UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI "M.FANNO"

CORSO DI LAUREA MAGISTRALE IN ENTREPRENEURSHIP AND INNOVATION

TESI DI LAUREA

"THE SUSTAINABILITY OF BLOCKCHAIN"

RELATORE:

CH.MA PROF.SSA SILVIA RITA SEDITA

LAUREANDO:YAGIZ CAFER CAKMAK

MATRICOLA N.: 2004966

ANNO ACCADEMICO 2021 – 2022

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Table of Contents

List of Figures

List of Tables

Abstract

Blockchain technology is considered one of the most fascinating technologies in the last 20 years. Blockchain system needs improvements due to their problems as all technologies are needed in their lifetime. The major problems are the energy consumption level and CO_2 emissions are released into the environment through mining activities. This thesis will discuss these issues and possible solutions about how to improve blockchain technology as being environmentally friendly.

Keywords: Blockchain, sustainability, Bitcoin, cryptocurrency, energy consumption, CO_2 emission

Acknowledgments

First of all, I would like to express my gratitude to Prof. Silvia Rita Sedita for both accepting me for this thesis and also showing me the correct ways of writing.

Secondly, I want to thank my family for giving me this master's degree opportunity and for supporting me when I feel sad. I also want to mention in the family part my cousin but actually a sister, Muge, my aunt but actually half mother, Sevim, and my grandma, Hadiye, who passed away when I was in Italy. You all helped me to be this Yagiz and I will always be grateful for what you have done for me.

Lastly but the biggest shoutout to everyone, except covid-19, who helped me in various ways during these two years in Padova either my great friends from Turkey that have been in my life for more than 10 years or the great people that I met in Italy that are from many different countries. I will always remember my time in Padova as a chapter in my life that even in the saddest times, great people will still be there for you. I want to take this 2 year of journey, not just as an education, but the connections I made with a lot of people that will last more than these 2 short years.

Introduction

The thesis focuses on the key aspects of the blockchain technology, sustainability and how the concept of "sustainability" evolved, the relationship between sustainability and the blockchain technology, the blockchain technology's criticized points, cryptocurrencies with how they evolve into green cryptocurrencies. Finally, it envisions some possible sustainable trajectories for cryptocurrency development.

The blockchain technology is a relatively new addition to Industry 4.0. Even though blockchain technology has been around in technology life for years, with the invention of Bitcoin, the technology gained a phenomenal adoption rate and recognition from different communities. Nowadays, it is comparable to the internet, and some activists in blockchain technology claim that it may even pass the adoption rate of the internet.

Sustainability has been a used term for centuries but in the last 50 years, it gained worldwide attention due to many climate disasters such as starting of global warming, the discovery of the Ozone layer, and so on. Many organizations started to do something to make the world a more liveable place for the current generation and the next generation. There have been many agreements such as the Paris Agreement, Kyoto Protocol, and goals like Millennium Development Goals (MDG) or Sustainable Development Goals (SDG) published. There are many people and organizations who say that in order to make the world nicer, every resource has to be used. One of these resources is blockchain technology. Even though blockchain technology can contribute to these goals, as in all technologies, blockchain has problems too. The most criticized things are the unsustainable algorithms and the use of coal, and natural gas to supply the energy consumption of mining activities in the blockchain system.

From one point of view, there are many unsustainable cryptocurrencies in the blockchain system but aside from these cryptocurrencies, there is a rise of green cryptocurrencies whose goal is to be sustainable. To compete better with these green cryptocurrencies, the second biggest player in the year 2022, Ethereum is planning to switch to a more sustainable consensus model.

In the conclusion, possible roadmaps that the blockchain industry could implement are illustrated. These possible roadmaps split into 4 dimensions; choosing less consumption consensus models, using renewable energy, pre-mining and carbon credits. In the next years, with the improvement of technology, these suggestions can be improved or will be added new ideas as well.

This master's thesis has aimed to contribute to the existing literature by setting three primary research objectives, which are the following:

- How can one technological invention reduce the environmental impact by applying principles of sustainability?
- What are the blockchain technology's potentials and how can it solve the major environmental problems such as increasing CO_2 emission levels?
- How can the blockchain technology evolve into a sustainable technology?

The literature review method has been used in the thesis. The keywords used while searching are the combinations of "Blockchain", "Sustainable", "Cryptocurrency", "Bitcoin", "Ethereum", "Energy consumption", "CO_2 emission", and "Green cryptocurrency". These mentioned keywords are matched within others in the Google system specifically Google Scholar. The dates of articles that are searched vary from 1969 to 2022 but especially the latest articles have been considered rather more valid because of the discovery of new ways within the blockchain in the recent years.

Chapter 1: Introduction to Blockchain

1. What is Blockchain?

The blockchain may be viewed as a shared database filled with validated, encrypted records that cannot be easily changed. The most straightforward analogy is with an accounting record book. Each "block" is merely a "line item" in the common record book. A fresh line item is introduced to the book for each new block added to the chain. Not just financial transactions, but any type of information can be included in the book.

The transaction data must be validated by various computers that have a replica of the recorded history before a line item may be recorded in the record book. Before consenting (or rejecting) on acceptance to add the line item to the record book, the computers ensure that each aspect of the transaction is allowed and legal. It is not possible to modify the record after it has been submitted. The line item must be identical in each copy of the record book. Because of this verification procedure, the blockchain's record cannot be changed. Any action to edit a record will be refused since the whole system has evidence that the input is incorrect (Hibbard, 2018).

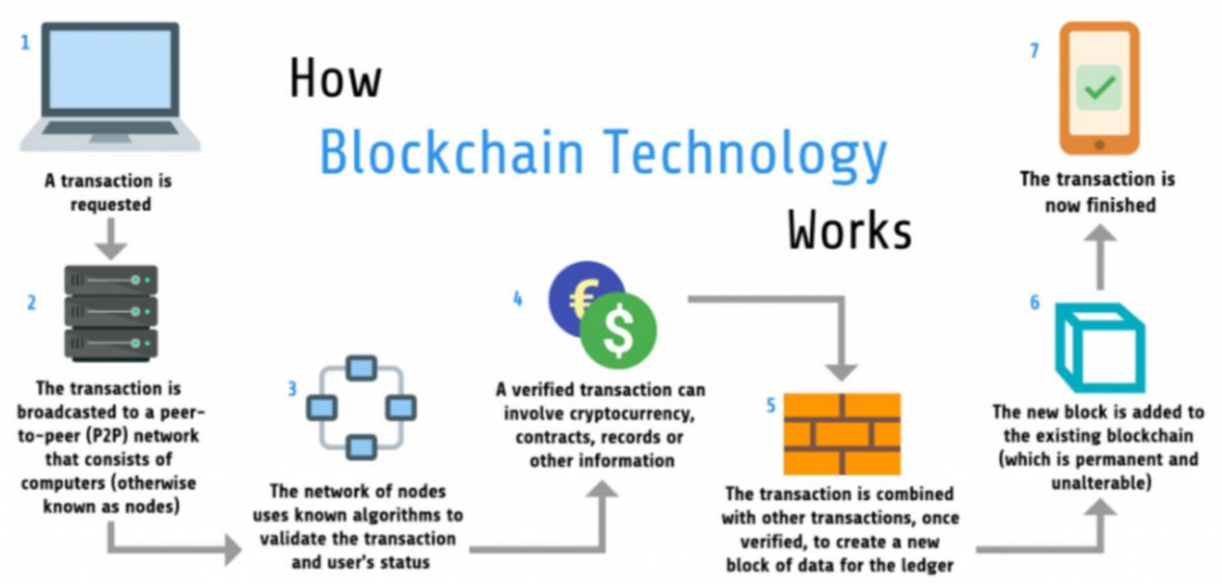
One of the most used terms in the blockchain system is called cryptocurrencies or in other words digital currencies. Cryptocurrencies are virtual valuables, that are a sort of digital money, that enables users to make payments to one another directly through a network. Cryptocurrencies have no fundamental or legal value; they are just worth what individuals are willing to pay for them in the market. In contrast, monetary systems get a portion of their worth from being designated as legal tender. There are numerous different types of cryptocurrencies, the most well-known of which is the Bitcoin and Ethereum (Reserve Bank of Australia, 2022).

There are also stable coins individuals cannot decide on. Each stable coin in distribution is supported by the $1 equal to its related reserve, which might be a US dollar or some other commodity. This makes the stable coin more or less $1 (Melinek, 2022).

Even though the prices are settled by users, the volatility of the cryptocurrency prices is too high, and it depends too much on many factors such as speculations, whales (users invested a lot in that specific currency for example, for bitcoin whales should hold at least 1000 bitcoin to be considered as a whale), and so on. In 2017 a Bitcoin whale single-handedly hit the all-time high of 20.000$ then dropped to 12.000$ (Gupta, 2022) losing 84% of its value at that time. Because of the extreme volatility, many more crashes happened such as March 2020 losing 50%, May 2021 losing 53%, etc (Lisa, 2021).

Figure 1 shows how transactions in the blockchain system work with the help of virtual currencies. In this process, cryptocurrencies such as Bitcoin, Ethereum, and many others are used to transfer from one side to another. Unlike other financial systems, the blockchain system does not require the approval of a central authority. Within the system, blocks validate each other and create trust.

Figure 1: How Blockchain Technology Works



Source: IP Specialist (2019)

The transactions can be done easily with a QR code within a trading platform for the blockchain system. On the left side of Figure 2, there is $1.6 Billion in gold and on the left side, there is just a QR code containing the same amount in Bitcoin. With just one QR code, one can send an enormous amount of money within minutes.

Figure 2: $1.6 Billion in gold vs $1.6 Billion in Bitcoin

Source: Spookiestevie (2020)

Although Blockchain is considerably new, according to Sarmah (2018), the base article of current blockchain technology is the paper titled "New Directions in Cryptography", published in 1976 by two pioneers in cryptographers (Diffie & Hellman, 1976). The authors described the best-known problems like privacy, security, cost, and delay in cryptography. Another article titled "How to time-stamp a digital document", published in 1990, brought a solution called "Time-stamp" to double-spending and making the same transactions multiple times also certifying the owner's document with date and time (Haber & Stornetta, 1990). Many papers contributed to the development of blockchain but an author or a group of authors called Satoshi Nakamoto, whose identity has not been disclosed, is known as the official founder of the blockchain. He has been recognized as the founder of Bitcoin, the leading currency based on blockchain technology, which was launched in 2008 with the paper titled "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008). Bitcoin is the first successful decentralized cryptocurrency-based blockchain technology. After the global success of Bitcoin, in February 2022, there are more than 10 thousand cryptocurrencies. The growth rate of new currencies is remarkable; last year, in February 2021, there were approximately 4500 cryptocurrencies (De Best, 2022).

There were many alternative electronic cash projects such as ecash and NetCash but none of them are comparable to Bitcoin's worldwide success (Yaga et al., 2019). The global market cap in March 2022 was $1.86T and Bitcoin's market cap was approximately $835 billion which represents around half of the total market cap. [1] To compare with other markets, Silver's market cap was $1.4 trillion, Amazon's and Google's market cap were around $1.7 trillion, and Gold's market cap was around $12.3T. [2] Compared to other markets and firms, although blockchain is still new, blockchain competes with decades of businesses or investment tools.

Bitcoin, the most successful cryptocurrency in the blockchain system, is a decentralized online payment system from one user to another without the need for the approval from a third party. After the transactions are made, transactions are tamper-proof so they cannot be changed. To avoid double-spending, the transaction date and time are recorded (this process is called timestamp), like at a notary's office, and shared with the system, where it can be accessible by everyone. Although the transactions will be available to everyone, the identities of the sender or the receiver are anonymous. The transaction chain is built with blocks that are equal to each other, and they are mined by miners who are solving puzzles to create a block. Miners, whose

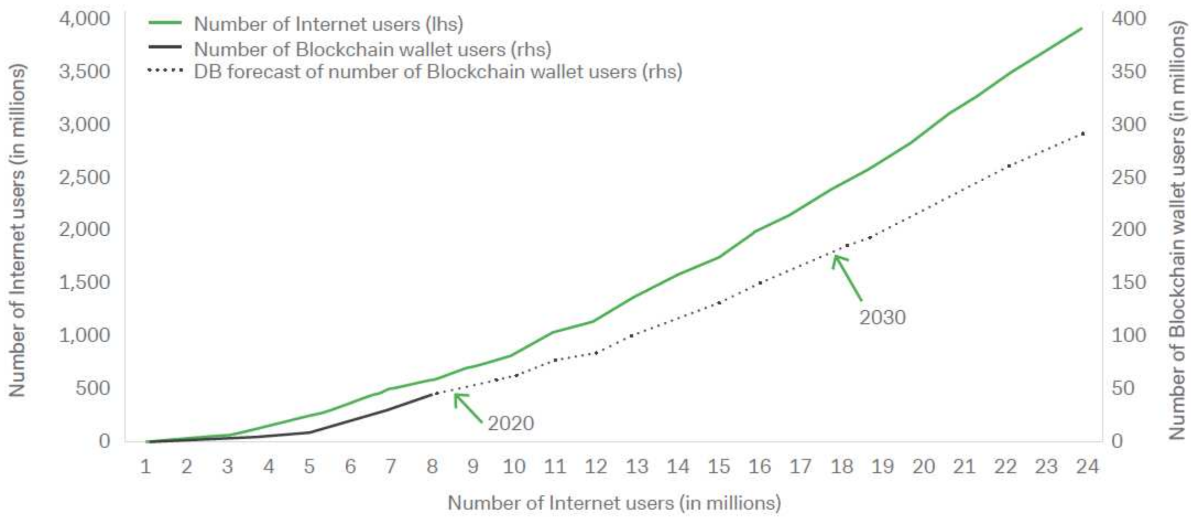
[1] coinmarketcap.com/charts/

[2] companiesmarketcap.com/gold/marketcap/

blocks are used, will get transaction fees from every transaction as an incentive to continue mining activity (Nakamoto, 2008). In the circulation, there are 21 million blocks, [3] and around every 4 years, or when 210,000 blocks are mined, block rewards will decrease to half and the final block will be mined in the 2140s (Conway, 2021).

One of the pioneer markets in cryptocurrency trading platform Binance's CEO Changpeng Zhao or known as CZ believes that in the following years, cryptocurrency user numbers will surpass the number of internet users one day (Brown, 2021). This is still speculation but a forecast from Deutsche Bank is also supporting the rise of the blockchain era (Figure 3).

Figure 3: Adoption rates of cryptocurrencies and the Internet



Source: Laboure & Reid (2020)

Figure 3 shows the rates of adoption of the internet and the blockchain until 2020. They look very similar to each other. After 2020, many companies adopted the blockchain. Many users entered because of the popularity and many laws published to regulate the market. Even now, it is still highly unknown or untrusted by so many firms, governments, and individuals. If regulations and a more transparent process will be in place, the rate of adoption will increase, together with the trust from many stakeholders.

[3] coinmarketcap.com/halving/bitcoin/

2. Blockchain types

One of the things that separate blockchain from the traditional banking system is that the blockchain system has open access to everyone. Later, some blockchain systems wanted to build a close source system. In that sense, a permission system has been built within the blockchain system. Some systems granted open access to their platform which means they are permissionless; some others granted permission only to those who wanted to join their platform. Based on the types of permission, blockchain can be divided into three main types groups (Table 1): public, private, and consortium (Mougayar, 2016).

A public blockchain system has no single owner, everyone can make transactions and also be in the consensus process. Since it is available for everyone to mine and publish blocks, some users may have harmful attitudes. The security of the system is done by consensus models. The most common examples of these security systems are proof of work (PoW), and proof of stake (PoS). Public blockchains are known as decentralized systems. Bitcoin and Ethereum are the best examples of public blockchain structures (Buterin, 2015). Public blockchains are also called permissionless since there is no authority to ask permission when joining or leaving (CAICT, 2018).

A private blockchain system is controlled and restricted by one centralized group. Transactions are shared by a certain amount of people within the knowledge of this privileged group. Consensus models and mining generally are not necessary since one firm or group controls block creation. A private blockchain structure is also called permissioned because of the centralization (Zheng et al., 2017).

Consortium blockchain systems are partially centralized systems. The system is controlled by some groups but the difference between private blockchain systems is that the privileged group may open permission to some groups or everyone. The consortium blockchain system is also called permissioned because even though the information is shared with people, it is still controlled by a group of people who can permit selected users or more (Sultan et al., 2018).

Table 1: Comparison of Blockchain types;

Property	**Public blockchain**	**Consortium blockchain**	**Private blockchain**
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Public or restricted	Public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

Source: Zheng et al. (2017)

3. Characteristics of Blockchain

Even though the blockchain system is highly associated with Bitcoin, blockchain is much more than that. Many factors can help to identify blockchain technology. There are 6 key aspects of the blockchain system, which will be described in the following.

3.1 Decentralization

Decentralization is not a novel concept. When putting together a technical setup, three basic network architectures are typically considered: centralized, decentralized, and dispersed. Even though the first blockchain applications are designed as decentralized, not all applications in the blockchain system can be considered decentralized. Every system has advantages and disadvantages.

Advantages of decentralization; decentralization can provide the same record to everyone in a trustless environment and that will elevate the platform while everyone is checking each other, with a decentralized information repository, each stakeholder has a current and shared perception of the data, decentralization can help to reduce levels of insufficiency in systems that rely too heavily on explicit employees, decentralization may also assist to simplify the transfer of assets, ensuring that assured services are delivered with greater efficiency and accuracy, as well as a lower risk of major disappointment (Bhalla, 2021).

About the disadvantages of decentralization, the anonymity of decentralization in the blockchain system became very popular among lawbreakers. One example is a virtual black market called "Silk Road" which operates mainly on Bitcoin. These illegal activities are one of the most criticized things in the blockchain system. These illegal activities are not just operating in the blockchain system, but also in the monetary system as well. Another disadvantage is volatility. Many virtual currencies that rely on decentralized blockchains are exceedingly unpredictable. Bitcoin prices, for example, may swing by 20% or more in one day. The major reason for such tremendous volatility in cryptocurrencies is that they are so young. This implies that states, traders, corporations, as well as other groups of individuals are debating whether to implement them, which may lead to severe instability.[4]

3.2 Immutability

When a transaction happens, it cannot be modified and the transactions are irreversible. Security will be created with the timestamp by acknowledging when the first block is added and it will be available to the public (Sultan et al., 2018).

As in every characteristic, immutability has disadvantages too. Although non-edible history sounds like a good idea if there is some key information for the company published, to be able to not change it might damage the company. There are ways to edit or delete the transaction such as forking, where a transaction chain divides into two ways and parties continue with an edited road, but parties must be convinced in this sense. If this is a private blockchain, it is easier to convince but if this is a public blockchain then it is quite impossible to remove the information (Doubleday, 2018).

3.3 Anonymity

The blockchain system shares every transaction to a public database so everyone can see the history of the transactions excluding the identities of the sender and receiver. The database will only acknowledge the nodes that are connected within the chain. In the database, one can only see the quantity, the price, and the randomly generated address of both parties.

A disadvantage of anonymity is that criminal activities may occur due to anonymous transfers. The truth is that even though the transfers are anonymous and difficult to track, it is not impossible to find the user such as tracking IP address (Lee et al., 2016).

3.4 Consensus driven

A centralized admin has the power to manage and improve any centralized system, such as a database containing critical information on driving licenses in a state. The

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[4] worldcryptoindex.com/advantages-disadvantages-decentralized-blockchains/

responsibility of implementing any adjustments, such as adding/deleting/updating identities of those who qualified for various permits, is undertaken by a central body, which continues solely responsible for keeping legitimate data.

Public blockchains that function as decentralized, self-regulating networks function on a global basis with no authority. They entail inputs from large numbers of contributors who operate on the validation and verification of blockchain transactions as well as block mining operations (Frankenfield, 2021).

3.5 Audibility

Time-stamp and traceability of the transactions through the nodes help to validate the transaction. Depending on the blockchain structure, audibility is different. The least audible blockchain type is private blockchain because only one group has the right to give permission. The highest audible structure is public blockchains because of high decentralization (Viriyasitavat & Hoonsopon, 2019).

3.6 Transparency

Due to the blockchain system's decentralized character, all activities may be publicly watched by owning a personal node or utilizing blockchain scanners, which let anybody to witness transactions taking place in real-time. Every node maintains its own replica of the transaction chain, which is refreshed as new blocks are validated and uploaded. This ensures that you could follow a virtual currency anywhere it went if you wanted to.

Marketplaces, for instance, have been attacked in the past, and customers who stored Bitcoin on the platform ended up losing all. Whereas the intruder may be completely anonymous, the Bitcoins they obtained are easy to trace. It would be revealed if the Bitcoins taken in these attacks were relocated or placed someplace (Hayes, 2022).

4. Tiers of Blockchain

The blockchain revolution started as a rebellion against the traditional system including banks and central organizations on the internet as Bitcoin. The core of blockchain is about being decentralized but some users can affect the volatility like in May 2021 and many other downfalls (Bovaird, 2021). Besides high volatility and many possible negative things, the remarkable thing about the blockchain system is that it is an improvable system, and the goal is looking limitless because it can influence and change many sectors such as finance, supply chain, healthcare, etc (Intelligence, 2022). With the improvement of blockchain, it may be the next disruptive technology after the internet, PC, mobile phones and so on. As blockchain improves, so do the benefits to gain from it.

According to Swan (2015), the evolution of blockchain is divided into 3 categories based on its applications (Table 2). Blockchain 1.0, Blockchain 2.0, and Blockchain 3.0. Blockchain 1.0 started with Bitcoin in 2008 and matured in a few years to Blockchain 2.0 (Zhao et al., 2016). Blockchain 1.0 was about cryptocurrencies such as Bitcoin which was the pioneer in Blockchain 1.0 and the most successful one out of all (Mainelli & Smith, 2015). Virtual currencies can decrease many of the expenses that non-virtual currencies have such as circulation costs. Besides the costs of these traditional systems, blockchain payment systems are more efficient compared to traditional ones. A transfer from one bank to another bank could take days on the weekends but with blockchain systems, day or night it will be transferred within an hour. In the Blockchain 1.0 era, it was about virtual currencies, ecosystems of these currencies that can allow the transactions on and the payment systems. One of the concerns in this era was about illegal activities such as money laundering that can give a negative opinion about blockchain systems in society. To avoid this, even though the transactions are done and shown as just in numbers, cryptocurrencies can be traceable to their source (Xu et al., 2019).

Blockchain 1.0 was about decentralizing the payment system but Blockchain 2.0 is decentralizing the trading markets where it is not just about cryptocurrencies. Blockchain 2.0 was about Dapps (Decentralized apps), DAOs (Decentralized autonomous organizations), DACs (decentralized autonomous corporations), smart contracts, and smart properties (Swan, 2015). Blockchain 2.0 started to develop after 2013 and is still in the developing phase even to this day. One of the pioneer cryptocurrencies in Blockchain 2.0 is Ethereum with Smart Contract implementation (Jackson, 2021). Smart contracts can support many things for example; the data protection need of the finance sector, lowering the risks and costs, having better accuracy in predictions, and so on (Chu et al., 2016).

Blockchain 3.0 is an advanced form of Blockchain 2.0 that was designed to increase the technology's features and fix current issues while allowing faster, more cost-effective, and more effective transactions. DAG (Directed Acyclic Graph) is one of the features that distinguishes and makes Blockchain 3.0 feasible. The data cannot be returned to the sender, and it will make the transactions faster which are 10 minutes in Bitcoin and 20 seconds for Ethereum (Joshi, 2021).

Blockchain 3.0 goals are to increase the popularity of technology, especially the usage of blockchain systems in sectors different than finance such as in government (Crosby et al. 2016). The main challenge of blockchain is to have a system for reliable and efficient information while keeping all the characteristics of being decentralized, immutability, and so on (Cheng et al., 2021). Although there is no actual date about when Blockchain 3.0 started, many articles guess the year by observing the cryptocurrencies that are considered in Blockchain 3.0. It is assumed that around 2017 with Cardano, Eos and so on, Blockchain 3.0 started (Viktor, 2020).

A message from Satoshi Nakamoto in 2010 shows that Nakamoto planned the blockchains' steps from the start;

"The design supports a tremendous variety of possible transaction types that I designed years ago. Escrow transactions, bonded contracts, third-party arbitration, multiparty signature, etc. If Bitcoin catches on in a big way, these are things we'll want to explore in the future, but they all had to be designed at the beginning to make sure they would be possible later." (Satoshi, 2010).

Table 2: Comparison of Blockchain tiers

	Blockchain 1.0	Blockchain 2.0	Blockchain 3.0
Principle	Virtual currencies	Decentralization of the markets and smart contacts	Application of blockchain to areas other than finance.
Dates	2008	2013	2017
Application	Finance sector	Finance sector	All sectors
Example	Bitcoin	Ethereum	Cardano
Problems	Illegal activities	Scalability and efficiency	Sectoral problems, building infrastructure

Source: Elaboration from Swan (2015), Zhao et al. (2016), Jackson (2021), Joshi (2021), Crosby et al. (2016), Cheng et al. (2021), Viktor (2020)

5. Mining

Mining is the first stage of Bitcoin and several cryptocurrencies to make new coins for circulation and validate new transactions. A blockchain system is formed by blocks validated by other blocks and a transaction chain is formed. In every block that is validated, miners will receive transaction fees as an incentive to keep mining. Miners solve difficult crypto puzzles to get a block. The quickest way to do them is to guess solutions randomly, the reward will belong proportionally to guesses which are hash rate (Narayanan et al. 2016). Since there are 21 million in total, miners will need more and more incentives such as increasing transaction fees because, on the other hand, the mining process keeps getting more and more expensive with needing more electricity and more equipment (Farell, 2015). To mine blocks, one can need strong equipment for their computer and internet because as the years' pass, the mining process becomes harder.

In the first years of bitcoin mining, one can need a normal computer and could mine a lot of bitcoins but in the last years, energy consumption increased a lot. To give an example; In October 2019, it required 12 trillion times more computing power to mine one bitcoin than it did when the first blocks were mined in January 2009. [5] Because of the increased intensity of mining procedures, miners either try to cheapen their costs or collaborate with other miners to create or join a "Mining Pool". Individual miners join mining pools to combine their resources with other miners and receive more regular payments. Earnings for completing blocks are distributed based on the amount of computing power donated to the pool. [6]

Halving dates are very important for mining pools to track their rewards. Halving is the process of halving the number of tokens or currencies that a miner earns for introducing a new block to the blockchain every four years. While many cryptocurrencies endure a halving, some do not have a halving. Nevertheless, the Bitcoin halving has received the greatest attention in the media. In 2009, the reward was 50, in 2012 decreased to 25, in 2016 12.5, in 2020 6.25, and as predicted in 2024 it will be 3.125 per bitcoin. With decreasing rewards, mining pools are forced to stick together in order to get maximum rewards (Crypto Answers, 2021)

For personalized miners (Arnosti & Weinberg, 2022), there are several ways to reduce the costs such as cheapening the electricity, getting new hardware, especially those designed to solve crypto puzzles such as ASICs (Application-Specific Integrated Circuits) use a thousand times less energy per guess, cooling systems or locations such as Iceland (Mallonee, 2019).

Miners are in a race to reduce costs so they can stay profitable, but it is unlikely to happen due to the centralized mining process. The centralized mining process and increasing the costs are pushing away personalized miners to group as Mining pools. One of the issues is that the hardware that miners use is distributed by large firms (Hileman & Rauchs, 2017). The second problem is highly centralized production by Bitmain which owns 75% of the production of all the market for mining equipment. Bitmain also uses its equipment to compete with other miners. Bitmain earned 53 million $ in 2016 and 199 million $ in 2017. [7] They were supporting AntPool

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[5] coinbase.com/learn/crypto-basics/what-is-mining

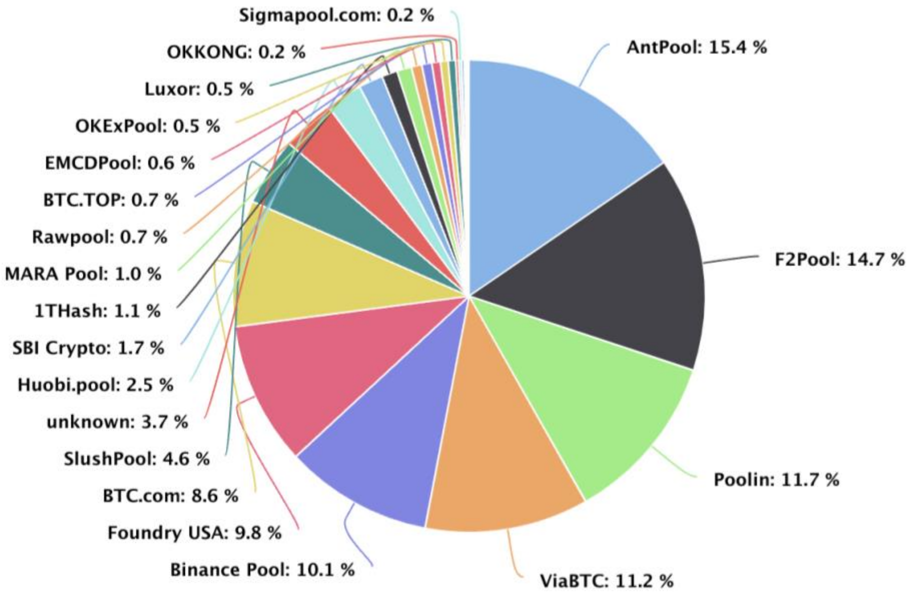
[6] bitpanda.com/academy/en/lessons/what-is-the-purpose-of-mining-pools-and-how-do-they-work/

[7] enterprise.press/wp-content/uploads/2018/09/BitmainProspectus.pdf

which is one of the biggest mining pools in China and the world until China banned mining (Le, 2021). These centralized attempts led individual miners to gather in Mining pools.

Figure 4 shows the mining pools' distributions by their hash rate shares starting from 2021 to 2022. Even though China banned mining and cryptocurrencies in 2021 (Quiroz-Gutierrez, 2022), the biggest mining pools are still located and operating even to this day in China. The biggest 4 mining pools (AntPool, F2Pool, Poolin, and ViaBTC) are located in China. In total, out of all hash rates generated in 1 year between 2021 and 2022, China has more than 61%, USA and Malta, on the other hand, have around 10% each, the Czech Republic has around 4.5% and Japan has 1.7%. In this one year also 3.7% are unknown which means they are either individuals who mine or mining pools that do not want to show their location for instance legal reasons however using VPN or TOR to hide their locations will decrease their network connection (Stoll et al., 2019).

Figure 4: Mining pool distribution between companies



Source: btc.com/stats/pool?pool_mode=year

The biggest problem with mining is energy consumption. Ethereum and Bitcoin mining alone represents more than 78 million tons of CO2, it is equal to more than 15.5 million cars (Knutson, 2022) or a combination of Israel and Croatia's CO2 in 2020 (Ritchie et al., 2020). The problem of energy consumption will be shown in more detail in the next chapter.

6. Consensus Models

Consensus mechanisms are methods for ensuring collective consent on a data set and the current condition of all data. When used in the class, a consensus system would allow each pupil to present identical tests.

Consensus mechanisms in blockchains guarantee that each player in the network has a replica of the same ledger and, as predicted, various consensus processes have differing effects on the security and the economic structure of the overarching cryptographic system (code of conduct) (Daily Bit,2018).

One of the main purposes of blockchain technology is to decide which miner publishes the following block. To decide who will publish the next block, there are many consensus models such as PoW, PoS, etc (Yaga et al., 2019). Out of all blockchain applications, the PoW model stands for almost 60% (Andoni et al., 2019).

6.1 Proof of Work (PoW)

Nakatomo designed Bitcoin with the PoW model by improving the concept of the Hashcash model from Adam Back (Nakamoto, 2008). Hashcash was designed to prevent spam mails (Back, 2002). Miners challenge other miners by solving a crypto puzzle of creating a hash number with a lot of zeros to publish the following block in the current blockchain system. This number is unique for that particular hash and can be only used once for the block which then measures the hash output of the block header. The block header has all the information from the last block that was added. Miner's mission is to get a lower hash outcome than the particular target. Miners cannot intervene to determine the outcome so they have to try a lot to predict the correct number. With more 0's the procedure is even more difficult which will consume more power as well. When miners find the correct one, the block goes back and gets validated by the past blocks. If it is verified, the miner or miners will get rewarded proportionally (Andoni et al., 2019).

Since the creation of hash numbers are random, the parallel lines (multiple transaction chains) may happen by many miners. If this happens, the system will keep all the chains. All chains will be abandoned except the longest chain because the longest chain has the majority so the most valid one. Malicious attacks can be done by 51% to control the rest of the network, 51% can intervene the new transactions from being accepted or they can reverse their transactions and lead to double spending (Muftic et al., 2016).

PoW has shown that it can handle many users, but it may not be applicable for some cases (Pilkington, 2016). Although blockchain developers are improving, speed and scalability are still the main issues. While Bitcoin operates 4.6 transactions per second, Visa operates 1700 on average (L, 2019)

The main critique of PoW is that the energy consumption is immense. PoW mining can consume a similar consumption level as Denmark by 2020 (Deetman, 2016). To solve this, alternative consensus models have been offered such as PoS. Even some currencies like Ethereum are shifting away from Pow to PoS just because of this high energy consumption (Ethereum, 2022).

6.2 Proof of Stake (PoS)

The PoW consensus model has some disadvantages. In order to resolve the problems connected to the PoW, the PoS model has been developed. PoS started in 2012 with Peercoin, the model inspired by Bitcoin's PoW model (King & Nadal, 2012). After this, many currencies started using this system.

The PoS model is based on the user. User gives their tokens as much as they want for staking to be accepted in the process. The more user bets, the more percentage of control the user has for the following block. Blocks generate themselves so there is no need for a miner or nodes do not challenge each other for crypto puzzles. For these reasons, the PoS model uses less energy than the PoW model (Lepore et al., 2020).

6.3 Practical Byzantine Fault Tolerance (PBFT)

In game theory, there is a problem called The Byzantine General problem, a crisis of decentralized units arriving at a consensus without a help of a trusted pivotal unit. The game theory asks in a decentralized network where nobody knows each other, how can this decentralized unit agree in trusting a central unit as a group. If all generals in an army or nodes in the blockchain, as a group wants to attack, if they start the siege at the same time, they will win because everyone will attack. If they attack at different times, they will be defeated. The problem is how they will organize when to attack because byzantine defense may intervene in the communication or send false information. [8]

In PBFT, all nodes are in the voting procedure to add the following block, but 2/3 of all nodes have to be agreed upon for a block to be added. With 1/3 the model can withstand. In this system, decisions are faster and more economic than in the PoW model. The model does not need a stake in the process unlike the PoS model (Salimitari & Chatterjee, 2018a).

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[8] river.com/learn/what-is-the-byzantine-generals-problem/

6.4 Delegated Proof of Stake (DPoS)

DPoS is a more advanced vote-based model of the PoS model. To verify the blocks, with voting, stakeholders choose some nodes as representatives (Bashir,2017). To join for voting, one must stake their coins and if one wants more votes then they have to stake more coins. While voting, coins are locked in smart contacts. During voting if there are fewer representatives, the process would be more efficient on the other hand, fewer representatives would make the system more centralized (Do et al., 2019). DPoS system is also energy efficient such as the PoS model (Oyinloye et al., 2021).

6.5 Federated Byzantine Agreement (FBA)

The present financial system is a jumble of closed systems. Because of the gaps between these systems, transaction costs are enormous and money travels poorly across political and geographical territorial borders. This conflict has hampered the expansion of financial services, leaving vast numbers of people financially mistreated. To address these issues, a financial infrastructure that allows for the type of organic development and innovation witnessed on the Internet while also preserving the integrity of financial activities is needed. Historically, we depended on strong entrance barriers to maintain integrity. There is a strong faith in proven financial institutions and work hard to regulate them. However, this exclusivity contradicts the purpose of organic growth. Growth necessitates new, innovative players, who may have limited financial and computing capabilities. Anyone should be able to join the global financial network, allowing new organizations to join and provide financial access to underserved populations. The problem for such a network is ensuring that participants accurately record transactions. Users will not trust suppliers to police themselves if the barrier to entry is low. With global reach, providers will not all rely on a single company to run the network. A decentralized system in which users jointly maintain the integrity by agreeing on the authenticity of one another's transactions is a tempting option. Such accord is dependent on a system for global consensus.

The FBA consensus model was introduced by Stellar Development Foundation in 2015 to solve these issues. In FBA, each member is aware of people who are significant to them. It waits for the great majority of those parties to agree on any transaction before declaring it finalized. Those significant players, in turn, do not consent to the transaction until their trusted individuals agree. When enough of the network approves a transaction, it cannot be reversed. Only then are any participants willing to consider the deal completed. The consensus of the FBA can safeguard the integrity of a financial network. Its decentralized management might promote organic growth (Mazières, 2015).

The difference between FBA from other consensus models is that it is built around a trust system. Nodes should have mutual agreements while communicating with one another. In the model, nodes choose which other nodes should trust to build their quorum slice. Although some scholars say this will generate a decentralization system but others claim that the trust could be manipulated and it may form a centralized system. (Thanujan et al., 2021)

6.6 Proof of Authority (PoAu)

The model does not support the nodes that should be completely published. It effectively works on nodes that have a known relationship to real-world data. In this system, published blocks must demonstrate their identity and be verified in the blockchain network. Essentially, the publishing nodes are risking their identity and reputation as publishing nodes on the line. The reputation of a publishing node is closely related to its conduct. Any malicious conduct by publishing a node might harm the node's reputation in the Blockchain network. If a node behaves in a way that Blockchain users approve of, its reputation will rise. Nodes with lower reputations are much less likely to be offered the opportunity to publish a new block. As a result, maintaining a good reputation is critical for publishing nodes. This paradigm is favored in permissioned blockchain because it necessitates a high level of confidence on the part of the nodes. (Khan et al., 2020).

6.7 Proof of Elapsed Time (PoET)

PoET was proposed by Intel in 2016 and it is similar to the PoW model but with considerably lower energy consumption. It enables a node to rest and transition to other duties for a set amount of time, enhancing network resource efficiency.

Proof of Elapsed time (PoET) is a consensus model that avoids excessive resource usage and power consumption by using a random node selecting mechanism. On a blockchain platform, the algorithm determines mining privileges and block winners based on a completely random elapsed time. The PoET method improves transparency by guaranteeing random outcomes are provable by exterior players by executing a recognized code within a safe environment (Frankenfield, 2022).

6.8 Proof of Activity (PoAc)

PoAc is the result of combining PoW and PoS. Mining begins immediately in PoAc, as it does in PoW. The main difference is that only block templates are mined instead of mining the entire block. Templates include header information as well as the miner's IP. The platform has now been changed to PoS after mining. To sign a new block, a set of validators is chosen.

The validator with the most coins is selected. If this procedure fails at any point, a new set of validators is allocated, and the cycle is repeated until an exact number of signatures is obtained (Sharma & Jain, 2019).

6.9 Proof of Burn (PoB)

In a blockchain network, PoB is an alternate mechanism for achieving a consensus. The notion is that miners should not squander energy or time proving that they have accomplished something tough. Miners must burn part of their previously acquired cryptocurrency to receive rewards under this method. To get money, tokens, or mining rights on the network, a user must first pay some cryptocurrency to an "eater address." Money sent to an eater address is irreversible, and no one can use it again, therefore it is referred to as burnt money and is no longer in existence. Burning coins, like the processes in PoW, is a costly action for the user yet requires no resources or energy. User gives up their potential short-term profit in exchange for a long-term profit and this is the only resource in PoB.

As previously stated, eater addresses are produced at random and are not connected with any private key. Because there is no relationship with any private key, the money held at an eater address is unreachable and cannot be spent. It should be emphasized that all PoB cryptocurrencies, including bitcoin, need the burning of proof of work mined currency. The more coins a participant burns, the more likely it is that she or he will locate the next block. This is also comparable to PoS, in which the wealthy would most likely get further wealthier.

To highlight its characteristics, it creates greater stability since we know that someone who accepts a short-term loss and spends his money in this manner will stay in the network for a longer time to make a profit. Furthermore, because there is no mechanism for the investors to become centralized, PoB promotes decentralization and the formation of a distributed network. Burning PoW mined coins, on the other hand, is a waste of energy and time. If the value of PoB coins one day exceeds the value of PoW burnt coins, we may conclude that PoB is more energy-efficient than PoW, and the squandered money, energy, and time would be recovered in some way (Bamakan et al., 2020).

6.10 Proof of Capacity (PoC)

Dziembowski et al. (2015) established the notion of Proof of Capacity (PoC), alternatively referred to as Proof of Space (PoSpace). Proof of Capacity is similar to PoW, except instead of relying on the miners' computational power, it depends on the hard drive storage (Salimitari & Chatterjee, 2018b). Burstcoin, which was launched in 2014, was the first cryptocurrency to use this algorithm. The proof-of-concept algorithm involves mapping the hard drive, which entails computing and storing solutions on the hard disk before mining begins. Some answers are more rapid than others. If a hard drive has the quickest (closest) answer to the most recent block's problem, it obtains the block.

This should be emphasized that contrary to bitcoin which requires specific gear like ASICs for PoW and CPUs/GPUs for miners, the only gear used in PoC is any standard Hard disk storage, and thus no one may benefit from special hardware. Furthermore, hard drive usage is reported to produce 30 times less energy consumption than ASIC-based mining, so even using an old hard drive would still be beneficial rather than always upgrading the hardware. Furthermore, because anyone can easily buy a hard disk drive, the decentralization of the network would not change (Bamakan et al., 2020).

Table 3 shows the advantages and disadvantages of each consensus model.

Table 3: Advantages and Disadvantages of each Consensus model

	Advantages	**Disadvantages**
PoW	- Manages decentralization very well. - High dependability.	- Immense amount of energy/ resource consumption. - Limited efficiency. - Can be considered as time-wasting.
PoS	- Somewhat fast. - Lower amount of energy consumption. - Better at efficiency. - Higher amount of input brings higher output.	- Needs higher expenditure. - Less decentralized compared to PoW. - Provide less security than PoW.
PBFT	- Without a need for multiple validations. - Unlike PoW, more energy-efficient due to lack of complex puzzles. - Low transaction costs.	- Huge communication costs. - Due to scalability issues, vulnerable to Sybil attacks which is an individual who generates or manipulates a significant number of nodes.
DPoS	- Little amount of energy consumption. - High speed. - Higher incentives. - Lower hardware costs.	- Individuals who puts higher amount of stakes can dominate the network. - Less resilience as a result of less decentralization.
FBA	- High throughout. - Network scalability. - Low transaction costs.	- Could lead to high level of centralization through trust.

PoAu	- Lower level of energy consumption compared to PoW. - Reputation prevents scams.	- Heavy centralization. - Since ID's are public, it could lead to be manipulated by third parties.
PoET [9]	- Less energy consumption compared to PoW. - Everyone has opportunity because of time objects	- Highly relied on Intel technology. - Not suitable for public blockchain.
PoAc	- Reduces %51 attacks. - Higher efficiency. - A higher level of security. - Lower amount of transaction fees.	- Higher need of resources. - Probability of double sign. - Difficult to accomplish.
PoB	- Less energy consumption compared to PoW. - By burning, the supply will decrease and the value will increase of that currency.	- Burned coins are taken with PoW method so sustainability part is questioning. - The method is acceptable only if the currency has high supply.
PoC	- Rely on the hard disk space. - Decentralization settled by simple devices. - Energy consumption level is so low.	- Prone to harmful acts. - Disk space problem

Source: Elaboration from Bera (2020), Ferrag & Shu (2021), Kaur et al. (2021), Oyinloye et al. (2021), Thanujan et al. (2021), Wang et al. (2020)

7. Forking

Virtual currencies such as Bitcoin and Ethereum are driven by a blockchain, which is a decentralized, open program that anybody can contribute to. Blockchains are, so-called because they are technically composed of blocks of data, like an extremely long railway that can be tracked all the way back to the network's initial transaction. They also depend on their users to continually improve their underlying code because they are publicly available.

A fork occurs when a group modifies the blockchain's system or core set of rules. When this occurs, the chain divides, resulting in a duplicate blockchain that contains all of the original information but is heading in a different direction. [10]

[9] academy.bit2me.com/en/what-is-proof-of-elapsed-time-poet/

[10] coinbase.com/learn/crypto-basics/what-is-a-fork

7.1 Soft Forks

A soft fork supports changing past transactions in the blockchain system. Nodes that have not been updated can keep on operating with nodes that have been updated. If no (or only a few) nodes upgrade, the new rules will be ignored (Yaga et al., 2019).

7.2 Hard Forks

A hard fork is a change to a blockchain implementation that is not backward compatible. At a given point in time (usually at a specific block number), all publishing nodes will need to switch to using the updated protocol. Additionally, all nodes will need to upgrade to the new protocol so that they do not reject the newly formatted blocks. Non-updated nodes cannot continue to transact on the updated blockchain because they are programmed to reject any block that does not follow their version of the block specification.

Non-updating publishing nodes will continue to produce blocks in the old format. User nodes that have not been upgraded will refuse newly formatted blocks and permit solely blocks in the old format. As a result, two copies of the blockchain operate concurrently. It should be noted that users on separate hard fork variants cannot communicate with one another. While the majority of hard forks are purposeful, software faults can result in unintended hard forks (Yaga et al., 2019).

One of the leading currencies Ethereum, which also supports smart contracts, was the biggest thing that happened to them in April 2016. One of the biggest projects of Ethereum called DAO (Distributed Autonomous Organization) within the first month of publication, from around 11,000 investors, got around 150 million $. One month later, on June 17th, the project got hacked. Based on that day’s exchange around 50 million $ as ether was stolen, because of a technicality mistake. Core designers led by Vitalik Buterin, who is the founder of Ethereum, agreed on hacking the hacker. In the end, they intervened and got the money back which they transferred to another smart contract but there was still a question about DAO’s design. Hacker could still reach the funds. One of the concerns was the platform was decentralized and if the developers fix the issue, then the core objective of being decentralized would be broken. Developers decide to intervene at the end with what is referred to as a “fork” which is a format for a decentralized network. The first proposal was “soft fork” due to a security flaw in the votes, they did not move with this option. The second and final option was the “hard fork” where another variation with different rules of the system has to be created. Miners, exchanges, and other apps must decide whether they want to stay in the old one or move to the new one (Wong et al., 2016).

8. Smart Contracts

Szabo, a computer scientist, and cryptographer created the concept of a "smart contract" in the mid-1990s, defining it as "a collection of commitments, expressed in digital form, including mechanisms within which the parties execute on these commitments." (Szabo, 1996). Szabo also predicted that smart contracts will be significantly more useful than their paper-based progenitors because of the logic, validation, and execution of cryptographic protocols. Nevertheless, the concept of smart contracts was never popular until the start of blockchain technology.

Smart contracts, in essence, are computer algorithms that electronically enable, validate, and execute contracts formed amongst multiple parties on blockchain. Because smart contracts are often placed on and protected by blockchain, they have various distinguishing features. First, the smart contract's program code will be stored and confirmed on the blockchain, ensuring the contract is tamper-resistant. Second, smart contract implementation is executed among anonymous, trustless individual nodes without central power or coordination by third-party authorities. Third, like an intelligent agent, a smart contract may have its virtual currency or other virtual currencies that it transfers when present criteria are met (Stark, 2016)

Many cryptocurrencies started to launch their smart contract functionalities such as Ethereum, Solana, Cardano, and so on (Newbery, 2021) These platforms and many more are offering their users to be used in their projects and trade with their tokens as well. Many people believe that smart contracts might replace traditional contracts because of their open nature and the fact that the contract code is known from the start and cannot be modified or altered by harmful parties. Smart contracts are quick, they operate promptly and independently, and no party may affect them.

However, there is some opposition to this belief: rather than reading a contract stated in simple English, the user must now study the code and grasp the programming language. Few individuals have the expertise to do so, and even fewer take the time to read it. As a result, some who oppose smart contracts say that the system is not "trustless" after all; users must still have faith in the creators and the organization. As in every network, there have been some attacks as well such as the famous DAO attack on the Ethereum network (Petersson, 2018)

Chapter 2: The relationship between blockchain and sustainability

1. Historical background of Sustainability

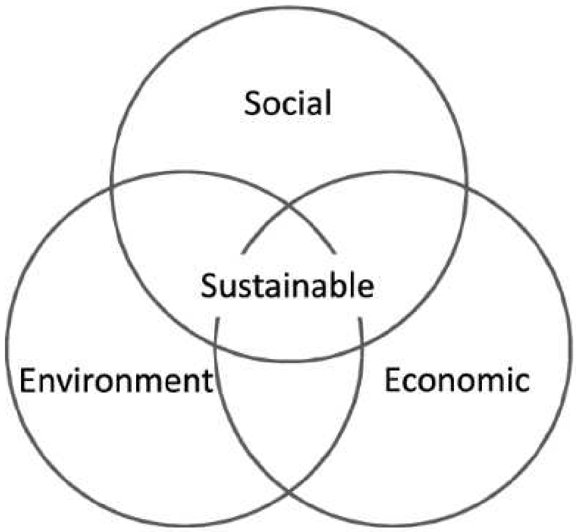
Sustainability as meaning can be traced until the 17th century. In the 17th century, the meaning is used by philosophers such as Descartes and Spinoza but the meaning that we use today was taken from the forestry sector. Wood was an important asset for both heating and building (particularly ships). With the understanding that woods were fast vanishing, individuals throughout Europe understood that they needed to approach this necessity carefully. For example, a study written in 1662 for the Royal Society by John Evelyn, outlined the loss of trees and the methods needed to restore it and was a great achievement (Solnick, 2013).

Almost 50 years later, a German forester Hans Carl von Carlowitz, used the phrase in his 1712 treatise Sylvicultura Oeconomica to describe how woods should be maintained throughout time (Wiersum, 1995). However, it was not until the 1970s that the word gained worldwide popularity. With the rise of modern environmental activism in the late 1960s and early 1970s and arguments about resource constraints, environmentalists were eager to demonstrate how environmental concerns might be related to mainstream development difficulties. In the mid-1980s, the commission, directed by former Norwegian Prime Minister Gro Brundtland, became the main focus of this discussion with a resulting in the seminal report Our Common Future in 1987. This study provided a contemporary concept of sustainability (or sustainable development which meant the same thing). The modern usage of the word got identified with a quote below(Scoones, 2007);

‘*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.’ (WCED 1987a: 43)*

Our Common Future did not only give the definition of sustainability but also defined the three pillars of sustainability. Sustainability is evaluated from three different perspectives: the economy, the environment, and social ecology (UN, 1969) as shown in Figure 5.

Figure 5: Three pillars of Sustainability



Source: Purvis et al. (2018)

In terms of economics, a society that generates revenue by abusing limited resources is unsustainable. Economists, on the other hand, think that any associated difficulties will naturally resolve themselves as we progress along the path of advances in technology.

In terms of the environment, people and nature as distinct entities, with humans acting as stewards. Environmentalists are concerned with maintaining the world, which will allow mankind to exist and evolve.

However, from an ecological standpoint, regarding people as an intrinsic component of the Earth rather than as different from the world and its resources. As a result, ecologists operate on the assumption that if we are to maintain the Earth, we must safeguard both mankind and nature (Sharman, 2021).

Although the meaning of sustainability was identified as we use it today in 1987, the fight to preserve sustainability started earlier. In 1968 there was a meeting in the UN (United Nations) about environmental issues and in 1969, environmental issues were acknowledged by the UN that if humans live like this, the next generations will have problems (United Nations, 1969). UN organized the Stockholm Convention in 1972 and UNEP (United Nations Environment Programme) is founded for preserving sustainability. [11] For the importance of this conference, every year on the 5th of June, we celebrate “World Environment Day”.[12] The following was said in the statement of the United Nations Conference on the Human

[11] unep.org/about-un-environment

[12] worldenvironmentday.global/overview

Environment, held in Stockholm in 1972 as the first of a series of worldwide conferences on the oncoming environmental crisis:

"A point has been reached in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences. Through ignorance or indifference we can do massive and irreversible harm to the earthly environment on which our life and well-being depend. Conversely, through fuller knowledge and wiser action, we can achieve for ourselves and our posterity a better life in an environment more in keeping with human needs and hopes. There are broad vistas for the enhancement of environmental quality and the creation of a good life. What is needed is an enthusiastic but calm state of mind and intense but orderly work, For the purpose of attaining freedom in the world of nature, man must use knowledge to build, in collaboration with nature, a better environment. To defend and improve the human environment for present and future generations has become an imperative goal for mankind-a goal to be pursued together with, and in harmony with, the established and fundamental goals of peace and of worldwide economic and social development." (United Nations, 1972)

These events started a wide recognition of environmental concerns. One of the leading examples is the Chipko movement that started in India in January 1974. The movement was about protesting about cutting down trees by hugging the trees until the lumberjacks left. This peaceful protest inspired other countries to the importance of trees. It ended up with a 15-year ban on cutting trees in India (Taneja, 2019)

In the 1980s many disasters and discoveries started to worry organizations and many individuals such as the discovery of the hole in the ozone layer in 1985 [13], the Chernobyl accident in 1986 (World Nuclear Association, 2022), and many more things. Firstly, the Montreal Protocol was agreed upon by all the countries which was the only UN agreement to be agreed upon with full consensus. The Montreal Protocol was published due to protect the ozone layer in 1987 and to this day, it is one of the most useful agreements. With the agreement, every year around two million people are saved from skin cancer (Roome, 2014).

Then the UN and the WCED (World Commission on Environment and Development) published a report called Brundtland Report or also known as Our Common Future in 1987. According to the Brundtland study, development plans were not taking into account natural resources and restrictions. Their analysis predicted a social and environmental disaster if the

[13] history.com/this-day-in-history/discovery-of-antarctic-ozone-hole-announced

world's emerging nations followed the same roadmap as Western Countries. The research stated that in order to avoid a catastrophe, wealthier nations must lower their resource needs and ecological implications while developing nations must discover alternative growth routes (UNEP, 2019). This report has been also criticized by different groups that the report proposes a scenario that incorporates the best of both worlds: less developed countries may enhance their living standards via economic development without jeopardizing future growth prospects or environmental quality. This idealized scenario may be fulfilled on a worldwide scale only if rich nations are convinced to slow their growth and make significant economic transfers from "the west" to "the rest." It is debatable whether the present youth is ready to forego consumption and pay more money now in order to give following generations opportunities for prosperity and decent environmental quality (Du Pisani, 2006).

In 1992, on the 20th anniversary of the Stockholm Convention, UNCED (United Nations Conference on Environment and Development) or as known as the Earth Summit was organized in Rio. The main goal of the summit was to generate a wide agenda and a new plan for global cooperation on environmental and development challenges that would help support global cooperation and development policy after the millennium. Agenda 21, a bold framework of activity asking for new ways to plan for the future to accomplish sustainable development in the twenty-first century, was one of the primary outcomes of the UNCED Conference. The ideas were spanned from new teaching techniques to alternative methods of resource conservation and contributing to a sustainable economy. [14] UNFCCC (United Nations Framework Convention on Climate Change) was also founded in Earth Summit and, in 2022, it has almost universal membership with 197 countries. The first response of UNFCCC to climate change was the Kyoto Protocol and then later on the Paris Agreement. [15]

There were already warning signals of disaster during the 1992 summit. In Rio, rich and poor countries fought repeatedly about who should compensate for different environmental measures. Nonetheless, the governments of the world decided to continue working out these concerns in forthcoming U.N. meetings (Plumer, 2012). One of those agreements that failed was the Kyoto Protocol signed in 1997 but started officially in 2005.

The Kyoto agreement's goal was to lower the amount of greenhouse gases. Greenhouse gases are released by humans and this is damaging the atmosphere which is related to climate change. According to the Kyoto Protocol [16], developed nations will cut their greenhouse gas

[14] un.org/en/conferences/environment/rio1992

[15] unfccc.int/process/the-convention/history-of-the-convention

[16] britannica.com/event/Kyoto-Protocol

emissions levels to lower than in 1990. The Kyoto Protocol was the first significant multinational effort to reduce global warming. The agreement has been supported by 191 nations since 1997 but was effective after 2005, except for the United States which was the second country with the most CO2 emission. Developing nations are not obliged to deliver the standards set by Kyoto Protocol. Some of these countries, such as China, which had the most CO2 emission, and Brazil are pro-industrial. Some wealthy nations, like the United States, Canada, and Russia, have yet to agree on emissions targets (National Geographic Society, 2021). Because two of the countries with the highest CO2 emission did not participate for different reasons, the protocol bounded to fail within the first 2 years.

In the year 2000, international leaders agreed in New York that the most concerning problem at the beginning of the millennium was to eradicate poverty and that the entire planet had the capacity and organizations had the expertise to do it. After generations of disputes among non-governmental organizations (NGOs) and authorities, international financial institutions, the United Nations system, etc. The global community finally reached a consensus on what was important and what should be accomplished by whom with the UN Millennium Declaration. Leaders had consistently said that they will spend all their energy to meet the Millennium Development Goals (MDGs) by 2015, which was included decreasing severe poverty, preventing the spread of HIV/AIDS, and delivering universal primary education as the goals is shown in Figure 6. [17]

Figure 6: Millennium Development Goals

Source: Flynn (2020)

[17] un.org/en/chronicle/article/millennium-campaign-successes-and-challenges-mobilizing-support-mdgs

Overall, the goals were considered successful. In 2015, when the MDGs timeline finishes, it was renewed for another 15 years under the name SDGs (Sustainable Development Goals) with more evolved goals. According to McArthur & Rasmussen (2017), because of the focused process, not less than 21 million people were saved with MDGs within these 15 years from 2000 to 2015.

2. Introduction to SDGs

At the Rio+20 summit in 2012, with the collaboration of the post-2015 development agenda, Members of the UN wanted to start SDGs (Sustainable Development Goals) which were continuous versions of the MDGs. [18] In the summit of New York in 2015, with the 2030 Agenda, 17 SDGs with 169 targets are published.

The Millennium Development Objectives (MDGs) were the most critical world future goals in United Nations history. They were focusing on eradicating extreme poverty, famine, and avoidable illness. According to Sachs (2015), the SDGs were going to carry the battle against extreme poverty but were going to add the difficulties of achieving more equal development and environmental sustainability, particularly the essential aim of mitigating the hazards of human-caused climate change.

The SDGs were adopted at the same time that another historic agreement was struck in 2015 at the COP21, the Paris Climate Conference. These accords, including the Sendai Framework for Disaster Risk Reduction, agreed upon in Japan in March 2015, gave a set of shared criteria and attainable objectives for reducing carbon emissions, dealing with the problem of climate change and natural disasters, and rebuilding better after a catastrophe. [19]

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[18] un.org/en/conferences/environment/rio2012

[19] undp.org/content/oslo-governance-centre/en/home/sustainable-development-goals/background.html

Figure 7: Sustainable Development Goals

Source: un.org/sustainabledevelopment/sustainable-development-goals/

Although the goals, as Figure 7 shows, covered many of the problems individuals, governments and many international organizations had, there will be obstacles even between these specified 17 goals to end these problems. One of the biggest challenges is the climate change which is the 13th goal. With floods, droughts, and heatwaves many villages and some developing nations are getting destroyed or taking very high damage that they cannot compensate for (McCarthy, 2019).

In order to face minimum challenges, the blockchain system can help in different ways. The blockchain system, with the help of its traceability and transparency characteristics, can track all participants' usage or resources and give transparency to the third parties or governments, international organizations and others about the problems and information about the progress easily. Also with smart contracts, the actions can be validated much faster and efficiently. The blockchain system can also build trust among the participants with being decentralized.[20]

Another important aspect that blockchain can help, is enforcing promises. For example, US President Donald Trump's decision to abandon the Paris Agreement. Concerns have emerged in other nations that the COVID-19 epidemic would hinder government attempts to meet climate-related obligations. Blockchain technology, using smart contracts, may reduce the possibility of backing down if nations back up their pledges with a cash deposit. If nations

[20] icommunity.io/en/blockchain-sdgs/

struggle to reach their carbon reduction objectives, their deposits might be removed and reallocated as cryptocurrencies to those who have reduced their carbon footprint, such as by planting trees or taking other climate action (Reinsberg, 2020).

Although the blockchain system can help directly or indirectly with all of these 17 problems, EESC (European Economic and Social Committee) and UNCTAD (United Nations Conference on Trade and Development) presented how the blockchain can do for these problems. This chapter and thesis will focus more on the goals which are more concerned with environmental sustainability rather than humanitarian problems such as poverty, and gender equality. These goals are shown in Table 4 with the potential of how blockchain can improve.

Table 4: How blockchain can help SDGs

	Description	Potential
Goal 6	Clean water and Sanitation	Develop a water trade system that is fair and dependable, actors will be given a chance to make decisions based on the data.
Goal 7	Affordable and Clean Energy	Energy consumption, data exchange, and efficiency in this process can be settled through blockchain and smart contracts.
Goal 11	Sustainable Cities and Communities	Enable basic utilities, energy, accommodation, and transportation with a respect to sustainability.
Goal 12	Responsible Consumption and Production	With the traceability and transparency features of the blockchain system, everything can be traceable from the start to the end so customer awareness will be increased, health risks will be decreased and resources can be controlled.
Goal 13	Climate Action	Blockchain can help by creating new financial ecosystems and technology platforms for selling renewable energy, as well as a platform for trading, tracing, and reducing greenhouse gas emissions.
Goal 14	Life Below Water	Procedures for monitoring water pollution and conserving marine resources.
Goal 15	Life on Land	Monitor each stage of a commodity's supply chain to determine where such items originally come.

Source: Elaboration from Parmentola et al. (2022), Slapnik (2019), UNCTAD (2021)

From one point of view, the blockchain system can help to solve or decrease the risk that had been done through individuals, organizations or governments to the environment, but the blockchain system has flaws such as the mining activities that cause high energy consumption and also using coal facilities to generate power. The blockchain system on one hand helps with these goals but also undermines the goals like climate action (Goal 13).

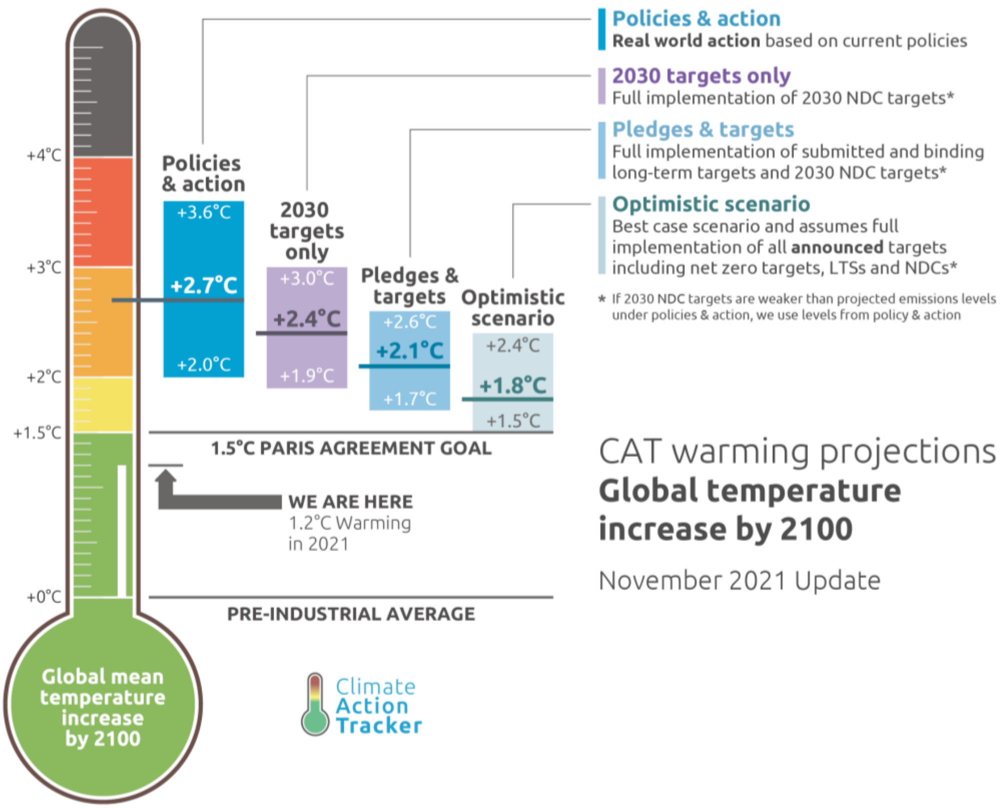
As usual, to preserve the environment, there is not just one agreement or goal to achieve. Another important agreement, that the blockchain system can help with, is the Paris Agreement that was signed in 2015.

3. Paris Agreement

The Paris Agreement, the most major global climate agreement so far, encourages all nations to make promises to reduce emissions on 12 December 2015 and entered into force on 4 November 2016. Governments establish targets referred to as nationally determined contributions (NDCs) with the objective of avoiding world average temperatures from rising 2°C (3.6°F) over pre-industrial times and extending attempts to maintain them under 1.5°C (2.7°F). It also aspires to achieve worldwide net-zero emissions in the mid-21st century. Governments were intended to examine their advancement toward following the pact every five years which will be the first one scheduled in 2023 (Maizland, 2021).

Many individuals and organizations believe that the agreement will not be achieved because even in the most optimistic scenario, which is in Figure 8, the agreement's goal of 1.5°C will be surpassed. The CAT warming projections were last updated in November 2021 and it is already 1.2°C.

Figure 8: CAT warming projection

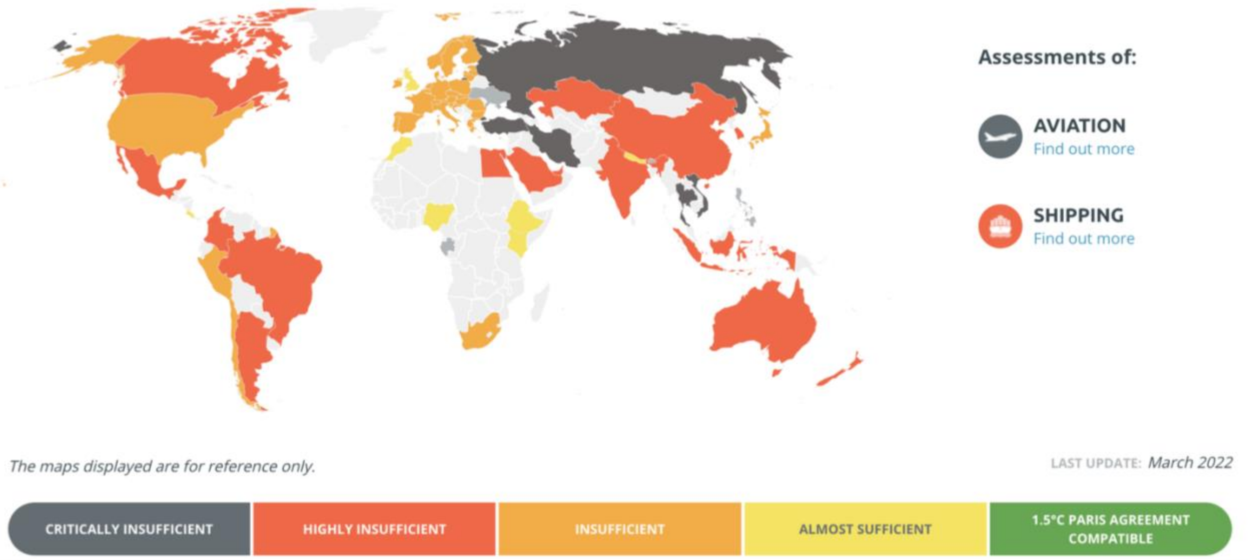


Source: Climate Action Tracker (2021)

As of March 2022, none of the countries in the Paris Agreement are compatible, as shown in Table 9, and just 5 countries are almost sufficient. All EU countries, USA and Japan are considered insufficient whereas China, India, Canada, and many more belong to a category of highly insufficient.

The increase of 2°, which is 0.2° above the optimistic level, is still serious. The freshwater would have been lost by %17 in the Mediterranean, an increase by 50 cm would happen in the sea level, production of wheat would plummet by %16, and rainfall intensity would rise by %7 (Giovetti, 2019).

Figure 9: Countries' compatibility according to the Paris Agreement



Source: Climate Action Tracker (2022)

Besides the fact that the inefficiency levels Figure 9 shows that these different levels of insufficient countries are industrialized and blockchain mining activities are not helping them to be sufficient because of the high energy consumption of mining activities.

4. Environmental problems of blockchain

Although blockchain can help with the SDGs and the Paris Agreement goals, it is not a fault-proof concept. The blockchain system has been criticized especially about the mining procedure of the PoW consensus model, which is the model for Bitcoin, and mining facilities' high energy consumption with the release of CO2. Mining pools are highly dependent on coal mining facilities. In the next years, these problems will determine the blockchain system's success.

4.1 Energy consumption

Although blockchain technology is considered one of the most promising technologies, as every technology has problems in its lifetime, it has a huge problem to solve which is the high amount of energy consumption. By solving this huge amount of energy consumption problem, the blockchain system can help a lot with environmental problems.

The problem of energy consumption comes from the decentralized structure. To validate transactions, one has to answer crypto puzzles. These complex answers that require an immense amount of electricity are mostly used in the PoW (Proof of Work) consensus model.

Miners who use the PoW consensus model, to compensate for their time while solving puzzles and electricity bills, take transaction fees to continue to mine coins.

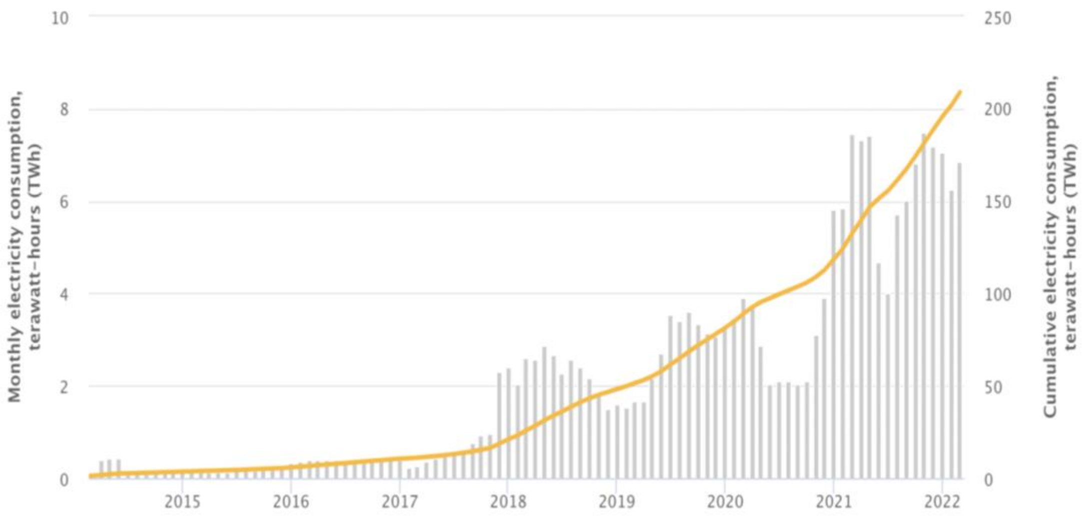
In the first years of bitcoin, because the crypto puzzles were easier, mining coins in the PoW system was not consuming energy on a global scale. Due to the high amount of supply of bitcoin, even with simple devices, individuals could mine bitcoin without using a lot of electricity (Schmidt, 2022).

Cryptocurrencies high energy consumption concerns increased regarding environmental damage, many cryptocurrencies switched or are making changes to switch from the PoW model to PoS or more energy-efficient consensus models. One of the leading examples is Ethereum (Ethereum, 2022).

The discussion of environmental sustainability has grown more popular with Elon Musk when he suspended Tesla purchases with bitcoin in May before the crash of bitcoin in 2021 with a following tweet;

"Tesla has suspended vehicle purchases using Bitcoin. We are concerned about rapidly increasing use of fossil fuels for Bitcoin mining and transactions, especially coal, which has the worst emissions of any fuel. Cryptocurrency is a good idea on many levels, and we believe it has a promising future, but this cannot come at great cost to the environment. Tesla will not be selling any Bitcoin and we intend to use it for transactions as soon as mining transitions to more sustainable energy. We are also looking at other cryptocurrencies that use <1% of Bitcoin's energy/transaction." (Musk, 2021)

Figure 10: Bitcoin energy consumption by years



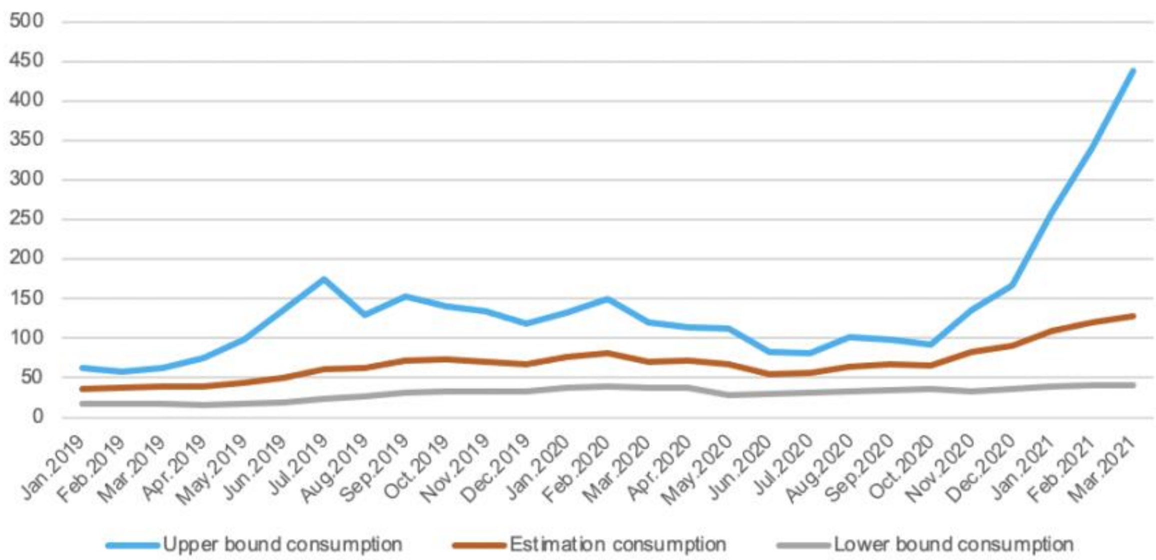
Source: ccaf.io/cbeci/index

Figure 10 shows the monthly amount of energy consumption as terawatt/hours in a cumulative way. After 2018 there is a huge increase due to the adaption of bitcoin worldwide and many new miners started mining because of this bitcoin growing as a household name.

As mentioned earlier, because crypto puzzles are getting harder to solve, miners started to adopt more efficient hardware that uses less componential power for them to solve the puzzles. Since there are a lot of devices that can do these things with a variety of energy consumption levels, there can only be predicted upper and lower amounts of electricity consumption levels.

Figure 11 shows the upper and lower amount of estimated consumption levels. Bitcoin, which is the major and most used currency, on average uses less than 150 TWh per year. Lower consumption prediction with more energy-efficient hardware, bitcoin uses a similar amount level that Hong Kong uses which is a bit less than 50 TWh per year. [21]

Figure 11: Bitcoin electricity consumption, TWh (annualized)



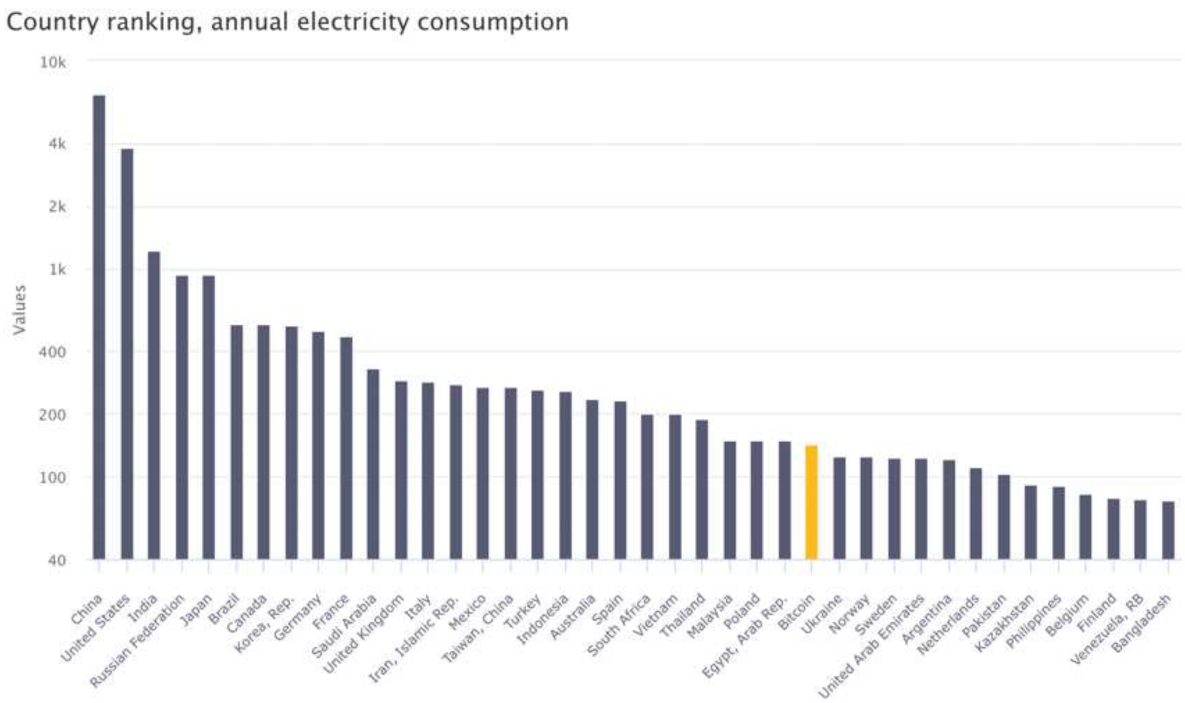
Source: Papageorgiou et al. (2021)

[21] eia.gov/international/data/world/electricity/electricity-consumption?pd=2&p=0000002&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&t=C&g=00000000000000000000000000000000000000000000001&l=249-ruvvvvvfvtvnvv1vrvvvvfvvvvvvfvvvou20evvvvvvvvvvnvvvs0008&s=315532800000&e=1546300800000&

Estimation consumption puts bitcoin at less than 150 TWh between countries Egypt and Ukraine as shown in Table 12.

Another possibility of bitcoin mining is done by hardware with less energy-efficient consumes less than 450 TWh per year. To make a comparison, France's yearly consumption is 470 TWh per year as shown in Figure 12.

Figure 12: Annual electricity consumption of countries



Source: ccaf.io/cbeci/index/comparisons

To be precise, the upper bound consumption depends not only on hardware energy efficiency but also on the market movements. For example, in March 2020, the market value for Bitcoin fell by up to 40% as a result of a global slump in global markets caused by the Corona epidemic.

Mining appeared to be no longer beneficial to some miners at that same moment, so energy consumption dropped (Baird, 2020). This occurrence also demonstrates how the upper estimate is largely dependent on economic conditions: Presuming that power costs fell at the same rate as cryptocurrency prices – which is feasible in an economic recession – the upper bound would stay constant. On the other side, if the price of electricity fell by 50%, e.g., due to lower consumption or increasing flow of renewable sources, or if a movement for virtual currencies led to a 100% boost in their market price, thus, a stage that we had already witnessed by the early part of 2018, our upper estimate would double for each of the circumstances, and even quadruple if both occurred at the same moment (Sedlmeir et al., 2020).

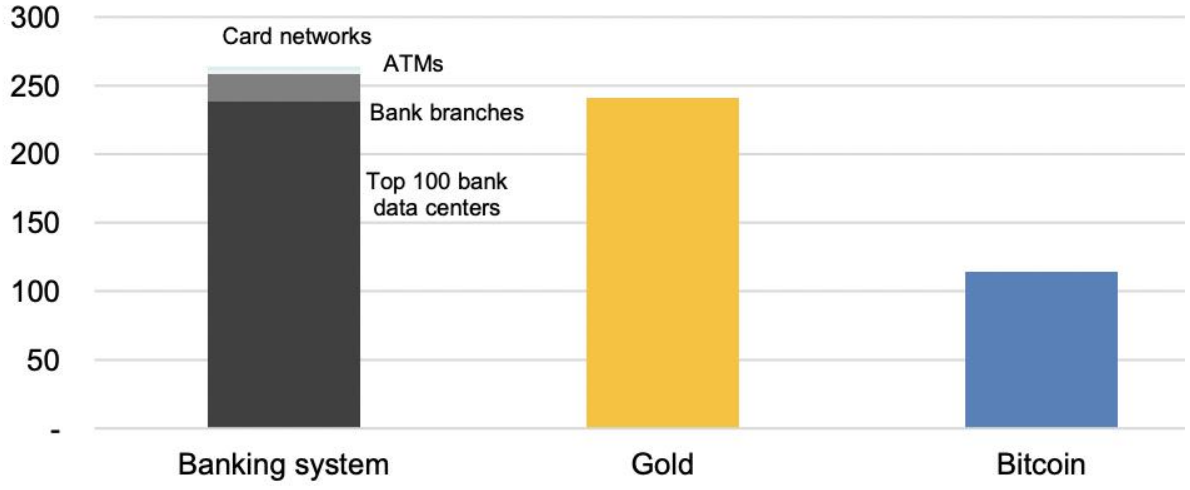
Since bitcoin was born to be a rival against central financialized systems such as banking system, gold. To make a fair comparison between rivals, one should examine in order to make a fair analysis.

Figure 13 shows the comparison from 2021 and, a collection from different studies, bitcoin's estimated energy consumption level is between 100-150 TWh in the years 2021-2022 and it will increase once the crypto puzzles are getting harder which it did even in one year from 113 TWh to 142 TWh because of the bitcoin's price skyrocketed from $10k to $60k.

Galaxy Digital, a New York-based crypto firm, examined four major sources of power consumption for the banking systems: data centers, bank branches, ATMs, and card network data centers. The banking system's global energy usage is estimated to be 238.92 TWh per year as shown in Figure 13.

Galaxy Digital also calculated yearly energy use of 240.61 TWh for the gold sector, as shown in Figure 13, based on World Gold Council greenhouse gas emissions estimates. The authors admit that this estimate may leave out certain important sources of energy usage, such as "the energy and carbon intensity of the tires used in gold mines." (Lagerquist, 2021).

Figure 13: Estimated Annual Energy Consumption (TWh/yr.)

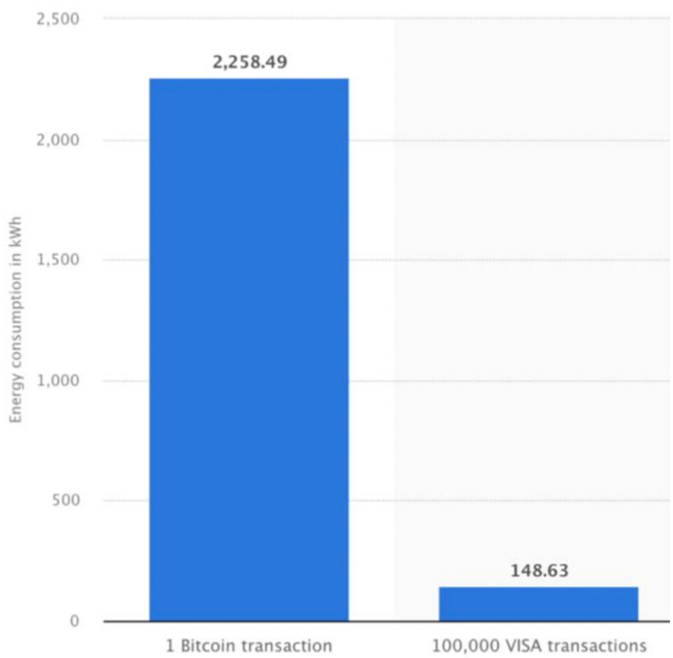


Source: Rybarczyk et al. (2021)

Despite the fact that bitcoin uses a lot of energy, it has already integrated the entire monetary system with no additional real-life electricity usage from physical locations, facilities, bills, or even human capital. Banking institutions, on the other hand, demand massive amounts of energy for both their online and offline parts, yet they can execute a large number of transactions at once (Eugenia, 2021).

Nevertheless, Bitcoin can only handle a limited number of transactions at once. One transaction alone needs a significant amount of computational power, even consuming enough electrical energy to run an ordinary family for many weeks. According to Digiconomist [22], with a single bitcoin transaction, energy consumption is equal to an average US household's electricity usage for more than 74 days. One transaction in Bitcoin, compared to a traditional method like Visa, wastes so much energy. The energy consumption calculated with KWh, 100,000 Visa transactions is not even close to 1 Bitcoin transaction as shown in Figure 14.

Figure 14: Energy consumption of Bitcoin transactions compared to Visa transactions



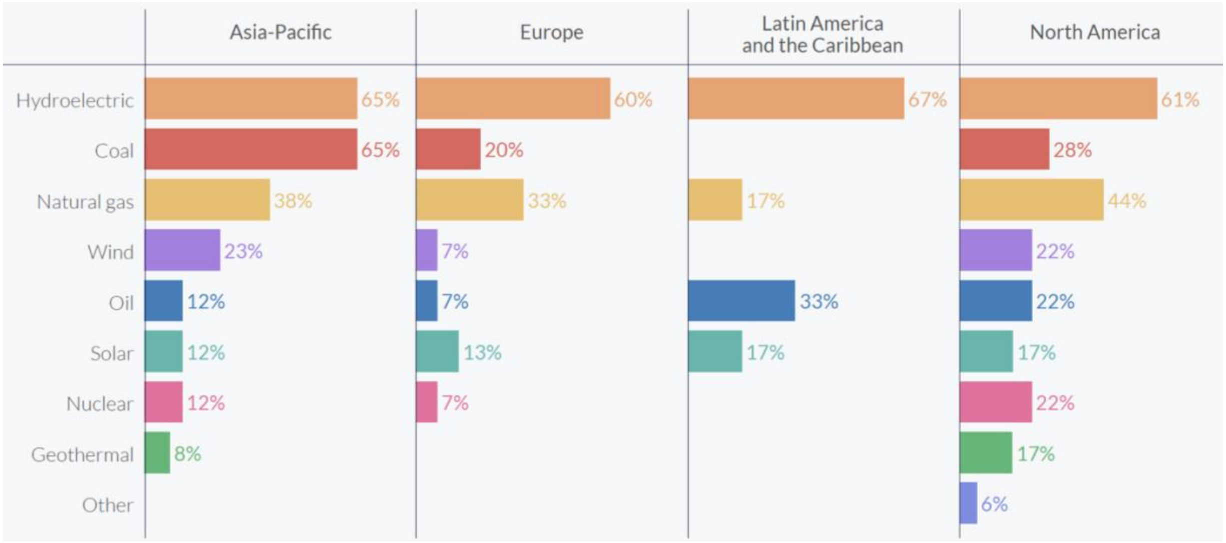
Source: De Best (2022)

Even though energy consumption may be high for bitcoin and the blockchain system, there is not just one way to reduce the damage to the environment.

The blockchain system, starting with bitcoin, can use more renewable energies. It is one of the heavy critics of the blockchain system because particularly in Asia, where most of the mining facilities are located, depends highly on coal facilities and fossil fuels. Figure 15 shows that the majority of the energy comes from hydroelectric in all continents with not less than 60%. After hydroelectric, the most common ones are coal and natural gas.

[22] digiconomist.net/bitcoin-energy-consumption

Figure 15: Energy sources in Mining by Region



Source: Blandin et al. (2020)

In the last 10 years, environmental concerns are deepened, and many countries and organizations started to do something about it, like the Paris Agreement and SDGs, the blockchain industry is questioned rightfully that the sector is dependent too much on coal industry. For example, China was leading the blockchain mining and was mostly dependent on the coal industry until 2021 when they banned all crypto-related activities because of the high energy consumption. [23]

One of the greenest mining is done in Nordic countries. Iceland and Sweden were the mining heavens, both of them are responsible for almost 1% of all bitcoin supply (University of Cambridge, 2022), with low energy costs due to the geothermal energy and high amount of renewable energy, and with cold, their equipment lasts longer so switching costs are decreased. But in late 2021, Iceland started to reject new miners and Sweden even thought about banning crypto because this high usage could be more useful to decarbonize another sector (Russell, 2022).

In 2021, while all countries were talking about the blockchain system's environmental issues, El Salvador announced that they will adopt bitcoin as a legal tender and will start using energy from volcanoes to power mining facilities. Currently, El Salvador has 30 volcanoes which 20 of them are active. From the turbines, up to 107 megawatts can be taken but only a few of them will be used for mining. Even with that few, 300 computers can run day and night (Gaubert, 2021).

[23] dw.com/en/china-central-bank-declares-all-cryptocurrency-transactions-illegal/a-59295079

According to de Vries (2019), switching to renewable energy will not solve the problem of energy consumption rather switching from the PoW consensus model to the PoS model may solve it because when one can calculate the energy consumption, it is mostly about the equipment, not the facilities. So solving the equipment's high energy consumption may have a better impact on the environment

4.2 The carbon footprint of blockchain

Another problem, that is highly criticized in the blockchain, is the carbon footprint. According to Digiconomist [24], the yearly carbon footprint of bitcoin is 114 tons of CO2 in 2022, which is a bit ahead of the Czech Republic, as CO2 emissions calculated in 2016, as seen in Figure 16 and put just bitcoin, out of all blockchain systems, behind 36 countries. To make a comparison between traditional banking system, not with countries, one single bitcoin transaction's CO2 emission is equal to 2,687,059 VISA transactions CO2 emission as well.

Figure 16: CO2 emissions in tons by countries in 2016

#	Country	CO2 Emissions (tons, 2016)	1 Year Change	Population (2016)	Per capita	Share of world
31	Pakistan	178,013,820	9.13%	203,631,353	0.87	0.50%
32	Venezuela	175,884,256	-1.90%	29,851,255	5.89	0.49%
33	Netherlands	163,419,285	1.63%	16,981,295	9.62	0.46%
34	Iraq	162,646,160	1.22%	36,610,632	4.44	0.45%
35	Algeria	156,220,560	0.17%	40,551,392	3.85	0.44%
36	Philippines	126,922,662	12.37%	103,663,816	1.22	0.35%
37	Czech Republic (Czechia)	111,825,428	1.39%	10,618,857	10.53	0.31%

Sources: worldometers.info/co2-emissions/

According to Rystad Energy (2021), China extracted over two-thirds of the world's Bitcoin in 2020, requiring roughly 86 terawatt-hours (TWh) of power, 63 percent of which was generated from coal-fired facilities. If China stopped mining Bitcoin, it would reduce the carbon footprint by 57 million tons—equivalent to what the whole nation of Portugal releases annually.

[24] digiconomist.net/bitcoin-energy-consumption

Despite China banned crypto mining, especially in Kazakhstan and USA, mining increased a lot in different countries. Just in Kazakhstan hash rate jumped from 1.4% to 8.2% from September 2019 to April 2021 and the biggest concern is Kazakhstan's 87% of the electricity comes from fossil oils (Mellor, 2021).

In recent years, many closed coal plants are reopened due to the increasing popularity of bitcoin and many other virtual currencies. A coal-fired power plant in Montana, called Hardin generating station, is re-opened by bitcoin miners in late 2020. In 2021, within the first 9 months, it already generated around 500 thousand CO2 (Milman, 2022). According to Mora et al., (2018), Bitcoin alone could push above the Paris Agreement's 2 °C limit within less than three decades.

Due to the growing concerns, in 2021, more than 200 companies and individuals started Crypto Climate Accord to decarbonize the crypto environment until 2040 (Crypto Climate Accord, 2021).

Chapter 3: The transition towards sustainable cryptocurrencies

1. Bitcoin history

Bitcoin is a public virtual currency that went public in January 2009. It was based on the principles presented in a white paper presented by the enigmatic and unknown Satoshi Nakamoto in 2008. The name of the individual or people who invented the technique is still unknown. Bitcoin promises reduced transaction costs than standard digital payment channels and, unlike monetary currencies, is run by a decentralized system (Frankenfield, 2021).

Bitcoin began its adventure at $0.0008 and within the first month, it climbed to $0.08 which just this increase alone stands around 9900% (Williams, 2022). It still meant nothing to many people as well as known investors and there were many speculations at that time that the investors will not succeed in the future. One of the key moments of that era was known as Bitcoin Pizza Day. Laszlo Hanyecz, one of Bitcoin's early users, used 10,000 bitcoins to buy a couple of Papa John's pizzas. Back in 2010, the purchase cost about $41. At the peak of Bitcoin, which is roughly $60.000, it costs around $680 million (DeCambre, 2021).

After this event happened, within a couple of years, Bitcoin increased to thousands of dollars and started to be compared to big technologies. As in other technologies, when the cryptocurrency industry started to develop and gain an immense amount of momentum, Bitcoin started to have rivals as well.

Figure 17: Cryptocurrencies as of 28 April 2013

Rank	Name	Symbol	Market Cap	Price
1	Bitcoin	BTC	$1,488,566,971.96	$134.21
2	Litecoin	LTC	$74,637,021.57	$4.35
3	Peercoin	PPC	$7,250,186.65	$0.3865
4	Namecoin	NMC	$5,995,997.19	$1.11
5	Terracoin	TRC	$1,503,099.40	$0.6469
6	Devcoin	DVC	$1,424,087.30	$0.0003261
7	Novacoin	NVC	$1,162,266.30	$4.25

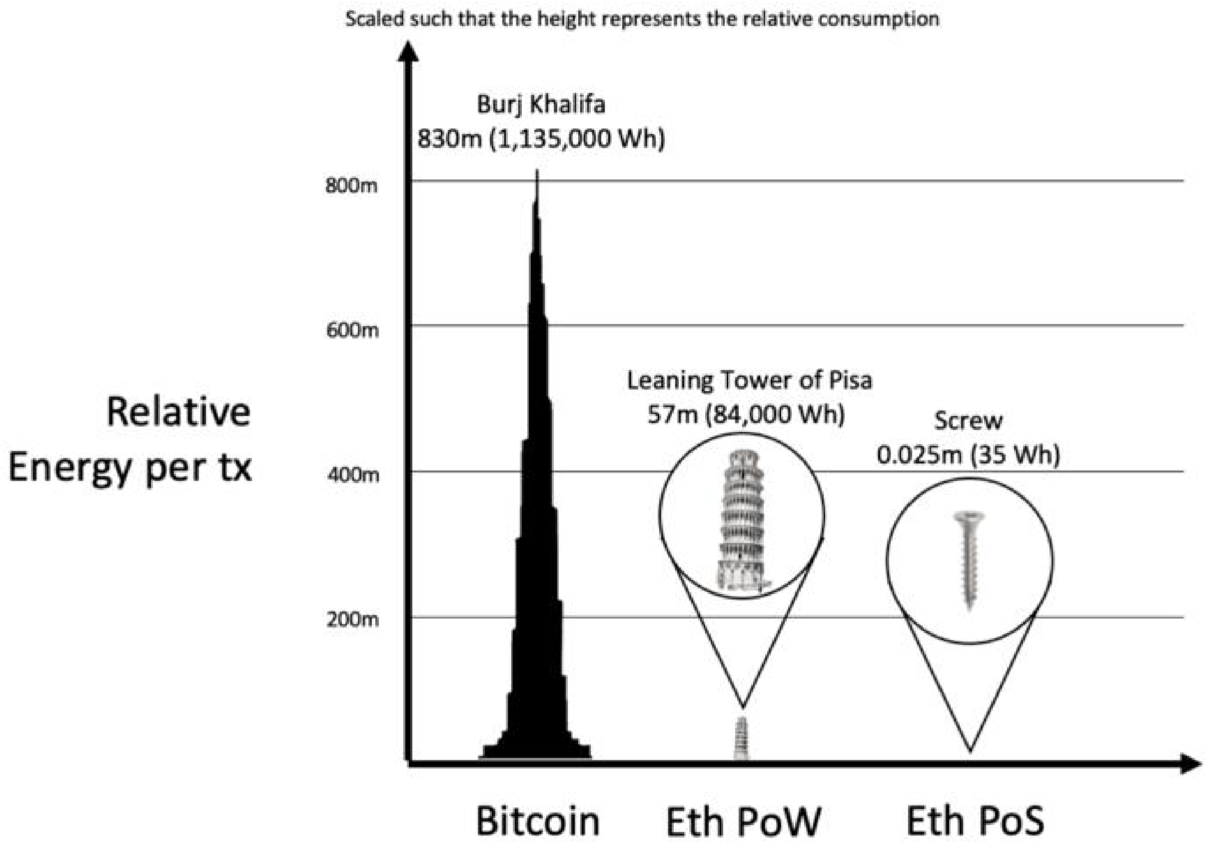
Source: coinmarketcap.com/historical/20130428/

Figure 17 shows the cryptocurrencies that were in the market in April 2013. Considering in 2022 there are thousands of cryptocurrencies, just 7 of them show that this was just the beginning. Even though 6 cryptocurrencies were the pioneers excluding Bitcoin, none of them were considered as rivals like Ethereum against Bitcoin.

2. Ethereum

Ethereum launched in 2015. Different than Bitcoin, Ethereum made use of different concepts and took the blockchain technology one step further. Bitcoin was considered a technology of Blockchain 1.0, Ethereum improved it to Blockchain 2.0 with smart contracts and decentralized applications (dApps). Ethereum has similar principles to Bitcoin such as decentralization and uses, rightfully criticized, the PoW (Proof of Work) consensus model. Due to many problems such as high electricity consumption, Ethereum will switch to the PoS model in 2022 which will make Ethereum more sustainable (Reiff, 2022).

Figure 18: Energy consumption of Bitcoin, Eth PoW and Eth PoS



Source: Beekhuizen (2021)

Figure 18 makes a comparison between Bitcoin and Ethereum's PoW model and a prediction from the estimated consumption level from Ethereum's PoS transition. According to the calculations in Figure 18, Ethereum will use %99.95 less energy because of the switching from the PoW model to the PoS model.

Cryptocurrency values are defined by their market capitalization. A specific cryptocurrency's all mined coins are considered as their market capitalization or in the short version, market cap. Market cap is equal to the total number of mined coins multiplied by the price of that time.[25] In Figure 19 demonstrates that more than half of the total market is divided between Ethereum and Bitcoin so, in order to predict the general cryptocurrency market, the effect of these cryptocurrencies needs to be understood.

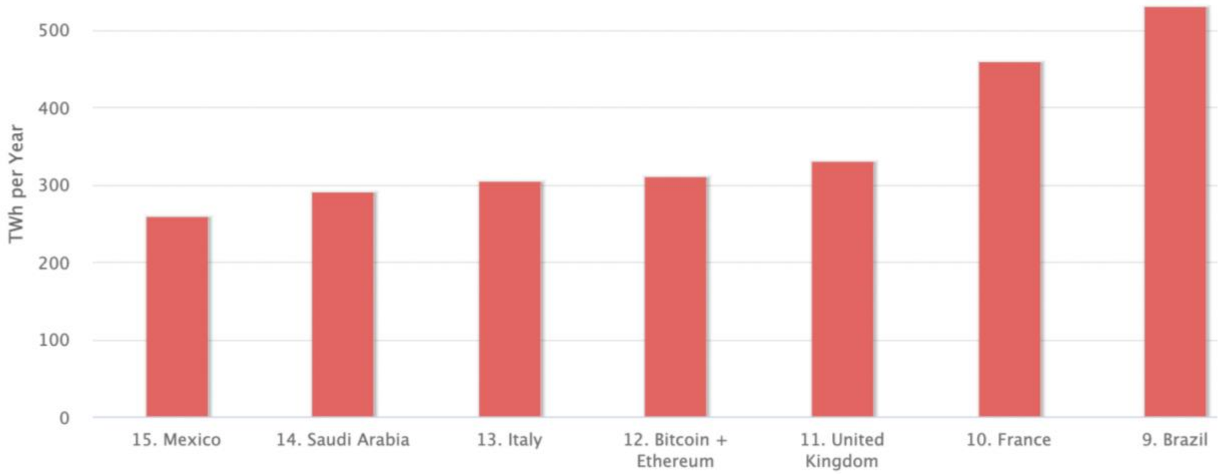
Figure 19: Cryptocurrency market cap breakdown as of May 2022

Source: livecoinwatch.com/crypto-market-cap

Since Ethereum and Bitcoin are the two biggest players in the market, critics about the cryptocurrency market come mostly from one of these virtual coins. According to Figure 20, if Bitcoin and Ethereum, with the PoW model, were a country, because of their energy consumption level, they would be the 12th country in the world. This high consumption level incentivized the cryptocurrency market to launch cryptocurrencies with a low amount of componential power or known as green cryptocurrencies.

[25] coinbase.com/learn/crypto-basics/what-is-market-cap

Figure 20: Energy consumption by country including Bitcoin and Ethereum



Source: digiconomist.net/ethereum-energy-consumption/

3. Green cryptocurrencies

Damage to the environment caused by cryptocurrencies, especially Bitcoin and Ethereum, raised lots of concerns which brought the term "green cryptocurrency". Green cryptocurrencies consume less energy compared to other cryptocurrency mining activities that revolve around high energy consumption levels (Walsh, 2021). In regard to sustainability and energy efficiency, many cryptocurrencies started their campaigns in different ways. Some of them decreased their transaction costs, some of them changed their consensus models or they implemented many other ideas into their projects. The following part will focus on 8 different green cryptocurrency projects and (Table 5) mentions the project with the challenges that they faced, are facing or they will face in the future.

3.1 SolarCoin

A cryptocurrency, SolarCoin, with a minimal carbon footprint was introduced in 2014 to stimulate and incentivize the adoption of solar panels. SolarCoin, which has been operating on PoS since November 2015, had switched to Ethereum-based EnergyWebChain, which has a reduced carbon impact, in 2021. The Energy Web Foundation created EnergyWebChain (EWC), which employs PoAu, a consensus mechanism that consumes far less carbon and energy than PoS or PoW (Sonnet, 2021). SolarCoin, contrary to Bitcoin, are not generated by machines completing complicated arithmetic problems.

SolarCoins are given to shareholders of collaborating solar power system as a reward for their energy efficiency acts. These solar power installations transmit energy generation data to the SolarCoin Foundation via a suitable surveillance system or interface. Once validated, the

Foundation provides the cryptocurrency at a rate of one SolarCoin for every one MWh of power produced, for the duration of the system's operation while SolarCoin remains accessible (Bloch, 2021).

3.2 Signum

Signum, previously named Burstcoin, is a cryptocurrency that was intended to be quite energy-efficient and to serve as an example of a green cryptocurrency (Frankenfield, 2021). According to Digiconomist [26], Bitcoin and its well-known Proof of Work generates 204 TWh of electricity use every year, 2117 kWh in every transaction, and over 36 kilotons of e-waste. Unlike Bitcoin, Signum uses the PoC (Proof of capacity) consensus model [27] and this model consumes %0.002 of Bitcoin's energy which is equivalent to 0.04 kWh per transaction. Signum reduces e-waste by employing user gear that is freely used which is one of the only ones to deserve to be called sustainable (Stahlberg, 2021).

3.3 Fantom

The platform was established in 2018 by well-known computer expert Dr. Ahn Byung Ik with the intention of developing a cryptocurrency that was both sustainable and scalable. Fantom's energy consumption is simply fractional, measuring around 0.000024-0.000028 kWh per transaction. In comparison, the worldwide US banking business consumes 263,720,000,000 kWh per year, whereas Bitcoin uses 102,370,000,000 per year. Fantom consumes just 8200 kWh per year, which is less than the yearly average of an individual US house. [28]

The Ethereum platform's annual usage is projected to be over 90 tWh. Considering this figure with facts on Ethereum data traffic and rounding it up to the Fantom network scale, Fantom would consume just 12,854 kWh per year. This means that Ethereum requires 7 million times higher energy. If Fantom handled ten times the current yearly traffic of Ethereum, overall consumption on the Fantom system would be roughly 128,542 kWh (128.54 MWh), which is still far from Ethereum's use (Fantom, 2021).

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[26] digiconomist.net/bitcoin-energy-consumption/

[27] signum.community/signum-faqs/

[28] dwealth.news/2022/04/sustainability-speed-and-smart-cities-fantoms-reimagined-approach-to-the-blockchain-trilemma/

3.4 Mina Protocol

The volume of transactions kept within most networks has expanded dramatically as cryptocurrency has gained attention. For example, the Ethereum platform was slightly more than 5 GB in April 2016 but has grown to more than 220 GB by April 2021. Massive amounts of transactions were published to the blockchain over five years. Mina Protocol aspires to create a lightweight platform with a specified size of 22 kB despite the number of operations performed on the platform. This scale should permit everyone to maintain a node and contribute to the network's security without requiring complex computer gear, as the PoW consensus model does. Mina Protocol does not need complex gears, therefore it makes the protocol sustainable.

Since the blockchain technology tend to be decentralized, operating a node has taken more computer energy as the network has grown. This has frequently created challenges for normal users to contribute to the blockchain's maintenance. Many believe that this exposes the blockchain to centralization danger since individuals with the highest computational power are more successful in handling the chain's huge size. To resolve this concern, Mina's creators employed a cryptographic approach known as zk-SNARKS to establish a payment-oriented network that does not demand every node to keep a full history of previous transactions. This successfully reduces the processing needs for supporting a full blockchain platform while also keeping it decentralized and safe. [29]

3.5 Holochain

Holochain was presented as a blockchain alternative, providing programmers with a platform for developing decentralized apps (dApps) (Walters, 2021). Conventional blockchain technology is data-centric, with one of its primary goals is being to maintain the integrity of data and provide a trust-free atmosphere. Holochain provides a more realistic method for how individuals interact and form ideas about reality in the actual world. In the actual world, no one keeps a complete record of everything that has transpired. Similarly, in the Holochain platform, users do not keep a copy of the full record, but rather only the records that concern them. [30] The developers made a comparison between the Holochain system and the English language;

[29] kraken.com/en-us/learn/what-is-mina-protocol

[30] medium.com/fmfw-io/what-is-holochain-9d464dcfa636

“Where is the English language stored? Every speaker carries it. People have different areas of expertise, or exposure to different slang or specialized vocabularies. Nobody has a complete copy, nor is anyone's version exactly the same as anyone else, If you disappeared half of the English speakers, it would not degrade the language much”. (Turland, 2018)

For the sustainability part, because mining is not necessary, nodes can function through computers that have low consumption of power or even on cell phones (Brock et al., 2018). Even HoloPort, a plug-and-play tool designed to provide Holochain programs, can be active all day and just consume 15W-45W [31] which is not much more than a lightbulb. [32]

3.6 Gridcoin

Gridcoin is a decentralized cryptocurrency that utilizes spare computer capacity to do academic research via the Berkeley Open Infrastructure for Network Computing (BOINC). BOINC was built in 2002 by the University of California and is a leading system in volunteer computing. BOINC is considered among technology in its field and has in its system more than 600.000 computers while actively supporting more than 30 research projects (Stichbury, 2018). BOINC allows researchers to build their independent programs freely, and Gridcoin pays users for offering access to underutilized computational power that would otherwise be accessible to these researchers.

Grindcoin uses the PoS algorithm and was introduced in 2013. (Matthews, 2022). The initiative's primary goal was to move computing resources away from mining and toward BOINC projects (Kondru et al., 2021). By adopting cryptocurrencies like Gridcoin instead of currencies with high power consumption like Bitcoin, energy usage may be reduced significantly while still being valuable to the science (Chohan, 2018).

3.7 Algorand

Algorand is a decentralized platform designed to address the Blockchain Trilemma all at the same maintaining speed, safety, and decentralization. Algorand adopts a Proof-of-Stake (PoS) protocol that shares validator incentives with all ALGO coin owners. Algorand, which was launched in 2019 by computer scientist and MIT professor Silvio Micali, is a permissionless, public blockchain platform that anybody may develop.

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[31] holo.host/faq/what-is-a-holoport/

[32] help.holo.host/support/solutions/articles/36000035595-will-holo-use-lots-of-electricity-how-much-electricity-will-my-holoport-use-

Algorand was intended to be a payments-focused infrastructure with fast transactions and a significant emphasis on quick completion [33]. Bitcoin is the least efficient in this category, with only 5 TPS (Transaction Per Second). The Ethereum platform has a capacity of roughly 13 TPS. Algorand can presently handle up to 1,300 TPS and hopes to reach 3,000 TPS in the coming years (Das, 2022).

In 2021, Algorand has collaborated with a pioneer organization called ClimateTrade, which helps transparency and traceability of CO2 emissions, to be the greenest cryptocurrency by being carbon negative. ClimateTrade uses blockchain-based answers to increase the effectiveness of sustainability activities for top businesses worldwide (Algorand, 2021). In April 2022, Algorand stated that they will launch a carbon-negative smart contract.[34]

3.8 BitGreen

BitGreen was launched in 2017 as a power-efficient option for Bitcoin, and its patented technology includes a low-energy Proof-of-Stake (PoS) method. Their emphasis on sustainability is achieved by promoting ecologically favorable decisions in a way comparable to SolarCoin. Participants are incentivized for making actions that minimize their environmental footprints, such as utilizing bike-share services, volunteering, or promoting sustainable businesses and organizations.

BitGreen Mobile, in addition to its cryptocurrency, is a mobile payment where people can explore sustainable options and interact with partner organizations to gain and use BitGreen bonuses (Popescu, 2022).

Table 5: Projects and Challenges of Green cryptocurrencies

Cryptocurrency	Project	Challenges
SolarCoin	Incentivize the adoption of solar panels by offering SolarCoin in exchange for Mwh.	Trading and convincing actors to use SolarCoin

[33] gemini.com/cryptopedia/what-is-algorand-cryptocurrency-blockchain#section-what-is-algorand

[34] martechseries.com/sales-marketing/marketing-clouds/algorand-the-worlds-first-carbon-negative-blockchain-announces-network-self-sustainability-funded-by-transaction-fees/

Signum	Sustainability through PoC consensus model.	Competition (There are a lot of similar projects)
Fantom [35]	Solve blockchain trilemma (security, scalability and decentralization)	Competing against Ethereum (one of the pioneers against Bitcoin)
Mina Protocol [36]	World's smallest, lightest blockchain and will remain 22 kb	Keeping it the same kb while growing
Holochain [37]	Sustainability comes from private chain, the absence of mining and also the absence of gears with high power consumption.	It is not going as promised in the whitelist, underachieved project for now.
Gridcoin	Move computing resources away from mining into scientific BOINC projects.	Even though Grindcoin launched in 2013, it is still highly unknown.
Algorand	Solving Blockchain Trilemma and being carbon neutral.	Competition is too fierced against Ethereum with other currencies and still adoption rate of Algorand is too low
BitGreen	Incentivize individuals with BitGreen coin to act sustainable with various activities such as bike sharing, volunteering and so on.	Even though BitGreen launched in 2017, it is still highly unknown.

Source: Elaboration from Bloch (2021), Frankenfield (2021), Nyaga (2022), Matthews (2022), Kondru et al. (2021), Zeitlin (2021)

[35] fantom.foundation/intro-to-fantom/

[36] kraken.com/en-us/learn/what-is-mina-protocol

[37] learn.bybit.com/altcoins/what-holotoken-hot-is-why-it-matters/

Chapter 4: Possible sustainable trajectories for blockchain technology and cryptocurrencies

The blockchain system is highly criticized for the high energy consumption level and CO2 emission level of the blockchain industry in the previous chapters. Even though these critics are mainly revolved around Bitcoin and Ethereum, there are an increasing amount of green cryptocurrencies that have projects about making the blockchain industry more sustainable. Although these green currencies are growing in numbers, the currencies with huge market caps like Bitcoin and Ethereum still dominate the total market. Just Bitcoin and Ethereum capture more than 50% of the market and also take a huge amount of investments. With more investments, their adoption rate is immensely growing with actors such as governments, individuals, and organizations while damaging the environment.

In the previous chapters, it is also mentioned that not just one solution will make the blockchain sector considered "sustainable". In this chapter and concluding the thesis, it will be mentioned various ways of making the blockchain sector more sustainable. If these suggestions altogether, maybe even more with potential technological improvements, the blockchain system will be aligned with the Sustainable Development Goals (SDG), the Paris Agreement, and many more upcoming environmental packs.

After deep research, there seem to be four suggestions that blockchain technology developers can consider making the blockchain industry sustainable.

1. Choosing less electricity consumption consensus models

The PoW consensus model, the most maybe even the only criticized consensus, consumes an immense amount of energy with just Bitcoin and Ethereum that can be comparable with the best-industrialized countries. Since the blockchain system identifies itself as sustainable, decentralized and also a public network, out of 10 major consensus models that are mentioned in Chapter 1, some of them should be eliminated from being considered as a model for the blockchain technology.

After elimination of the consensus models due to some factors such as being more centralized, not sustainable enough, either difficult to adopt or not for public blockchain which the ideal definition of a blockchain system is a public decentralized ledger. Only PoS, PBFT, DPoS, and PoC are left out of the ten consensus models. These four consensus models are sustainable enough to adopt because of their low energy consumption. Especially PoS and PoC have been adopted by many projects such as Ethereum 2.0 for PoS or Signum for the PoC model.

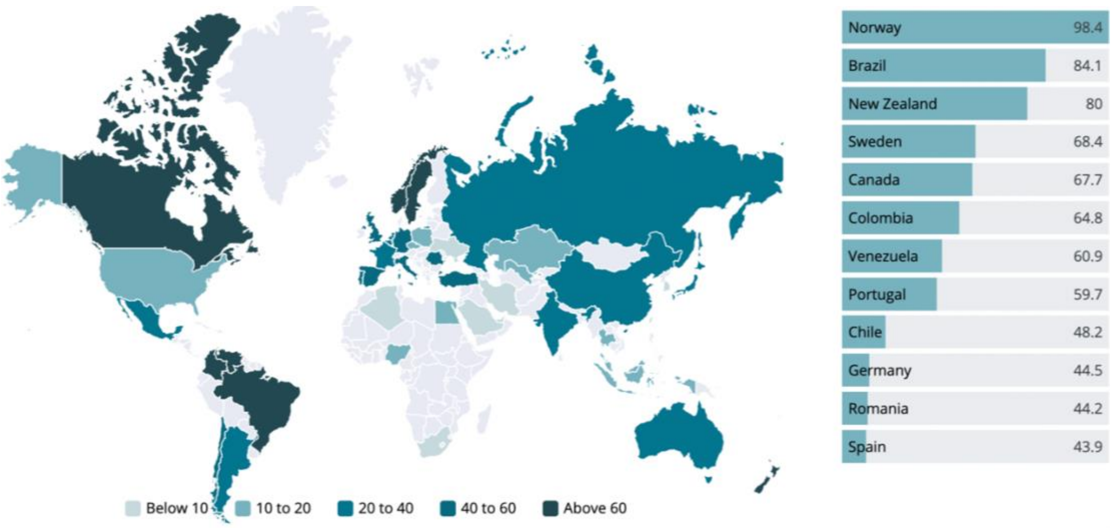
2. **Using renewable energy**

The cryptocurrencies such as Bitcoin or Ethereum use mining to create blocks and this process is done through mining. Mining requires a lot of energy especially the criticized PoW consensus model and miners or mining pools take energy from somewhere which is mostly based on the coal sector. Just the coal sector provides 39% of worldwide CO2 emissions. [38]

There are no claim that renewable energy sources will not produce any CO2 emission, but they are more efficient in comparison to for example coal sector. A gigawatt-hour of wind-generated electricity emits 4 tons of CO2; meanwhile, the very same voltage produced by a coal-fired power station emits 820 tons of CO2. [39]

Besides wind power, there are 4 main energy sources that are renewable. Solar energy, geothermal energy, biomass energy and hydropower energy (EIA, 2021). Figure 21 shows the electricity generated from renewable sources per country in 2020.

Figure 21: Share of renewables in electricity production per country in 2020



Source: Enerdata (2020)

The problem with renewable energy is that it is not even enough to take care of the internal electricity of that country. One of the most recent example is El Salvador. They are generating from volcanoes, which is geothermal energy, to supply bitcoin mining's required energy but the energy dependence of El Salvador is around 80% so they are not even handling their own electricity very well, not alone giving extra energy to bitcoin mining (Artiga &

[38] theworldcounts.com/stories/negative-effects-of-coal-mining

[39] be-the-story.com/en/environment/the-cleanest-countries-leading-the-way-to-renewable-energy/

López, 2021). So for this suggestion to come alive, every country has to spend more money on investing in renewable energy.

The popularity of these 5 above-mentioned renewable sources, hydropower is responsible for more than 54% of all and taking from dams that are built from rivers. China is producing 40% of all hydroelectric out of all countries. After hydropower, Wind energy is the second most used renewable energy and produces 24% of all renewable energy in the world. China and US are responsible for approximately 85% of all wind-powered energy. Solar power is the third most used one but the fastest growing one out of all with a percentage of 25. Many different countries are investing in solar energy ranging from China, the US, Italy, Spain, United Arab Emirates, and so on. After solar power biomass and geothermal energy comes with the last two most used ones (Power Technology, 2020).

3. Pre-mining

Pre-mining is the activity of mining or creating a large number of cryptocurrency tokens or "coins" before the release to the public of a currency. Pre-mining is sometimes connected with initial coin offerings (ICOs) as a method to compensate program creators, programmers, or early investors. A coin may go through a pre-mining period for a variety of purposes;

-A coin might be pre-mined to fund future currency advancement.

-ICO currencies may be pre-mined for pre-sale to their shareholders and followers.

-Pre-mining might arise as a result of unethical and unfair acts by programmers or the bitcoin market exchange network (Hayes, 2021).

Since there will be no mining with ICO, there will not be any computing power that will waste a huge amount of electricity. Because of the absence of computing power, pre-mining could be a solution for a blockchain system to be sustainable.

4. Using blockchain technology in Carbon credits

A carbon credit is a certificate that reflects one ton of CO2 reduced from the environment. They might be obtained by a person or a firm via an intermediary or specifically by those who collect the carbon. However, this only applies to the "voluntary market." The compulsory or "compliance market" is another concept.

Governments impose a quota on how many tons of carbon various sectors – oil, transportation, energy, or waste management — can emit in the regulatory marketplace. If an oil business, for instance, exceeds a certain limit, it must purchase or utilize accumulated credits to remain inside the carbon quota. If a corporation remains under the cap, the credits can be saved or sold (Thompson& Miranda, 2021).

Blockchain offers a stable and dependable infrastructure that is effective and easy, open and inclusive, and considered important for developing Carbon Credit Markets. The Blockchain's irreversible algorithmically secure distributed database enables the dependable issuing and monitoring of carbon credits. Small and medium-sized businesses may readily use public blockchains, lowering the entrance barrier for the carbon credit industry. Moreover, the details available by organizations is transparent and open to everybody. Lately, free automated market makers (AMMs) on blockchains have been established, enabling the exchanging of digital products instantly on the Blockchain with no middleman and minimum computational costs. They supply the framework (Saraji & Borowczak, 2021).

Conclusion

This part outlines the key points concerning the thesis aims, questions, and contributions. It also reviews the study's limitations and presents opportunities for future research.

This study aimed to understand the blockchain technology that was improved, the term as we know it nowadays, by Nakamoto (2008). The study also aimed to explore the potential of blockchain technology in terms of sustainability. The final aim of the thesis was to point out the potential trajectories for blockchain and cryptocurrencies to help sustainability. To achieve the abovementioned points, the thesis answered the following questions;

1. What is blockchain technology?
2. What are the blockchain technology's potentials and how can it solve the major environmental problems such as increasing CO2 emission levels?
3. How can the blockchain technology evolve into a sustainable technology?

- Blockchain technology is a database filled with validated, encrypted records that cannot be easily altered. The transaction data must be validated by different computing devices that have a copy of the transaction record history before a line item may be recorded in the record book. Before accepting or denying on the decision to add the line item to the record book, the computers make sure that each block of the transaction is acceptable and legal. After the transaction has happened, it is not possible to change the record. The line item must be the same in each replica of the transaction record history. Any action to edit a record will be denied since the whole system has evidence that the input is faulty. This definition is taken from Hibbard (2018).

- According to 17 SDGs and the Paris Agreement, blockchain can help with the help its characteristics such as traceability and transparency, can track all participants' usage or resources and give transparency to the third parties or governments, international organizations and others about the problems and information about the progress easily. Also with smart contracts, the actions can be validated much faster and efficiently. The blockchain system can also build trust among the participants by being decentralized. Blockchain can also enforce promises that countries or organizations made, the most recent example is, that blockchain could help with the concept of enforcing promises, US President Donald Trump's decision to leave the Paris Agreement. If blockchain could help, the US would have to pay their shares and would also help in different points for example, with that money that is taken from the US, many trees could have been planted or it can be given to other countries that are struggling to meet the expectations.

- The sustainability problem of blockchain comes from two of the most criticized things about blockchain. These issues are generated from mining activities. Either a specific consensus model that is being used in the blockchain uses an extreme amount of energy, which can be comparable with countries' yearly energy consumption, or to compensate for this need, the mining needs to supply energy demand, mining pools or organizations take the energy from mostly coal sector. The mining pools are mostly located in China and 65% of them use coal. In other continents, even though the demand has decreased, it is still one of the top solutions that mining pools use.

- The following suggestions are mentioned in the thesis. Choosing less electricity consumption consensus models, using renewable energy, pre-mining and implementation of carbon credits. Even though it will be improved in the technology in the future, regarding the current condition in technology, these four suggestions are the most critical ones. Mostly because the problems come from mining and designing the mining input with output, could be one of the key solutions. For these suggestions can be useful, not just one mining pool or government, but rather the whole blockchain community should unite and make decisions and maybe even possible regulations within the community.

The author chose “the sustainability of blockchain” as a topic because not only that it is an interest but hopes to fill the void in the discussion of “Is the blockchain sustainable?” that has been going around since 2021 in the crypto environment. Besides contributing to the debate objectively, there has been a need for the sustainability of blockchain with suggestions for the future. During the research before starting to write the thesis, the author recognized a gap in this field. With this thesis, the author would like to shed a light on the blockchain sector both negatively and positively.

The main limitation was the lack of complete documents. Every article has touched a different spot or just focused on one key topic but the articles, were almost never, about the whole sustainability such as UN meetings, the Paris Agreement, and SDGs. The articles have focused on only one agreement or just one key characteristic such as traceability or only one sector such as finance.

References

Algorand. (2021, April 22). Algorand Pledges to be the Greenest Blockchain with a Carbon-Negative Network Now and in the Future. Retrieved from https://www.algorand.com/resources/algorand-announcements/carbon_negative_announcement

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., ... & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *100*, 143-174.

Arnosti, N., & Weinberg, S. M. (2022). Bitcoin: A Natural Oligopoly. Management Science. Retrieved from https://doi.org/10.1287/mnsc.2021.4095

Artiga, C., & López, M., 2021. *BITCOIN ADOPTION AND MINING IN EL SALVADOR*. [online] Library.fes.de. Available at: <http://library.fes.de/pdf-files/bueros/fesamcentral/18743.pdf> [Accessed 16 May 2022].

Back, A. (2002). Hashcash-A Denial of Service Counter-Measure. Retrieved from https://www.researchgate.net/publication/2482110

Baird, K (2020, March 24) Bitcoin's hash rate retraces 40% this month, slips under 100 ehash/s. Retrieved from https://beincrypto.com/bitcoins-hash-rate-retraces-40-this-month-slips-under-100-ehash-s/

Bamakan, S. M. H., Motavali, A., & Bondarti, A. B. (2020). A survey of blockchain consensus algorithms performance evaluation criteria. Expert Systems with Applications, 154, 113385.

Bashir, I. (2017). Mastering blockchain. Packt Publishing Ltd.

Beekhuizen, C. (2021, May 18). Ethereum's energy usage will soon decrease by ~99.95%. Retrieved from https://blog.ethereum.org/2021/05/18/country-power-no-more/

Bera, S. (2020, September 18). Consensus algorithms in blockchain: Pros & cons. Retrieved from https://coinjoy.io/media/133/consensus-algorithms-in-blockchain-pros-and-cons

Bhalla, A. (2021, June 22). What is decentralization in blockchain? Retrieved from https://www.blockchain-council.org/blockchain/what-is-decentralization-in-blockchain/

Blandin, A., Pieters, G. C., Wu, Y., Dek, A., Eisermann, T., Njoki, D., & Taylor, S. (2020). 3rd global cryptoasset benchmarking study. *Available at SSRN 3700822*.

Bloch, M. (2021, May 17). Cryptocurrency: What is SolarCoin? Retrieved from https://www.solarquotes.com.au/blog/cryptocurrency-solarcoin-mb1997/

Bovaird, C. (2021, June 2). Bitcoin price volatility reached its highest in a year during may. Retrieved from https://forbes.com/sites/cbovaird/2021/06/02/bitcoin-price-volatility-reached-its-highest-in-a-year-during-may/

Brock, A., Atkinson, D., Friedman, E., Harris-Braun, E., McGuire, E., Russell, J. M., ... & Harris-Braun, W. (2018). Holo Green Paper. *Green Paper*.

Brown, B. (2021, March 4). 4 Billion Crypto Adopters Will Outnumber Internet Users Within Years, Predicts Binance CEO. Retrieved from https://www.ccn.com/4-billion-crypto-users-bigger-than-internet-binance-ceo/

Buterin, V. (2015). On public and private blockchains. Ethereum blog, 7(1).

CAICT (China Academy of Information and Communication Technology), & Trusted Blockchain Initiatives. (2018, December). Blockchain White Paper. Retrieved from http://www.caict.ac.cn/english/research/whitepapers/202003/t20200327_278197.html

Cheng, H. K., Hu, D., Puschmann, T., & Zhao, J. L. (2021). The landscape of Blockchain research: impacts and opportunities. *Information Systems and e-Business Management*, *19*(3), 749-755.

Chohan, U. W. (2018). Environmentalism in cryptoanarchism: Gridcoin case study. *Available at SSRN 3131232*.

Chu, Y., Ream, J., & Insights, D. S. C. (2016). Getting smart about smart contracts.

Climate Action Tracker. (2021, November 9). The CAT thermometer. Retrieved from https://climateactiontracker.org/global/cat-thermometer/

Climate Action Tracker. (2022, March). Countries. Retrieved from https://climateactiontracker.org/countries/

Conway, L. (2021, November 29). Bitcoin halving. Retrieved from https://investopedia.com/bitcoin-halving-4843769

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. Applied Innovation, 2(6-10), 71.

Crypto Climate Accord. (2021). CRYPTO CLIMATE ACCORD. Retrieved from https://cryptoclimate.org/accord/

Crypto Answers (2021, October 25). Bitcoin halving dates history & future dates. Retrieved from https://cryptoanswers.com/faq/bitcoin-halving-dates-history/

Daily Bit. (2018, April 26). 9 types of consensus mechanisms that you didn't know about. Retrieved from https://medium.com/the-daily-bit/9-types-of-consensus-mechanisms-that-you-didnt-know-about-49ec365179da

Das, N. (2022, January 16). What is Algorand and why is it known as the Ethereum killer? Retrieved from https://www.outlookindia.com/website/story/business-news-what-is-algorand-and-why-is-it-known-as-the-ethereum-killer/406919

De Best, R. (2022, March 22). Number of cryptocurrencies worldwide from 2013 to February 2022. Retrieved from https://www.statista.com/statistics/863917/number-crypto-coins-tokens/

de Vries, A. (2019). Renewable energy will not solve bitcoin's sustainability problem. Joule, 3(4), 893-898.

DeCambre, M. (2021, May 22). Bitcoin pizza day? Laszlo Hanyecz spent $3.8 billion on pizzas in the summer of 2010 using the novel crypto. Retrieved from https://www.marketwatch.com/story/bitcoin-pizza-day-laszlo-hanyecz-spent-3-8-billion-on-pizzas-in-the-summer-of-2010-using-the-novel-crypto-11621714395

Deetman, S. (2016, March 29). Bitcoin could consume as much electricity as Denmark by 2020. Retrieved from https://www.vice.com/en/article/aek3za/bitcoin-could-consume-as-much-electricity-as-denmark-by-2020

Diffie, W., & Hellman, M. (1976). New directions in cryptography. *IEEE transactions on Information Theory*, *22*(6), 644-654.

Do, T., Nguyen, T., & Pham, H. (2019, July). Delegated proof of reputation: A novel blockchain consensus. In Proceedings of the 2019 International Electronics Communication Conference (Pp. 90-98). https://doi.org/10.1145/3343147.3343160

Doubleday, K. (2018, November 27). Blockchain Immutability — Why Does it Matter? Retrieved from https://medium.com/fluree/immutability-and-the-enterprise-an-immense-value-proposition-98cd3bf900b1

Du Pisani, J. A. (2006). Sustainable development–historical roots of the concept. *Environmental sciences*, *3*(2), 83-96.

Dziembowski, S., Faust, S., Kolmogorov, V., & Pietrzak, K. (2015, August). Proofs of space. In Annual Cryptology Conference (pp. 585-605). Springer, Berlin, Heidelberg.

EIA (U.S. Energy Information Administration). (2021, May 20). Renewable energy explained. Retrieved from https://www.eia.gov/energyexplained/renewable-sources/

Enerdata. (2020). Share of renewables in electricity production. Retrieved from https://yearbook.enerdata.net/renewables/renewable-in-electricity-production-share.html

Ethereum. (2022, May 17). Proof-of-stake (POS). Retrieved from https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/

Eugenia, O. (2021, March 23). Energy consumption: Cryptocurrency vs traditional banks. Retrieved from https://www.iyops.org/post/energy-consumption-cryptocurrency-vs-traditional-banks

Fantom. (2021, November 23). Fantom, the eco-friendly blockchain. Retrieved from https://fantom.foundation/blog/fantom-the-eco-friendly-blockchain/

Farell, R. (2015). An Analysis of the Cryptocurrency Industry. Retrieved from https://repository.upenn.edu/wharton_research_scholars/130

Ferrag, M. A., & Shu, L. (2021). The performance evaluation of blockchain-based security and privacy systems for the Internet of Things: A tutorial. IEEE Internet of Things Journal.

Frankenfield, J. (2021, October 25). Signum (SIGNA)—Formerly Burstcoin (BURST). Retrieved from https://www.investopedia.com/terms/b/burstcoin.asp

Frankenfield, J. (2021, November 30). Consensus mechanism (Cryptocurrency). Retrieved from https://www.investopedia.com/terms/c/consensus-mechanism-cryptocurrency.asp

Frankenfield, J. (2022, January 13). Proof of Elapsed Time (PoET). Retrieved from https://www.investopedia.com/terms/p/proof-elapsed-time-cryptocurrency.asp

Frankenfield, J. (2022, May 12). Bitcoin (BTC). Retrieved from https://www.investopedia.com/terms/b/bitcoin.asp

Gaubert, J. (2021, October 29). Volcanoes are being harnessed to power Bitcoin mining in El Salvador in this new pilot project. Retrieved from https://www.euronews.com/next/2021/10/29/volcanic-energy-is-creating-bitcoin-in-el-salvador

Giovetti, O. (2019, November 8). Why the Paris climate agreement matters (especially for humanitarian work). Retrieved from https://www.concernusa.org/story/paris-climate-agreement-humanitarian-work/

Gupta, A. (2022, January 7). What are whales and how do they manipulate cryptocurrency? Retrieved from https://www.jumpstartmag.com/what-are-whales-and-how-do-they-manipulate-cryptocurrency/

Haber, S., & Stornetta, W. S. (1990, August). How to time-stamp a digital document. In *Conference on the Theory and Application of Cryptography* (pp. 437-455). Springer, Berlin, Heidelberg.

Hayes, A. (2021, October 25). Premining. Retrieved from https://www.investopedia.com/terms/p/premining.asp

Hayes, A. (2022, March 5). Blockchain explained. Retrieved from https://www.investopedia.com/terms/b/blockchain.asp

Hibbard, R. (2018, May 22). Blockchain explained in Layman's terms. Retrieved from https://levelup.gitconnected.com/blockchain-explained-in-laymans-terms-8b01a7255465

Hileman, G., & Rauchs, M. (2017). Global cryptocurrency benchmarking study. Cambridge Centre for Alternative Finance, 33, 33-113.

Intelligence, I. (2022, February 11). The growing list of applications and use cases of blockchain technology in business and life. Retrieved from https://businessinsider.com/blockchain-technology-applications-use-cases?r=US&IR=T

IP Specialist. (2019, October 15). How blockchain technology works. Retrieved from https://medium.com/@ipspecialist/how-blockchain-technology-works-e6109c033034

Jackson, R. (2021, November 22). Third-generation blockchains will pick up the Defi slack left by Ethereum. Retrieved from https://news.bitcoin.com/third-generation-blockchains-will-pick-up-defi-slack-left-by-ethereum/

Joshi, N. (2021, May 11). Everything you need to know about blockchain 3.0. Retrieved from https://www.bbntimes.com/technology/everything-you-need-to-know-about-blockchain-3-0

Kaur, M., Khan, M. Z., Gupta, S., Noorwali, A., Chakraborty, C., & Pani, S. K. (2021). Mbcp: Performance analysis of large scale mainstream blockchain consensus protocols. IEEE Access.

Khan, D., Jung, L. T., Hashmani, M. A., & Waqas, A. (2020, January). A Critical Review of Blockchain Consensus Model. In 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) (pp. 1-6). IEEE.

King, S., & Nadal, S. (2012). Ppcoin: Peer-to-peer crypto-currency with proof-of-stake. self-published paper, August, 19(1).

Knutson, Ted. (2022, January 20). Crypto Energy Consumption Enormous But It Needn't Be, Congressional Panel Hears. Retrieved from https://forbes.com/sites/tedknutson/2022/01/20/crypto-energy-consumption-enormous-but-it-neednt-be-congressional-panel-hears/?sh=7f4021d24abb

Kondru, K. K., Saranya, R., & Chacko, A. (2021). A Review of distributed supercomputing platforms using Blockchain. *Advances in Distributed Computing and Machine Learning*, 123-133.

L., K. (2019, January 30). The blockchain scalability problem & the race for visa-like transaction speed. Retrieved from https://towardsdatascience.com/the-blockchain-scalability-problem-the-race-for-visa-like-transaction-speed-5cce48f9d44

Laboure, M., & Reid, J. (2020). The Future of Payments Part III. Digital Currencies: the Ultimate Hard Power Tool. Retrieved from https://www.dbresearch.com/PROD/RPS_EN-PROD/PROD0000000000504589/The_Future_of_Payments_-_Part_III__Digital_Currenc.pdf

Lagerquist, J. (2021, May 18). Bitcoin's energy use is less than half of banking, gold sectors: Report. Retrieved from https://ca.finance.yahoo.com/news/bitcoins-energy-use-is-less-than-half-of-banking-gold-sectors-report-175813423.html

Le, K. (2021, July 29). Crypto mining rig giant Bitmain divests from AntPool, the world's biggest mining pool. Retrieved from https://forkast.news/bitmain-divests-from-antpool-mining-pool/

Lee, L., Bedi, S., Tsang, K. F., Harms, A., & Bakshi, D. (2016). HASTINGS BUSINESS LAW JOURNAL. Hastings Business Law Journal, University of California, 12(2). Retrieved from https://repository.uchastings.edu/hastings_business_law_journal/vol12/iss2/

Lepore, C., Ceria, M., Visconti, A., Rao, U. P., Shah, K. A., & Zanolini, L. (2020). A survey on blockchain consensus with a performance comparison of PoW, PoS and pure PoS. Mathematics, 8(10), 1782.

Lisa, A. (2021, June 30). 7 of the biggest bitcoin crashes in history. Retrieved from https://finance.yahoo.com/news/7-biggest-bitcoin-crashes-history-180038282.html

Mainelli, M., & Smith, M. (2015). Sharing ledgers for sharing economies: an exploration of mutual distributed ledgers (aka blockchain technology). Journal of financial perspectives, 3(3).

Maizland, L. (2021, November 17). Global climate agreements: Successes and failures. Retrieved from https://www.cfr.org/backgrounder/paris-global-climate-change-agreements

Mallonee, L. (2019, November 3). Inside the Icelandic facility where bitcoin is mined. Retrieved from https://wired.com/story/iceland-bitcoin-mining-gallery/

Matthews, L. (2022, May 5). The 28 most sustainable cryptocurrencies for 2022. Retrieved from https://www.leafscore.com/blog/the-9-most-sustainable-cryptocurrencies-for-2021/#20-gridcoin-grc

Mazieres, D. (2015). The stellar consensus protocol: A federated model for internet-level consensus. Stellar Development Foundation, 32, 1-45.

McArthur, J., & Rasmussen, K. (2017, March 30). How successful were the millennium development goals? Retrieved from https://www.theguardian.com/global-development-professionals-network/2017/mar/30/how-successful-were-the-millennium-development-goals

McCarthy, J. (2019, July 17). 4 big obstacles to the global goals, according to the man who helped build them. Retrieved from https://www.globalcitizen.org/en/content/obstacles-facing-the-un-global-goals/

Melinek, J. (2022, April 26). Stablecoins are here to stay, but will they see wider adoption? Retrieved from https://techcrunch.com/2022/04/26/stablecoins-are-here-to-stay-but-will-they-see-wider-adoption/

Mellor, S. (2021, July 15). Is China's Bitcoin crackdown cutting mining's emissions—or shifting them somewhere else? Retrieved from https://fortune.com/2021/07/15/china-bitcoin-crackdown-mining-emissions-hash-rate/

Milman, O. (2022, February 18). Bitcoin miners revived a dying coal plant – then CO2 emissions soared. Retrieved from https://www.theguardian.com/technology/2022/feb/18/bitcoin-miners-revive-fossil-fuel-plant-co2-emissions-soared

Mora, C., Rollins, R. L., Taladay, K., Kantar, M. B., Chock, M. K., Shimada, M., & Franklin, E. C. (2018). Bitcoin emissions alone could push global warming above 2 C. *Nature Climate Change*, *8*(11), 931-933.

Mougayar, W. (2016). The business blockchain: promise, practice, and application of the next Internet technology. John Wiley & Sons.

Muftic, S., Sanchez, I., JRC, E., & Beslay, L. (2016). Overview and analysis of the concept and applications of virtual currencies. Joint Research Centre, Italy Retrieved from http://publications. jrc. ec. europa. eu/repository/handle/JRC105207.

Musk, E. (2021, May 13). Tesla & Bitcoin. Retrieved from https://twitter.com/elonmusk/status/1392602041025843203

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. Decentralized Business Review, 21260.

Narayanan, A., Bonneau, J., Felten, E., Miller, A., & Goldfeder, S. (2016). Bitcoin and cryptocurrency technologies: a comprehensive introduction. Princeton University Press.

National Geographic Society. (2021, August 3). Dec 11, 1997 CE: Kyoto Protocol Signed. Retrieved from https://www.nationalgeographic.org/thisday/dec11/kyoto-protocol-signed/

Newbery, E. (2021, September 21). 6 Top Cryptocurrencies With Smart Contracts. Retrieved from https://www.nasdaq.com/articles/6-top-cryptocurrencies-with-smart-contracts-2021-09-21

Nyaga, C. (2022, April 12). Fantom price prediction: FTM stages a 45% comeback as DeFi rebounds. Retrieved from https://www.banklesstimes.com/news/2021/09/15/fantom-price-prediction-ftm-stages-a-45-comeback-as-defi-rebounds/

Oyinloye, D. P., Teh, J. S., Jamil, N., & Alawida, M. (2021). Blockchain Consensus: An Overview of Alternative Protocols. Symmetry, 13(8), 1363.

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.

Parmentola, A., Petrillo, A., Tutore, I., & De Felice, F. (2022). Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs). Business Strategy and the Environment, 31(1), 194-217.

Petersson, D. (2018, October 24). How Smart Contracts Started And Where They Are Heading. Retrieved from https://www.forbes.com/sites/davidpetersson/2018/10/24/how-smart-contracts-started-and-where-they-are-heading/?sh=f987f6b37b63

Pilkington, M. (2016). Blockchain technology: principles and applications. In Research handbook on digital transformations. Edward Elgar Publishing.

Plumer, B. (2012, June 7). The 1992 Earth Summit failed. Will this year's edition be different? Retrieved from https://www.washingtonpost.com/blogs/ezra-klein/post/the-1992-earth-summit-failed-will-this-years-edition-be-different/2012/06/07/gJQAARikLV_blog.html

Popescu, O. (2022, January 9). Most energy efficient cryptocurrencies. Retrieved from https://www.trality.com/blog/most-energy-efficient-cryptocurrencies

Power Technology. (2020, January 6). The world's most used renewable power sources. Retrieved from https://www.power-technology.com/analysis/featurethe-worlds-most-used-renewable-power-sources-4160168/

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. Sustain Sci 14 (3): 681–695.

Quiroz-Gutierrez, M. (2022, January 5). Crypto is fully banned in China and 8 other countries. Retrieved from http://fortune.com/2022/01/04/crypto-banned-china-other-countries/

Reiff, N. (2022, February 21). Bitcoin vs. Ethereum: What's the difference? Retrieved from https://www.investopedia.com/articles/investing/031416/bitcoin-vs-ethereum-driven-different-purposes.asp

Reinsberg, B. (2020, June 11). Three ways blockchain could get the world to act against the climate crisis. Retrieved from https://theconversation.com/three-ways-blockchain-could-get-the-world-to-act-against-the-climate-crisis-139503

Reserve Bank of Australia. (2022, March 30). Cryptocurrencies. Retrieved from https://www.rba.gov.au/education/resources/explainers/cryptocurrencies.html

Roome, N. (2014, January 27). The Brundtland Report's Key Insights. Retrieved from https://www.nbs.net/articles/looking-backward-to-move-forward-revisiting-the-brundtland-report

Ritchie, H., Roser, M., & Rosado, P. (2020). CO_2 and greenhouse gas emissions. Our world in data.

Russell, R. (2022, February 24). Can cryptocurrency ever be environmentally friendly? Retrieved from https://www.dw.com/en/bitcoin-can-cryptocurrency-mining-ever-be-environmentally-friendly/a-60818440

Rybarczyk, R., Armstrong, D., & Fabiano, A. (2021). On Bitcoin's Energy Consumption: A Quantitative Approach to a Subjective Question. *Galaxy Digital Mining*, 1-13. Retrieved from https://www.lopp.net/pdf/On_Bitcoin_Energy_Consumption.pdf

Rystad Energy. (2021, July 14). Bit late for bitcoin: How China's crackdown is reducing more emissions than whole countries emit. Retrieved from https://www.rystadenergy.com/newsevents/news/press-releases/bit-late-for-bitcoin-how-chinas-crackdown-is-reducing-more-emissions-than-whole-countries-emit/

Sachs, J. D. (2015, March 30). Why the sustainable development goals matter. Retrieved from https://www.weforum.org/agenda/2015/03/why-the-sustainable-development-goals-matter/

Salimitari, M., & Chatterjee, M. (2018). A survey on consensus protocols in blockchain for iot networks. arXiv preprint arXiv:1809.05613.

Saraji, S., & Borowczak, M. (2021). A blockchain-based carbon credit ecosystem. arXiv preprint arXiv:2107.00185.

Sarmah, S. S. (2018). Understanding Blockchain Technology. Computer Science and Engineering, 8(2), 23–29. https://doi.org/10.5923/j.computer.20180802.02

Satoshi. (2010, June 17). Transactions and scripts: DUP hash160 ... Equalverify CHECKSIG. Retrieved from https://bitcointalk.org/index.php?topic=195.msg1611#msg1611

Schmidt, J. (2022, May 18). Why does bitcoin use so much energy? Retrieved from https://www.forbes.com/advisor/investing/cryptocurrency/bitcoins-energy-usage-explained/

Scoones, I. (2007). Sustainability. Development in practice, 17(4-5), 589-596.

Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The Energy Consumption of Blockchain Technology: Beyond Myth. Business & Information Systems Engineering, 62(6), 599–608. https://doi.org/10.1007/s12599-020-00656-x

Sharma, K., & Jain, D. (2019, July). Consensus algorithms in blockchain technology: A survey. In 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT) (pp. 1-7). IEEE.

Sharman, J. (2021, July 8). The three pillars of sustainability. Retrieved from https://www.thenbs.com/knowledge/the-three-pillars-of-sustainability

Slapnik, T. (2019, May 29). Blockchain: technology for the social economy 4.0. Retrieved from https://www.eesc.europa.eu/sites/default/files/files/blockchain_for_sdgs_-_slapnik_-_brussels144.pdf

Solnick, S. (2013). Ulrich Grober: SUSTAINABILITY: A cultural history. TLS. Times Literary Supplement, (5729), 22-23.

Sonnet, F. (2021, April). What is SolarCoin ? (2021 revised). Retrieved from https://www.linkedin.com/pulse/what-solarcoin-francois-sonnet/

Spookiestevie. (2020, May 13). Gold sucks! Send tweet. Retrieved from https://www.reddit.com/r/Bitcoin/comments/gj6ho2/gold_sucks_send_tweet/

Stahlberg, H. (2021, July 1). Blockchain goes green: Signum - the world's first truly sustainable blockchain steps into the light. Retrieved from https://finance.yahoo.com/news/blockchain-goes-green-signum-worlds-060000083.html

Stark, J. (2016, June 4). Making sense of blockchain smart contracts. Retrieved from https://www.coindesk.com/markets/2016/06/04/making-sense-of-blockchain-smart-contracts/

Stichbury, J. (2018, October 26). What is Gridcoin and how can it advance science? Retrieved from https://dzone.com/articles/what-is-gridcoin-and-how-can-it-advance-science

Stoll, C., Klaaßen, L., & Gallersdörfer, U. (2019). The Carbon Footprint of Bitcoin. Joule, 3(7), 1647–1661. https://doi.org/10.1016/j.joule.2019.05.012

Sultan, K., Ruhi, U., & Lakhani, R. (2018). Conceptualizing blockchains: Characteristics & applications. arXiv preprint arXiv:1806.03693.

Swan, M. (2015). Blockchain: Blueprint for a new economy. " O'Reilly Media, Inc.".

Szabo, N. (1996). Smart contracts: Building blocks for digital markets. Retrieved from https://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html

Taneja, R. (2019, March 26). Chipko movement: When villagers hugged trees to save them from cutting. Retrieved from https://www.ndtv.com/india-news/chipko-movement-in-1970-chipko-andolan-people-hugged-trees-to-save-them-from-cutting-2012950

Thanujan, T., Rajapakse, C., & Wickramaarachchi, D. (2021, September). A community-based hybrid blockchain architecture for the organic food supply chain. In 2021 International Research Conference on Smart Computing and Systems Engineering (SCSE) (Vol. 4, pp. 77-83). IEEE.

Thompson, L., & Miranda, L. (2021, October 30). What are carbon credits? How fighting climate change became a billion-dollar industry. Retrieved from https://www.nbcnews.com/business/business-news/are-carbon-credits-fighting-climate-change-became-billion-dollar-indus-rcna3228

Turland, C. (2018, October 9). FAQ. Retrieved from https://github.com/Holochain/holochain-proto/wiki/FAQ

UN. (1969, May 26). Problems of the human environment : report of the Secretary-General. Retrieved from https://digitallibrary.un.org/record/729455?ln=en

UNCTAD. (2021, June 25). Harnessing Blockchain for Sustainable Development: Prospects and Challenges, Geneva, 25 June 2021. Available: https://unctad.org/webflyer/harnessing-blockchain-sustainable-development-prospects-and-challenges

UNEP. (2019, November 15). Thirty years on, what is the Montreal protocol doing to protect the ozone? Retrieved from https://www.unep.org/news-and-stories/story/thirty-years-what-montreal-protocol-doing-protect-ozone

United Nations. (1972, June 16). Report of the United Nations Conference on the Human Environment, Stockholm, 5-16 June 1972. Retrieved from https://digitallibrary.un.org/record/523249?ln=en

University of Cambridge. (2022, January). Bitcoin Mining Map. Retrieved from https://ccaf.io/cbeci/mining_map

Viktor, E. (2020, April 22). Blockchain 3.0: Beyond bitcoin and first-generation distributed ledgers, from Aion to Cardano, EOS and Zilliqa. Retrieved from https://dailyhodl.com/2020/04/22/blockchain-3-0-beyond-bitcoin-and-first-generation-distributed-ledgers-from-aion-to-cardano-eos-and-zilliqa/

Viriyasitavat, W., & Hoonsopon, D. (2019). Blockchain characteristics and consensus in modern business processes. Journal of Industrial Information Integration, 13, 32–39. https://doi.org/10.1016/j.jii.2018.07.004

Walsh, D. (2021, May 13). What is 'green' cryptocurrency Chia and just how eco-friendly is it? Retrieved from https://www.euronews.com/next/2021/05/12/what-is-green-cryptocurrency-chia-and-just-how-eco-friendly-is-it

Walters, S. (2021, October 10). Holochain Review: DLT Trying to Make Blockchains Obsolete. Retrieved from https://www.coinbureau.com/review/holochain-hot/

Wang, Q., Huang, J., Wang, S., Chen, Y., Zhang, P., & He, L. (2020). A comparative study of blockchain consensus algorithms. In Journal of Physics: Conference Series (Vol. 1437, No. 1, p. 012007). IOP Publishing.

WCED (World Commission on Environment and Development) (1987a) Our Common Future: Report of the World Commission on Environment and Development, Oxford: Oxford University Press.

Wiersum, K. F. (1995). 200 years of sustainability in forestry: lessons from history. Environmental management, 19(3), 321-329.

Williams, G. (2022, February 15). Bitcoin: A Brief Price History of the First Cryptocurrency. Retrieved from https://investingnews.com/daily/tech-investing/blockchain-investing/bitcoin-price-history/

Wong, J. I., & Kar, I. (2016, July 18). Everything you need to know about the Ethereum "hard fork". Retrieved from https://qz.com/730004/everything-you-need-to-know-about-the-ethereum-hard-fork/

World Nuclear Association. (2022, April). Chernobyl Accident 1986. Retrieved from https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx

Xu, M., Chen, X., & Kou, G. (2019). A systematic review of blockchain. Financial Innovation, *5*(1), 1-14.

Yaga, D., Mell, P., Roby, N., & Scarfone, K. (2019). Blockchain technology overview. arXiv preprint arXiv:1906.11078.

Zeitlin, M. (2021, August 10). A Beginner's Guide to Algorand (ALGO). Retrieved from https://www.sofi.com/learn/content/what-is-algorand-algo/

Zhao, J. L., Fan, S., & Yan, J. (2016). Overview of business innovations and research opportunities in blockchain and introduction to the special issue. *Financial innovation*, *2*(1), 1-7.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017, June). An overview of blockchain technology: Architecture, consensus, and future trends. In *2017 IEEE international congress on big data (BigData congress)* (pp. 557-564). Ieee.

Consulted websites

Bethestory.com. (2021, December 29). The cleanest countries: leading the way to renewable energy. Retrieved from https://www.be-the-story.com/en/environment/the-cleanest-countries-leading-the-way-to-renewable-energy/

Bit2me academy. (2020, July 20). What is proof of elapsed time (Poet)? Retrieved from https://academy.bit2me.com/en/what-is-proof-of-elapsed-time-poet/

Bitcoin Halving Countdown. (n.d). Retrieved from coinmarketcap.com/halving/bitcoin/

BitMain Technologies Holding Company 比特大陸科技控股公司. Retrieved from http://enterprise.press/wp-content/uploads/2018/09/BitmainProspectus.pdf

Bitpanda. (n.d.). What is the purpose of mining pools and how do they work? Retrieved from https://www.bitpanda.com/academy/en/lessons/what-is-the-purpose-of-mining-pools-and-how-do-they-work/

Britannica, T. Editors of Encyclopaedia (2021, November 30). Kyoto Protocol. Encyclopedia Britannica. https://www.britannica.com/event/Kyoto-Protocol

BTC.COM. (n.d.). Pool stats - BTC.com. Retrieved from https://btc.com/stats/pool?pool_mode=year

Bybit Learn. (2022, January 14). What HoloToken (HOT) is & why it matters. Retrieved from https://learn.bybit.com/altcoins/what-holotoken-hot-is-why-it-matters/

Coinbase (n.d.). What is a fork? Retrieved from https://www.coinbase.com/learn/crypto-basics/what-is-a-fork

Coinbase. (n.d.). What is market cap? Retrieved from https://www.coinbase.com/learn/crypto-basics/what-is-market-cap

Coinmarketcap. (n.d.). Historical snapshot - 28 April 2013. Retrieved from https://coinmarketcap.com/historical/20130428/

Crypto market cap graphs & volume charts - Live coin watch. (n.d.). Retrieved from https://www.livecoinwatch.com/crypto-market-cap

Cryptopedia Staff. (2022, March 30). Algorand (ALGO): A Blockchain Breakthrough in Speed and Efficiency. Retrieved from https://www.gemini.com/cryptopedia/what-is-algorand-cryptocurrency-blockchain#section-what-is-algorand

Deutsche Welle (www.dw.com). (2021, September 24). China: Central Bank declares all cryptocurrency transactions 'illegal'. Retrieved from https://www.dw.com/en/china-central-bank-declares-all-cryptocurrency-transactions-illegal/a-59295079

Digiconomist. (n.d.). Bitcoin energy consumption index. Retrieved from https://digiconomist.net/bitcoin-energy-consumption

Digiconomist. (n.d.). Ethereum energy consumption index. Retrieved from https://digiconomist.net/ethereum-energy-consumption/

Dwn Staff. (2022, April 17). Sustainability, Speed and Smart Cities: Fantom's Reimagined Approach to the Blockchain Trilemma. Retrieved from https://dwealth.news/2022/04/sustainability-speed-and-smart-cities-fantoms-reimagined-approach-to-the-blockchain-trilemma/

Fantom. (n.d.). Intro to Fantom. Retrieved from https://fantom.foundation/intro-to-fantom/

FMFW.io. (2021, September 14). What is HoloChain? Retrieved from https://medium.com/fmfw-io/what-is-holochain-9d464dcfa636

Global cryptocurrency market charts. (n.d.). Retrieved from https://coinmarketcap.com/charts/

Herfkens, E. (n.d.). The Millennium Campaign: Successes and Challenges in Mobilizing Support for the MDGs. Retrieved from https://www.un.org/en/chronicle/article/millennium-campaign-successes-and-challenges-mobilizing-support-mdgs

History.com Editors. (2020, April 7). Discovery of ozone hole announced. Retrieved from https://www.history.com/this-day-in-history/discovery-of-antarctic-ozone-hole-announced

Holo Support. (2019, January 5). Will Holo use lots of electricity? How much electricity will my HoloPort use? Retrieved from https://help.holo.host/support/solutions/articles/36000035595-will-holo-use-lots-of-electricity-how-much-electricity-will-my-holoport-use-

Holochain. (n.d.). What is a HoloPort? Retrieved from https://holo.host/faq/what-is-a-holoport/

Icommunity Labs & Tech. (n.d.). Blockchain and its impact on the SDGs (Sustainability objectives). Retrieved from https://icommunity.io/en/blockchain-sdgs/

Kraken. (n.d.). What Is Mina Protocol? (MINA). Retrieved from https://www.kraken.com/en-us/learn/what-is-mina-protocol

Market cap of gold (precious metal). (n.d.). Retrieved from https://companiesmarketcap.com/gold/marketcap/

PRNewswire. (2022, April 21). Algorand, the World's First Carbon-Negative Blockchain, Announces Network Self-Sustainability Funded by Transaction Fees. Retrieved from https://martechseries.com/sales-marketing/marketing-clouds/algorand-the-worlds-first-carbon-negative-blockchain-announces-network-self-sustainability-funded-by-transaction-fees/

Signum. (n.d.). Signum FAQs. Retrieved from https://signum.community/signum-faqs/

The University of Cambridge. (n.d.). Cambridge bitcoin electricity consumption index (CBECI). Retrieved from https://ccaf.io/cbeci/index/comparisons

The University of Cambridge (n.d.). Cambridge bitcoin electricity consumption index (CBECI). Retrieved from https://ccaf.io/cbeci/index

The World Counts. (n.d.). A cheap but dirty fuel source…. Retrieved from https://www.theworldcounts.com/stories/negative-effects-of-coal-mining

U.S. Energy Information Administration. (n.d.). International. Retrieved from https://eia.gov/international/data/world/electricity/electricity-consumption?pd=2&p=0000002&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&t=C&g=00000000000000000000000000000000000000000000000001&l=249-ruvvvvvfvtvnvv1vrvvvvfvvvvvvfvvvou20evvvvvvvvvvnvvvs0008&s=315532800000&e=1546300800000&

UNDP. (n.d.). Background on the goals. Retrieved from https://www1.undp.org/content/oslo-governance-centre/en/home/sustainable-development-goals/background.html

UNEP. (n.d.). About UN Environment Programme. Retrieved from https://www.unep.org/about-un-environment

UNEP. (n.d.). About World Environment Day. Retrieved from https://www.worldenvironmentday.global/about-world-environment-day

UNFCCC. (n.d.). History of the convention | UNFCCC. Retrieved from https://unfccc.int/process/the-convention/history-of-the-convention

United Nations. (n.d.). Take action for the sustainable development goals. Retrieved from https://un.org/sustainabledevelopment/sustainable-development-goals/

United Nations. (n.d.). United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992. Retrieved from http://un.org/en/conferences/environment/rio1992

United Nations. (n.d.). United Nations Conference on Sustainable Development, 20-22 June 2012, Rio de Janeiro. Retrieved from https://www.un.org/en/conferences/environment/rio2012

What is Mining?. (n.d.). Retrieved from https://coinbase.com/learn/crypto-basics/what-is-mining

What is the Byzantine generals problem?. (n.d.). Retrieved from http://river.com/learn/what-is-the-byzantine-generals-problem/

Worldcryptoindex. (n.d.). Advantages and disadvantages of decentralized blockchains. Retrieved from https://www.worldcryptoindex.com/advantages-disadvantages-decentralized-blockchains/

Worldometers. (n.d.). CO2 emissions. Retrieved from https://www.worldometers.info/co2-emissions/