the National Research Council's Our Common Journey report [35] is a broadly used way to approach the topic [36–38]. In the document, the NRC declares a need for a sustainability transition that "should be able to meet the needs of a much larger but stabilizing human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty"[35] This call to action, later known under the concept of "sustainable development" [36], created an unprecedented challenge [39]. Since that time, different organizations and initiatives around the world have tried to address sustainability issues. However, with some exceptions, such as ozone depletion, many "wicked" sustainability issues remain at dangerous levels [40,41].

In 2012, with the objective of unifying efforts and producing a set of goals that would address urgent environmental, economic and social challenges, the UN decided to start working on what is now known as the Sustainable Development Goals (SDGs). By 2015, the U.N. had identified 17 goals aimed to end poverty, protect the planet and ensure prosperity for all. This latest approach is similar to the goal established in the NRC report, recognizing the global importance of social and ecological objectives of sustainability; that is, the well-being of present and future generations depends upon the ecosystem services provided by the planet, which are being heavily impacted by human activity [40]. This perspective of sustainability bounds the understanding of sustainability issues as actions or situations that threaten either the human population's needs, life support systems, or both.

Heretofore, little research exists about blockchain's connection with and value for addressing sustainability topics such as environmental protection or social issues. In their study, Giungato, Rana, Tarabella, and Tricase, [14] analyzed current trends in social, environmental and economic topics of Bitcoin and blockchain. They suggest that the technology may overcome criticism and drive social change. Chapron [25] proposed that the technology that supports cryptographic currencies provides an opportunity to support sustainability. He explains that the unique characteristics of blockchain could increase trust, empower citizens and avoid corruption. Similarly, Kewell, Adams, and Parry [5], through affordance theory, offered a series of real-life applications showing how blockchain can contribute to the sustainability agenda. Recently, an increasing number of authors have shown how blockchain could be used to address different sustainability topics. It could be shaped to improve conservation, easing and simplifying transparent fundraising donations [42]. Its advantages can increase food security, through traceability of contaminated food [43]. Finally, the energy supply could be enhanced by decentralized energy systems, where peer-to-peer energy exchanges are possible using this new technology [44].

In order to advance understanding of how blockchain can provide new tools to develop sustainability solutions and identify its main challenges, an analysis of the sustainable issues that blockchain is already helping to address was carried out. A literature review, interviews, and examples of real-life applications were conducted to explain what intrinsic characteristics of blockchain, that are not present in other technologies, have been crucial to developing tools that have successfully addressed sustainability issues. Also, from the same sources, it was expected to clarify what commons needs and difficulties those sustainability issues had, and how blockchain's characteristics could help or actually resolve them.

This research addressed the following research questions:

- Can blockchain technology be used to help achieve the United Nations' sustainable development objectives (SDGs), a globally accepted framework for understanding crucial sustainability issues?
- What are the unique characteristics of blockchain that make this possible?
- What do the sustainability issues that blockchain can help solve have in common?
- What challenges lay ahead for blockchain in terms of its adoption and scalability?

2. Materials and Methods

For the literature review of this study, Google Scholar and Web of Science were used to search articles with the terms "blockchain" and ("sustaina*" or "environment*" or "social") in their titles, abstracts, and subjects to add literature. Due to the novelty of the topic and the fact that most of its development has been outside of the academic community, non-traditional/grey sources were added to the analysis, with the objective of collecting a robust amount of literature to support the research. These non-traditional sources were obtained through interviews, newspapers and discussions with academic and non-academic experts interested in the subject.

Until 2016, there were few publications about blockchain, with most of them dedicated to Bitcoin and finance [31]. However, a search in Web of Science showed that in 2017 almost 200 articles were written with "blockchain" in the title or as the topic, a substantial increase compared to 40 publications in 2016. In addition to the increasing number of publications, a shift from the financial-oriented research was noted, with more new applications of blockchain being covered by studies in recent years.

With a topic as new as blockchain, interviews as data sources must play a crucial role to develop the research. As Rubin & Rubin [45] note "[q]ualitative interviewing projects are especially good at describing social […] processes, that is, how and why things change." They also affirm that the credibility of using interviews as a research methodology is enhanced in the recruitment process by ensuring that interviewees are knowledgeable, have different perspectives, and support the testing of emerging theories [45]. Nonetheless, these desired characteristics of the research method have to be adjusted with a pragmatic approach which includes limitations of time and funding [45].

In this study, eleven interviews were conducted (See appendix 1 for the list of the interviewees) from five different fields: technology (n=3), NGOs (n=2), finance/business (n=2), governance (n=2), and academia (n=2). These fields were chosen to elicit different perspectives since each of them approaches innovation, challenges and opportunities from a particular angle [46]. The selection of the interviewees was based on expertise in their respective fields, knowledge about blockchain, and upon recommendation from professional advisors to this study.

The semi-structured interviews that were conducted allowed open responses from the participants [47] and the possibility of spontaneously adapting questions based on the interviewee's responses [48]. The questions were adapted throughout the process to pursue emerging ideas based on previous interviews [45]. The main topics tackled during the interviews, following a constructivist style, were a) the unique characteristics of blockchain, b) how it can be used to address sustainability issues, and c) what are the future challenges of the technology? Transcriptions of the interviews were analyzed using descriptive and "in vivo" coding [49] looking for patterns and emerging concepts.

To complement the methods mentioned above, and considering the pragmatic approach of the research, the use of real-life applications of blockchain was necessary to exemplify the circumstances in which the technology is providing a new tool to address sustainability issues. The literature review and the interviews provided a set of blockchain applications to start the analysis. The selection of the applications was based on the opportunities blockchain offers for addressing sustainability issues differently (e.g., faster, better, more efficiently, etc.) or resolve situations that were unmanageable prior the application of the technology (e.g., what blockchain offers that was not present before).

To structure the results of the research, the framework established by the United Nations' Sustainable Development Goals was used, organizing and applying interviewees' perspectives, literature review and real-life applications to three of the SDGs. To keep the analysis focused, the use of blockchain technology was assessed in relationship to just three of the SDGs. This enabled an in-depth consideration of the technology's use in this context that would have been hard to achieve if all 17 SDGs were considered. Whereas further research can target other specific SDGs, the sample chosen for this study relies on the conviction that the findings are extendable to the 17 goals to one degree or another and that the SDGs are interconnected [50]. This means that by addressing a particular goal, the study can advance knowledge applicable to all SDGs related to it.

The selection of SDG 2 Zero Hunger, SDG 7 Affordable and Clean Energy, and SDG 14 Life Under Water was based on the expertise, insights and background of the interviewees, the literature found, and the real-life applications analyzed. Additionally, the choice of these goals aimed to include all three concepts of the "Triple Bottom Line"—a framing which became popular after publication of Elkington's "Cannibals With Forks: The Triple Bottom Line of 21st-Century Business" [51]. The framework looked for expanding the initial focus on financial/economic results in organizations, adding two new performance areas to the table: social and environmental aspects. In this study, SDG 2 (Zero Hunger) could be defined as a social objective. The economic component could be associated with SDG 7 (Affordable and Clean Energy). Finally, the SDG 14 (Life Under Water) could refer to the concept of an environmental issue. With the possibility of classifying the rest of the SDGs as social, environmental, economic or mixed goals, it is viable to expand the analysis and results of this study to them.

The three SDGs are described below, with examples of how blockchain is already addressing some of their objectives. These are followed by a discussion focusing on showing the commonalities found among the sustainability issues and the solutions cited, and the challenges of the technology to increase its use around SDGs.

3. Blockchain Applications addressing the United Nations' Sustainable Development Goals

As Pablo Prieto, CEO of the Peruvian technological firm TIVIT Peru, suggested in his interview "Although so far, this emerging technology has its main development lines linked to the financial sector […], its application to solving environmental, social, public and governmental issues is an obligatory step." Based on consensus among all the interviewees, the use of blockchain to address sustainability issues is possible and desirable. According to them, it is offering new advantages that were not present before, hence, making it possible to solve challenges that until today were hard to address. Along these lines, the United Nations Development Programme states that blockchain has the potential to tackle different sustainability issues "accelerating development progress that truly leave no one behind." [52] To structure the study, applications, literature and quotes from the interviewees are presented grouped into three SDGs.

3.1 Sustainability Goal number 2: Zero Hunger

The second goal of the United Nations is to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" [53]. As the UN states, currently, if it is done right, agriculture, fishery, and forestry can provide food for everybody in the world. Thus, the challenge is to rethink the way we produce and distribute food. More than 800 million people are undernourished, with most of them located in developing countries, which causes half of the deaths of children under five [54]. Also, agriculture is the most significant employer in the world, meaning a substantial amount of people rely on it to survive economically. Indeed, solving world hunger is not an easy task and, as Ban-Ki moon expressed, its achievement depends upon delivery on *all* SDGs [55].

The eight targets established for the goal are oriented to two main topics: Hunger and Food Security. Regarding the second subject —Food Security— blockchain is providing technological solutions due to its capacity of allocating a digital identifier to food products enabling the traceability of food in supply chains with its respective information (expiry date, origin, etc.). Under this perspective, the interviewee Sara Eckhouse, Executive Director of the NGO FoodShot, adds "I know there's a lot of interest in blockchain in terms of supply chain traceability and verification". Along the same lines, Yarime Masaru, Associate Professor at Hong Kong University of Science and Technology, explains, "Normally, it's very difficult to see […] where are the things that are produced or transferred and, potentially, the blockchain can be used to monitor and trace all of these". As Yamire Masaru states, before blockchain, the traceability of assets through complex supply chains where many parties were involved was challenging.

In 2016, Walmart, in collaboration with IBM started to test the integration of blockchain in its supply chain, to reduce food waste [56]. Walmart developed the Wal-Mart Food Safety Collaboration Center in China, whose objective is to "help accelerate the development and adoption of food safety solutions that can be openly shared and scaled throughout the supply chain" [57]. The first pilot was developed in China, with the objective of creating traceability of pork from farm-to-table. The project did allow to digitally track individual pork products in minutes, knowing the origin, the factory, the batch number, storage temperature and shipping details. Also, the technology allows to know if the product is authentic and safe, and when it expires. If a food contamination issue arises at the farm or factory, it would be known which products to recall, and which may be left on the shelves. In this case, the transparency and the traceability provided by blockchain increased food security at the retail level; that is, in Walmart stores.

The recall of only contaminated products instead of the entire production -which is usually the solution provided in those cases- could help to reduce food waste, helping to lessen, for example, the more than 30% of food waste per year (133 billion pounds) that currently happens in the United States [58]. Recently, a number of E. coli outbreaks hit the United States, leading to the disposition of tons of products (such as romaine lettuces) for the lack of capacity of clearly identifying the origin and location of the affected products. The FDA, to enhance food safety and reduce food waste, is analyzing the implementation of blockchain to enhance the traceability of food in the country [59].

The advantages that blockchain offers to improve supply chains, and traceability in general, can increase food security and reduce food waste.

3.2 Sustainability Goal number 7: Affordable and Clean Energy

SDG 7 is to "ensure access to affordable, reliable, sustainable and modern energy for all" [53]. The goal looks for international cooperation to facilitate access to clean energy- research and technology- and promotes investment in energy infrastructure [60] since, according to the UN, energy is central to almost every major sustainability challenge and opportunity. With one in five people still lacking access to electricity, 3 billion people relying on wood, coal or animal waste for cooking and heating, and energy being the most significant contributor to climate change [53], there is no doubt that energy is a critical sustainability challenge.

Most of the power grids around the world are centralized. Nevertheless, those usually big and centralized systems —with multiple barriers to entering the network— often don't have the capacity to efficiently deal with the volatility of renewable energy sources such as solar energy [61]. With a solar industry growing at a record pace, and considering that a big segment is led by residential photovoltaic systems [62], the lack of proper energy grid systems could obstruct the expansion of renewable energy sources. Professor Yarime Masaru states that with blockchain "you can […] potentially exchange electricity between different households, so that can really facilitate a distributed energy system." Blockchain offers the opportunity to develop small or micro grids, managing the generation and consumption of energy competently [63]. Furthermore, small grids can reduce the long distance transportation of energy which is associated with losses of energy [64].

The blockchain-based, distributed energy grids proposed are possible thanks to a new concept called "Smart Contacts" that was developed a few years ago [65]. In simple terms, Smart Contracts are contracts that are coded -in other words, a program- that run on blockchain technology [66]. On this program, it is possible to define rules and penalties around an agreement in the same way that a traditional contract, but the enforcing of those obligations is done automatically and with no need of a notary or a lawyer. SunContract and Dexentralize are two projects that operate blockchain platforms that allow trading of energy in small grids. Using smart contracts, they enable a network where the surplus of renewable energy from the "prosumers" -consumers of energy that also have the ability to generate it- is safely and automatically sent to those consumers that need it. All the transactions can be verified by anyone at any moment, increasing the transparency and trust in the system.

Apart from easing the spread of renewable energy, small grids could be applied in cases where power generation systems are available but there is a lack of or there are problems with the transmission lines. This is the case of Puerto Rico after Hurricane Maria, where close to 80% of the transmission lines were damaged [67]. In the transition to restore the energy around the island, micro or small grids can be established, granting access and distribution of energy from those available sources to the nearest consumers without the need for a central authority regulating and validating transactions [68].

Another suite of blockchain applications to address this SDG in the energy sector comes from the cryptocurrency side. As previously mentioned, while some cryptocurrencies such as Bitcoin have a significant environmental footprint [14], many others don't work with a consensus protocol based on races, thus considerably decreasing or almost eliminating the energy consumption of its operation. Using these eco-friendlier cryptocurrencies to promote sustainability activities can be an option. One of these initiatives was developed by The SolarCoin Foundation. It created "SolarCoin" which promotes the generation of clean energy by rewarding owners of solar panels with digital coins; that is, one SolarCoin per one megawatt hour (MWh) of solar energy produced. In this case, blockchain is a technology that provides the tools to an efficient, automatic and transparent management of the allocation of the rewards presented by SolarCoin. Being a decentralized currency, it allows The SolarCoin Foundation to distribute the payments to anywhere in the world, without the transaction costs associated with intermediaries. A project with a similar objective is The Sun Exchange which looks for funds for solar projects around the world (mainly in Africa). The funders provide money and receive rental income through a blockchain-based payment system.

Blockchain technology can play a role in the achievement of SDGs by offering tools that didn't exist before. Ideas like SolarCoin and The Sun Exchange could promote the adoption of clean energy, offering additional benefits or facilities to the generation using renewal sources. Moreover, SunContract and Dexentralize contribute to the access to affordable, reliable, efficient and modern energy services.

3.3 Sustainability Goal number 14: Life Below Water

The 14th of the 17 Sustainable Development Goals focus is--"Conserve and sustainably use the ocean, seas, and marine resources"[53]. With oceans covering 75% of the world's surface, 3 billion people directly depend on marine and coastal biodiversity to survive. And, since oceans play a crucial role in regulating environmental systems around the world, there is no doubt that the protection of oceans and their biodiversity is essential for the present well-being and future of the planet. Under this context, the UN established ten targets for this goal which can be summarized in three categories: ocean health, biodiversity protection, and economic development.

Some of the most known applications of blockchain technology to protect biodiversity are the ones related to improvement in supply chains. World Wide Fund for Nature (WWF) launched a project to stop illegal fishing and slavery in the tuna industry in the Pacific's Islands. By using blockchain technology, "a simple scan of tuna packaging using a smartphone app will reveal where and when the fish was caught, by which vessel and fishing method" [69]. The objective of the initiative, created with the help of WWF (New Zealand, Fiji, and Australia), ConsenSys, TraSeable, and Sea Quest, is to include a verification in the tuna packages certifying that the product was legally caught with no slave labor involved. Therefore, with consumers who are nowadays very aware of the social and environmental impacts of the products they buy [70], this project should decrease the consumption of products associated with illegal fishing or poor human rights conditions.

Concerning ocean health objectives, decrease the pollution of the seas is crucial. With only 9% of plastic being recycled, it is expected that by 2050 12,000 million metric tons of plastic waste will be in landfills or the environment [71]. The Plastic Bank, through the program Social Plastic, is globally recognized as one of the most innovative solutions to shrink the presence of plastic in the oceans. By promoting recycling, the Plastic Bank is trying to stop the flow of plastic into an ocean using blockchain technology [72]. The organization is setting up collection centers in third world countries, from where a big portion of the plastic debris in the oceans come [73]. There, people could, at first, offer used plastic in exchange for money or goods. However, the project was facing the difficulty of people being mugged after they got their money from the plastic they delivered. To address this issue, working with Cognition Foundry and IBM, the Plastic Bank set up a new reward system where people now can get tokens -a pre mined cryptocurrency with almost no environmental impact- in exchange for the plastic they offer. The system offers two types of tokens. The first one can be exchanged by the owners as a regular cryptocurrency with other people or for fiat currency at the non-profit's stores. The second type of token can be exchanged for goods from Plastic Bank where items such as school supplies, hygiene products and even smartphones (for token management and internet access) are available.

Plastic collected through The Plastic Bank is recycled and sold at a premium as Social Plastic. The project, which is operating in Haiti, Indonesia, and the Philippines (with a future expansion to other countries), expect to reduce the presence of plastic in the ocean and help people who live in poverty.

The approach used by WWF that relies on its transparency and traceability could be used in different ocean-related products, where supply chains could be improved by the security that blockchain offer. The use of tokens, as in the Plastic Bank example, is a novel way to reduce the ocean's pollution and, at the same time, improve the life-quality of people in developing countries.

3.4 Architecture of trust and SDGs

In the three SDGs analyzed, and via their respective sustainability issues, different levels of trust were shown not to be operating properly. In SDG 2, there is a lack of trust in the institutions and intermediaries that distribute food, causing food insecurity and waste. With companies not being able to properly identify what products are contaminated and where they are in the supply chain, for example, the government must request the discard of an entire production in order to prevent a health issue. If companies participating in supply chains are able to prove to government actors that a blockchain application can precisely determine where assets are at all times, food security would increase, and food waste and potential food illnesses should decline.

For SDG 7, in the case of the token applications of blockchain, the technology is addressing the lack of intermediary trust. SolarCoin provides the platform that enables trust between those who donate money to promote solar generation and those who generate the energy. Regarding micro-energy grids managed through smart contracts, blockchain offers a means to address the arrival of non-traditional energy sources. With different actors participating in the energy transition to greener energy technologies, blockchain enables distributed trust for those who want, for example, to generate solar energy, but don't want to wait until the respective institutions define and establish the infrastructure.

Finally, on SDG 14, on one side, Leviathan trust is not present in the tuna industry. With institutions that should be able to ensure socially and environmentally responsible practices in the fishing sector, the example of WWF described how blockchain's capacity of tracing tuna can bring trust to the ecosystem, letting costumers buy with more confidence different products. On the other side, the Plastic Bank is dealing with the distrust in intermediaries by giving tokens using a cryptocurrency wallet. With banks not giving access to accounts to some people, the distributed trust present in a blockchain-based wallet allows Plastic Bank's initiative to operate in a complex context where it has to deal additionally with deficient peer-to-peer trust (with people stealing payments others get from the plastic they were recycling.)

This section, structured around three SDGs, showed solutions in private, government, and non-profit sectors, under diverse contexts, and at different scales already addressing sustainable issues. For UN's goal called "Zero Hunger", applications of blockchain offering new ways to face food security and food waste were reviewed. Solutions to promote clean energy and energy services were presented around SDG 7: Affordable and Clean Energy. Finally, blockchain's applications to reduce ocean's contamination and to protect sea life were shown to address the SDG "Life Below Water". Next, in the discussion section, the commonalities of these issues and solutions, and the challenges to use blockchain to address sustainability issues are presented.

4. Discussion

4.1 Commonalities

After exploring blockchain innovations that could potentially be applied in the context of sustainability, it is possible to identify commonalities among solutions to sustainability problems that blockchain could address, which are summarized in Figure 3.

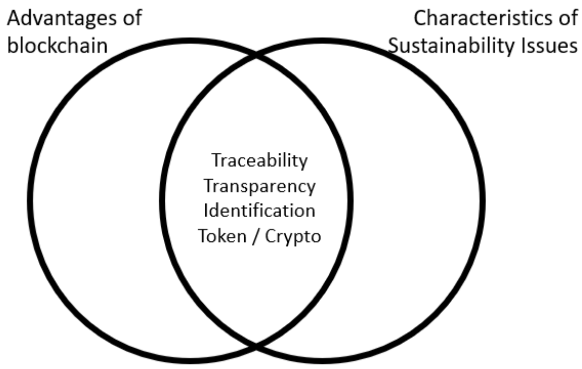

Figure 3. Intersection of advantages of blockchain and characteristics of the sustainability issues reviewed.

From the examples of WWF and Walmart, it could be concluded that supply chains can be improved by applying blockchain. Upgrading the traceability of products—their dereviations and the logistics supporting their delivery-to-market—can make transparent any asset around the world which may include sustainability-sensitive products based on animals or environmental resources. Effective and efficient traceability can increase food security and reduce food waste or reduce illegal activities such as violations of human rights or biodiversity destruction. Sara Eckhouse points out that "… I've seen blockchain focusing on food safety or traceability or […] fighting human trafficking or […] kind of poor labor practices." For example, another application of blockchain to improve traceability is used by The TrustChain Initiative**.** The project traces diamonds from mines to retails stores to verify that the product is not a "Blood Diamond", a mineral brought to market through inhumane labor practices [74].

Some argue that we are living a crisis of trust [75] that could hinder sustainability solutions [25]. Blockchain may help to reduce distrust [76]. The project of WWF and the Sun Exchange initiative offer an example of how blockchain applications display high transparency operating in environments of mistrust. Sasa Pesic, Researcher and Consultant, Ira A. Fulton Schools of Engineering, Arizona State University, states that blockchain "[a]s a mean to enforcing trust in an environment where trust does not naturally exist - it came to stay." The immutability of the information stored, its distributed nature, and the possibility of enabling a permissioned blockchain (so the general public can see information saved there) reduce the likelihood of fraud, increasing the general trust about the systems. As L. Walker from the World Economic Forum argues [77], the improved transparency of blockchain could be applied to regulate the carbon credits and greenhouse gas emissions around the world. Other issues that blockchain's transparency can improve are the raising of funds for different initiatives [42]. GiveTrack and BitHope manage donations in blockchains that can be checked by everybody, guaranteeing that the funds reach the intended projects and reducing the possibility of frauds. Smart Contracts, like the ones reviewed on the SunContract and Dexentralize examples, can work to provide the necessary trust to some complex systems such as energy grids.

In all the examples reviewed, the systems work with an ID. For example, this ID allows identifying every tuna, pork product, MWh generated, fund donated, etc. As previously stated, blockchain provides an effective tool to manage the identification of both physical and virtual assets. This means that when there is a sustainability issue related to IDs, the technology offers the tool to solve it. While mostly an unknown issue, 1.5 billion people have no proper legal identification, and 50 million children are born every year without a birth certificate and legal identity [78]. Darren Tapp, Researcher at Dash, mentions "I can envision one application would be Identity Management […] so you could basically register an identity on the chain and have a public key associated with that identity". The WISeID project looks for providing to every person on the planet a legal digital identity, aligned with the UN´s SDG 16 "Peace, Justice, and Strong Institutions" that aims to "by 2030, provide a legal identity for all, including birth registration" [53]. It could be used to help refugees or migrants who usually lack of proper identification [79]. The World Food Programme, for example, gave Syrian refugees the ability to pay for food using an iris scan via a blockchain application. The iris scan is recorded in blockchain, creating an ID without sharing personal information [80]. One more use for blockchain could be in developing countries, where the management of land rights is complicated and is prone to fraud [81]. In some of these countries, the registration and control of lands is done using books to keep the records, easing the process in case somebody wants to make unauthorized changes to the information. Currently, several countries are developing projects to store and manage land rights using blockchain networks, reducing frauds [82].

Finally, knowing that the first and currently most famous applications of blockchain are the cryptocurrencies, it is important to understand how digital currencies and tokens could be used to solve sustainability issues. As Dierksmeier and Seele, [83] propose, it could be possible to promote ethical goals using cryptocurrencies. The Plastic Bank and the Solar Coin projects exemplify situations where some form of tokens or cryptocurrencies are given to people who engage in sustainable practices. RecycleToCoin is another project that, like Plastic Bank, aims to increase the recycling of plastic in Europe [84]. Cryptocurrencies also allow providing bank services to people who usually would be outside of the financial world. While making a transfer would have been a solution to the initial thief-related issues of The Plastic Bank initiative, almost none of the people who participated in the project had a bank account. According to data from the World Bank [85] "around 2 billion people don't use formal financial services, and more than 50% of adults in the poorest households are unbanked". Blockchain allows people to have a digital wallet to store currencies or tokens, reducing the likelihood of being robbed for example. "I believe that places where there's no or an insufficient banking infrastructure, cryptocurrencies can be used to empower individuals to basically have access to a wider financial network" suggests Darren Tapp, proposing that financial inclusion could grow with the use of blockchain.

4.2 Challenges

As an emerging technology, blockchain has plenty of challenges to overcome before it will be widely adopted. In the first place, according to the Gartner Hype Cycle for Emerging Technologies [86], blockchain is currently at the peak of inflated expectations. It is not difficult to find news and articles that declare that blockchain will change the planet in the same way the Internet did [87]. Todd Taylor argues "I think one of the biggest mistakes people are making, in addition to just the technology needing to mature, is that they just try to shove blockchain in places where it doesn't belong." Similarly, Ward Hendon adds "it's also a very frustrating time because there is this hype cycle […] so it's really important to have as many perspectives as you can because, like most new things and new technologies, is sort of a shiny new object, and corporations are jumping on to see if they can incorporate tech and create competitive, you know, differentiation." Currently, it seems that blockchain is being offered as the answer to everything, but realistically the technology still has a long path to cover to reach its full capacity [86]. From a sustainability standpoint, there is the risk of using blockchain-based applications to address social or environmental issues when the technology is not necessarily needed. Pablo Prieto, regarding the perception of blockchain just as a trend, adds "I think it is not a passing fad, even though its application is through technology, it is based on a new paradigm that is aligned with the trends of a globalized world where the social networks are our communication and relationship channels, that allows us to tear apart the geographic barriers, bring cultures together, teaching and dis-educating with the diversity of the information we produce, distribute and consume in our condition of active users of distributed data."

Also, it is necessary to address the risks associated with blockchain. As with many other new technologies, there is uncertainty about its future and the unexpected uses that blockchain may have. Patricia Burnett, attorney at Weiss Brown, reflects "… let's be thoughtful in these designs [blockchain applications] so that we don't, down the road, realize that there were unintended consequences…" For example, one advantage of blockchain is at the same time one of its disadvantages: once information is stored in blockchain, it cannot be erased. With some sensible or risky information such as personal IDs or medical records, the decision of which data should be added is complex. If used to address sustainability issues, the development of blockchain-related tools must be done in consideration of potential unexpected impacts different applications may have, taking into account previous experiences and inviting different stakeholders to the decision-making process. Another risk of the technology is to blindly believe in the information stored in blockchain. Although once the information is stored in blockchain, it is immutable, the process whereby the data is added to the system should always be monitored. As Sara Eckhouse explicates "[…] if you can't trust the original source… there still needs to be some kind of a way to say 'yes, what this person is saying is true' and I don't think the blockchain actually solves that." The advantages that are offered by blockchain don't resolve the issues related to the source of the information, creating the requisite of auditing the origin to fully trust in the data that is stored and shared.

A distributed network is meant to be integrated by different actors. And the scalability of the technology depends on how widespread its use among institutions. Currently the adoption of blockchain and the participation of organizations in shared ecosystems is voluntary, leaving the question of how to incentivize them to adhere to it to enhance the data they manage. Todd Taylor elaborates "the reality of building ecosystem level applications is that it's very difficult because it requires all of the members to participate. So, how do you create an incentive structure such that you can attract all of the members of a given network to participate?". As it was showed in the case of the WWF's application of blockchain to trace tuna, more companies could adhere to the network, creating an ecosystem where *all* tuna products are social and environmentally certified. But what is needed to have more organizations use these systems? "We need collaboration […] and say, 'what is it that could incentivize you?'…" explains Hanieh Sadat, Managing Partner of GenesysOne Capital as an answer that she then summarized as "economic incentives model, that's what we need to figure out." Nevertheless, in the distributed and unstandardized reality of blockchain, it is complicated to determine who should find and offer those incentives. At this time, based on applications reviewed for this study, the incentives offered are determined case by case, usually pushed by either the technology companies introducing the solution or the organizations looking for support.

A possible answer to the scalability of the technology could come from standardization. But there is no agreed-upon formal definition of blockchain. A consensus about what blockchain is (and what blockchain isn't) could improve the adoption curve by simplifying the understanding of the technology. Regulation could bring not only consensus around blockchain but also address other challenges of the technology. Ward Hendon argues "I believe, and this is putting my lawyer regulatory hat on, that we're not going to have mainstream adoption of this until we have clearer regulations […] in countries where there is oversized influence like the United States, we need to have crisper cleaner regulation before more capital is going to be comfortable coming into the market." This approach is similar to the perspective of Professor Yarime Masaru, who however thinks that blockchain may still need more time before regulation is applied: "So, at this moment, as I said, there are many companies and many standards, and they are somehow competing with each other, and nobody knows which will be the best or which won't be the most appropriate in the end. […] Initially I think, just let them compete, let them invent whatever they think is important. But then, probably at a certain stage, I guess the public authority could intervene or working together between industry and the government or public sector so that in the end that we need to have a kind of standardization, so that we can facilitate all these exchange interactions having the same standard."

This call for regulation, which would need some form of governance, is not shared for everybody. Some blockchain experts, especially those linked to the cryptocurrency aspect, don't agree. Sasa Pesic thinks that some form of centralized governance "is against the core principles of the blockchain technology." In spite of that view against centralization, many regulations efforts are being conducted around the world [88]. In the cryptocurrency realm, some countries have established regulations, mostly related to taxes, trading and legality [89]. In the world of permissioned or private blockchain where not much has been achieved, there are many parallel initiatives pursuing standardization. One of the most famous is Hyperledger started by the Linux Foundation in 2015 whose objective is to advance cross-industry blockchain technologies.

Finally, it is necessary to note that blockchain is a means and not an end. As reviewed in this study, blockchain offers a new tool to address some sustainability issues in novel ways. However, as a technology, it is likely not enough *by itself* to solve these problems. This expanded perspective should ease and enhance the analysis around the institutions related to the sustainability issue. For instance, while in the case of SDG 2, the use of technology to face food contamination will probably bring numerous actors to collaborate on solutions, by contrast, the distributed micro-energy grids may not find the same help from all those participating since traditional, large-scale energy companies, as an example, could see them as their competition.

5. Conclusion

With what seems to be the ending of the buzz around Bitcoin, blockchain emerges as a technology that promises to offer advantages never seen before. From a sustainability standpoint, this study found four commonalities about some of those advantages in the context of characteristics of three, representative UN SDGs: traceability, transparency, identification and tokenization. This list is by no means definitive, and its objective is to provide a glance of opportunities created by blockchain. Further research could extend the analysis to the other 14 SDGs not covered by this study, as well as increase the number of perspectives and applications examined to find more attributes of the technology that can be used to address sustainability issues. The rapid expansion of blockchain, with new applications and approaches being constantly created, demands continuous assessment of its interface with the SDGs.

The potential opportunities offered by blockchain should be contrasted with the challenges it faces as an emergent, powerful technology, all of them being complex. Beyond the peak of high expectations around this technological innovation, which at some point will pass, the risks associated with its use must be considered. The temptation and novelty of applying blockchain as a tool can be at the expense of not thinking about the potential unintended consequences it could cause. Also, it is necessary to identify where trust in blockchain starts and ends. The processes used to add information to blockchain systems and what happens after data are taken from it are open to mistakes and misuses. Thus, it must be planned how to enhance security and trust around those steps.

Scalability is a typical challenge for emerging technologies. And blockchain is no exception. So far, we have still not seen a global, multi-stakeholders, working solution of blockchain being applied to a sustainability issue. While it has its own technical challenges to expand its use, the integration of new actors to a blockchain ecosystem is still necessary to increase its adoption. But, the lack of standardization may be a factor hindering this process. To promote these standards, some form of regulation or governance could be appropriated. However, it is still not clear who should push for such regulation, since the spirit of the technology is, precisely, decentralization, thus leaving space for further research to understand the pros and cons of governance of this important, new technology.

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Appendix A

List of interviewees:

1. Darren Tapp, Researcher, Dash, USA.
2. Pablo Prieto, CEO, TIVIT Perú, Peru.
3. Yarime Masaru, Associate Professor, Division of Public Policy, Hong Kong University of Science and Technology, Hong Kong.
4. Ward Hendon, Adjunct Professor, Anderson Business School, University of California-Los Angeles, USA.
5. Todd Taylor, Professor of Practice, Thunderbird School of Global Management, Arizona State University, USA.
6. Sasa Pesic, Researcher and Consultant, Ira A. Fulton Schools of Engineering, Arizona State University.
7. Hanieh Sadat, Managing Partner, GenesysOne Capital, USA.
8. Sara Eckhouse, Executive Director, FoodShot Global, USA.
9. Patricia Burnett, Attorney, Weiss Brown, USA.
10. Miguel Angel Calisto, Congressman, Chile.
11. Rhayza Margarita Rodríguez Sandoval, Digital Pre-sales, Telefónica, Chile.

References

1. Iansiti, M.; Lakhani, K.R. The Truth About Blockchain. **2017**, 11.
2. Davis, J. The crypto-currency. *New Yorker* **2011**, *87*, 62–70.
3. Maurer, B.; Nelms, T.C.; Swartz, L. “When perhaps the real problem is money itself!”: the practical materiality of Bitcoin. *Soc. Semiot.* **2013**, *23*, 261–277.
4. Kranzberg, M. Technology and History:" Kranzberg’s Laws". *Technol. Cult.* **1986**, *27*, 544–560.
5. Kewell, B.; Adams, R.; Parry, G. Blockchain for good? *Strateg. Change* **2017**, *26*, 429–437.
6. Crosby, M. BlockChain Technology: Beyond Bitcoin. **2016**, 16.
7. Underwood, S. Blockchain beyond bitcoin. *Commun. ACM* **2016**, *59*, 15–17.
8. Reijers, W.; Coeckelbergh, M. The Blockchain as a Narrative Technology: Investigating the Social Ontology and Normative Configurations of Cryptocurrencies. *Philos. Technol.* **2018**, *31*, 103–130.
9. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. **2018**, 9.
10. Reijers, W.; O’Brolcháin, F.; Haynes, P. Governance in Blockchain Technologies & Social Contract Theories. *Ledger* **2016**, *1*, 134–151.
11. Bitcoins Maybe; Blockchains Likely Available online: https://www.americanscientist.org/article/bitcoins-maybe-blockchains-likely (accessed on Jan 14, 2019).
12. Schiller, B.; Schiller, B. 2018 Is Going To Be A Massive Year For Blockchains, The Tech Behind Bitcoins Available online: https://www.fastcompany.com/40502720/2018-is-going-to-be-a-massive-year-for-the-blockchain-the-tech-behind-bitcoins (accessed on Jan 14, 2019).

13. Extance, A. The future of cryptocurrencies: Bitcoin and beyond. *Nat. News* **2015**, *526*, 21.
14. Giungato, P.; Rana, R.; Tarabella, A.; Tricase, C. Current Trends in Sustainability of Bitcoins and Related Blockchain Technology. *Sustainability* **2017**, *9*, 2214.
15. Vranken, H. Sustainability of bitcoin and blockchains. *Curr. Opin. Environ. Sustain.* **2017**, *28*, 1–9.
16. Foteinis, S. Bitcoin's alarming carbon footprint. *Nature* **2018**, *554*, 169.
17. Grinberg, R. Bitcoin: An innovative alternative digital currency. *Hastings Sci Tech LJ* **2012**, *4*, 159.
18. Athey, S.; Parashkevov, I.; Sarukkai, V.; Xia, J. Bitcoin pricing, adoption, and usage: Theory and evidence. **2016**.
19. Baur, A.W.; Bühler, J.; Bick, M.; Bonorden, C.S. Cryptocurrencies as a disruption? empirical findings on user adoption and future potential of bitcoin and co.; Springer, 2015; pp. 63–80.
20. Brito, J.; Castillo, A. *Bitcoin: A primer for policymakers*; Mercatus Center at George Mason University, 2013;
21. Pilkington, M.; Crudu, R.; Grant, L.G. Blockchain and bitcoin as a way to lift a country out of poverty-tourism 2.0 and e-governance in the Republic of Moldova. *Int. J. Internet Technol. Secur. Trans.* **2017**, *7*, 115–143.
22. Beck, R. Beyond Bitcoin: The Rise of Blockchain World. *Computer* **2018**, *51*, 54–58.
23. Kiviat, T.I. Beyond bitcoin: Issues in regulating blockchain transactions. *Duke LJ* **2015**, *65*, 569.
24. Tapscott, D.; Tapscott, A. How blockchain will change organizations. *MIT Sloan Manag. Rev.* **2017**, *58*, 10.
25. Chapron, G. The environment needs cryptogovernance. *Nature* **2017**, *545*, 403–405.
26. Zheng, Z.; Xie, S.; Dai, H.; Chen, X.; Wang, H. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In Proceedings of the 2017 IEEE International Congress on Big Data (BigData Congress); 2017; pp. 557–564.
27. Lamport, L.; Shostak, R.; Pease, M. The Byzantine generals problem. *ACM Trans. Program. Lang. Syst. TOPLAS* **1982**, *4*, 382–401.
28. Jeffries, A. 'Blockchain' is meaningless Available online: https://www.theverge.com/2018/3/7/17091766/blockchain-bitcoin-ethereum-cryptocurrency-meaning (accessed on Jan 14, 2019).
29. Greenspan, G. Private Blockchains are More Than 'Just'Shared Databases. **2015**.
30. Werbach, K. *The Blockchain and the New Architecture of Trust*; Mit Press, 2018; ISBN 0-262-03893-5.
31. Yli-Huumo, J.; Ko, D.; Choi, S.; Park, S.; Smolander, K. Where is current research on blockchain technology?—a systematic review. *PloS One* **2016**, *11*, e0163477.
32. Chen, G.; Xu, B.; Lu, M.; Chen, N.-S. Exploring blockchain technology and its potential applications for education. *Smart Learn. Environ.* **2018**, *5*.
33. Dagher, G.G.; Mohler, J.; Milojkovic, M.; Marella, P.B. Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology. *Sustain. Cities Soc.* **2018**, *39*, 283–297.
34. Marsal-Llacuna, M.-L. Future living framework: Is blockchain the next enabling network? *Technol. Forecast. Soc. Change* **2018**, *128*, 226–234.
35. National Research Council *Our common journey: a transition toward sustainability*; National Academies Press, 1999; ISBN 0-309-08638-8.

36. Bettencourt, L.M.; Kaur, J. Evolution and structure of sustainability science. *Proc. Natl. Acad. Sci.* **2011**, *108*, 19540–19545.
37. Clark, W.C. Sustainability science: a room of its own. **2007**.
38. Miller, T.R. Constructing sustainability science: emerging perspectives and research trajectories. *Sustain. Sci.* **2013**, *8*, 279–293.
39. Sachs, J.D. From millennium development goals to sustainable development goals. *The Lancet* **2012**, *379*, 2206–2211.
40. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin III, F.S.; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J. Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* **2009**, *14*.
41. Raworth, K. A safe and just space for humanity: can we live within the doughnut. *Oxfam Policy Pract. Clim. Change Resil.* **2012**, *8*, 1–26.
42. Baynham-Herd, Z. Technology: Enlist blockchain to boost conservation. *Nature* **2017**, *548*, 523.
43. Ahmed, S.; ten Broek, N. Food supply: Blockchain could boost food security. *Nature* **2017**, *550*, 43.
44. Andoni, M.; Robu, V.; Flynn, D. Blockchains: Crypto-control your own energy supply. *Nature* **2017**, *548*, 158.
45. Rubin, H.J.; Rubin, I.S. *Qualitative interviewing: The art of hearing data*; Sage, 2011; ISBN 1-4522-8586-1.
46. Rapley, T. Interviews ‘in Seale, C., Gobo, G., Gubrium, JF and Silverman. *Qual. Res. Pract.* **2004**.
47. Longhurst, R. Semi-structured interviews and focus groups. *Key Methods Geogr.* **2003**, 117–132.
48. Given, L.M. *The Sage encyclopedia of qualitative research methods*; Sage Publications, 2008; ISBN 1-4522-6589-5.
49. Saldaña, J. *The coding manual for qualitative researchers*; Sage, 2015; ISBN 1-4739-4359-0.
50. Le Blanc, D. Towards integration at last? The sustainable development goals as a network of targets. *Sustain. Dev.* **2015**, *23*, 176–187.
51. Elkington, J. Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environ. Qual. Manag.* **1998**, *8*, 37–51.
52. United Nation Development Programme Beyond bitcoin Available online: https://feature.undp.org/beyond-bitcoin/ (accessed on Feb 16, 2019).
53. United Nations Sustainable Development Goals Available online: https://www.un.org/sustainabledevelopment/ (accessed on Jan 21, 2019).
54. McGuire, S. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. *Adv Nutr* **2015**, *2015*, 623–624.
55. Achieving Zero Hunger Depends upon Delivery on All Sustainable Development Goals, Secretary-General Says in Message to World Food Programme Executive Board | Meetings Coverage and Press Releases Available online: https://www.un.org/press/en/2016/sgsm17519.doc.htm (accessed on Jan 14, 2019).
56. Kshetri, N. 1 Blockchain’s roles in meeting key supply chain management objectives. *Int. J. Inf. Manag.* **2018**, *39*, 80–89.
57. Seattle, F.S.N. 1012 F.A.F.F.; Washington 98104-1008 A new era of food transparency with Wal-Mart center in China Available online: https://www.foodsafetynews.com/2017/03/a-new-era-of-food-transparency-with-wal-mart-center-in-china/ (accessed on Jan 14, 2019).

58. Buzby, J.; Farah-Wells, H.; Hyman, J. The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States. **2014**.
59. Emem, M. U.S. FDA Eyes Blockchain to Enhance Food Safety in the Wake of E. coli Outbreak Available online: https://www.ccn.com/u-s-fda-eyes-blockchain-to-enhance-food-safety-in-the-wake-of-e-coli-outbreak (accessed on Feb 4, 2019).
60. Gielen, D.; Boshell, F.; Saygin, D. Climate and energy challenges for materials science. *Nat. Mater.* **2016**, *15*, 117.
61. Monacchi, A.; Elmenreich, W. Assisted energy management in smart microgrids. *J. Ambient Intell. Humaniz. Comput.* **2016**, *7*, 901–913.
62. Solar Industry Research Data Available online: /solar-industry-research-data (accessed on Feb 4, 2019).
63. Mengelkamp, E.; Gärttner, J.; Rock, K.; Kessler, S.; Orsini, L.; Weinhardt, C. Designing microgrid energy markets: A case study: The Brooklyn Microgrid. *Appl. Energy* **2018**, *210*, 870–880.
64. Architecture of a microgrid energy management system - Jimeno - 2011 - European Transactions on Electrical Power - Wiley Online Library Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/etep.443 (accessed on Feb 4, 2019).
65. Kosba, A.; Miller, A.; Shi, E.; Wen, Z.; Papamanthou, C. Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts. In Proceedings of the 2016 IEEE Symposium on Security and Privacy (SP); IEEE: San Jose, CA, 2016; pp. 839–858.
66. Christidis, K.; Devetsikiotis, M. Blockchains and Smart Contracts for the Internet of Things. *IEEE Access* **2016**, *4*, 2292–2303.
67. Glanz, J.; Robles, F. How Storms, Missteps and an Ailing Grid Left Puerto Rico in the Dark. *N. Y. Times* 2018.
68. Fuentes, J. Restoring Power to Puerto Rico Using the Blockchain. *Medium* 2017.
69. How blockchain & a smartphone can stamp out illegal fishing and slavery in the tuna industry Available online: https://www.wwf.org.au/news/news/2018/how-blockchain-and-a-smartphone-can-stamp-out-illegal-fishing-and-slavery-in-the-tuna-industry (accessed on Jan 14, 2019).
70. The Sustainability Imperative Available online: http://www.nielsen.com/us/en/insights/reports/2015/the-sustainability-imperative (accessed on Jan 14, 2019).
71. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782.
72. Cleaning our Oceans of Plastic | Haiti | UNFCCC Available online: https://unfccc.int/climate-action/momentum-for-change/planetary-health/cleaning-our-oceans-of-plastic-haiti (accessed on Feb 7, 2019).
73. Schmidt, C.; Krauth, T.; Wagner, S. Export of plastic debris by rivers into the sea. *Environ. Sci. Technol.* **2017**, *51*, 12246–12253.
74. IBM Is Tackling Blood Diamonds With Blockchain 2018.
75. Intelligence, E. Edelman Trust Barometer: 2017 annual global study. *Exec. Summ.* **2017**.
76. Shackelford, S.J.; Myers, S. Block-by-block: leveraging the power of blockchain technology to build trust and promote cyber peace. *Yale JL Tech* **2017**, *19*, 334.

77. Walker, L. This new carbon currency could make us more climate friendly.; 2017; Vol. 19.
78. WISeKey Unveils its Digital Identity BlockChain Platform CertifyID in NYC; State-of-the-Art Technology is in line with the UN Sustainable Development Goals to Provide Every Person on the Planet with a Legal Digital Identity by 2030 Available online: https://www.wisekey.com/investors_press-release/wisekey-unveils-its-digital-identity-blockchain-platform-certifyid-in-nyc-state-of-the-art-technology-is-in-line-with-the-un-sustainable-development-goals-to-provide-every-person-on-the-planet (accessed on Jan 14, 2019).
79. Can blockchain help us better assist refugees and migrants in transit? Available online: http://www.eurasia.undp.org/content/rbec/en/home/blog/2017/11/3/Can-blockchain-help-us-better-assist-refugees-and-migrants-in-transit-.html (accessed on Feb 16, 2019).
80. Programme, W.F. What is 'blockchain' and how is it connected to fighting hunger? Available online: https://insight.wfp.org/what-is-blockchain-and-how-is-it-connected-to-fighting-hunger-7f1b42da9fe (accessed on Feb 16, 2019).
81. Anand, A.; McKibbin, M.; Pichel, F. Colored coins: Bitcoin, blockchain, and land administration.; 2016.
82. African startups bet on blockchain to tackle land fraud. *Reuters* 2018.
83. Dierksmeier, C.; Seele, P. Cryptocurrencies and business ethics. *J. Bus. Ethics* **2018**, *152*, 1–14.
84. BCDC World's First "Global" Plastic-Offset Scheme Launched by BCDC Available online: https://www.prnewswire.com/news-releases/worlds-first-global-plastic-offset-scheme-launched-by-bcdc-657453753.html (accessed on Jan 14, 2019).
85. The World Bank Financial Inclusion Available online: http://www.worldbank.org/en/topic/financialinclusion/overview (accessed on Jan 14, 2019).
86. Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017 Available online: https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/ (accessed on Jan 14, 2019).
87. Blockchain: the internet's second generation. *Dir. Mag.* 2016.
88. Council, G.B.B. Global Blockchain Business Council (GBBC) Announces Release of Annual Report 2019. **2018**.
89. Staff, G.L.R.D. Regulation of Cryptocurrency Around the World Available online: https://www.loc.gov/law/help/cryptocurrency/world-survey.php (accessed on Feb 8, 2019).