BLOCKCHAIN FOR SUSTAINABILITY

GROUND ZERO

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FOREWORD

As digitalization continues to transform our economies and societies globally, we are presented with a unique opportunity to harness the potential of disruptive technologies to accelerate our collective sustainability ambitions and our transition towards a more inclusive and sustainable economy on a healthy planet. Digital innovations can indeed help address some of the world's most pressing challenges such as climate change, biodiversity loss, food security, poverty, and inequality. But these outcomes will not be automatic, they need to be deliberately shaped and sought if we are to realize the benefits of digitalization.

For example, over the last few years, we have witnessed significant interest and considerable investment in Web3 and blockchain technologies, fueled by highly anticipated transformational outcomes across sectors of the real economy. Blockchain, and more broadly distributed ledger technologies, have been expected to fundamentally disrupt the way money works and moves around the world, how sustainability data is collected across food supply chains, the way people manage their identity, how ecosystem services from natural capital and other assets get tokenized and how carbon accounting is transparently performed, just to name a few examples.

In this way, it can be said that blockchain applications will be offering new opportunities for promoting sustainable development, thereby contributing to the achievement of many SDGs such as SDG1 (no poverty), 5 (gender equality), 8 (decent work and economic growth), 10 (reduced inequalities), 11 (sustainable cities and communities), 14 (life below water), 15 (life on land) and 17 (partnerships for the SDGs).

But as stated earlier, these outcomes will only materialize if there is a deliberate effort to steer blockchain technology in that direction. As it stands, many issues remain that will need to be addressed if the potential is to be unleashed, from regulatory gaps to the energy consumption of blockchain protocols to more emphasis on sustainability aligned business models. This will require collective effort, multi-stakeholder engagement and nurturing a growing yet fragile sustainability-focused community of practice.

This report is a first step in this direction, it provides an overview of blockchain, discusses some of the emerging trends and examples linked to sustainability and discusses some of the issues that do require further attention. In that sense, it hopes to trigger broader discussions and healthy debates about the future of this technology so that together, we can endeavor to shape it for a better future for all.

Aiaze Mitha
Global Lead, digital finance for the SDGs, UNDP

B4S: GROUND ZERO

The Precautionary Principle in International Environmental Law sets forth that, when the environmental and social risks entailed by a given human activity are uncertain, the regulatory inaction is unjustified. Consequently, despite blockchain's amazing potential for decentralization, transparency, traceability and community building, which we find thrilling and tempting, we need to ask ourselves: should we promote the global adoption of this particular technology?

If "yes", we want to know why. If "no", still. If "we don't know", what is the cost-benefit of keeping at it blindfolded? What is the real ecosystemic cost of extracting, manufacturing, using and discarding the material and energetic resources required by blockchain-based products and services? As a society, can we afford to adopt new technologies at a large scale without previously assessing their environmental, social and economic impact? What would the consequences be?

I'd like to thank and congratulate this multidisciplinary research team for studying hundreds of sources of information and patiently, collaboratively and respectfully working to draft this first iteration of the report Blockchain for Sustainability (B4S) - Ground Zero, a free and open resource that invites us to keep going.

Thanks for reading.

Máximo Mazzocco
Founder of Eco House Global

OPENING WORDS

The world is changing. The social and financial dynamics of societies have shifted, and in a few years, it'll be hard to remember how everything worked in the past. Blockchain & Crypto are all about transparency, efficiency, and trust—not on people alone, but powered by technology. We are witnessing the dawn of a completely new society. And this new society wouldn't be completely transformed if impact endeavors—both social and environmental—weren't at the core of this shift.

It is only a matter of time until the general population starts demanding product and service companies at large to create a positive impact on communities and the environment. New generations demand both transparency and a clear purpose that goes beyond making a profit and includes having a positive impact on the world. Imagine a future where donations and positive impact are embedded at a protocol level, at a transactional level. Imagine a life where in every transaction you make, in everything you do, you are making an effective and positive impact on other people's lives, and on our beloved Earth.

That world is not far from us. It is actually incredibly near. And the time has come to make it a reality.

Borja Martel
Co-founder of Lemon Cash

EXECUTIVE SUMMARY

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- Blockchain could either provide innovative solutions to help ease the critical global setting we are experiencing, with major environmental, social and governance challenges, or become yet another threat to our environment and make matters worse.
- One the one hand, there are several use cases for this technology that currently evidence its impact and its transformative potential (see section II "Uses in Environment, Society, and Governance").
- On the other, the use of Proof-of-Work (PoW) as consensus mechanism on public blockchains, such as Bitcoin, creates a significant environmental impact (see section III "Environmental Impact of Blockchain").
- This report is intended to prompt the active and entrepreneurial blockchain community to continue working to reduce the environmental impact of this technology and promote use cases that will help fight the climate and environmental crisis. It is also aimed at driving awareness in the environmental community around how blockchain can help them achieve their goals and boost their impact.

How Blockchain Works

- Traditionally, information is recorded and stored in centralized, managed and controlled databases where an intermediary validates the information and disseminates it to the right stakeholders. This role grants the intermediary significant power over the system and the possibility to charge large commissions for its services.
- Blockchain is a new technology that makes it possible to record, store and manage information in an immutable, transparent and decentralized way (see section I "Understanding Blockchain"), by combining in a novel way technologies widely used in other fields: cryptography (hashes, digital signatures, public-private keys), computer science (linked lists, distributed networks), and accounting/finance (ledgers).
- Open and mass-adopted systems require a process to guarantee the validity of recorded information and the security of the general system. This process is usually referred to as consensus mechanisms, with proof of work (*PoW*) and proof of stake (*PoS*) being the best known and most widely used.
- The PoW requires the user who records a new block to solve a complex cryptographic puzzle, which requires significant computational power (costly in terms of gear needed and energy consumption).
- The PoS requires that users who want to validate new blocks invest/freeze part of their digital assets associated to a blockchain to then be granted the possibility to validate a block.
- Both consensus mechanisms share the same concept: users wanting to validate a block need to run high costs to do so (weather computational or financial), which acts as a barrier and makes it almost impossible for a user to control the system or engage in harmful behaviors.

Blockchain Environmental, Social and Governance Use Cases

- There are several and diverse blockchain use cases that have a significant impact on the environmental, social and governance aspects. Nevertheless, there are multiple segments that could potentially bring about a positive impact should this technology be applied. Blockchain has been around for barely 15 years and it's continuously being improved and developed.
- On the environmental front, the most promising applications of blockchain are guaranteeing supply chain traceability and transparency, and certifying products and services under a variety of production and environmental standards (Open Vino case study). It can also be used for environmental control and monitoring (as is the case of Plastic Bank and public-private collaborations). Lastly, blockchain can benefit the carbon credits market, by adding trust and transparency and creating a more promising future (see Treefy and Solar Coin).
- A good example of blockchain's social impact is its significant contribution to financial inclusion by lowering barriers to financial services such as payment methods, credits, insurance and international wire transfers, specially remittances (see Lemon, OpenIDL and AlipayHK).
- Blockchain is also used for smart contracts and Decentralized Autonomous Organizations (DAOs) which offer new alternatives to collaborate and govern, especially when applied to digital ecosystems. Nation states and international organizations are starting to implement blockchain to improve their own system's transparency and security (like in Estonia, Chile and Argentina).

Environmental Impact of Blockchain

- In terms of energy and computing efficiency we could say that blockchain is mildly more inefficient than centralized systems, although it offers important security and decentralization advantages. The problem to be solved will determine which technology should be used.
- Nevertheless, public blockchains that use Proof-of-Work (PoW) as consensus mechanism, such as Bitcoin, have a wildly larger energy consumption, representing a huge environmental impact as over 60% of the energy that is used by these systems is non-renewable.
- For example, Bitcoin is thought to have consumed 104 TWh during 2021, a similar consumption level to that of Kazakhstan, #34 in the world energy consumption ranking.
- The use of non-renewable energy sources award Bitcoin a footprint of 56.3 $MtCO_2e$ for 2021, similar to that of Greece and amounting to 0.19% of global emissions.
- Bitcoin is not widely used as payment method, which creates a high energy consumption and emissions toll when viewed per transaction. Each Bitcoin transaction is thought to consume 2,138.78 KWh with a total emission of 1,192.92 kg CO_2, while 100,000 transactions processed by a credit card take up 148.63 KWh with a carbon footprint of 45.12 kg CO_2.

- Bitcoin in particular, and all cryptocurrencies using PoW, not only use vast amounts of energy but they also require highly specialized gear to solve cryptographic challenges more efficiently, which creates ewaste amounting to 30.7 metric tons per year or 272 g of ewaste per transaction.
- As crypto benchmark Bankless says, "the solution to PoW's energy consumption is to turn PoW off." This is what the second most important cryptocurrency, Ethereum, did in September 2022 by migrating from PoW to PoS, reducing its energy consumption by 99.95%.
- Despite these challenges and others that may arise, there is no doubt that blockchain is a technology that will have a profound effect on the digital world, and therefore, on our analog reality.

INTRODUCTION

INTRODUCTION

In a pressing global context, amidst a profound climate and environmental crisis, it is increasingly necessary to devise concrete and sustainable solutions that help shape policies in favor of inclusion, adaptation, mitigation and environmental regeneration.

Blockchain, through its decentralization, transparency, traceability, immutability, reliability and security, is becoming one of today's most disruptive and promising technologies, with both a real and potential impact on all activities and industries.

Therefore, we wonder if, within this critical global setting, a technology such as blockchain could contribute to solving the existential challenges that humanity faces on Earth or if, quite the contrary, it would exacerbate the problem and, in turn, pose yet another threat to our environment. We are aware of how difficult it is to answer this complex question in an environment of uncertainty, added to the fact that this technology, in its current state, is less than 15 years old and is under a continuous process of development and evolution.

Nevertheless, there are already numerous applications, on a global and/or local scale, that allow us to study, analyze and have a glimpse at its transformative potential, as well as its possible limitations and disadvantages, bearing in mind that, with time and further use, the current situation could change.

In Section I "Understanding Blockchain", we explain how the technology works and its advantages over pre-existing centralized systems, as blockchain allows information to be recorded, stored and managed in a way that is immutable, transparent and decentralized.

This, like any other technology, is neither positive nor negative in itself, it depends on how it is applied and how human beings end up using it. In this sense, blockchain can be used very broadly, both by private and public players — be they governments, start-ups, companies, international organizations or non-profit organizations — that seek to leverage this technology in pursuit of a better environment and a better society. In Section II "Uses in Environment, Society and Governance", we dive deeper to clarify the impact that this technology can have on these three foundational pillars of modern societies.

Finally, and acknowledging that all economic activity has an effect on the environment we inhabit, in Section III "Environmental Impact of Blockchain", we analyze, based on available information, how its use impacts nature.

Through this detailed study, we can confirm that blockchain technology has an enormous transformative potential for practically all sectors of human activity. We believe that, in the future, as this technology grows and the use of renewable energy sources becomes widespread, its benefits will far outweigh the current environmental costs.

Blockchain based on the Proof-of-Work consensus system, like Bitcoin to present or Ethereum until September 2022, represent a substantial environmental impact due to the high electricity consumption that such a consensus mechanism entails and the high amounts of e-waste they produce.

Blockchain is an evolving technology, with significant and constant advances in efficiency and environmental impact. A good example of this is Ethereum, which for two years worked to migrate from Proof-of-Work as a consensus mechanism to a Proof-of-Stake, which meant a 99.95% reduction in its energy consumption and an increase in its scalability, which boosted the adoption of its applications.

Blockchain's characteristics of immutability, decentralization and transparency also enable a much wider universe of applications than mere cryptocurrencies, with a highly positive and disrupting impact on social, economic and governance aspects, through existing and future solutions. For example, how consumers and citizens control activities or take part in organizations in areas as diverse as certifying food, validating carbon credits or writing smart contracts, among many other uses.

This report will highlight case studies where this technology is applied, such as companies that develop blockchain-organized and managed reforestation projects, governments that use this technology to guarantee the security and transparency of their information, non-profit organizations that guarantee the traceability and transparency of their projects, digital communities that define their own rules, processes and ways of cooperating through a DAO, among several other use cases that showcase this technology's potential.

Blockchain facilitates decentralization, contributes to transparency, collaborates with cooperation and ensures information security. In a digitally limitless world, such a technology will have a profound and wide-ranging impact on a resource-constrained society and environment.

We believe that the active and entrepreneurial blockchain community has a fundamental role to play: its tireless work will make it possible to reduce the environmental impact of this technology and promote use cases that will help fight the climate and environmental crisis. In addition, environmental organizations can implement blockchain-based solutions and projects that tap into the technology's traits of decentralization, immutability and transparency to attain better results.

For a technology invented barely 15 years ago, the growth and reach of blockchain has been extraordinary. However, it has yet to mature into massive, secure and usable products, projects and applications. This process is well underway, yet we will have to be patient to begin to see the result. In the meantime, we need to continue demanding that it adopts less polluting consensus mechanisms than the Proof-of-Work, which currently has a very large negative environmental impact.

SECTION ONE

UNDERSTANDING BLOCKCHAIN

SECTION ONE

UNDERSTANDING BLOCKCHAIN

Introduction to Blockchain

Blockchain is a new technology that makes it possible to record, store and manage information in an immutable, transparent and decentralized way. While all the elements that make up this technology have existed for years and have been used extensively, for example, hash functions, public-private keys and information registries, combining these elements in a novel way gave rise to the uniqueness of the blockchain.

This section is aimed at explaining to the reader the operation, benefits, limitations, history, and use cases of this technology. It is essential to understand these issues in order to properly analyze their transformative potential, both for sustainable development and for the environment. This technology proposes new forms of governance and relationship with information and data in a world where digital life is increasingly relevant.

First of all, we will review how blockchain works, comparing it with traditional databases and distinguishing the different elements that make up this technology. We will then discuss its relationship with cryptocurrencies and differentiate between the two concepts, with special emphasis on the evolution of blockchain and its applications beyond digital money.

Blockchain (decentralized) vs. Databases (centralized)

Traditionally, information is recorded and stored in centralized, managed and controlled databases where a trusted third party validates the information and disseminates it to third parties. This third party, usually called an intermediary, has the information, while most users cannot freely access or verify it. The intermediary usually holds an important share of power over the system and in many occasions, charges important commissions for its services.

Centralized systems currently have significant shortcomings:

1. Records can be lost/destroyed, relying on the owner to have secure copies;
2. The database operator must be trusted to validate the records correctly;
3. The transaction listing may not be complete, but the parties should rely on the operator to include all relevant records; and
4. The operator must be trusted not to modify the information in the database.

In general, it is in the database owner's and manager's own (long-term) interest to have backups, validate records, record all information and not modify it. However, in a centralized registry we depend on the reliability and integrity of the owner/manager, which is often not the case.[1]

Blockchain offers an alternative system to the centralized database, either in its public (*permissionless*) or private (*permissioned*) version, with highly desirable features. However, it is important to mention that it is not always superior to databases, since it also has important limitations, both in its operation and in its potential scalability.

1 For example, Google manages AdX, the leading online advertising platform, and abuses its position by manipulating online auctions, hiding information from advertisers and publications. See Orteu (2022), "Project Bernanke: manipulating online advertising auctions?," Dynamic Markets, 01/04/2022. Link: https://bit.ly/38BHCKT

In particular, blockchain has 3 major advantages over centralized databases:

1) Decentralization: there is no central authority that owns and manages the system's information. In turn, each user can have a copy of all the information on the blockchain.
2) Immutability: once the information has been registered and validated, it cannot be modified by any participant, as any attempt is easily detectable.[2]
3) Transparency: all system users can verify and access the information recorded and stored.

On the other hand, blockchain has some disadvantages over traditional databases:

- Lower efficiency: a centralized information system (databases) is usually more efficient, which may involve lower energy consumption, greater speed or other desirable variables depending on the context.[3]
- Storage and processing: as a result of its lower efficiency, it is not usually the optimal medium for storing large amounts of information (which are usually stored outside the blockchain — *offchain* —) or running large programs. Although progress is being made in this area, it still has limitations.[4]
- Permissions and participation: databases usually have permission systems with very detailed granularity (what each user can and cannot do) and are easily revocable, features that cannot be replicated in blockchain.
- Storage of credentials: due to the immutability of the information, it is essential to safeguard the system access credentials because, once registered or modified, the information cannot be altered.[5]

Currently, the main challenge for blockchain is to create simple, intuitive and secure products that encourage wide adoption by non-specialized consumers, since for the moment it continues to be a niche tool that has not developed applications, services or mass products designed for the general public (some incipient cryptocurrency-based payment applications are moving in this direction).

Origin

The central idea behind blockchain arose in 1991, as a proposal to facilitate the signing of a document digitally, leaving a record of when it was signed (*time-stamped*) and validating that it was not modified.[6] In turn, the oldest blockchain in operation is "analog" and has been published in the classified ads section of the New York Times since 1995.[7]

However, blockchain technology as such started to be massively used as digital money, also called cryptocurrencies, and was introduced in the seminal work of Nakamoto (2008) which defines how Bitcoin works (see section "Blockchain vs. cryptocurrencies").[8] Although its first application was Bitcoin, its uses are much broader and are not limited to simple transactions, i.e., Bitcoin is just one of many blockchain applications (see section II: "Environmental, Social and Governance Uses and Benefits of Blockchain").

2 The registered information cannot be deleted. Any modifications must be made by adding new information that corrects the information already included in the blockchain. In other words, this modification must be validated and entered in a new block.

3 Blockchain is typically slower and more costly (in terms of energy) than traditional databases, in part because it requires a higher level of tasks than a centralized database, such as signature verification, consensus mechanisms and copying information at each node. See "*Blockchain Vs Database: Understanding The Difference*", Gwyneth Iredale, 101 Blockchains, 30/07/2021. Link: https://101blockchains.com/blockchain-vs-database-the-difference/ For a more detailed study, see Chen, S., Zhang, J., Shi, R., Yan, J., & Ke, Q. (2018, July). *A comparative testing on performance of blockchain and relational database: Foundation for applying smart technology into current business systems.* In International Conference on Distributed, Ambient, and Pervasive Interactions (pp. 21-34). Springer, Cham.

4 For example, Ethereum limits the size/complexity of transactions to be performed on its platform. See "*Gas and Fees*", Ethereum.org, retrieved on 08/04/2022. Link: https://bit.ly/3xiPM54

5 This leads to a major security problem in some cases, for example, with cryptocurrencies, since if a third party manages to access an account's login credentials, they can transfer your funds and that transaction cannot be reversed. Likewise, if the user loses the credentials, he/she cannot recover the deposited funds.

6 Haber, S., Stornetta, W.S. (1991), *How to time-stamp a digital document*, Journal of Cryptology, 3, 99–111. Link: https://doi.org/10.1007/BF00196791

7 The managers publish the hash of all new information recorded in their immutable information registry service in the New York Times, and after sharing the hash, anyone can verify that the information has not been modified. "*The World's Oldest Blockchain Has Been Hiding in the New York Times Since 1995*," Vice, 08/27/2018. Link: https://bit.ly/3S90xxT

8 Nakamoto, S. (2008), A peer-to-peer electronic cash system, Bitcoin. Link: https://bitcoin.org/bitcoin.pdf

How the Blockchain Works[9]

As mentioned earlier, blockchain reuses in a novel way technologies widely used in other fields: cryptography (hashes, digital signatures, public-private keys), computer science (linked lists, distributed networks), and accounting/finance (ledgers). The best way to explain blockchain is to briefly detail the components and then the integrated operation of the system.

Registration Information

The blockchain is a register (*ledger*) including a record of any change regarding the information that composes it, whether its creation, modification or exchange, since every change is recorded in the blockchain in a sequential order that includes date and time of the modification (*time stamped*) and who made it.

To make a modification to the blockchain, whether recording, transferring or editing information, the user must announce it to all participants in the system and prove that the modification is valid by cryptographically signing it with a public-private key.

However, to incorporate the information into the system, special users, called mining nodes, must validate the modification of the information, verify that the transaction is possible and that the person can carry it out.[10]

Consensus Mechanisms

Depending on the context where the blockchain is used, the process of information validation by miners can be simple and straightforward, or on the contrary, complex and costly. Technically this process is called consensus mechanism and defines the way in which blockchain information is validated and conflicts are resolved in an automated way.

In systems where users trust each other, the process of validating information modifications can be assigned to certain users randomly and/or through simple rules that verify that the person who made the modification was authorized to do so.

In the blockchain where users do not trust each other, the consensus mechanism is more complex and by definition must be costly to perform for the mining nodes — so as to discourage actions harmful to the system — but rewarded — so that there are users interested in performing such a task and ensuring the proper functioning of the blockchain.

There are many consensus mechanisms, with proof of work (*PoW*) and proof of stake (*PoS*) being the best known and most widely used.[11]

With PoW, the miner solves a cryptographic puzzle that requires significant computational power, and also results in high equipment cost and energy consumption that serves no particular purpose except to generate a cost to the miners. To encourage certain nodes to perform the proof of work, the first miner to solve the puzzle is rewarded by the system.

In PoS those interested in validating new blocks must first invest/freeze part of their digital assets associated with said blockchain in order to be assigned new blocks to validate randomly and proportionally based on the assets frozen by the

9 We also recommend a series of complementary materials:
- *"What is 'Blockchain' in 5 minutes"*, Play Ground, YouTube. Link: https://youtu.be/Yn8WGaO__ak
- *"Blockchain 101 — A Visual Demo"*, Anders Brownworth, YouTube, 05/11/2016. Link: https://youtu.be/_160oMzblY8 *"Blockchain 101 — Part 2 — Public / Private Keys and Signing"*, Anders Brownworth, YouTube, 29/12/2017. Link: https://youtu.be/xIDL_akeras

For a more detailed analysis, we recommend: Yaga, D., Mell, P., Roby, N. and Scarfone, K. (2018), *Blockchain Technology Overview*, NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology, Gaithersburg, MD, https://doi.org/10.6028/NIST.IR.8202

10 Regarding cryptocurrencies, this implies that the person announcing a transaction owns the assets he or she wishes to transfer and that the owner of the assets is actually announcing the transfer.

11 There are more consensus mechanisms such as *Proof of Elapsed Time (PoET)*, *Proof of Burn (PoB)*, *Proof of Activity (PoA) and others. For more information on alternative consensus mechanisms see: "A (Short) Guide to Blockchain Consensus Protocols,"* CoinDesk, 04/03/2017. Link: https://bit.ly/3CkYHnw

user over the total assets invested. PoS is based on the assumption that the more a user invests in the system, the more interest he has in the system being reliable, thus ensuring that transactions are correct. To encourage certain nodes to fulfill the role of validators, they are rewarded for their work.

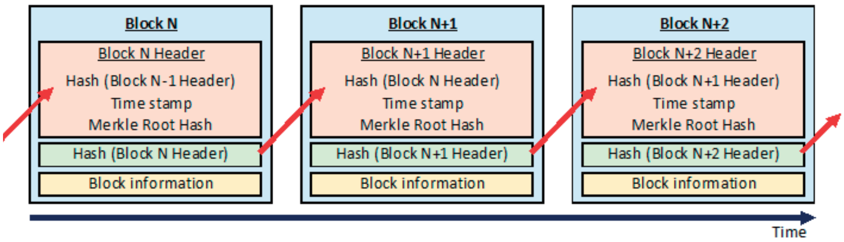
These systems seek to minimize the likelihood of malicious users conducting practices that are harmful to the overall system (such as altering information from previous blocks) by making them extremely costly.[12] However, the risk remains that a user or group of users could achieve 51% control of the blockchain (represented by the computational power in PoW or the proportion of assets in PoS) and modify it in their favor and to the detriment of the other users of the system.

Blocks and Blockchains

A block is composed of records validated through the consensus mechanism predefined by the system (as seen in the previous section), the date and time of its creation (*time stamp*), a hash of the header corresponding to the previous block, a hash of the "Merkle"[13] tree that summarizes all the information in the block, and a hash of the header of the current block.

Hash is a cryptographic function that summarizes and encrypts the information, namely, it compresses and guarantees the security of the processed information (see next section on cryptographic techniques). By incorporating the hash of the header of the previous block into the header of the current block, and then repeating the process with the hash of the header of the current block into the header of the next block (see fig. 1 below), the blocks are cryptographically linked to each other chronologically.

Fig. 1: Cryptographically linked blocks



Source: own elaboration

Information is modified or added to the system through the creation of new blocks, where the previous information remains intact and a record of the evolution of the system's information is generated, transparent to all its users. Likewise, if someone tries to modify information in previous blocks, it can be easily detected by all the users of the system that have a copy of the entire blockchain, due to the properties of the hash function that we will explain in the next section.

In other words, system users propose modifications or add information to the blockchain, but such information must be validated by a verifier/miner node. Only after the verification process the block is added to the blockchain, being

12 A second objective of consensus mechanisms is to resolve conflicts between nodes, particularly when two blocks are created and communicated simultaneously, with two different versions of the blockchain existing in real time. It is usually settled by considering the longest block as valid, so the version of the block that first adds an additional block is considered valid and all the information of the discarded block must be re-validated.

13 The Merkle tree is a structure of data processed repeatedly through a hash function. For more information, see [Merkle tree — Wikipedia](https://en.wikipedia.org/wiki/Merkle_tree).

linked to the previous and subsequent block, guaranteeing the immutability and transparency of information.

Information Compression and Security

The information stored in the blockchain is processed by cryptographic functions called hashes, which aim to compress the information and safeguard its security. The hash function transforms any digital information, regardless of its size and format, into an alphanumeric text of predetermined length (see Table 1).

Table 1: Hash function examples (SHA-256)

Input – x	**Output** – hash (x)
"0"	5feceb66ffc86f38d952786c6d696c79c2dbc 239dd4e91b46729d73a27fb57e9
"1"	6b86b273ff34fce19d6b804eff5a3f5747ada 4eaa22f1d49c01e52ddb7875b4b
Complete entry of Satoshi Nakamoto from Wikipedia in Spanish	1a5682f39238c23fbcbf0460c3cabae1b6afb 17b58b4572430745370d3de8b3d
"the magic of hashing"	e1e32a8e5cd62bc17f82c8bc64300c50e44c da686085c12256188ccad905bc42

Source: own elaboration using the hash function of blockchain.mit.edu

This cryptographic tool has three very important advantages:

- Avalanche effect: the slightest change in the input results in a totally different output.
- Resistance to pre-imaging: it is computationally infeasible to determine the input from the output.[14]
- Collision resistance (second-degree preimage resistance): it is computationally infeasible for two different inputs to generate the same output.[15]

Then, all users having the same input will reach the same output, however, if any part of the input is modified by any user, this user will achieve a (very) different output than the rest of the users. This implies that, if a malicious user modifies his copy of any block, the hash function of his block will be modified, and it will be different from the hash added in the subsequent block of the chain (all subsequent blocks will be invalid) and from the copy of the hash of the block available to the rest of the users of the system.[16]

The hash function is a central component of the blockchain system, as it guarantees its security and immutability, allowing any modification to the system to be easily detected by all users, and even compresses the size of the information that is stored and communicated.

The second cryptographic tool central to the blockchain system are asymmetric cryptographic keys, also known as public private keys, used to validate the digital identity of users in the system. Any action on the blockchain must be signed

14 It is important to note that it is computationally infeasible, but not impossible, to solve hash functions, given that in the future, technological advances such as quantum computing could solve these computationally complex problems. Even Satoshi Nakamato addresses this issue in his correspondence and concludes that in the future the entire system should be re-encrypted with a new, more secure and advanced hash function to prevent the security of the blockchain from being breached. For more details, see: Satoshi, N. (2014), *The Book of Satoshi: The Collected Writings of Bitcoin Creator Satoshi Nakamoto*, edited by Phil Champagne, published in 2014.

15 You would have to run the function an average of 2^{218} times to find a particular collision or output.

16 If a malicious user modifies a block, the hash function of that block will be different from the hash function that was originally used to link the next block, meaning that the entire block chain following the modified block will be invalidated. The malicious user must then "update" all the blocks after the modified block so that the blocks are again linked correctly.
Because all users have a copy of the blockchain, each user will be able to see that the modified version of the blockchain is different from his own, showing that the node performed some malicious activity, so that version of the blockchain will be discarded by the rest of the users. However, if the harmful node manages to transform its modified version of the blockchain into the longest version available, the predefined consensus mechanism will take it as valid, transforming it into the official version. In order to create a longer version of the blockchain, the noxious user must have more than 51% of the system's computational capacity (in PoW) or more than 51% of the share (in PoS). Usually called a 51% attack, it constitutes one of the vulnerabilities of the blockchain system in its permissionless versions. For more information see: "What is a 51% Attack?", Coindesk, 12/10/2021. Link: https://bit.ly/3CkYOiW

with the private key of the user performing the action.[17] Subsequently, other nodes use the user's freely available public key to validate the modification after verifying that the user has actually performed the action and is authorized to do so.

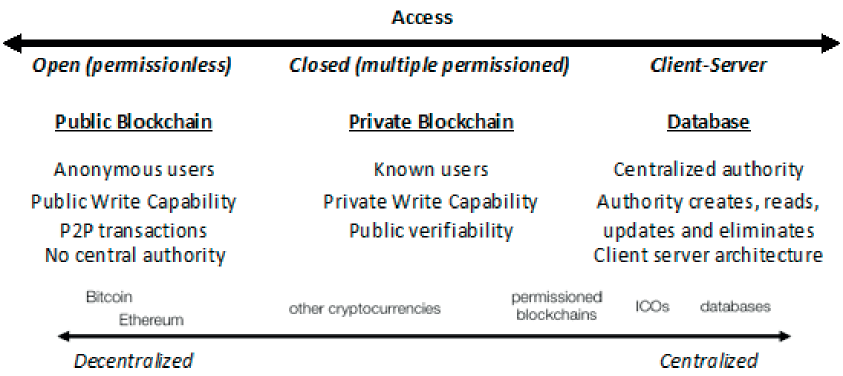
In anonymous systems, such as cryptocurrencies, the same user can have multiple anonymous public private keys, while in other systems the user must validate his identity (outside the blockchain) to access a public private key, this decision being central to the design of a blockchain architecture.

Characterization of Blockchain

It could be said that there is a continuum of options depending on the centralization or decentralization of the system chosen to store and manage information or records. Traditional databases are a fully centralized option, while an open or public (*permissionless*) blockchain such as Bitcoin is fully decentralized (see fig. 2). Then there are a variety of intermediate options, among which it is worth highlighting a private (*permissioned*) blockchain.

In public blockchain, any user can access, assume the role of verifier and make changes in the blockchain (being fundamental the consensus mechanism to guarantee the security and trust of the system) while in private blockchain only the creator of the blockchain can limit the access to the system, the roles, who can write or verify the modifications, but the transparency is guaranteed because all its members have access to all the information of the system.

Fig. 2: Access and centralization



Source: own elaboration

Blockchain vs. Cryptocurrencies

As previously mentioned, Bitcoin is the first modern blockchain application as we define it today, and cryptocurrencies in general, not just Bitcoin, are currently the most widely adopted application within blockchain technology, with nearly 300 million users (Crypto.com, 2022).[18] However, it should not be forgotten that cryptocurrencies are only one application among the many uses that blockchain technology can be put to.

17 The public key and the private key are mathematically related to each other, but the private key cannot be determined from the public key. When a transaction occurs, the user signs the transaction cryptographically with his private key allowing the signature to be verified with the corresponding public key. A user's address is the hash of their public key (plus some additional information used to detect errors).
Private key → public key → hash (public key) → user address
A user's address is their public "identity" on the blockchain. A user can create one or multiple public-private key combinations, however, the blockchain creator/manager can define the conditions of such a process.

18 Crypto.com (2022), *Crypto Market Sizing Global Crypto Owners Reaching 300M*, January 2022. Link: https://bit.ly/3eiSaSw. The total number of wallets is usually a poor approximation for estimating the total number of holders of any cryptocurrency because a user may have multiple wallets, but mainly because some exchanges and mining pools centralize the holding of assets corresponding to thousands of users.

On 10/11/2021 all cryptocurrencies as a whole reached a total valuation of $2.97 trillion while in October 2022 their value hovered around $800 billion.[19] Trust in cryptocurrencies is based on their use of proven cryptographic tools such as hash functions or public-private keys, and on the transparency and immutability of information, characteristics of blockchain technology in general.[20]

As awareness, trust and adoption of cryptocurrencies have advanced, so have new uses, services and applications related to this digital infrastructure called blockchain. Although its adoption is incipient, it is advancing very rapidly as evidenced by the development of new and improved blockchain platforms.

First Generation: Bitcoin and Digital Money

The first generation of blockchain refers to Bitcoin, whose sole function was to operate as digital money. The objective was to create a form of electronic cash that would allow online payments to be made directly between the parties without the intervention of a centralized financial institution, generating confidence in the validity of the transactions thanks to the proof of work that validated the transactions.

With the popularization of Bitcoin, alternative cryptocurrencies, or "*AltCoins*", emerged, offering slightly different combinations and applications, but always with the same objective, to provide a form of electronic money. Simultaneously, however, many individuals in the ecosystem discovered that the technology used by cryptocurrencies, currently known as blockchain, could have many more applications besides digital money.

Second Generation: Ethereum and Digital Contracts

The second generation of blockchain is made up of platforms that not only record accounting transactions, but also allow information to be stored and processed within the blockchain, enabling decentralized applications to be created.

The leading exemplar of this generation is the Ethereum platform, developed by Vitalik Buterin and presented in a 2013 publication entitled *"Ethereum: The Ultimate Smart Contract and Decentralized Application Platform"* which proposes a decentralized computing platform where thousands of machines distributed around the world work together, with no one having authority over another, and with enough time and resources, can run any type of application.[21]

Ethereum includes its own digital currency called Ether ($ETH), which can be used for normal transactions like BTC, and in turn is needed to pay for the computing power used when running decentralized applications and reward those who provide it.

To date, applications running on the Ethereum platform are usually smart contracts, where the parties agree on joint terms that are then processed independently by the platform ensuring compliance (see Smart Contracts section). Thus the Ethereum protocol managed to go one step beyond the monetary, creating a distributed blockchain network that allows anyone, anywhere, to develop and publish code to give life to all kinds of contracts, programs and decentralized applications.

19 See "Total Crypto Market Cap Chart," CoinGecko, retrieved 8/21/2022. Link: https://bit.ly/3rLoEYw

20 Many believe that the value of cryptocurrencies comes from a new monetary institutional arrangement without government intervention. Likewise, this belief is made possible by the security provided by the underlying technology.

21 *"Ethereum: The Ultimate Smart Contract and Decentralised Application Platform"*, Vitalik Buterin, 2013. Link: https://bit.ly/3emleqT

Third Generation: Towards Web3 and the DAOS

The main objective going forward is for blockchain to become scalable by becoming more efficient in terms of energy consumption and processing power so that this technology can deploy its full potential and continue its process of massification and adoption.

On the one hand, new blockchain-based platforms are emerging, such as Cardano, Polygon, IOTA among others. On the other, platforms such as Ethereum have been evolving and implementing more efficient and modern ways of working that allow the ecosystem to scale. However, upgrading a decentralized system without a central authority presents significant technical and political challenges (inside and outside the platform) that make it difficult to move forward with changes in technology and/or system operating rules.

For example, on September 15, 2022 Ethereum successfully migrated from proof-of-work (PoW) as a consensus mechanism to proof-of-stake (PoS)-a process known as "The Merge"-to improve the energy efficiency of its system, and enable the operation of multiple chains simultaneously resulting in greater efficiency and scalability.[22]

However, there is always a risk that when a decentralized system is upgraded, a fork may occur, i.e. a significant number of users may not accept the new upgrade, and continue to use the previous system, competing with the upgraded system. This already happened in July 2016, when a part of Ethereum miners and users created an Ethereum fork, called Ethereum Classic, a parallel blockchain with a lot less traffic and volume. It would seem that a fork of Ethereum from the migration to PoS has been avoided, but as of today, that risk remains latent.

The adoption of decentralized applications and programs is giving rise to a new way of organizing the internet, known as Web3, which seeks to bring the decentralization enabled by blockchain to traditional internet services. In addition, the aim is to promote the adoption of Decentralized Autonomous Organizations (DAOs). Technically, DAOs is a more complex form of smart contract, but its goal is to enable and facilitate that group of people with a common goal can be organized under a democratic, participatory and productive model through blockchain technology. The ultimate goal of this and/or future generations of blockchain is to work towards a decentralized digital society.[23]

22 *"The Merge"*, Ethereum.org, retrieved on 09/30/2022. Link: https://ethereum.org/en/upgrades/merge/
"Ethereum Founder Buterin Forecasts Blockchain Merge on Sept. 15", Bloomberg, 12/08/2022. Link: https://bloom.bg/3rPVho6

23 EFANOV, Dmitry; ROSCHIN, Pavel. *The all-pervasiveness of the blockchain technology*. Procedia computer science, 2018, vol. 123, p. 116-121.

SECTION TWO

USES IN ENVIRONMENT, SOCIETY, AND GOVERNANCE

SECTION TWO

USES IN ENVIRONMENT, SOCIETY, AND GOVERNANCE

Blockchain is a technology that allows information to be recorded in a decentralized way and in a way that cannot be manipulated, facilitating cooperation between individuals and systems. Blockchain makes it possible to automate processes and reduce costs; to generate standardized, consistent, and integrated data to a network with real-time updating, exchanging information in a reliable, transparent, and efficient manner; to verify records instantly and independently; to track data origin, determine rules, and ensure compliance to facilitate transactions between two or more parties, among other benefits.

The objective of this section is to analyze the ways in which this technology can be applied to address the environmental, social and governance (ESG) challenges facing modern society, through real use cases. We envision a much more promising future for this technology, which, even in its incipient phase, is showing signs of its great transformative potential.

Environment: Transparency, Coordination, and Security for the Environment

Although blockchain technology is an incipient tool, its application in addressing environmental issues provides innovative and efficient solutions. The use of blockchain in industrial supply chains, in environmental control and monitoring processes, and in the carbon credits market are some of the most relevant applications that this tool may have. Similarly, this technology can be used not only to audit and monitor environmental impacts, but also to report on compliance with regulatory standards and best environmental management practices. Finally, in carbon credit markets, the decentralized consensus and validation systems offered by this technology can be used to address accounting, efficiency, and transparency issues related to the management of information on transactions, ecosystem conservation, and restoration measures, and climate change mitigation and adaptation.

Supply Chain

In the production of any good or service, there is a whole chain composed of links of activities and actors involved, from obtaining the necessary raw materials to the final product and even beyond, in the disposal of waste. Consumer demand and regulations for greater transparency and responsible environmental and social practices have extended corporate environmental responsibility throughout the supply chain. The implications are not only environmental, but also ethical and commercial in scope, as markets are beginning to demand from companies products that minimize environmental impact and incorporate high standards of integrity and sustainability. In this context, the opportunity offered by blockchain to provide traceability, transparency, immutability, and trust to the supply chain is clear. For example, companies that wish to implement sustainable practices, most of the time, do not have mechanisms in place to trace and monitor the activities of their suppliers, which can be detrimental to their own objectives and even their reputation. Organizing a supply chain on blockchain would allow all participants to have information about activities and products at every stage ensuring their origin and proper processing.[24] Such a process would make it possible to trace processes throughout the entire production chain, to have reliable, transparent, and accessible information, to control variables of interest, and to accredit processes and environmental standards, among other benefits.[25]

A particularly promising near-term application of blockchain is in the agricultural industry, where distributed accounting technologies — such as blockchain — and smart contracts offer a unique opportunity to improve efficiency, transparency, and traceability for the exchange of value and information in the agricultural sector (see FAO, 2018 and 2019)[26]. The certification of products under specific standards is one example of how these technologies can be applied to supply chains, due to the traceability and reliable information on the origin and processes involved in the production chain of certain goods, facilitating certification processes under different quality seals, as in the case of organic, vegan, carbon neutral, etc. products. Similarly, blockchain can also help foster a circular economy by documenting the stages of products and materials beyond their first use.

Finally, the use of this tool is also of interest for the implementation of public policies. For example, in a state that proposes to tax carbon emissions, the traceability of and inability to alter the information recorded on the activities in the blockchain would facilitate the levying of differential rates, encouraging more sustainable production. Moreover, these technologies can also contribute to carbon credit markets by allowing traceability and reliability (see section Carbon Market and Blockchain).

OPEN VINO

Open Vino is an example of how blockchain can be used to certify production standards, as it allows wineries to self-certify their wine production by complementing blockchain technology with the Internet of Things (IoT).

Sensors placed in specific locations and points of the production process collect data on environmental conditions, temperatures, and soil acidity, among other aspects. This information is automatically recorded in the blockchain platform, and based on this information, complying with certain quality standards and processes, the winery can certify its production in a decentralized and cost-free way, through Open Vino (BioDigital Certification).

Although the current Open Vino application was designed for wine production, it could be applied to multiple agri-food chains and different quality standards (organic, carbon neutral, etc.), offering the customer transparency and trust, and the producer a way to link the quality of its production processes to the final product.

24 Blockchain can be applied not only to environmental issues but also to other various issues, such as managing disruptions in the chain, achieving end-to-end visibility of products and processes, and resolving disputes automatically (through smart contracts), among other applications. Ver Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). *Blockchain for the future of sustainable supply chain management in Industry 4.0*. Resources, Conservation and Recycling, 163, 105064.

25 IBM currently offers blockchain solutions for healthcare, logistics, and food supply chains. More information is available on IBM's website: https://www.ibm.com/ar-es/blockchain-supply-chain

26 FAO (2018). *"Emerging Opportunities for the Application of Blockchain in the Agri-food Industry"*. Available at: https://drive.google.com/drive/u/0/folders/1jUY9pH-FvvGQYE4s_0aTVCTBG7IHtjOid

FAO (2019). *"E-agriculture in action: Blockchain for agriculture. Opportunities and challenges"*. Retrieved from: https://www.fao.org/3/CA2906EN/ca2906en.pdf
FAO identifies at least four major benefits of using these technologies:
1) This technology allows the origin of products to be traced, with a positive impact on food safety, quality, and sustainability.
2) The use of smart contracts enables automated, conflict-free payments that can reduce transaction costs, lower risks for buyers and sellers, and increase their cash flow and working capital.
3) It allows for digital identities to be built using registered assets, providing accurate information — both to the supply chain and to the public sector, which can be used to inform production and marketing decisions, to generate credit history, and to create an environment for better informed policies. Furthermore, the registration of physical assets, such as land titles, can serve as collateral for accessing financing.

It can help implement and monitor international commitments, such as World Trade Organization (WTO) agreements as well as the Paris Agreement on Climate Change.

Environmental Control and Monitoring

Every country, even every industry, has different legal and regulatory frameworks and standards that regulate and establish the processes necessary to audit environmental impacts, to control the correct treatment of materials, waste, and effluents, to limit environmentally harmful activities, and to ensure compliance with good practices in different production chains. These actions are extremely important to ensure sustainable development, but on many occasions, these control and monitoring processes are susceptible to being altered or corrupted. Blockchain can be a very useful tool to reduce these problems and make these processes more efficient and transparent.

PLASTIC BANK

The oceans are essential to climate stability and environmental health because they absorb carbon dioxide generated by anthropogenic activities and are home to millions of species and the livelihoods of millions of people. However, many species have become extinct or endangered due to industrial fishing or habitat alteration and increased pollution levels. Mitigating the effects of human-caused environmental damage to marine ecosystems is an urgent challenge and a priority.

Plastic Bank is an initiative created in 2013 with the objective of recovering plastics from the ocean and generating value and jobs by recycling, treating, and reselling it. Advised and powered by IBM, Plastic Bank started using blockchain, where through the organization's app, collectors hand over a piece of plastic and receive a token in return. The token allows to track the destination given to the plastic and can also be sold.

Once collected, the plastic is treated and converted into a material called *Social Plastic*, which in turn is used to manufacture new products, all under the supervision of the collector, who can trace it throughout its processing and reintroduction into the circular value chain.

PUBLIC-PRIVATE PROGRAMS

These issues concern not only the private sector but also the public sector, which is looking to blockchain for solutions to complex problems, such as waste treatment. For example, the United Kingdom, through GovTech Catalyst, a program that supports providers who present innovative and digital solutions to public problems, organized a competition to address the problem of tracking waste from the moment it is produced, throughout its entire territory.[27] Five companies were selected and the winning projects included waste traceability solutions using electronic chips and sensors, the use of blockchain, and data analytics. One of these projects, called Vastus, introduced a tracking system to help unify different records currently used by companies to report waste management data.[28] Such blockchain-based technology would make it possible to keep track of all waste movements in the UK, to make information available, to track waste from source to treatment and final disposal, and to help producers and administrators comply with regulations.

27 "GovTech Catalyst", UK Goverment, 05/21/2018. Link: https://bit.ly/3zvXKs3

28 "Anthesis waste tracking system wins development funding from GovTech Catalyst Challenge," Anthesis Group, 02/19/2019, link: https://bit.ly/3zz9s5c

In Argentina, there are incipient initiatives that address the issue of waste through innovative and digital solutions. The Colmena project in the province of Misiones, for example, encourages recycling by connecting waste generators with waste collectors and recyclers through an application.[29] In this venture, waste is weighed on electronic scales linked to a software system that allows the platform's virtual currency reward to be calculated.[30, 31] Similar initiatives also exist in India and the United States.[32]

Internet of Things

Blockchain-based control, monitoring or certification systems face the challenge of how to interpret or connect with the physical world, i.e., how to obtain information from the real world and process it digitally. For example, environmental data collection is carried out in the world through tools or physical means (hardware), either by means of sensors, cameras, satellites, or even data obtained by human observation of an auditor. For that reason, data incorporated into the blockchain can still be manipulated before being recorded.

Complementary technologies, such as the Internet of Things, where the interaction of autonomous and automated devices with their own connection can facilitate the collection of automated and independent information, subsequently recorded on the blockchain. Blockchain could reduce software fraud and ensure the transparency and openness of data, although said information could still run the risk of being manipulated at the time of measurement with the device, with previously adulterated information being recorded. For this reason, blockchain-based monitoring systems still require additional control systems to ensure the reliability of the information detected and then recorded.

Carbon Market and Blockchain

Carbon credits are tradable certificates that represent the elimination or reduction of one ton of carbon dioxide equivalent emissions from the atmosphere.[33] Carbon credits and their market emerged from the Kyoto Protocol, in which 36 countries made commitments to reduce greenhouse gas emissions through the implementation of national mitigation measures. To achieve these objectives, the Protocol established three market mechanisms that provide some flexibility in meeting these goals, creating what is known as the carbon market, through the trading of Emission Rights and Certified Emission Reductions from projects.

In addition to the carbon credit market that arose from the need to comply with mandatory commitments, there is a voluntary market through which interested parties freely negotiate certified emission reductions based on projects that seek to reduce environmental impact. These initiatives are not related to imposed regulations but, on the contrary, are projects audited and certified by independent entities, which seek to absorb or reduce greenhouse gases to be sold in voluntary markets and purchased by those seeking to reduce or offset their carbon footprint. Once these credits have been used, they must be withdrawn from circulation to avoid double counting.

29 Proyecto Colmena, link: https://www.colmenaproject.io/

30 The mechanism used by the blockchain is *Delegated Proof of Stake*.

31 According to the initiative's website, the project is currently undergoing implementation testing.

32 Bloomberg, (03.18.2021). *Even Garbage Is Using Blockchain Now: Pilot projects that use innovative data collection to encourage recycling and responsible waste management are underway in Argentina, India, and the U.S.* Available at: https://bloom.bg/3D4ob8Y

33 See Carbon Neutral (06.03.2022). *Mercado de Carbono: Voluntario vs. Regulado*. Retrieved from: https://bit.ly/3TXG68k

These markets are not without their critics and challenges related to their lack of transparency and robust accounting. According to the United Nations report on blockchain and sustainability, the current voluntary carbon credit market has several inefficiencies: it is structured in multiple centralized markets, without interconnection; carbon market regulations and certificate issuances are complex and carried out by centralized institutions that do not act in unison[34]; the markets have high financial thresholds that do not allow individuals to participate and lack transparency, which further limits the information available to its participants; and, finally, the time taken by projects, as well as the investment in their verification by certifying entities, involves spending large amounts of money, and therefore only large projects are economically viable. [35]

The lack of transparency and robust accounting is not exclusive to voluntary markets; the cooperative international transfer mechanisms established under the Paris Agreement do not escape this problem, due to the heterogeneity of the accounting and control systems, which makes it difficult to evaluate, trace, and compare countries' actions.[36] In fact, this point is of relevance and has been expressly highlighted in the agreement, which states that *"where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards nationally determined contributions, [Parties shall] promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting (...)."*[37]

In the face of these challenges, blockchain presents itself as a possible solution. On the one hand, credit traceability would increase confidence in the instruments and reduce asymmetric information, which would improve efficiency and reduce validation, transaction, and operating costs. In turn, the system would increase liquidity and encourage more agents to participate in the market. On the other hand, blockchain could mitigate transparency issues, withstand manipulation, and avoid double counting of transactions. This would not only improve the credibility of this market, encouraging the creation of more projects aimed at reducing carbon in the atmosphere, but would also increase the overall credibility of regulations and/or market mechanisms to address the climate crisis, and reduce undesired conduct, such as "*green washing*".[38]

Finally, blockchain could also be used in the implementation of the Paris Agreement in order to improve and homogenize transaction control mechanisms, to achieve the goals set.[39] In fact, for the OECD (2019) the certificate issuance system would become much more efficient if a blockchain were used to ensure transparency and reliability of information, effective control of quotas and circulation certificates, market integrity, and robustness in accounting, in addition to automating transactions and enabling an increase in overall efficiency.[40]

TREEFY

Treefy is a technology-based start-up that aims to address climate change through the large-scale restoration and conservation of native biodiversity. To this end, it is working on a business model focused on calculating individual carbon and envi-

34 The fact that carbon markets are structured and controlled by different mechanisms centralized in different jurisdictions could lead to double counting of credits, affecting the credibility of these instruments to effectively reduce environmental impact.

35 United Nations Environment Programme (2022). *"Blockchain for sustainable energy and climate in the Global South"*. Available at: https://bit.ly/3R9N35l

36 For more details, see: Schletz, M., Franke, L. A., & Salomo, S. (2020). *"Blockchain Application for the Paris Agreement Carbon Market Mechanism— A Decision Framework and Architecture". Sustainability, 12*(12), 5069.

37 Paris Agreement. Article 6.2, cooperative international transfer mechanisms to enable countries to meet their emission reduction commitments (nationally determined — NDCs).

38 *"Green washing"* is a marketing strategy that seeks to create an image of ecological responsibility even though environmentally damaging actions are still being carried out.

39 *"Trading of* CO_2 *certificates: Blockchain as a solution"*, Lexology, Härting Rechtsanwälte, 03/29/2022, link: https://bit.ly/3DxSl6e

40 OCDE (2019). "Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure", link: https://bit.ly/3TR6FvW
For more details on how blockchain can bring transparency and accountability under the Paris Agreement, see: Schletz, M., Franke, L. A., & Salomo, S. (2020). *"Blockchain Application for the Paris Agreement Carbon Market Mechanism — A Decision Framework and Architecture"*. Sustainability, 12(12), 5069.

ronmental footprints and on selling non-fungible tokens (NFTs) and carbon or ecosystem services credits, supported by the digitization and tokenization of restored plots of forest on the basis of blockchain.

Treefy is defined as an ecotech for ecological restoration and conservation, which integrates natural assets with blockchain, granting users direct access to preserving and restoration the ecosystem. Certain projects would even allow the issuance of certified or ecosystem services carbon credits that can be traded in voluntary markets, offering a return to the token owner.

Treefy set a global target of restoring and conserving 50 million hectares of land (by 2030) that has suffered soil degradation and/or a loss of biodiversity, starting in the short term with the conservation and restoration of 1 million hectares of native biodiversity.

SOLARCOIN

Energy, but increasingly electrical energy, is a requirement for the growth and development of any country, region, or community. However, most of the energy used comes from fossil fuels, which generate significant carbon emissions.

SolarCoin, a project created in 2014, aims to incentivize the generation of renewable energy, particularly solar energy, through the creation of a cryptocurrency given to those who produce this type of energy.

Solar energy producers receive 1 SolarCoin (the project's virtual currency) for each MWh of electricity produced using solar panels. After validating that this solar energy has been generated, either automatically or by submitting certain documentation, a SolarCoin is generated and transferred to the producer of said energy and everything is recorded in the blockchain. The beneficiaries can receive the cryptocurrency in any virtual wallet and sell it freely, meaning an additional source of income that favors the adoption and expansion of this renewable energy source.

Sustainable Tokens

We could classify as sustainable tokens those blockchain-based projects that grant tokens and meet the following requirements:

1) Working for environmental sustainability: token supported by projects or actions that have a positive and sustainable impact on the environment.
2) Financing sustainable projects: issuing, trading, or exchanging tokens to finance or encourage sustainable projects.
3) Traceability and transparency: facilitating and guaranteeing reliable information on a sustainable project with a positive impact.

Treefy, Plastic Bank, or SolarCoin are some examples of this new type of application of blockchain technology for environmental sustainability.

Society: Digital Access and Financial Freedom

Blockchain technology offers innovative alternatives to address different social issues, such as those related to financial inclusion and individual and financial freedom.

Financial Inclusion: Blockchain and Its Potential Applications

According to the World Bank, financial inclusion means that individuals and businesses have access to useful and affordable financial products and services that meet their needs — transactions, payments, savings, credit, and insurance — delivered responsibly and sustainably.[41] In this regard, financial inclusion is considered a key tool for reducing extreme poverty and increasing prosperity and even facilitating the achievement of several of the Sustainable Development Goals.

World Bank estimates show that 76% of the world's population currently owns a bank account (2021 data) and that this figure experienced a 50% growth in ten years (2011-2021). However, with around 24% of the global population unbanked, there is still much work to be done in pursuit of financial inclusion.[42]

Fintechs, as a disruptive business model, have enabled a breakthrough in financial inclusion. These companies are a real and convenient alternative, particularly for the unbanked, mainly because they are free of charge, digitized, simple to use, fast, and require minimal documentation to open and operate.

Cryptocurrencies and other blockchain applications that form a subset within fintech can also contribute to financial inclusion. In this context, they can offer valuable solutions that help reduce costs and access barriers to the national and international financial market, or reduce the asymmetry of information that exists in the credit and insurance markets, which would increase their levels of efficiency and therefore the accessibility of their financial services. In particular, Carballo (2020) considers that blockchain technology can contribute in four categories of financial services: savings; credit; insurance; and payments and transfers. [43]

Market Access and Savings

Following this logic, blockchain, and in particular digital currencies, can facilitate (democratize) access to and ownership of financial tools and assets at low cost (fast, secure, simple, without major requirements).[44] Furthermore, in economies with high levels of inflation, economic instability, limits to the conversion of local currency to more stable assets, and widespread distrust in institutions, digital financial services and (stable) cryptocurrencies can facilitate the reservation of value, or simply act as an alternative means of exchange to carry out different transactions.[45]

41 World Bank (03.29.2022). *Financial Inclusion. Financial inclusion is a key enabler to reducing poverty and boosting prosperity.* Available at: https://www.worldbank.org/en/topic/financialinclusion/overview

42 World Bank (2021). "The Global Findex Database 2021: Financial Inclusion, Digital Payments, and Resilience in the Age of COVID-19." Retrieved from: https://www.worldbank.org/en/publication/globalfindex

43 Carballo, I. E. (2020). Blockchain and financial inclusion: Theoretic Nexus and Opportunities for Foreign Trade. *Integración & Comercio Magazine*, No. 46, 107-128, pp. 116. Link: https://bit.ly/3DaPAWK

44 At this point, fintechs in general enabled the increase of people with access to a bank account.

45 Infobae (04.17.2022). *¿Por qué en la Argentina cada 100 adultos hay 12 que compraron criptomonedas por encima del promedio de la región?* Available at: https://bit.ly/3VZbR2x

LEMON

In Argentina, there is a platform called Lemon, an exchange that allows cryptocurrencies to be exchanged for fiat money or other cryptocurrencies.[46] This fintech, which integrates crypto, through its application and associated VISA card, presents an alternative financial service that allows users to perform cryptocurrency transactions, convert Argentine pesos into different digital currencies, send money or cryptocurrencies between friends within the application, and make purchases in Argentine pesos or other currencies at any merchant that accepts cards. This example demonstrates how, quickly and easily, by downloading an application, people can access financial services and, in turn, crypto-asset markets traded on them at very low cost.

Finally, virtual currencies and other blockchain-based financial services promote competition and innovation, pushing traditional financial services, such as banks and insurers, but also central banks and multilateral bodies (such as the Bank for International Settlements, which groups the main central banks worldwide) to develop more efficient digital channels and to innovate. For example, since crypto began, central banks have begun to take an active interest in issuing digital currencies[47] and some countries have begun to experiment and have adopted cryptocurrencies as legal tender.[48]

Credit Market

From an economic point of view, asymmetric and incomplete information on users' credit and transaction history restricts the supply of credit, particularly harming the most vulnerable.

On the one hand, blockchain could offer solutions to reduce these information gaps by generating transparent, immutable, and secure credit histories of economic agents, which could be transferred by the customer to different financial institutions. This would be beneficial for the entities or potential creditors, since they could access accurate information and evidence about the client's profile and make more agile — or automated — decisions, reducing management times, allocation, credit risk, etc. Likewise, it would also benefit potential users as they could migrate their credit information (“showcase their reputation”) to other entities or lenders and obtain better rates or faster disbursements. All these changes would lead to an improvement in the overall functioning of the industry by reducing entry costs linked to the lack of information on the history of the agents, and would promote competition in the market.

On the other hand, blockchain could also encourage investment by individuals and lower barriers to the flow of money, making it possible to allocate capital to more profitable projects, such as direct loans between two agents (P2P or peer-to-peer). This technology could also break down barriers to international money flows, making it possible to allocate capital to projects with higher returns (better capital allocation).

46 Lemon, link: https://www.lemon.me/

47 Inter-American Development Bank (07.07.2022). ¿Existe un futuro para las monedas digitales emitidas por los bancos centrales en América Latina y el Caribe? Available at: https://bit.ly/3NkOWuR
Visual Capitalist (08.25.2022). *Visualized: The State of Central Bank Digital Currencies.* Available at: https://bit.ly/3gJbrgl

48 El Salvador incorporated Bitcoin as legal tender in 2021. The Central African Republic also did so in 2022, and other countries are considering issuing virtual currencies.

ETHICHUB

EthicHub, based on blockchain technology, aims to connect Mexican coffee farmers with international funding sources at affordable interest rates.[49] The company's motto is to "break the boundaries of money," allowing it to flow to places where capital yields better results. In turn, through generating a credit and payment history, EthicHub allows financiers to have relevant information about farmers and continue to invest in their projects.[50]

Insurance Market

In the insurance market, blockchain technology and its applications — such as smart contracts — can, on the one hand, help automate collections, reducing the time, potential friction, and bureaucracy involved in the insured-insurer relationship. On the other hand, recording accurate and incorruptible information allows all parties to access verifiable data in a quick and accessible manner, share policyholder histories, and optimize risk management.

OPENIDL

OpenIDL is an American Association of Insurance Services (AAIS) blockchain that connects industry data and enables its members to automate regulatory reporting and compliance with the rules to which they are subject, while improving efficiency and accuracy for insurers and state insurance departments.[51]

Remittances

Remittances, money sent by migrants to family members in their countries of origin, are mainly used for food, health services, education, and health care, among others. Because of their impact on the countries and families that receive them, they are considered to be the financial services with the greatest potential to impact the economy and financial inclusion, and in turn, one of the areas where blockchain could have the greatest immediate impact, given the complexity and high costs of current systems.

According to the International Fund for Agricultural Development (IFAD, 2017), approximately US $529 billion was sent in remittances to developing countries in 2018[52] (a figure that more than tripled the amount of the official development assistance allocation), of which 75% went to cover immediate needs.[53] Estimates indicate that around 200 million migrant workers send remittances home, and approximately 800 million are the beneficiaries of these flows. Furthermore workers send home on average between $200 and $300 every month or two, which represents only 15% of what they earn, but 60% of the estimated income of the household that receives it.[54]

Various sources agree on the importance of these cash flows for developing countries, as they contribute to poverty reduction and economic growth.[55] In particular, they have a very significant effect on the families that receive them; they are the migrant's main direct vehicle for helping his or her family, contrib-

49 EthicHub, see: https://www.ethichub.com/es/?hsLang=es

50 EthicHub. *What is EthicHub?* Available at: https://bit.ly/3W1BGPz

51 OpenIDL, see: https://openidl.org/

52 According to World Bank estimates, remittances to low-and middle-income countries reached around USD 605 billion in 2021. See: World Bank (05.11.2022). *A war in a pandemic — Implications of the Ukraine crisis and COVID-19 on global governance of migration and remittance flows*. Available at: https://bit.ly/3D9kZZH

53 IFAD (2017). "Remittances, investments and the Sustainable Development Goals." Available at: https://bit.ly/3VZ2lMS

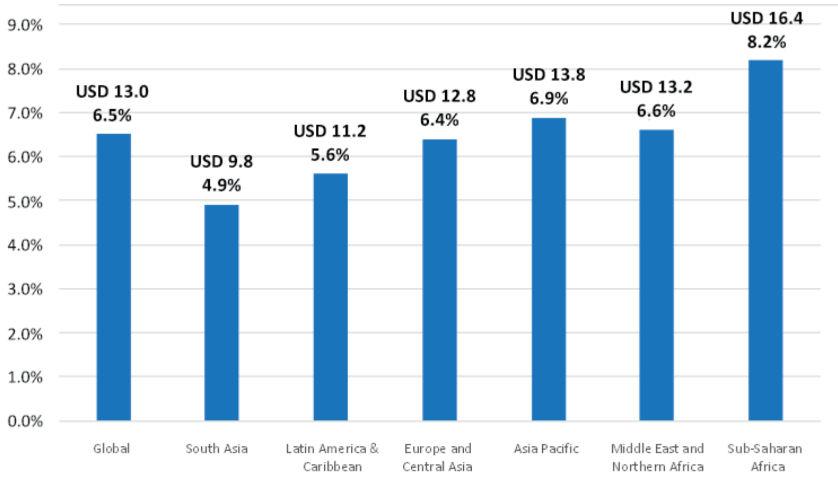
54 IFAD (06.15.2022). "12 reasons why remittances are important." Available at: https://bit.ly/3D8oFel

55 For more information on poverty reduction, see: Banga, R., & Sahu, P. K. (2010). "Impact of remittances on poverty in developing countries. *UNCTAD, United Nations, Switzerland*, 35(2), 45-68.
For more information on the relationship between remittances and growth, see: Francois, J. N., Ahmad, N., Keinsley, A., & Nti-Addae, A. (2022). *"Heterogeneity in the long-run remittance-output relationship: Theory and new evidence"*. Economic Modelling, 110, 105793. This study analyzed 80 developing countries between 1970 and 2014, and found that a 10% increase in remittances would be associated with a 0.66% permanent increase in GDP. However, this result is not uniform among countries and there is great heterogeneity.

uting to reducing poverty, improving health, nutrition, education, housing, and sanitation, and increasing resilience in the face of uncertainty (savings).[56]

While there is a general consensus on the importance of remittances for low-income countries and family economies, it is also recognized that their cost is excessively high. According to World Bank estimates, the global average percentage cost of sending USD 200 was equivalent to 6.5%, or USD 13 (see figure 3 below). United Nations Goal 10 seeks, by 2030, to reduce the transaction costs of migrant remittances to less than 3% and to eliminate remittance corridors with costs above 5%, values that are far from those currently in force.

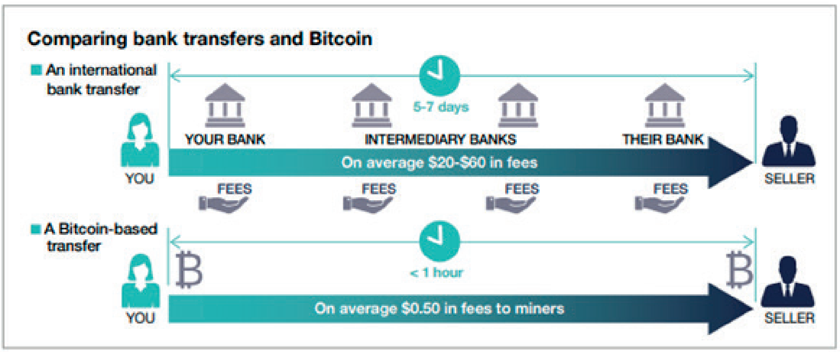
Fig. 3: Cost of sending $200: percentage of total and in dollars (Q4 2020)



Source: World Bank[57]

For its part, the OECD (2019) estimates that an international transfer through banking entities costs USD 20-60 and takes, on average, between 5 to 7 days (see Figure 4 below[58]), while an intermediary-free transfer through the Bitcoin network (or other cryptocurrency) has an average cost of USD 0.50 (fifty cents) and takes less than an hour, greatly reducing monetary costs and waiting time.

Fig. 4: Comparison between bank transfer and Bitcoin



Source: OECD (2019)

56 IFAD (2017), for its part, argues that remittances impact and contribute to the SDGs at the domestic level by helping to reduce poverty (SDG 1), hunger (SDG 2), achieve good health and well-being (SDG 3), quality education (SDG 4), and gender equity (SDG 5); at the local level, through access to clean water and sanitation (SDG 6), clean and affordable energy (SDG 7), responsible consumption and production (SDG 12), and climate action (SDG 13); at the national level, through decent work and economic growth (SDG 8), and reducing inequality (SDG 10); and internationally, through a joint commitment to work to leverage the impact of remittances on development (SDG 17).

57 World Bank (2021). "Resilience: COVID-19 Crisis Through a Migration Lens" *Migration and Development Brief 34*." Retrieved from: https://bit.ly/3DbDywF

58 OCDE (2019). *OECD Blockchain Primer*. Retrieved from: https://bit.ly/3gJ3RCJ

Considering the values transacted worldwide in remittances and their importance for developing countries and the families that receive this money, the reduction of transaction costs and times could have a very relevant impact on these economies. In this situation, blockchain and virtual currencies emerge as a valuable tool to send money in remittances almost instantly at low cost.

ALIPAYHK AND BANK CHATERED: REMITTANCES BETWEEN HONG KONG AND THE PHILIPPINES

AlipayHK (a company of Chinese conglomerate Alibaba offering digital payment services in Hong Kong), in a joint venture with Standard Chartered Bank, launched the first cross-border remittance service based on blockchain technology in 2018: GCash.[59] GCash is a digital wallet, operated by Philippine telecommunications company Globe Telecom, that makes it possible to receive remittances sent by Filipino migrants from AlipayHK in Hong Kong securely, quickly (almost instantaneously), and at a competitive exchange rate, using blockchain technology.

The service operates with the interaction of two virtual wallets, a bank, and a blockchain network. AlipayHK users send remittances to GCash in the Philippines and, in turn, Standard Chartered Bank provides the instant currency settlement service for such transactions to be carried out in real time.[60] When a user sends a remittance request, all network participants (AlipayHK, GCash, and Standard Chartered Bank) are notified. Owing to blockchain technology, the verification and execution of the transaction occur simultaneously and allow the parties involved (sender and recipient) to track the money throughout the process, from sending to receiving, without the need for intermediaries.

Financial Freedom: Potential as a Tool for Inclusion and Democracy

As detailed above, in terms of accessibility, inclusion, and democratization, it is worth noting that, unlike the traditional monetary system, blockchain can be used by anyone anywhere in the world, just by having a smartphone and mobile connectivity.

In terms of financial freedom, blockchain technology, and in particular virtual currencies, make it possible to hold and send value across time and space, without institutional constraints. Furthermore, the decentralization inherent to this technology allows transactions to be carried out anonymously without any third party other than the interested parties, which means that their use cannot be blocked or controlled by any entity or authority. This takes on another significance and greater relevance in countries with authoritarian governments or in conflict zones, since it facilitates immediate access to monetary resources which, in situations of extreme vulnerability, act as a concrete "lifeline" for millions of families.

Some considerations

While blockchain is a tool with great potential in the financial industry, it still faces significant challenges. On the one hand, in order to foster financial inclusion, access, and democratization of services, blockchain must be known and under-

59 Inquirer.net (2018), *AlipayHK and GCash launch cross-border remittance service powered by Alipay's blockchain technology*, 06/26/2018, link: https://bit.ly/3DaQgeV

60 See: Standard Chartered Bank (06.25.2018). *We have been appointed by Ant Financial as core partner bank for its new blockchain cross-border remittance service.* Retrieved from: https://bit.ly/3SE6gM0

stood. Financial inclusion will be possible as long as sufficient levels of knowledge and trust have been achieved among citizens to operate with it.

The high number of *phishing* crimes and scams in the traditional financial market suggests that the risks are even higher for blockchain-based projects, as these involve an additional degree of complexity and unfamiliarity. Facilitating their adoption and use, and recognizing and reducing these risks for users, are other significant challenges facing the industry.

Finally, it is important to note that, although virtual currencies have great advantages in terms of reducing transaction costs and accessibility, making financial inclusion possible for thousands of people, the lack of regulation and the anonymity of their participants can facilitate activities that are illicit or harmful to society as a whole, such as money laundering, tax evasion, financing of terrorism, illegal trafficking, and human trafficking, among others.[61]

Governance: the Value of Decentralization

Governance is a structure of rules, processes, and procedures of a given system that organizes the decision-making process to meet the objectives for which it was created.

Most of today's institutions use centralized governance mechanisms, i.e., the authority to define how to organize and make decisions is concentrated in only a few actors. There are different types and forms of centralized governance, e.g., state governments, corporate boards, boards of civil society organizations, etc.

In theory, one of the positive aspects of this type of governance is that change is often carried forward without resistance, making problem solving easier. However, the difficulty arises when there is a failure in the central authority, since the rest of the structure will not be able to solve it by itself and may even be unable to detect it in the first instance. Likewise, centralization hinders inclusive decision-making when complex realities arise that require integrated, synergistic, or simply collaborative approaches between different parties or systems that may or may not share a vision, mission, or values.

Today, with technological advances, forms of governance have begun to emerge that are different from those adopted in the past. The blockchain is a disruptive technology that challenges centralized governance and proposes solutions to many of its problems. The fact that every node contains all the information of the network not only prevents (or makes it very costly) to control the network from a single node, but also provides greater security and stability to the network, since, if one point or node fails, the system as a whole does not collapse.[62]

Decentralized governance blockchain technology provides alternatives to the traditional forms of organization on which society is based: contracts and organizations. The cases of Smart Contracts and decentralized autonomous organizations (DAOs) are some of the examples that are bringing about a change in the governance paradigm.

61 However, while the technology is anonymous in that it does not allow the wallet address to be linked to the individual, once this link is established, the transaction history keeps a record of all movements between wallets and can therefore be used as evidence in legal proceedings. A case that illustrates how blockchain is used as evidence is the Silk Road case (marketplace on blockchain where illegal goods were traded). See: ComputerWorld (02.09.2015). *Four technologies that betrayed silk roads anonymity*. Retrieved from: https://bit.ly/3f6UGve

62 Who is responsible for governing a blockchain? Generally, to draw a simplified outline of blockchain ecosystems, the governance of a blockchain network is based on four fundamental communities: 1) Developers: technicians and programmers who manage and maintain the core code of the blockchain. 2) Node operators: users who have on their computers a complete copy of the registry of the network databases and whom must be consulted by the developers in case of changes since they must execute the operations on the nodes; 3) Token owners: those who are part of the ecosystem by virtue of owning blockchain tokens and, depending on the specific consensus mechanism, participate in the governance, their participation in the governance being proportional to their percentage share in tokens; 4) Founding organization: the “founding” team of the platform that assumes different roles to manage the network, either by raising funds to finance the project, generating marketing campaigns, and/or mediating between the different actors of the community and investors.

Smart Contracts

A smart contract is a digital contract, written in computer code on a blockchain network, that is automatically executed if certain predetermined conditions and terms are met. They are often used to automate agreements without the need for intermediaries or loss of time, or to automate processes, executing actions when certain conditions are met. For example, it can be used for a payment to suppliers in the supply chain when one or more conditions are met.

Smart contracts are not radically different from traditional contracts, but what changes is the way they are drafted and executed. The terms of the contract are written by means of codes that are automatically executed when different nodes verify that the pre-established conditions have been met (through a decentralized system). Its main benefits are automation, a reduction in time and bureaucracy, the absence of intermediaries, accuracy, inviolability, transparency, and decentralization (see Table 2 below). However, its advantages may become weaknesses when it comes to correcting errors and undoing them in the system or saving programmers' mistakes.

Table 2: Differences between a Smart Contract and a traditional legal contract

Smart Contract	Traditional legal contract
Autonomous and self-sufficient	Dependent on third parties
Secure and tamper-proof	Susceptible to errors and fraud
Decentralized	Centralized

Currently, digital contracts are programmed to run and self-execute on digital assets and not on physical assets, as they cannot corroborate changes in the real world on their own. One technology which, through hardware (sensors), software (with the ability to process collected information), and an internet connection, helps to establish the connection between the real world and the digital world is the Internet of Things. However, the applications thereof are still in their initial stages, so these types of contracts coexist and, in some cases, complement traditional contracts.

Decentralized Autonomous Organization

A decentralized autonomous organization, or DAO, is a type of organizational structure through which a set of individuals coordinate their collaboration around a common goal or goals, in a self-managed or self-governed, global (without borders), and free (without bureaucracies external to the organization itself) manner. These types of organizations are built on smart contracts in which their rules, organization, and administration are defined.

Unlike traditional organizations, a DAO does not have a hierarchical structure, nor directors or presidents who can centralize decision-making. Decisions are made by a deliberation of all members, who authorize — or not — each initiative, transaction, or movement. In this way, each decision arises from proposals and is submitted to a vote, in order to guarantee that every member of the organization has an active role, a voice, and a vote. In fact, there are different models that establish the participation and membership in this type of organization, which freely self-determines the way in which voting, decision-making, and other DAO actions are carried out.

The main characteristics of DAOs are as follows:

1. Their open source code allows all transactions to be recorded and stored in the blockchain network, making them transparent and incorruptible.
2. Their decentralization, since they do not have hierarchical structures, but rather are based on functions.
3. Their self-determination to establish their own governance system and the way in which decisions are made, generally based on consensus protocols involving all of their members.
4. Their ability to create exchange tokens (or digital assets) to ensure economic sustainability and to provide their owners a voice and voting power.
5. Their use of Smart Contracts, which codify and program actions to be executed according to predetermined parameters, which allow members to be linked or joint projects to be developed.

DAOs are a recent phenomenon that has been growing, from their first experiences applied to cryptocurrencies, to their most recent applications to form organizations focused on diverse topics and purposes. However, there are still many unresolved challenges that hinder the adoption of this concept in practical cases. One of the main challenges to be solved is the lack of knowledge, and consequent mistrust, of this type of organization. Another challenge is related to choosing the type of governance adopted by decentralized autonomous organizations. Because many DAOs are governed by deliberative and general voting processes, they are often slow to make decisions and execute actions. A problem that arises from this situation is the lack of participation and interest of many users in voting, which could result in decisions that do not represent the interests of the community as a whole.

Another challenge faced by DAOs is the legal setting. The regulatory framework for this type of organization is uncertain and presents a dilemma for states when it comes to legislating and regulating these types of activities, which slows down the adoption of this type of instrument by many users who do not yet have sufficient confidence in this new organizational paradigm.

Finally, DAOs are still vulnerable to attacks and hacks, since DAOs remain codes and protocols susceptible to modification or abuse by their members or external agents (particularly problematic in blockchain where the damage done is immutable and irreversible). Organizational security issues are likely to be addressed and improved as these types of applications are adopted, but to date they are a major challenge to overcome in order to generate sufficient trust in the technology.

Nation States and Government Digitization

There are still gaps to be bridged at the international level to facilitate the development and implementation of blockchain by nation states and international organizations. However, there are some experiences of adoption in different countries that show how these technologies can be used and how these tools are increasingly being chosen to address public issues.

THE CASE OF ESTONIA

Estonia, a global leader in digitization, leads the rankings of digitization of public services[63] with 99% of public procedures digitized, ranked 7th in the European Union's *Digital Economy and Society Index*[64] in 2021.

This country began to build its e-government system in 1997; in 2001, its citizens could file their taxes online; in 2002, they acquired their digital identity and signature; and in 2005, they had access to digital voting.

Estonia's digital system is mainly based on three components:

1) The virtual identity of its citizens who, using a unique number, can access all public services in the country and sign documents digitally (signature with the same validity as a holograph);

2) The X-Road system of 2021, a decentralized software structure (as an alternative to a centralized database), organizes the effective exchange of standardized information and security between institutions, under the principle of requiring data on individuals only once, enabling all public and private agencies to have access to information, and enabling citizens to access information about the entities that information about them, increasing the transparency of the use of data by governments;[65]

3) The KSI blockchain that ensures the protection and integrity of the State's electronic information was incorporated in 2008 and began operating at scale in 2012.[66]

For example, in 2012 Estonia migrated the Probate Registry system of the Ministry of Justice to the KSI platform, and currently there are already several public registries running on this blockchain, such as the Healthcare Registry, the Land Registry, the Business Registry, the Probate Registry, the Digital System of the Court of Justice, and their Official Gazette (PWC, 2019). [67]

For Estonia, the implementation of blockchain technology in government was not only strategic, but also a priority, due to cybersecurity issues following the 2007 cyberattack that affected the country's electronic services, leaving it without access to public services and portals for hours. Following this incident, the security of the system became critical. Beyond its blockchain developments, Estonia has "data embassies" in other countries, where it stores blockchain backups of digital assets crucial to the country.

63 e-Estonia (11.15.2021). *Estonia – a European and global leader in the digitalisation of public services*. Available at: https://bit.ly/3swkELV

64 European Commision (2022). *The Digital Economy and Society Index (DESI)*. Available at: https://bit.ly/3st5JCf

65 Anna Piperal (n/d). What a digital government looks like. Ted Talk on YouTube. Available at: https://www.youtube.com/watch?v=kaU7IPlg9PA

66 For more information, visit the website of Estonia: E-Estonia. KSI Blockchain. Available at: https://bit.ly/3Dg1e30

67 PWC (2019). *Estonia – the Digital Republic Secured by Blockchain*. Available at: https://pwc.to/3fayQXJ

ARGENTINA

Argentina has fallen behind in terms of digitization. In particular, it ranks 59th out of 63 in the IMD World Digital Competitiveness Ranking 2021,[68] or 68Lato out of 99 cases, according to BBVA Research's multidimensional digitization index, DiGiX 2022.[69]

In recent years, Argentina has stood out internationally for being in the world rankings for the highest use of cryptocurrencies, which is a typical example of *bottom-up adoption*, in which citizens push to put the issue of blockchain technology on the state's agenda.

In this regard, the National State, subnational jurisdictions, and some specific state agencies began to explore the technology, developing application projects of various scopes and fields of action. One of these cases is the *Blockchain Federal Argentina* (Federal Blockchain of Argentina, BFA), an open platform that integrates multiple services and applications on blockchain, to be used by the public, academic, private, and civil society sectors, promoted by the *Dirección Nacional del Registro de Dominios de Internet* (National Directorate of the Internet Domain Registry)[70], the *Cámara Argentina de Internet* (Internet Chamber of Argentina, Cabase), and the *Asociación de Redes de Interconexión Universitaria* (Association of University Interconnection Networks, ARIU).[71]

According to the initiative's official website, there are 23 service application cases on BFA, such as image and document certifications, food traceability, title validation, and contract verification, among others. Transactions in BFA are free of charge and its consensus model is based on *proof of authority* (PoA), where only a certain number of authorized nodes can validate the blocks, which do not compete, nor receive any reward. The storage of information and documents is kept outside the blocks, which only store the *hashes* of that information. Each user is responsible for storing their documentation as they see fit.

CHILE: OPEN ENERGY

Chile's National Energy Commission incorporated blockchain technology with the aim of certifying certain energy sector information and facilitating its reliable dissemination. According to the official website, this tool works as a "digital notary" since it makes it possible to certify that the information provided in this portal has not been altered or modified and, in turn, to generate a record of its existence.[72] Once the information is linked to the blockchain, a "certificate of trust" is issued, which can be viewed by the public on the official website.

Energía Abierta uses the Ethereum network to track data related to the energy sector, such as concessions, projects, electrical installations, and registered facilities for distributed energy production. The certificates are available on the official website and can be exported in different formats (see Figure 5 below).[73]

68 Statista (2022). *Position of Argentina in the Digital Competitiveness Ranking in 2021, by factor*. Available at: https://bit.ly/3UetF8n

69 BBVA Research (06.07.2022). *DiGiX 2022 Update: A Multidimensional Index of Digitization*. Available at: https://bit.ly/3D92TXR

70 Dependent on the Legal and Technical Secretariat of the Presidency of the Nation.

71 Blockchain Federal Argentina. Official website. Available at: https://bfa.ar/bfa/que-es-bfa

72 Open Energy. Blockchain. Why is it important? Available at: http://energiaabierta.cl/blockchain/porque-es-importante/

73 See: To see the available certificates, go to: http://energiaabierta.cl/certificados/

Fig. 5: Blockchain-based 'certificate of trust' Model

Source: Open Data on Chile's Energy

SECTION THREE

ENVIRONMENTAL IMPACT OF BLOCKCHAIN

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ENVIRONMENTAL IMPACT OF BLOCKCHAIN

Every human activity and every technology generates, to a greater or lesser extent, an impact on the environment. This is not different with blockchain. The objective of this section is to analyze the environmental impact of the blockchain and its main application today, cryptocurrencies, from two perspectives: carbon emissions, due to energy consumption, and e-waste generation.

In general, blockchain does not produce an environmental impact that differentiates it from other systems such as centralized databases. On the other hand, however, massive public blockchains, particularly those that use *proof of work* (PoW) as a consensus mechanism, consume a lot of energy (generated with high percentages of fossil fuels), producing a significant amount of carbon emissions and e-waste.

Originally, the two major cryptocurrencies, Bitcoin and Ethereum, were public blockchains using PoW, producing a significant environmental footprint. Part of the environmental impact was reduced from Ethereum's successful migration to PoS (*proof of stake*), a process known as "the Merge", which resulted in an approximate 99.95% reduction in its electricity consumption. However, Bitcoin, the largest cryptocurrency, continues to use PoW and has not yet planned to change its consensus mechanism.

By design, PoW involves a zero-sum competition (one wins and the others lose) between miners to solve a computationally complex (of no practical use[74]) and expensive puzzle, due to the high energy consumption required to solve it. The fact that the riddle is difficult and expensive is what guarantees the security of the system, and the reward for solving the riddle (a cryptocurrency) is what incentivizes miners to participate in this competition.

The higher the reward value, the more incentive miners have to solve the puzzle, increasing competition between miners, energy consumption and e-waste (due to the constant need to upgrade equipment to be extremely efficient), without generating any efficiency improvement in the system.

Therefore, PoW always involves high energy consumption, which in turn generates emissions because of the use of non-renewable energy sources since most miners are located in countries with hydrocarbon energy matrices, which makes Bitcoin and other cryptocurrencies unsustainable.

In terms of environmental impact, PoW is the problem, not blockchain. There are very efficient blockchain systems, both public and private, that consume little power, and the successful migration of Ethereum has demonstrated that there are viable alternatives to established systems. As crypto benchmark Bankless says, "the solution to PoW is to turn PoW off."

In general, blockchain is slightly more energy intensive than traditional systems, however, it also provides important operational and design advantages that alternative systems do not provide. From an environmental point of view, its impact appears to be greater, but it facilitates the development and implementation of systems and policies for the environment, society and governance (see Section II "Environmental, Social and Governance Uses and Benefits of Blockchain").

74 The puzzle is a computational problem to be solved that has no application in itself, other than being difficult to solve. In other words, the only goal of such a riddle is to make it difficult to solve, and therefore costly, not to make it useful. Literally, Bitcoin is about generating random numbers until you find one that fulfills certain conditions.

Blockchain Energy Efficiency

There are a variety of ways to apply blockchain, which generally differ in two dimensions: chosen consensus mechanism and access to it (public vs. private blockchain). Therefore, system efficiency is a direct consequence of energy consumption, which depends on the consensus mechanism used and how it is applied.

Sedlmeir et al. (2020) compares the approximate energy efficiency of different variants of blockchain and centralized systems to perform a transaction, and concludes that centralized systems are more efficient than any version of blockchain, including private versions, with an energy cost per transaction of 0.01 J in a simple server, 0.1 J in a centralized system, and 1 J in a private blockchain.[75]

The energy differences between these technologies are not so great, particularly if we consider that they differ in terms of security and redundancy, so the choice of the appropriate technology will depend on the functionalities required in each application.[76] For example, choosing a private blockchain means that each user can have a copy of the information, leading to higher energy costs due to increased redundancy and security.

However, there are important differences between centralized systems and public blockchains, but even within this classification, there are significant variations depending on the consensus mechanism chosen. The authors estimate that a transaction on a public blockchain using PoW as a consensus mechanism consumes 1,000,000,000,000 J (10^9 J), while a public blockchain without PoW consumes approximately 103 J (10^3 J) per transaction.

By definition, the consensus mechanisms and redundancy implicit in blockchains imply higher energy consumption than centralized systems. However, this new technology has valuable technical, political and economic implications far beyond its energy consumption.

Cryptocurrencies

Currently, cryptocurrencies are the main public blockchain application, and as previously mentioned, they were central to the development of this technology. Therefore, it is important to understand the dynamics and environmental impact of this application.

The most controversial point regarding cryptocurrencies is their energy consumption. In this section we will analyze its environmental impact, as well as the future of this technology, which is only 15 years old, is constantly evolving and has made great advances in terms of sustainability.

There is no consensus on the methodology to be used to measure the electronic consumption of the different cryptocurrencies, so there are several alternative estimates that usually estimate confidence ranges on technical and/or economic elements that we know about the technology. In general, we will use the most widely accepted in the specific literature, but we will also mention alternative measurements, which often highlight interesting elements.[77]

75 The same authors clarify that these are approximate estimates and may vary depending on hardware, security measures and other specifications in each case. These are not exact measurements, but general ones.

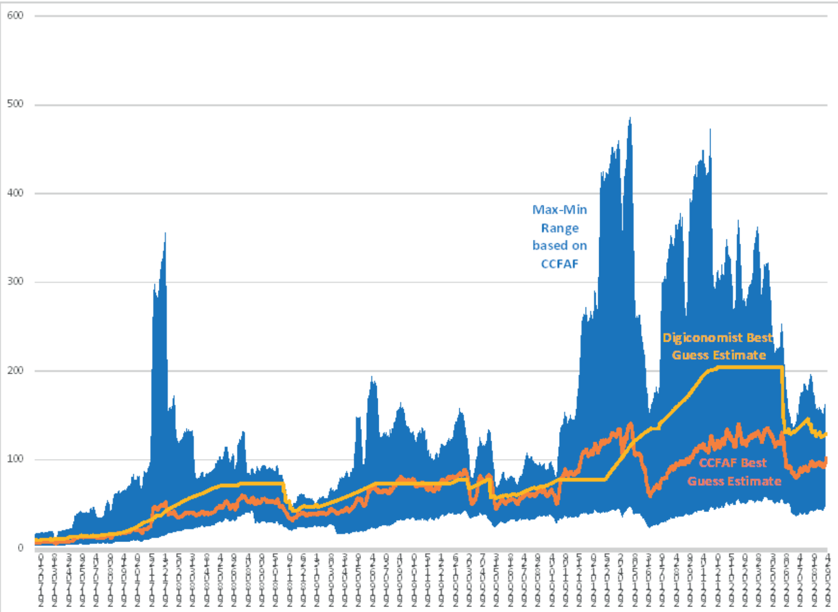
76 For more information on trade offs when choosing this technology, one can see Kannengießer, N., Lins, S., Dehling, T., & Sunyaev, A. (2019). *What does not fit can be made to fit! Trade-offs in distributed ledger technology designs*. In Proceedings of the 52nd Hawaii international conference on system sciences.

77 For a discussion of the different methodologies used, good practices in this type of estimation and detailed analysis of many of the studies mentioned in this paper, see Lei, N., Masanet, E., & Koomey, J. (2021). *Best practices for analyzing the direct energy use of blockchain technology systems: Review and policy recommendations*. Energy Policy, 156, 112422. The authors consider the CCFAF data to be the best possible estimate for Bitcoin.

Bitcoin

Undoubtedly, the cryptocurrency that consumes the most energy is Bitcoin, both for its wide adoption compared to the rest of the digital currencies, as well as for its design (see figure below). The proof of work (PoW) chosen by Satoshi, (2008) by definition, is expensive in computational power and thus energy, and the fact that it is so expensive is what makes it both secure and immutable.[78] Similarly, other cryptocurrencies that use PoW consume ample amounts of energy, but they tend to be less widely adopted. It is noteworthy that Bitcoin's energy consumption has increased as its adoption and value has increased (see Figure 6 below).

Fig. 6: Bitcoin: annualized energy consumption (TWh) — estimates and confidence range[79]



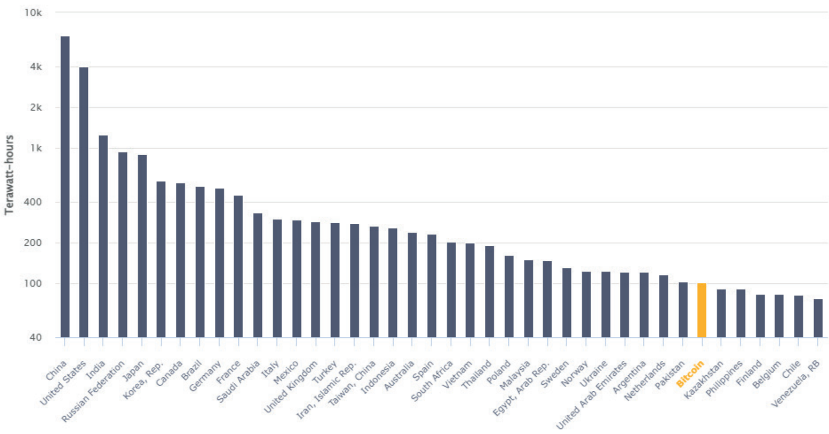
Source: Prepared by the Authors Based on CCFAF and Digiconomist (latest available data): 10/5/22)

Bitcoin's annualized energy consumption is so high that it can be compared to the electricity consumption of entire countries, ranking 34th, a level similar to that of Kazakhstan (see Figure 7 below).

78 In order to overcome the chosen consensus mechanism, a miner would have to have more than 50% of the computational power (and energy consumption) of the entire Bitcoin network, which is implausible and very costly.

79 The accuracy of estimates of Bitcoin energy consumption is disputed, however, there are estimates and confidence ranges widely accepted in the literature. The first is the "Cambridge Bitcoin Electricity Consumption Index" (CBECI), prepared by the Centre for Alternative Finance (CCFAF) at Cambridge University's Judge Business School, and the second is the "Bitcoin Electricity Consumption Index" (BECI) prepared by researcher Alex de Vries and published on the Digiconomist portal (see below the evolution of Bitcoin energy consumption according to both estimates). Due to the limitations of the methodologies, both CBECI and BECI estimate a lower range assuming that all miners use the most advanced hardware available and are extremely efficient in energy management (particularly the cooling of such equipment). There are other estimates of Bitcoin consumption, using different methodologies or assumptions, e.g., Stoll et al. (2019), Zade et al. (2019), Krause and Tolaymat (2018), Coinshares (2022), NYDIG (2021), among several others.

Fig. 7: Bitcoin vs. countries: annualized electricity consumption as of 10/05/2022 (TWh, logarithmic scale)



Note: Consumption for each country is based on EIA estimates, for 2019 or the most recent year.

Source: CCFAF (2022)

Ethereum

The second most widely used cryptocurrency is Ethereum, which until 09/15/2022 used PoW as a consensus mechanism — just like Bitcoin — but has migrated to PoS significantly reducing (99.95%) its energy consumption (see section "PoW Alternatives" for more information on Ethereum's migration).[80]

For example, on 09/13/2022 Ethereum using PoW (which we will henceforth identify as Ethereum-PoW) consumed 77.77 TWh (annualized), but as of PoS implementation, e.g. on 09/16/2022, Ethereum consumed only 0.0124 TWh (annualized) (see Figure 8 below).[81]

Before migration to PoS, Ethereum-PoW electricity consumption was similar to the consumption of the Netherlands (ranking 31st) according to EECI's estimate or that of Ecuador (ranking 69th) according to EEPUB's estimate (data as of 5/17/22). If Bitcoin and Ethereum-PoW consumption (BECI + EECI) were added together, energy consumption was 306 TWh, higher than that of Italy (ranking 12th).[82]

Overall, Bitcoin was estimated to make up 2/3 of the total energy consumption of cryptocurrencies, while the rest accounted for an additional 1/3.[83] Ethereum's migration to PoS substantially reduced the power consumption of cryptocurrencies in general, but it remains high as Bitcoin continues to use PoW.

80 For more information on the importance of PoW to PoS migration in the Ethereum network, see *"Ethereum's energy consumption,"* jmcook.eth, 2/9/2022. Link: https://bit.ly/3OGgjiA

81 During the PoW stage, Ethereum's energy consumption increased when its adoption and/or value increased (same behavior as Bitcoin).
There are two alternative estimates of energy consumption by Ethereum. The first one, called "Ethereum Electricity Consumption Index" (EECI) made by researcher Alex de Vries and published in the Digiconomist portal, following the same methodology used to calculate the energy consumption of Bitcoin (with different assumptions), and another one made by researcher Kyle McDonald (which we identify with the acronym EEBUP, corresponding to "Ethereum Energy: A bottoms up Approach").
For information on the methodologies used, see:

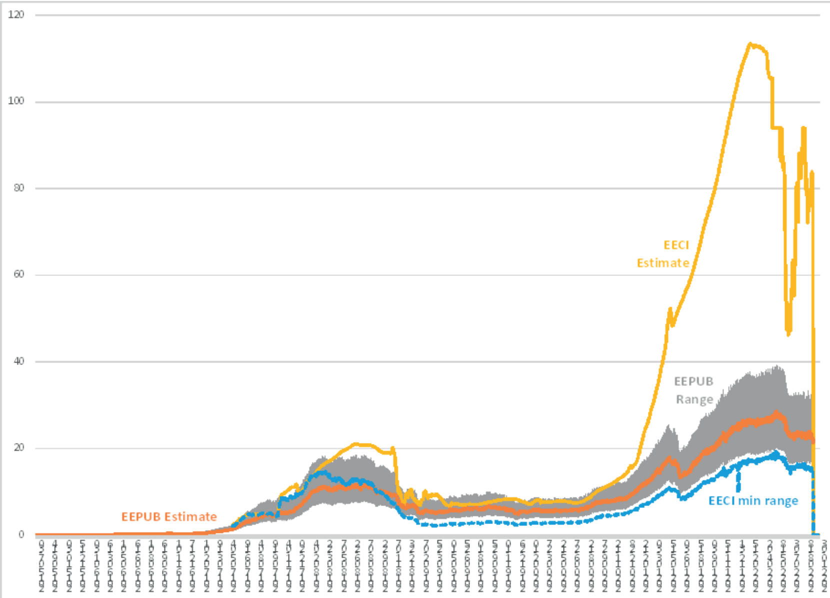
- EECI: *"Ethereum Energy Consumption Index"*, Digiconomist, retrieved 5/17/22. Link: https://bit.ly/3EzN5zC
- EEBUP: McDonald, K. (2021). *Ethereum Emissions: A Bottom-up Estimate*. arXiv preprint arXiv:2112.01238. and *"Ethereum Emissions: A Bottom-up Estimate"*, Kyle McDonald, retrieved 05/17/22. Link: https://bit.ly/3rO1pgv (Discontinued after Ethereum migration to PoS).

Despite the methodological differences, Ethereum.org, the organization responsible for the development of such a platform accepts both estimates as valuable and representative. See: *"Ethereum energy consumption"*, Ethereum.org, retrieved 5/17/22. Link: https://bit.ly/3yxCxgL and *"Ethereum's energy usage will soon decrease by ~99.95%," Ethereum.org, 05/18/2021, retrieved 05/17/22.* Link: https://bit.ly/3ExRMKi

82 Additionally, one could add the power consumption of other PoW-using cryptocurrencies such as Dogecoin (4.34 TWh), Bitcoin forks or Litecoin.

83 Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2020). *Energy consumption of cryptocurrencies beyond bitcoin*. Joule, 4(9), 1843-1846.

Fig. 8: Ethereum: annualized energy consumption (TWh) — estimates and confidence range



Source: own elaboration based on Digiconomist (data as of 10/5/22) and McDonald, K. (2021)

Energy origin

From the electricity consumption of the different cryptocurrencies, it is possible to estimate their carbon footprint. However, the carbon equivalent generated by the electricity consumption of cryptocurrencies depends on the origin of the energy used, i.e., whether they come from renewable or non-renewable sources.

There are two ways of estimating the origin of the electricity consumed, each with its advantages and disadvantages. The first consists of surveys of the miners themselves in which they self-report the percentage of renewable energy they use.[84] According to the CCFAF survey (2020), 76% of miners use renewable energy as part of their electricity mix, but only 39% of all electricity consumption used for mining comes from renewable energy (see Figure 9 below).[85]

Regarding energy sources, 62% of miners state that they use hydroelectric power, 38% coal, 36% natural gas, 17% wind power (see CCFAF (2020) for more detail). The energy mix varies between regions, but hydroelectric power always predominates, followed by natural gas or coal (coal is not used in Latin America), and thirdly other energy sources.

The second alternative, based on the geographic location of the miners, assumes that they use renewable energy in the proportion of the electricity matrix of the region where they are located.[86] In other words, if a miner is located in Texas, U.S.A., it is estimated that the miner consumes renewable energy, natural gas and coal in the same proportion as the overall electricity grid in that region (methodology originally developed by Vries et al. 2022).[87]

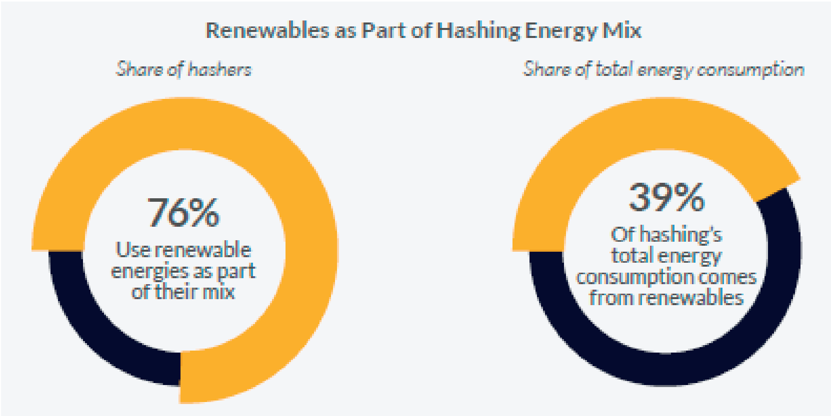
84 The problem with this methodology for estimating the carbon footprint of cryptocurrencies is the inaccurate, inexact or dishonest reporting by miners of their energy consumption mix.

85 CCFAF (2020), *3rd global cryptoasset benchmarking study*. Link: https://bit.ly/3R8uChB

86 The location estimates are based on the IP of miners that must be provided to participate in the mining pools. In addition, it is supplemented with data from hardware vendors and other sources of information. See *"Bitcoin Mining Map"*, CCFAF, retrieved on 05/20/2022 (link: https://ccaf.io/cbeci/mining_map) y Stoll, C., Klaaßen, L., & Gallersdörfer, U. (2019). *The carbon footprint of bitcoin*. Joule, 3(7), 1647-1661.
A challenge of this methodology is that the IPs of the miners can be modified via VPN. For example, a significant number of miners are reported in Ireland or Germany, but there is no evidence that there are any facilities of that size in those countries, leading to the assumption that the miners modified their IPs to simulate being in those jurisdictions.

87 de Vries, A., Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2022). *Revisiting Bitcoin's carbon footprint*. Joule, 6(3), 498-502.

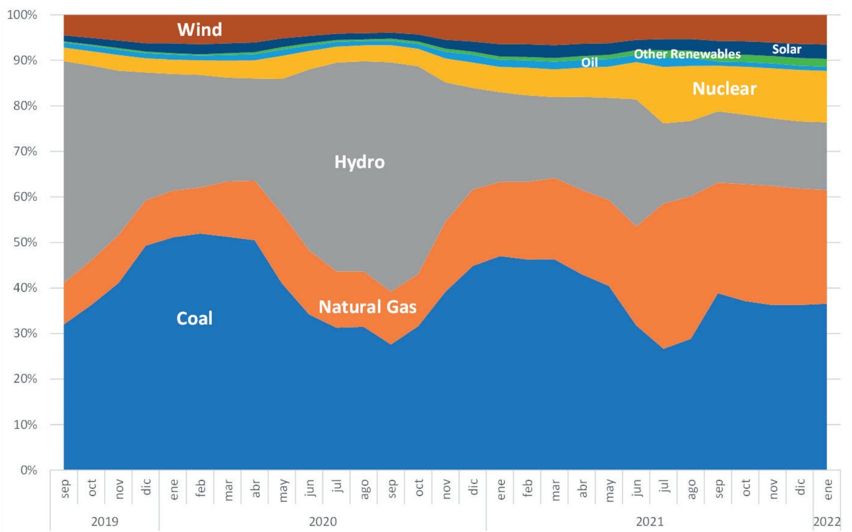
Fig. 9: Renewable energy: percentage of miners using some renewable energy and total percentage of energy coming from renewable sources.



Source: CCFAF (2020)

On this information we can observe that in January 2022 Bitcoin miners were located in the United States of America. (38% of the total), followed by those from China (21%), then Kazakhstan (13%). Until mid-2021, China dominated Bitcoin mining, even reaching a series high of 75% of the total in September 2019. Based on this information, we can estimate what type of energy is used by the miners in this network (see Figure 10 below).

Fig. 10: Origin of the electricity consumed by the Bitcoin network



Source: Prepared by the authors based on CCFAF as of January 2022.

The crypto community in general has the objective of continuing to increase the proportion of renewable energy, with several publications proposing alternatives in that direction.[88] However, its implementation and progress have not yet been observed. In turn, many believe (while others argue) that cryptocurrencies can contribute to the development of renewable energies, by stabilizing demand on the grid and incentivizing their development (see section "Renewable energies: a realistic alternative?").

Carbon Equivalent Emissions

Based on estimates of electricity consumption, the location of miners and information on the electricity generation mix, we can calculate the equivalent carbon emissions from mining cryptocurrencies. There are a variety of studies estimating the carbon equivalent emissions of Bitcoin, Ethereum-PoW or cryptocurrencies in general, which depending on the assumptions and methodologies adopted may differ substantially.

Bitcoin mining is estimated to have generated 56.3 $MtCO_2e$ during 2021 (estimates similar to De Vriers et al. (2022), 65.4 $MtCO_2$ annually according to August 2021 data), and that cumulative emissions would reach 202.4 $MtCO_2e$ by the end of 2022 (see Figure 11 below).[89] By way of comparison, Greece's emissions are 56.6 $MtCO_2$, equivalent to 0.19% of total global emissions.[90]

De Vriers et al. (2022) estimates that of the total CO_2 emissions generated by the Bitcoin network in August 2021, Kazakhstan was responsible for more than 25% of the emissions (while only processing 18% of the hashrate in that period), by generating so much electricity on the basis of hard coal (lots of emissions). Then we have the United States of America, with 15.1% of emissions, where a significant mix of electricity generated by natural gas (Texas) and coal (Kentucky, Georgia) is used.

An interesting exercise to visualize the challenge of carbon emissions generated by Bitcoin is carried out by Mora et al. (2018), where they estimate that it would take only 16 years to consume the available carbon budget to avoid a 2°C temperature rise, assuming Bitcoin begins to be widely adopted for all electronic payments. [91]

In conclusion, the large energy consumption generated by PoW-based cryptocurrencies have a significant impact on carbon emissions, since the generation of the required electricity involves emissions. Definitely, if electricity generation were 100% renewable, the environmental impact of POW-based cryptocurrencies would be lower (see, for example, the low emissions generated by Bitcoin mining in the hypothetical case that all power was hydroelectric). However, today only 13.5% of energy comes from renewable sources, and the energy transition will last several decades, being a reality with which we have to coexist and assuming a renewable matrix at present is utopian.[92]

88 For example, see: NYDIG (2021). *Bitcoin net zero*. Link: https://bit.ly/3yDn0MW

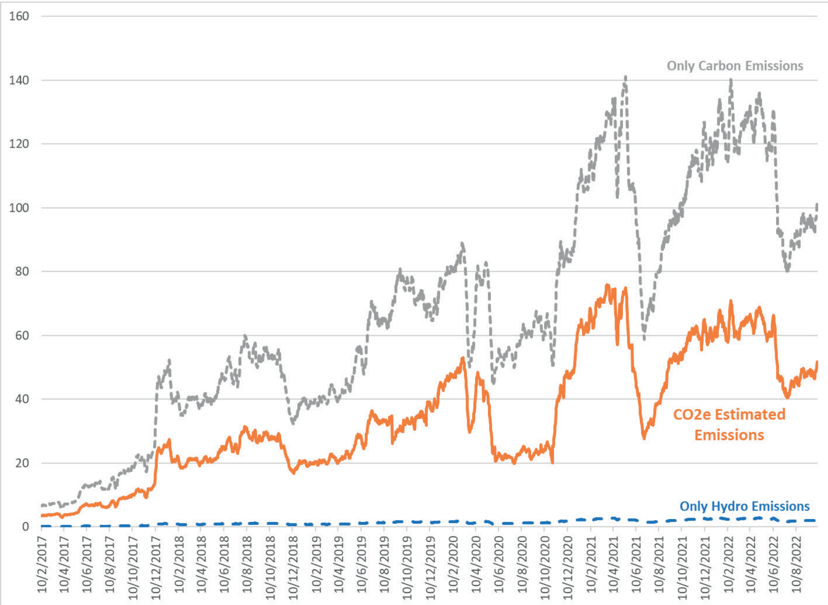
89 Prior to Ethereum's migration to PoS, McDonald (2021) estimated Ethereum-PoW emissions to be 7.98 $MtCO_2e$ while Digiconomist estimated annual emissions 55.27 $MtCO_2$.

90 A third source, Stoll et al. (2019) estimates Bitcoin emissions at 22.0-22.9 $MtCO_2$, Etherem-PoW ranking 77 (North Korea) and 83 (Angola) in carbon emissions.

91 Mora, C., Rollins, R.L., Taladay, K. et al. (2018). *Bitcoin emissions alone could push global warming above 2°C*. Nature Clim Change 8, 931–933. Link: https://doi.org/10.1038/s41558-018-0321-8 The work has been criticized basically for two questionable technical assumptions. First, including mining machines that were no longer profitable at the time the work was done, and second, the technical impossibility for Bitcoin to process the volume of transactions that the model estimates it should process (scalability problem). For the first aspect see Houy, N. (2019), *Rational mining limits Bitcoin emissions.* Nat. Clim. Chang. 9, 655. (Link: https://doi.org/10.1038/s41558-019-0533-6) y Masanet, E., Shehabi, A., Lei, N. et al. (2019) *Implausible projections overestimate near-term Bitcoin CO_2 emissions.* Nat. Clim. Chang. 9, 653–654 (Link: https://doi.org/10.1038/s41558-019-0535-4). For the second, see: Dittmar, L., Praktiknjo, A. (2019) *Could Bitcoin emissions push global warming above 2 °C?*. Nat. Clim. Chang. 9, 656–657 (Link: https://doi.org/10.1038/s41558-019-0534-5).

92 Hannah Ritchie, Max Roser and Pablo Rosado (2021), *Renewable Energy*, OurWorldInData.org, link: https://bit.ly/3CBvhl6

Fig. 11: Bitcoin: carbon equivalent emissions



Note: until 09/31/2019 the global energy mix is used as reference, between 01/10/2019 and 01/31/2022 the energy mix according to the geographic location of the miners is used, and from 02/01/2022 until the latest available data the energy mix as of 01/31/2022 is used until new information is available.

Source: Prepared by the authors based on CCFAF (data up to 10/5/2022)

Cryptocurrencies vs. Centralized Means of Payments

At present, cryptocurrencies involve significant energy consumption and consequent carbon emissions, even though their adoption still remains a minority, both as a percentage of the population that has acquired a cryptocurrency and as a percentage of the total value transacted. In other words, despite its low level of use compared to other means of payment, it has a significant environmental impact.

Cryptocurrency adoption remains low internationally, even though it is growing rapidly. A first indicator is the number of users who use cryptocurrencies. For example, crypto.com (2022) estimates that by December 2021 the total number of crypto users will reach 295 million, mainly driven by the adoption of Bitcoin (176 million) and Ethereum (23 million), and they anticipate reaching one billion users by the end of 2022.[93] However, it is not only the number of people using cryptocurrencies (users or merchants) that is relevant, but also the intensity of use (how many transactions are made with them).

Compared to electronic means of payment or credit cards alone, cryptocurrencies are still not widely used. During 2020, there were an estimated 37.6 million transactions in Bitcoin and 344.8 million transactions in Ethereum, well be-

93 Crypto.com (2022), *Crypto Market Sizing Global Crypto Owners Reaching 300M*, January 2022. Link: https://bit.ly/3eiSaSw

low the 468 billion transactions recorded by the major purchase card companies (VISA, MasterCard and others) or the estimated 766 billion electronic (non-cash) transactions that transpire in a year.[94]

So, to put the energy consumption and carbon emissions generated by PoW-based cryptocurrencies into perspective, the energy consumption and emissions per transaction of a cryptocurrency (usually Bitcoin) are often compared to those of a centralized payment method, such as a credit card (usually VISA) (see Table 4 below).[95]

Table 4: Energy consumption and emissions from cryptocurrency transactions

Means of Payment	Energy consumption	Emissions
1 Bitcoin transaction	2.138.78 KWh	1.192.92 kg CO_2
1 Ethereum-POW transaction	227.67 KWh	126.98 kg CO_2
1 Ethereum-POS transaction (100,000 transactions)	0.02606 KWh (2,606 KWh)	-
100.000 VISA transactions	148.63 KWh	45.12 kg CO_2

Source: prepared by the authors based on Digiconomist (05/2022 and 10/2022)

Since Ethereum's migration to PoS, its energy consumption per transaction has been substantially reduced (99.95% less than before) and each transaction is currently estimated to consume 26.06 Wh (i.e. 0.02606 KWh), being in a similar range but higher than that of centralized payment means.

Many people criticize the comparison between decentralized systems such as Bitcoin/Ethereum and centralized systems such as VISA/Mastercard because they consider that cryptocurrencies are not a means of payment, but an independent monetary and/or financial system.[96] However, in our opinion, its main application continues to be as a payment method, which merits such a comparison, although in the future with the evolution of these platforms and the development of new applications, a different interpretation and/or comparison may be appropriate.

In summary, the emissions of cryptocurrencies, particularly cryptocurrencies that use PoW as a consensus mechanism, are very high. This is without considering that the level of adoption of cryptocurrencies is still very low compared to that of other means of payments such as cards or mobile payments. If more people use cryptocurrencies, or their intensity of use increases, the environmental impact of cryptocurrencies will continue to grow rapidly. Therefore, it is important to analyze ways in which blockchain can maximize the social impact while minimizing its environmental impact.

Alternatives to PoW

The high energy consumption of cryptocurrencies and the emissions generated as a result of electricity generation are mainly due to the choice of the consensus

94 For Bitcoin, daily confirmed transactions were considered, according to Blockchain.com, retrieved on 05/25/22 (link: https://bit.ly/3EvhfnP) and for Ethereum daily total transactions, according to Etherscan, retrieved on 05/25/22 (link: https://etherscan.io/chart/tx). For "Non-cash payments", we took into account the estimates made by Capgemini Financial Services Analysis (2020), "*"World payments report 2020"* (link: https://bit.ly/3emHP7R) based on ECB and BIS data and for "Card payments", we took into account the total number of transactions made as reported by Nielsen Report (2020), retrieved on 25/05/22, (link: https://bit.ly/3yxKH8V)

95 There are slightly different estimates of energy consumption, but they also demonstrate the low efficiency of PoW with respect to centralized systems. Deutsche Bank (2021) estimates that a Bitcoin transaction consumes 118 KWh, an Ethereum-PoW transaction consumed 20 KWh, and a card payment transaction (VISA-Mastercard) consumed 0.00649 KWh. For more information, see: Deutsche Bank (2021), T*he Future of Payments: Series 2, Part II. When digital currencies become mainstream*, January 2021, link: https://bit.ly/3fZHk4j.

96 Some consider cryptocurrencies to be a means of payment, while others consider them to be a financial asset or a monetary system. In addition, platforms such as Ethereum, Cardamo or Polygon offer additional uses to traditional money. To date we believe that the best comparison is still with centralized means of payments, however, works such as Valuechain (2022) or McCook (2018) compare Bitcoin and other cryptocurrencies to paper money issues, the global financial system, etc. Valuechain (2022), *Bitcoin: Cryptopayments Energy Efficiency*, 16/06/2022, link: https://t.ly/UQ6s and McCook, H. (2018), *The cost & sustainability of Bitcoin*, 07/29/2018, Unpublished Working Paper.

mechanism mostly used today. By design, solving the puzzles presented by PoW requires a significant computational, hence energetic, and ultimately monetary cost, which seeks to guarantee the security and immutability of the system.

Therefore, to reduce the environmental impact of cryptocurrencies, the first question to ask is whether PoW is reasonable. As Ethereum's migration to PoS has well demonstrated, using alternative consensus mechanisms, whether PoS or PoA, in and of itself strongly reduces energy consumption. So, for some (since there is no consensus) there is currently a *trade-off* between system security (PoW) and higher energy efficiency (PoS/PoA).[97]

With that dilemma in mind, the crypto community has taken two stances. On the one hand, many developers consider that the only solution to PoW power consumption would be to "just turn it off".[98] That has been the stance taken by Ethereum, which in a lengthy process known as "The Merge" migrated from PoW to PoS without the system being offline at any time.[99] It was a highly complex task that began in 2020, ended on September 15, 2022, and to date is considered highly successful due to the high adoption by the Ethereum community (users, wallets, exchanges, etc.) that avoided a fork and allowed a reduction in system power consumption close to the 99.95% originally predicted. In Figure 8 "Ethereum: annualized energy consumption", we can observe how from the adoption of PoS the energy consumption used by Ethereum collapses.

Estimates such as that of Platt et al. (2021) even consider that PoS-based systems can be equally or more efficient than centralized systems such as VISA.[100] Other works such as Sedlmeir (2020) consider that PoS blockchain could potentially have higher energy requirements than centralized systems (but well below blockchain with PoW), given that each node in the network must process and store all transactions. However, the focus should be on the energy consumption of consensus mechanisms and not on idle nodes (see EU 2020).[101]

A second alternative to PoW that is currently being analyzed is the possibility that the work to be performed by the computers is useful and generates value. This option known as Proof of Useful Work ((*PoUWorUPoW*) has no practical applications but is a concept that is being widely analyzed and could guarantee a high level of security and generate value by channeling computation to useful tasks.[102]

A third alternative would be to incorporate more efficient and less costly (in terms of energy and environment) intermediate systems, where most transactions occur, are aggregated, and then reflected in their final format on the Bitcoin blockchain. This is the proposal promoted by "The Lightning Network" for Bitcoin, which seeks to implement an intermediate system for transactions between two nodes, allowing a "parallel channel" to be opened (technically it is a smart contract *off the chain*) where multiple transactions are made, and only when this channel is closed is it recorded in the Bitcoin blockchain.[103] Intermediate systems, which reduce the number of transactions to be performed on the Bitcoin blockchain, offer more efficient and less costly consensus mechanisms and allow reducing the environmental impact of Bitcoin.[104]

97 Blockchain widely adopted with PoS with consensus mechanisms are highly secure. For example, see *"Why Proof of Stake (Nov 2020)"*, Vitalik Buterin, 06/11/2020 (link: https://vitalik.ca/general/2020/11/06/pos2020.html) or *"Proof of Stake FAQs"*, Ethereum Wiki, retrieved 05/27/22 (link:https://eth.wiki/concepts/proof-of-stake-faqs). However, some questions persist, see: M. Saad, Z. Qin, K. Ren, D. Nyang and D. Mohaisen (2021), *e-PoS: Making Proof-of-Stake Decentralized and Fair*, in IEEE Transactions on Parallel and Distributed Systems, vol. 32, no. 8, pp. 1961-1973, 1 Aug. 2021, doi: 10.1109/TPDS.2020.3048853.

98 This quote is often attributed to the crypto benchmark Bankless. Ver: http://podcast.banklesshq.com/

99 For more information on Ethereum's migration from PoW to PoS, see *"The Merge"*, Ethereum, retrieved 05/27/2022. Link: https://ethereum.org/en/upgrades/merge/ and *"The Ethereum Proof-of-Stake Merge"*. Link: https://ethmerge.com/

100 Platt, M., Sedlmeir, J., Platt, D., Tasca, P., Xu, J., Vadgama, N., & Ibañez, J. I. (2021). *2021 IEEE 21st International Conference on Software Quality, Reliability and Security Companion (QRS-C), 2021, pp. 1135-1144.*

101 For example, the computing power used could be used to solve complex climate models, which is of no use to the miner, but would be socially beneficial. Papageorgiou, O., Sedlmeir, J., Fridgen, G., Vlachos, I., Kostopoulos, N., Damvakeraki, T., & Slapnik, T. (2021). *Energy Efficiency of Blockchain Technologies*. European Union Blockchain Observatory & Forum.

102 Ball, M., Rosen, A., Sabin, M., & Vasudevan, P. N. (2021). *Proofs of Useful Work*. Haouari, M., Mhiri, M., El-Masri, M., & Al-Yafi, K. (2022). *A novel proof of useful work for a blockchain storing transportation transactions*. Information Processing & Management, 59(1), 102749. Lihu, A., Du, J., Barjaktarevic, I., Gerzanics, P., & Harvilla, M. (2020). *A proof of useful work for artificial intelligence on the blockchain*. arXiv preprint arXiv:2001.09244.

103 For more information, see https://lightning.network/ and its white paper: Poon, J. and Dryja, T. (2016), *The Bitcoin Lightning Network: Scalable Off-Chain Instant Payments*, link: https://lightning.network/lightning-network-paper.pdf

104 See: Divakaruni, Anantha, y Zimmerman, Peter. 2022. *The Lightning Network: Turning Bitcoin into Money*. Working Paper No. 22-19. Federal Reserve Bank of Cleveland. Link: https://doi.org/10.26509/frbc-wp-202219.

Renewable Energies: a Realistic Alternative?

The environmental impact of cryptocurrencies is mainly defined by their electricity consumption, therefore, if the energy used by miners were renewable, their emissions would be considerably reduced (a renewable energy matrix would substantially reduce emissions). However, energy is fungible, i.e., energy from renewable sources is equal to energy from fossil fuels, making it very difficult to differentiate which type of energy each miner uses or to implement any system that guarantees the use of clean energy mining.[105]

The first problem is the high level of energy consumption of cryptocurrencies in a world of insufficient renewable energy. That is, there are not enough renewable energy sources to cover the consumption of cryptocurrencies and if cryptocurrencies demanded more renewable energy they would displace other energy consumers towards non-renewable sources.[106]

Additionally, some, such as Bitcoin Clean Energy Initiative (2021) or the governor of Texas, conjecture that increased demand from cryptocurrency miners (PoW primarily) will allow for increased renewable supply by stabilizing energy demand.[107] However, multiple papers question its effectiveness and regulators and energy providers are highly concerned about crypto's power consumption, which in many cases are subsideized with public resources.[108]

To begin with, many electricity systems (e.g. Argentina, China, etc.) do not have rapidly fluctuating prices to reflect system supply and demand, so miners have no incentive to change their behavior quickly. Second, in many countries, energy consumption is subsidized with public resources, therefore, cryptocurrency mining ends up being subsidized. Third, the price effect that crypto mining can generate in times of oversupply is negligible, so it does not drive investment in renewable energy.[109] Fourth, due to the short lifetime of crypto mining hardware, it is essential that it is active for as long as possible to maximize the return on investment, staying on without pause except in extraordinary circumstances (as it is not very sensitive to price variations, it generates higher base power consumption).[110]

To maximize their investment, miners require cheap energy, regardless of its origin (renewable or non-renewable), and higher levels of hardware utilization as long as the hardware is efficient (estimated lifetime of 1.3 years, "E-waste"section). Neither of these two behaviors seems to contribute to the development of renewable energies.

On the other hand, the high mobility of cryptocurrency mining facilities has encouraged the capture and use of methane produced by oil wells that cannot be stored or transported (lack of pipelines), and ends up being released into the atmosphere or burned generating CO_2 emissions, a process usually known as flaring. Some miners (2.4% of the total hashrate by Coinshare 2022) take advantage of this energy source avoiding 0.11 tons of methane emissions, equivalent to 2.1 $MtCO_2$.[111]

105 Neither the technology nor its users can validate what type of energy each miner uses. There are projects to certify the origin of electricity, however, they require face-to-face visits and have not been widely adopted (see Sustainable Bitcoin Standard, see: https://www.sustainablebtc.org/).

106 The bitcoin miner is unlikely to be the "marginal consumer" who, faced with rising energy prices, will reduce his consumption. It is likely to be other consumers who disconnect before the first miner does.

107 For example: Bitcoin Clean Energy Initiative (2021), *"Bitcoin is Key to an Abundant, Clean Energy Future"*, 04/2021. Link: https://bit.ly/3nCNGHh. Also *"Texas Governor Abbott Turns to Bitcoin Miners to Bolster the Grid and His Re-Election"*, Bloomberg, 01/27/22.

108 See *"Kosovo bans cryptocurrency mining after blackouts"*, BBC, 05/01/22, *"New York is close to a bitcoin mining crackdown — here's what that means for the industry"*, CNBC, 5/22/22, and *"La criptominería pone en jaque al sistema eléctrico de Tierra del Fuego"*, Clarin, 4/27/22.

109 *"Crypto Mining for a More Stable Grid?"*, Borenstein, S., Energy Institute Blog, UC Berkeley, March 21, 2022.

110 Crypto equipment has a useful life of 1.5 years (18 months), after which it must be replaced to remain competitive, which is why miners should maximize its use in the short term.

111 See: Sny de Vries, A. (2019). *Renewable energy will not solve bitcoin's sustainability problem.* Joule, 3(4), 893-898. Others believe that crypto would serve to incentivize hydrogen production based on this discarded gas in wells. Syntnikov, P., & Potemkin, D. (2022). *Flare gas monetization and greener hydrogen production via combination with crypto currency mining and carbon dioxide capture.* iScience, 103769. Also see, *"Oil drillers and Bitcoin miners bond over natural gas,"* Reuters, 05/21/21, link: https://reut.rs/3yFZFdq.

Electronic Waste

After energy consumption, the second most important environmental impact is caused by the electronic waste generated by cryptocurrency miners. The equipment usually used to solve PoW puzzles suffers rapid degradation due to their continuous and intensive use, but they are also quickly replaced in order to remain competitive in an industry where technology and equipment efficiency is advancing as fast as PoW-based cryptocurrencies.

Of the 53.6 million metric tons (Mt) of global e-waste generated in 2019, only 17.4% was collected and recycled, and e-waste is expected to double by 2050.[112] In this context, cryptocurrencies contribute to the production of more e-waste, particularly Bitcoin, with their specialized mining equipment.

Energy Efficiency and Competition

As all miners compete with each other to solve the puzzle proposed by the PoW, those who have more powerful (and efficient[113]) devices could solve it faster increasing their probability of being rewarded.

The race among miners to have the best hardware has driven major advances in hardware energy efficiency, particularly for Bitcoin, improving at rates of x50.[114] However, previously purchased equipment can become economically obsolete very quickly.[115] If a miner starts using more powerful hardware (he will be more likely to solve the puzzle first) and more efficient (he will have incentives to buy more machines), implying that the rest of the miners will have to acquire such more powerful machines to remain competitive. If everyone has more powerful and efficient machines, the difficulty of the puzzles will increase, and thus the old (less efficient) hardware will no longer be economically profitable.[116]

As a result, the hardware used to mine cryptocurrencies quickly becomes obsolete, either because of its continuous and uninterrupted use, or because new equipment makes it economically unviable.[117] In addition, specialized equipment (ASICs) cannot be reused for other functions, but only for mining the cryptocurrency for which they were created. On the other hand, generic equipment, such as the GPU for Ethereum-PoW mining, can be reused as they become economically unviable or inefficient for mining cryptocurrencies, extending their useful life and reducing e-waste.[118]

Bitcoin and E-waste

Because the hardware used to mine Bitcoin cannot be reused, and because its economic obsolescence can be calculated based on the efficiency of new machines and the price of Bitcoin, de Vriers and Stoll (2021) estimate that Bitcoin generates 30.7 metric tons per year of e-waste (May 2021) or 272g of e-waste per transaction (112.5 million transactions in 2020).[119] In other words, each Bitcoin transaction produces on average more e-waste (240g) than an iPhone 13 Pro Max.

112 *Forti, V., Bald´e, C.P., Kuehr, R., Bel, G., (2020).* The Global E-waste Monitor 2020: Quantities, Flows and the Circular Economy Potential. *UNU/UNITAR SCYCLE, ITU, ISWA.* *"With E-waste Predicted to Double by 2050, Business as Usual Is Not an Option"*, United Nations University, 09/17/2019. Link: https://bit.ly/3yzglmu

113 Greater energy efficiency does not necessarily imply lower overall consumption, since reducing mining costs incentivizes investment in more machines to increase the probability of solving the puzzle first.

114 For example, the Bitmain Antminer S19 XP (140Th), launched in June 2022, consumes 0.02 J/Gh, while the Botmain Antiminer S3, launched in July 2014, consumed 0.77 J/Gh. This represented a 38.5-fold improvement.

115 McCook (2018) estimates that the technical feasibility periods of ASIC hardware is higher than its economic feasibility. In other words, well-functioning equipment is discarded because it is no longer profitable. For their part, de Vriers and Stoll (2021) estimate the average lifetime of an ASIC for Bitcoin to be 1.29 years.

116 Assuming constant prices, the new equipment consumes less energy (lower cost) and has higher computing power (higher probability of solving the puzzle, higher revenue). If the cryptocurrency price rises, the less efficient equipment becomes economically profitable, increasing network consumption and lowering system efficiency.

117 Competition to develop and produce mining equipment is one of the reasons for the global shortage of microprocessors. *"Crypto-miners are probably to blame for the graphics-chip shortage"*, The Economist, 6/19/2021. Link: https://econ.st/3ae1SmZ

118 The lifetime of GPUs for normal use is estimated to be 3 years, and the lifetime of non-ASIC equipment can easily be extended. Ver Gaidajis, G., Angelakoglou, K., Aktsoglou, D. (2010), *E-waste: environmental problems and current management*, J. Eng. Sci. Technol. Rev. 3, 193–199. Link: https://doi.org/10.25103/jestr.031.32

119 De Vries, A., & Stoll, C. (2021). *Bitcoin's growing e-waste problem. Resources, Conservation and Recycling*, 175, 105901.

The amount of e-waste generated by Bitcoin is comparable to the waste generation by telecommunications and computer equipment such as that of the Netherlands (30 kt) (Vriers and Stoll, 2021). Additionally, the authors estimate that, due to the growing demand for this type of equipment, the electronic waste generated annually by the Bitcoin network could reach 64.35 kt.

Conclusion

The environmental impact of blockchain is not radically different from that produced by other modern technologies. However, Proof-of-Work public blockchains are by design highly polluting since they use large amounts of electricity from non-renewable sources.

Ethereum's migration to PoS was a first step towards reducing the environmental impact of cryptocurrencies in general, but Bitcoin should follow suit, which is unlikely due to the rejection of its community, and the industry of miners, investors and equipment built around it.

Technological advances, both in terms of renewable energies and consensus mechanisms, could contribute to the reduction of emissions from cryptocurrencies in general, but the truth is that there is still no clear picture as to when they would be applied, nor is there a full understanding of their possible effects.

FINAL THOUGHTS

A NEW BEGINNING

F I N A L T H O U G H T S

A NEW BEGINNING

We have reached the end of this journey on the uses of blockchain technology, its sustainability from the environmental, social and governance aspects, as well as its energy consumption and e-waste generation, with the aim of comprehensively examining its impact and potential.

Our research clearly shows that blockchain infrastructure will, in a not-so-distant future, have a much more relevant impact on multiple economic sectors and aspects of our daily lives. Its fast-paced and constant evolution makes it difficult to accurately predict future scenarios. However, we foresee that the blockchain will bring about deep transformations in society, the economy and global politics.

The potential for transformation is particularly significant when it comes to the environment. Three large groups of activities can benefit greatly from its use: supply chain, environmental control and monitoring, and the carbon market. Tokenization also has the capacity to channel private capital towards the safekeeping and regeneration of the environment.

On the social front, we are witnessing a new form of exchange of goods, services and assets between people, which eliminates intermediaries and promotes financial inclusion. However, as with any technology, there is a risk of blockchain being used for illegal activities or to cause harm. Regulation could mitigate these negative externalities but could also limit the power for innovation inherent to the blockchain ecosystem.

As to governance, smart contracts and DAOs make native digital collaboration possible, using decentralized platforms and without the need for intermediaries. At the same time, more and more governments implement blockchain-based projects to ensure transparency and data immutability.

However, cryptocurrencies have a significant environmental impact, due to their energy-intense processes and the amount of e-waste generated mainly by the use of Proof-of-Work (PoW) as a consensus mechanism. It should be noted that, as shown by Ethereum's migration from PoW to PoS, there are more efficient and less polluting alternatives available.

Many questions remain unanswered regarding blockchain's present and future:

- How will consensus mechanisms evolve and what will that mean for their security and/or efficiency?
- Will other blockchain products and use cases be developed and adopted widely, besides cryptocurrencies?
- How will this technology be deployed at-large for greater transparency and coordination in sustainability-related projects?
- What will the communication and exchange of information and values be like on a global level?
- Will decision-making within organizations and transactions between individuals and organizations evolve?

Despite these questions and others that may arise, there is no doubt that blockchain is a technology that will have a profound effect on the digital world, and therefore, on our analog reality.