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The Price of Speculation: Cryptocurrencies and Climate Change

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Abstract: Cryptocurrencies are a form of digital currency whose popularity has rapidly increased over the past decade. What distinguishes them from other electronic currencies is their underlying technology known as the blockchain, a decentralized public ledger in which transactions among the network peers are accurately and securely recorded. The validation and mining process, where new coins are issued, is highly computationally intensive and thus requires vast amounts of energy. The literature estimates energy consumption levels of the cryptocurrency mining to be as high as those of countries such as Angola, Iceland or Cuba, and a corresponding emission of at least 3-15 million tons of CO^2. We discuss these estimated impacts of Bitcoin and other cryptocurrencies on both energy levels and the environment, and then outline alternative applications that could promote climate change mitigation. We argue that despite the latter applications and the possible benefits from the technology, particularly in the energy sector, the financial uses of blockchain are creating significant environmental costs without any clear social or economic benefit stemming from this largely speculative activity.

Introduction and Summary

Cryptocurrencies are power-hungry by nature, bearing significant environmental costs. Despite some promising applications of their underlying blockchain technology, particularly in the energy sector, its best-known use is currently cryptomining, a process with a devastating impact on climate change, with no apparent purpose other than speculative gains.

In 2008, Satoshi Nakamoto introduced the digital currency Bitcoin – the first cryptocurrency – with an underlying technology that required no central third party but worked via the decentralized administration of a data protocol, referred to as the blockchain. The basic idea was first conceived by Haber and Stornetta in 1991[1,] Bitcoin became known as the first application of the blockchain technology – a distributed ledger that is stored in a decentralized, peer-to-peer[2] network and allows the storage of information, in a system that, in theory, performs accurate and irreversible data transfer in a decentralized database without a central authority. The Bitcoin market capitalization was approximately one billion U.S. dollars in 2013 and increased manyfold since then, having reached an all-time high of roughly $3 trillion in November 2021 before taking a precipitous fall in 2022[3]. Since the development of this cryptocurrency, many others have entered the market and currently, and now there are more than 20,000 different such coins in existence.

The surge in prices and volume of cryptocurrencies around 2018 led to a boom in energy demand that was accompanied by a growing debate about the networks' energy consumption, as the technology requires high computational power to validate the transactions. The process of validating transactions and linking them into the blockchain, referred to as 'mining', allows all the network participants to verify the transactions, typically through solving a cryptographic puzzle, and rewards the successful ones with new coins. The processing power required by all participants during such processes, including the ones that did not solve the computational problem, is defined as the *hash rate*, describing all the attempts per second to 'mine' a new coin. Most literature focuses on the energy resources that are spent on the creation and transaction of cryptocurrencies, particularly Bitcoin, based on hardware efficiency and hashing rates.

Estimated energy usage varies significantly given the various assumptions embedded in the modeling, yet all indicate significant levels of consumption. Stoll et al. (2019) estimate that after the 2018 price surge, Bitcoin's annual electricity consumption had a magnitude of 45.8 terawatts per hour[4] (TWh), a number that sits between that of New Zealand and Singapore's[5]. Krause and Tolaymat (2018) analyze the power requirements for four cryptocurrencies, including Bitcoin, and show estimated figures of 16.6TWh for all cryptocurrencies in 2018. The authors highlight the escalating energy demand that stems from the growing

[1] Haber, S. and Stornetta, W. (1991) How to time-stamp a digital document. Crypto'90, Incs 537 (437-455)

[2] Peer-to-peer (P2P) networks or workgroups are networks that require no authentication server and allow the network peers to share resources. Devices are linked together with equal permissions for processing data.

[3]Available at: https://coinmarketcap.com/currencies/bitcoin/, last accessed June 2022.

[4] Terawatts per hour is a unit of energy that measures the amount of energy output produced over one hour. A terawatt is equivalent to one trillion watts (10^{12}W) and is often used when describing major energy production or consumption such as that of entire countries. For magnitude reference, consider that a small led lightbulb can consume 15 watts per hour to produce a certain amount of light. According to the U.S. Energy Information Administration, the average annual electricity consumption for a U.S. residential household in 2020 was approximately 10,000 kilowatts hour, which gives an average of about 893kWh per month produced. One kilowatt corresponds to one thousand watts. In: U.S. Energy Information Administration *F.A.Q. How much Electricity does an American home use*. Available at: https://www.eia.gov/tools/faqs/faq.php?id=97&t=3, last accessed June 2022.

[5] Available at: https://ourworldindata.org/energy (annual electricity consumption), last accessed August 2022.

participation of ‘miners’, the increasing difficulty of the mining process, and the growing volume of trading. (Schinckus et al., 2020).

The power-hungry nature of cryptocurrencies raises concerns over the carbon footprint of this new mining activity and the harmful impacts it can have on climate change. The Paris Agreement in the COP21 Conference was ratified to mitigate GHG emissions and keep global warming below 2ºC. As mining primarily uses fossil fuels to generate electricity, cryptocurrencies add a new and significant degree of environmental damages, undermining prospects for achieving that goal. Considering country-specific CO^2 emissions and the geographical location of the activity, cryptocurrencies were estimated to have generated 3-15 million tons of CO^2 ($MtCO^2$) between January 2016 and June 2018 (Krause and Tolaymat, 2018). Further estimations put the annual carbon emission for the Bitcoin network alone as approximately 22.9$MtCO^2$, a level comparable to those produced by Jordan or Sri Lanka (Stoll et al., 2019).

There are, however, alternative applications of the blockchain technology that are not designed to be energy-intensive but rather are intended to promote innovation and efficiency gains, particularly in the energy sector. Smart-contracts – self-executing codes that provide secure mechanisms for electronic collaboration using the decentralized peer-to-peer networks – allow some climate change mitigation and more efficient resource allocation, while industry wide applications manage the production, flow and storage of renewable energy resources. Other non-financial usages of blockchain include developments in the Internet-of-Things[6] (IoT), automation of processes or data management that could also play a role in the decarbonization. More problematic financial uses include Non-Fungible Tokens and Central Banking Digital Currencies (CBDCs). Some argue that these initiatives can be part of the fight against climate change. For example, they promote cryptocurrencies as a novel approach to green financing, promoting green certificates and cryptocurrencies tied to the carbon credit market, in an attempt to offset the industry’s carbon footprint. Other suggested shifting the power supply from fossil generation resources to renewable energy or using alternative coins that are not as energy intensive as the Proof-of-Work consensus mechanism.

[6] The Internet of Things describes physical objects (or groups of such objects) with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.

Organization of the paper

This paper summarizes the literature on the cryptocurrencies' use of energy and their estimated carbon footprint. It provides a brief account of the underlying blockchain technology to allow a better comprehension of the network's energy consumption estimations and further outlines alternative uses of the technology that attempt to offset environmental damages. We then look at other blockchain applications and discuss the role, if any, that financial applications of blockchain technology can play in a greener future. This paper is far from being a comprehensive coverage of cryptocurrencies but, rather, it provides a thorough literature review of its environmental impacts.

Given the massive energy requirements of the cryptocurrencies' network, we argue that its purely speculative or anti-social furtive purposes comes at great environmental cost and as such, initiatives involving cryptocurrencies should not be pursued. However, we also argue that underlying blockchain technology has shown promising developments particularly in the energy sector, with several initiatives promoting decentralized exchanges of renewable energy resources that allow some moments of climate change mitigation. Whether these are worth the environmental cost remains to be seen.

The remainder of the paper is organized as follows. Section 2 provides an overview of the blockchain technology and cryptocurrencies, in particular of the Bitcoin network. Section 3 reviews the literature on the energy consumption of cryptocurrencies and Section 4 compiles their estimated environmental impacts. Section 5 goes through so-called alternatives uses of cryptocurrencies, namely in the offsetting of its environmental impacts, as well as financial and other non-financial applications of blockchain technology. Section 6 concludes.

2. Cryptocurrencies and the blockchain technology

Cryptocurrencies are a digital currency based on a cryptographically secured distributed ledger, the blockchain. A ledger can be defined as a collection of accounts, stating the current rights of ownership of a particular asset: "it provides a means to store Information Technology chronologically and redundantly[7] on a decentralized database" (Sedlmeir et al., 2020, p.600). The blockchain accurately and continuously records transactions among decentralized nodes, without the need for verification by an intermediary.

[7] Meaning each node has a copy of the blockchain.

According to Lewis (2016)[8], the application of the blockchain technology is only deemed appropriate when there are issues with trust, consensus, immutability, or a mix of the three.

Blockchains achieve the synchronization previously assured by a central authority by linking transactions to form blocks and adding them to the existing data structure (the chain). Each node of the network is an equal peer, and independently verifies the transactions, propagates valid ones, and builds proofs of valid transactions. The valid transactions are then added to the blockchain. This process of validating, or solving, a block and its transactions is referred to as 'mining', and the processing power used during this validation can be measured by its hash rate. The hash rate is the number of attempts per second to solve a block in the blockchain during the mining, for all nodes participating in the process – even the ones that fail to solve it. 'Miners' can generate new blocks after completing all the previous data in the block, with each block containing the hash (the hash of a block can be thought of as its solution) of the previously accepted block in the blockchain. Thus, each block contains information regarding all the blocks that came before, hence the term blockchain.

Agreement about which new blocks to append – which transactions are valid – is reached using a consensus mechanism. Permissionless blockchains, as is the case of Bitcoin and other blockchain technologies that use public key cryptography, require no form of registration, and thus need a consensus mechanism that can guarantee the integrity and security of the system. Bitcoin in particular resorts to the Proof-of-Work scheme (PoW), which only allows the creation of a new block from a set of transactions if a solution to a computationally intensive cryptographic puzzle is found.

The mining process entails a run between nodes to compute a solution for such a puzzle and to add a valid transaction into the blockchain. Continuously, each node collects a number of valid transactions into a block and tries to compute a cryptographic hash of the block that meets certain constraints, i.e., a checksum[9] for the block that is both one-way (easy to compute a hash of a given block but difficult to compute a block that matches a given hash) and collision resistant (it is difficult to find two blocks that yield the same hash). (Vranken, 2017). The latter guarantees that double-spending and manipulation do not occur. The computations to find and verify a cryptographic hash of a block allow the network to gain consensus about the state of transaction, and so the primary purpose "of the mining process is to maintain the integrity of the decentralized blockchain, by facilitating the many millions of transactions occurring across the cryptonetwork" (Krause and Tolaymat, 2018, p.1). Changing the transactions of a single block in the chain

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[8] In 30 things you can do with a blockchain | by Rhian Lewis | Medium, March 24, 2019.

[9] A checksum is a sequence of numbers and or letters used to verify transmissions and check data for errors. It is generated through an algorithm program that generates a fixed length string based on a given input.

would also change the hash of that block. Since every block contains the hash of the previously accepted block, to maintain the consensus of the blockchain one would also need to compute the cryptographic hash of all the blocks that came after the altered one, which demands a massive amount of hash rate, thus making the blockchain very difficult to tamper with (Li et al., 2019).

Finding a hash that meets the criteria mentioned above is also a computationally intensive task and therefore it typically involves a block reward. In the case of Bitcoin, the successful miners receive an amount of new Bitcoins and a transaction fee for every transaction included in the block (Vranken 2017). Hence, the issuance of Bitcoin and similar cryptocurrencies is done during the mining process. To keep the average time for solving a puzzle constant and to ensure the security and functionality of the network, the difficulty of the cryptographic puzzles is frequently increased, thus requiring higher computational power to be solved. For the Bitcoin network, for instance, a miner could expect to find little more than two blocks a day in 2011. The difficulty to find a valid hash is adjusted on average every 10 minutes, in order to maintain the time between each block addition constant, so that by 2018, the same miner could expect to find a block every 472,339 years (Stoll et al., 2019). While the difficulty and computational requirements of the mining process will continue to increase in order to account for the number of participants attempting to solve the puzzle, the rewards for the addition of a new block are halved every 210,000 blocks mined, which corresponds to approximately 4 years. As the amount of Bitcoin was set in the original algorithm with a fixed cap of 21 million, the initial block reward was of 50 bitcoins in 2009, but it was only of only 6.25 Bitcoins in May 2022. The mining of new Bitcoins is expected to last until 2140, reaching approximately 21 million of total coins issued. Afterwards, transaction fees will provide the only incentive to continue mining.

Energy Use

Vast amounts of energy are required to reach consensus of ownership and transaction on a permissionless blockchain, like Bitcoin, and power demand will only continue to increase as more coins are mined. The consensus mechanism implies a race among the nodes in the network to find a valid hash as quickly as possible, which requires a significant amount of energy. “In addition to consensus, the redundancy underlying all types of blockchain technology can make cryptographic solutions considerably more energy-intensive than a centralized alternative” (Sedlmeir et al., 2020, p.600). Even if all current PoW schemes change their consensus agreement to a less computationally demanding scheme, the current ledgers are of such magnitude (since each block contains all the information of the previous blocks in an enormous blockchain) that energy consumption levels is likely to continue to be significant (Ibid).

Despite the growing awareness about the high levels of energy spent by permissionless blockchains, the surge in prices, particularly of Bitcoin during 2018, boosted the investment made by network participants in mining hardware that are now largely application-specific-integrated-circuit (ASIC) based. First generation miners used central processing units (CPUs) in conventional computers, but promptly changed to higher performance hardware, in terms of the number of hashes computed per second, at higher energy efficiency rates (measured in the number of hashes computed per Joule). At the end of 2010, miners switched to graphic processing units (GPUs), with increased computational power and efficiency. Since 2013, ASIC based mining systems have prevailed in Bitcoin mining, being able to perform a much higher number of calculations than its GPU counterparts, all the while demanding less power per calculation. However, some cryptocurrencies and algorithms are ASIC-resistant, and can only be mined using a more conventional GPU (or CPU).

Most advanced blockchain technologies are currently only used by chip manufacturers that run their own ASIC in their own data center. Vranken (2017) pointed to the dangers of a possible oligopolistic market within the industry, according to whom the five largest mining companies mined over 85% of the blocks in 2016. From IPO filings disclosed in 2018, Stoll et al. (2019) highlight the three major mining producers, Bitmain, Canaan and Ebang, with Bitmain holding almost 2/3 of the total Bitcoin hashing rate. The prevalence of ASIC miners on a blockchain network can have nefarious side effects. Given their outstanding hash rate, the centralization of mining pools decreases the decentralization of Bitcoin by making an attack possible, e.g., the 51% attack: when the attackers, a group of network nodes which have at least 51% of the total network computational power, can mine faster than anyone else, they gain the ability to single-handedly confirm transactions and add new blocks, after which a "central" authority is said to exist (Zile and Strazdina, 2018).This is because a key addition of the cryptocurrencies protocol is that if two distinct blockchains exist with conflicting transaction history, a miner defers to the longest one when validating new transactions. As attackers can compute Proof-of-Work faster than other miners, their transactions will be connected to the longest chain, which will then become the consensus (Ye et al., 2018). In such a scenario, transactions can be reversed even before their confirmation, which can lead to the double-spending of the coins (also known as a double-spending attack).

The Proof-of-Work Mechanism, purposely designed to be energy-intensive, is not the only way to achieve consensus in a distributed and decentralized system. The best-known alternative scheme is the Proof-of-Stake (PoS), where there is a random mechanism that determines who is allowed to mine and attach the next block. The probability of being selected is linked to the amount of capital (cryptocurrencies) that the node has locked for such a purpose. It does not involve the computationally intensive steps of PoW and is therefore considered to be more energy efficient. As mentioned, in PoW systems miners consume a lot of computational power when competing for mining opportunities, thus making the system energy intensive and unsustainable (Li et al., 2020). Getting rid of PoW's energy consumption is said to come at the cost of security, as decreasing the computational difficulty of the consensus makes attacks more likely. Simulation experiments show that PoS schemes consume only around 75% of the energy consumption needed for PoW systems (Zhang and Chan, 2020).

In another type of blockchain, usually referred to as permissioned blockchains, only a restricted group of participants can take place in the consensus, meaning that all participants are known (Sedlmeir et al., 2020). In this scenario, consensus is often called Proof-of-Identity or Authority. Beyond these consensus mechanisms, there are several other non-PoW blockchains that entail a lower energy consumption, with much less verification and communication on the chain.

Non-PoW blockchains and permissioned blockchains, which are mostly used in enterprise contexts, have generally higher energy consumption than that of non-blockchain centralized systems but the levels are also many orders of magnitude lower than those of PoW cryptocurrencies. *However—and this the key point -for large blockchains, the natural redundancy in achieving consensus in a large distributed ledger may also lead to significant energy consumption, regardless of the consensus mechanism used.* We discuss this consumption in more detail in the next section.

3. Energy consumption of cryptocurrencies

Most estimates of cryptocurrency energy consumption are based on the mining of Bitcoin, the first and best-known blockchain applicability so far. The validation process of Bitcoin's blockchain requires vast amounts of electricity, mainly because it relies upon the PoW consensus mechanism that is designed to be computationally intensive, as seen above. There is no agreement on the best way to measure the energy usage in blockchain. Various assumptions and methodologies are used in the literature, resulting in a high level of uncertainty. Several challenges arise when estimating electricity usage as i) the overall number of cryptocurrencies is uncertain, ii) the mining efficiency differs highly between devices and iii) cryptocurrencies are untraceable by design, making it difficult to identify the status of mining activity (Li et al., 2019).

Up until 2018, estimates and media coverage relied heavily on the Bitcoin energy consumption index, created for the website Digiticonomist by the economist Alex de Vries[10]. De Vries' index uses the average price of Bitcoin over a given span of time, the number of Bitcoins mined over the same period, an assumption about the percentage of Bitcoin mining revenues that is spent on electricity (60%) and another

[10] Available at: Bitcoin Energy Consumption Index - Digiconomist. Last accessed March 2022.

on the average price of electricity for Bitcoin mining. The latter was placed at $5cents/kWh. According to this index, Bitcoin energy consumption was as high as Hong Kong's in 2017 – around 44 TWh/year – and amounts to 73 TWh a year, based on the values from July 2018 through November 2019.

These energy consumption estimates have been criticized by some analysts and advocates for being inflated due to an overestimation of the amount of revenue spent on electricity during the mining activity. For example, cryptocurrency "enthusiast" Marc Bevand[11] assessed the Digiticonomist estimates and claimed a range in his data of electricity costs of between 6.3% and 38.6% of mining revenues, far below the estimated 60% threshold and implying significantly lower ranges of energy usage. The upper bound for the electricity consumption in the index assumes that 100% of the mining power came from the least efficient hardware that at the time was still mining profitably, and that none of the mining power was improved through more efficient hardware – a worst case scenario of miners adding up to 6.78TWh/year. The best-case scenario assumes that miners run on one out of three most efficient hardware and estimates energy consumption at 2.85TWh. Bevand's best educated guess for electricity consumption puts it at 4.12-4.73TWh/year as of July 2017, a much lower value than the one presented by Digiticonomist for 2017. As of January 2018, the figures increased to 18.40TWh – as much as the reported amount for Iceland in 2016 (18.1 TWh/year).

During 2018, however, the surge in prices resulted in a more than four-fold increase of the computational power required to solve a Bitcoin puzzle and electricity consumption increased accordingly, as estimated by Stoll et al. (2019). The authors capture this increase in power consumption, developing three scenarios to represent the geographic footprint of Bitcoin mining, based on pool server IP, device IP and node IP addresses. As we will discuss in the next section, the geographical footprint of the activity is essential to assess which type of energy resources are being used during mining and thus its corresponding environmental impact. Their results show that, as of November 2018, the annual electricity consumption of Bitcoin had a magnitude of 45.8 TWh.

But of course, Bitcoin is only one of many cryptocurrencies in the market. Gallersdörfer et al. (2020) estimate that Bitcoin accounts for 2/3 of the total energy consumption of the cryptocurrency network, with understudied cryptocurrencies accounting for the remaining 1/3: thus, cryptocurrencies beyond Bitcoin add "nearly 50% on top of Bitcoin's energy hunger, which alone may cause considerable environmental damage" (Ibid, p.1844).

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[11] Bevand, Marc. 2017. Electricity consumption of Bitcoin: a market-based and technical analysis (zorinaq.com). Last accessed March 2022.

Krause and Tolaymat (2018), extend the analysis and determine the power requirements for Bitcoin and three other cryptocurrencies: Ethereum, Litecoin and Monero, selected from the top 20 by market capitalization. All these networks resort to PoW schemes, hence their energy consumption can be measured by the hash rates of the networks (the number of calculations performed every second). As of August 2018, there were roughly 50 quintillion hashes performed by the Bitcoin network per second[12]. “The increasing hash rates are caused by both increasing participation of miners and increasing difficulty of the calculations” (Ibid, p. 2), reflecting the increase in energy usages. The authors follow the methodology proposed by Bevand (2017)[13], in which the hash rate of the network is multiplied by the power efficiency of the mining equipment, making the energy consumption dependent on the type of computer hardware that is used. Based on 2017 estimates, Bitcoin’s estimated energy consumption is about 8.3 trillion kWh/year, as much as Angola or Panama. For the year 2018, an assumption on Bitcoin’s market share (50%) was made, resulting in an estimation of 16.6 trillion kWH/year – a level similar to that of Slovenia or Cuba. The latter assumption was made with a certain degree of uncertainty, with the authors estimating that Bitcoin represents 73% of the total power demand of the four currencies in 2017, and 68% in 2018. Moreover, Bitcoin was found to consume a considerable amount of power in relation to others, in overall “magnitude, per coin and per US$ value created” (Ibid, p.5.).

In April 2018, Monero cryptocurrency conducted a hard fork (a change in the algorithm’s code) to change its Proof-of-Work algorithm to be ASIC-resistant. ASIC-resistant is a term used for protocol and mining algorithms that are optimized for the use of general-purpose central or graphic processing, in such a way that mining coins with ASIC devices is either impossible or brings no significant benefit when compared to traditional CPUs or GPUs. And although ASIC devices can perform a much higher number of calculations per second than those equipped with traditional processing units while being more power efficient per calculation, this change in the code of Monero’s mining algorithm to be ASIC-resistant and primarily run with GPUs was expected to decrease energy usage, since the hashing rates would drop substantially (Li et al., 2019). In fact, as noted by Gallersdörfer et al. (2020), this switch led to an abrupt decrease in the network’s computational power of more than 80%.

In an econometric study, Schinckus et al. (2020) study the effects of cryptocurrencies’ trading on primary energy consumption, showing a significant impact of the activity on energy consumption levels. Such results confirm that cryptocurrency trading increases global energy consumption with important

[12] Available at: Bitcoin Hashrate Chart (bitinfocharts.com). In January 2022, the hash rate of Bitcoin increased to over 200 quintillion hashes per second. Last accessed March 31, 2022.
[13] Refer to footnote 11.

consequences on climate change, as it has been pointed out by several contributions in the literature. The article examines the effects of cryptocurrencies trading on the energy consumption over the period 2014-2017, using Bitcoin and 1636 cryptocurrencies' trading volume, shown to increase energy consumption levels. While they proxy hash rates by trading volume of all cryptocurrencies due to the limitation of data for hash rates, the results can be replicated using the hash rates, in line with all literature, for the known cryptocurrencies. However, such data might not exist for all 1636 identified cryptocurrencies, as the crypto network is designed to operate secretively.

Summarizing, PoW mining remains the major blockchain scheme in the market and it consumes the largest amount of energy. The energy consumption associated with this scheme is highly dependent on the increase in the hashing algorithm, which in turn is dependent on both the increasing participation of miners and the increasing difficulty of the mining process (as reaching the consensus becomes more computationally intensive). Furthermore, since mining efficiency differs widely between devices, and cryptocurrency is untraceable by design, it is difficult to accurately estimate energy usage during the mining process. For example, estimates for the energy consumption of Bitcoin mining in 2018 range from 18.40TWh to 73TWh. The range amplitude reflects the uncertainty of tracing cryptocurrency activity, but even assuming the best-possible scenarios, the lower end figures are extremely high and point to an extremely dangerous consumption of energy. As the figures increase to the average and highest estimates, so do the dangers of this energy intensive activity.

However, we can already observe some attempts in reducing long-term energy requirements, such as Monero's hard fork in 2018 and Ethereum's future move to a Proof-Of-Stake scheme. This switch in the Ethereum network, also known as "the Merge"[14], is set for August of 2022, and implies a significant drop in the energy consumption of Ethereum mining, since PoS schemes consume much less electricity than the energy-intensive PoW. Theoretical findings report a 'low' energy use for PoS systems as opposed to the 'high' levels recorded for PoW (Li et al., 2020). Simulation experiments show that energy consumption can be reduced by around 75% if switching the consensus mechanism from PoW to PoS[15] (Zhang and Chan, 2020).

[14] In Locke, Taylor. 2022. Ethereum's blockchain is nearing a huge turning point that could push Ether's market value ahead of Bitcoin's, *Fortune*, March 23, 2022. Available at: https://fortune.com/2022/03/23/ethereum-merge-bitcoin/

[15] Zhang and Chang (2020) created an agent-based model for the blockchain system, that can be used to mimic different consensus mechanisms. It consists of node agents and block agents and has a fixed market with 100 participants. To assess the different energy consumption levels, the simulation length of each experiment was set to 300,000 minutes and the computing power and difficulty degree of blocks were generated randomly.

Regarding Non-Fungible Tokens, or NFTs (a blockchain application for something that is considered indivisible, irreplaceable and with a unique value, in this case the proof of ownership of the digital 'asset'), their energy consumption is also dependent on the type of consensus mechanism that is agreed to. Given that most NFTs' market, including MakersPlace, Nifty Gateway, and SuperRar, all belong to the Ethereum[16] network, which still resorts to the Proof-of-Work scheme, NFTs do currently represent increased energy demand (although their popularity is dropping[17] and its acceptability questioned[18]). After the switch of the Ethereum network to a Proof-of-Stake scheme, the energy usage associated with NFTs is expected to drop substantially.

4. Environmental Costs of Cryptocurrencies

As we have seen, the mining of power-hungry cryptocurrencies demands massive and increasing amounts of electricity. Like all other energy consuming activities, energy consumption maps onto climate change primarily if it is fueled by fossil fuels, such as coal or gas. "Consequently, the emission factors of electricity depend on the constitution of the generation resource mix, which varies among countries as well as regions" (Gallersdörf et al., 2020, p.1844). To keep global warming below 2ºC – as internationally agreed in Paris COP21 – reducing net carbon emissions during the second half of the century is crucial. In 2021, global CO^2 emissions from energy combustion and industrial processes increased 6% from the previous year, reaching a level of 36.3 gigatonnes (International Energy Agency, 2021). Adding to this increasing energy demand is the cryptocurrencies' network, with estimates putting emissions within 3-15 million tons of CO^2 for the period of 2016 until 2018, while others estimating higher levels of 22 to 22.9 million tons of CO^2 for the period of 2018 alone. Estimates vary, as translating energy usage into carbon emissions increases the uncertainty of the results, although they all point to the environmental damage that can be directly tied to the cryptocurrencies network. With the accelerated growth of cryptocurrencies and assuming the rate of adoption broadly follows that of technologies, electricity demand could increase to levels capable of

[16] Available at https://ethereum.org/en/nft/, last accessed March 2022.

[17] According to the Wall Street Journal, the NFT market is plummeting. The sale of NFTs fell from a daily average peak of about $225,000 in September 2021 to about $19,000 last May, with many collectors selling their tokens for much less than the original price. In Vigna, 2022. NFT Sales Are Flatlining – Is this the begging of the end of NFTs? *The Wall Street Journal*, May 3 2022. Available at https://www.wsj.com/articles/nft-sales-are-flatlining-11651552616

[18] As reported by the Media outlet the Verge, popularity of NFTs are decreasing due to concerns of environmental damage: *ArtStation, an online marketplace for digital artists, canceled its plans to launch a platform for NFTs within hours after getting a lot of backlash from people who think dealing in crypto art is environmentally unethical. Artists called NFTs an "ecological nightmare pyramid scheme" and ArtStation's plans to offset emissions a "scam" on Twitter*. In Calma, Justine. 2021. The Climate Controversy Swirling around NFTs. *The Verge*, March 15 2021. Available at: https://www.theverge.com/2021/3/15/22328203/nft-cryptoart-ethereum-blockchain-climate-change

producing enough emissions to exceed 2ºC of global warming in the decades to come. The large carbon footprint for such a small share of global cashless transactions is of great environmental concern.

Mora et al. (2018) published a peer-reviewed article, pointing to the obvious dangers of developing another energy intensive activity – crypto mining – without a clear objective other than profit. The authors estimate that computer processing power needed for Bitcoin mining would result in a global temperature rise of 2ºC by 2050 alone, putting emissions of Bitcoin mining for the year of 2017 at approximately 69 $MtCO^2$. The energy consumption was estimated by multiplying the energy efficiency of suitable hardware for Bitcoin mining and the number of hashes required to solve each mined block[19]. Additional information on the company claiming the given block and corresponding countries was collected, to estimate the carbon footprint of mining. For the resulting list of countries, the types of fuels used for electricity generation were assessed and the average standards of CO2 emissions for the generation of electricity with those fuels was used, mapping the total carbon emissions. By multiplying the electricity consumption of every block in 2017 by the electricity CO2 emissions in the country that was assumed to mine the block, the authors estimated the total emissions for that year's Bitcoin network.

To assess the carbon footprint of mining, the geographical composition of cryptocurrencies' blocks matter greatly, as uncertainty about the location can lead to inaccurate estimations. The findings of Stoll et al. (2019) suggest a high concentration of Chinese and to a lesser extent U.S. mining, mostly from fossil fuel resources. Mining activity was tracked based on pool[20] activities, device IPs and node IP address. Pool network activities links more than two-thirds of the computing power to Chinese pools (68%) that suggests the use of coal, followed by 17% in the EU and 15% in the US. Regarding the device IPs, more than 2 thousand devices are traced to the same mining producer, Bitmain, with a significant concentration in the US (19%), Venezuela (16%) and Russia (11%). As for node IP addresses, 93% of the communication made in network came from U.S. soil. These findings are important as they allow mapping the geographic footprint of the activity and assess their estimated carbon emissions with more accuracy. Despite this, some industrial-scale operations are moving from China to Canada to take advantage of cleaner and cheaper energy and there is also a record of mining activities using Icelandic geothermal power. Miners tend to relocate to where energy costs are the lowest, which ranges from areas that provide the cheapest fossil energy to those that are known for their natural resources and alternative means of energy. The latter

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[19] The data for each mined block contains their difficulty, which was used to estimate the number of hashes following the methodology of O'Dwyer and Malone (2014), with hashes = difficulty x 2^{23}. For further reference see O'Dwyer, K. and Malone, D. (2014). Bitcoin Mining and Its Energy Footprint. *25^TH IET Irish Signals & Systems Conference 2014*. https://doi.org/10.1049/cp.2014.0699

[20] Mining pool, in the cryptocurrency context, is the pooling of resources, i.e., processing power, by miners over a network. The miners then split the reward according to the amount of work each contributed to finding a block.

suggests that electricity decarbonization could help mitigate Bitcoin’s environmental impact – “but only where the costs of electricity from renewable sources is cheaper than fossil fuels” (Mora et al.,2018, p.2).

Krause and Tolaymat (2018) apply country-specific CO^2 emissions factors to the median daily energy requirements of cryptocurrencies networks, to map the geographical effect of the energy mix on the carbon footprint. The energy required per coin mined is the median value of all calculated values from 1 January 2016 to 30 June 2018. The energy consumed per coin mined (MWh per coin) has increased substantially in the previous two and a half years for all cryptocurrencies as a result of the 2017 price boom. The authors suggest that any *cryptocurrency mined in China would generate four times the amount of* CO^2 *compared to the amount generated in Canada* (Ibid, p.5). Applying the highest and lowest carbon emission factors (India and Canada) as upper and lower bounds, 3–13 million tons of CO^2 can be attributed to the Bitcoin network between January 2016 and June 2018. Using the same approach, the authors estimated that Ethereum, Litecoin and Monero mining generated 300-000–1.6 million tons of CO^2 combined. Thus, for the study period, cryptomining of these four is responsible for at least 3–15 million tons of CO^2 emitted, with Bitcoin being the largest contributor.

Stoll et al. (2019) further analyze Bitcoin’s environmental impact, with an estimated annual carbon emissions ranging between 22 and 22.9 Mt CO^2 – a ratio that sits between the levels produced by Jordan and Sri Lanka or comparable to the level of Kansas City. The authors use average emission factors as proxy to balance the effect of higher emissions at the margin and mining in regions with high shares of clean energy and note that hydropower accounts for around 80% of the electricity generated in the provinces of Yunnan and Sichuan (China), but that mining activities are also intensively based in coal reliant regions like Beijing. The contribution of Li et al. (2019) further estimates that if there is 4.7% of mining activity happening in China, at least 19.12~19.42 thousand tons of carbon dioxide can be linked to the Monero network.

In sum, the electricity demand of the cryptocurrencies network is creating significant environmental damage. Mapping of the geographic location of the mining activity points to the use of fossil generation resources in countries such as China, U.S., Russia or even Venezuela. While there are also records of renewable energy resources sustaining the industry, these power-hungry cryptocurrencies promote environmental degradation by causing more carbon footprint but by also representing an inefficient use of scarce resources. The table below summarizes the main estimates of cryptocurrencies electricity consumption and respective carbon emissions that were presented throughout the paper.

Table 1: Estimates of Cryptocurrencies Electricity Consumption and Green House Gas Emissions (Annual Figures)

	Electricity Consumption (in TWh per year)		Green House Gas Emissions (in million tons of CO^2 per year)		
Estimates for the Cryptocurrencies' network	**2017**	**2018**	**2016**	**2017**	**2018**
Digiticonomist	44	73		-	
Bevand (2017)	4.12 to 4.73	18.4*		-	
Mora et al. (2018)	-		-	69	-
Krause and Tolaymat (2018)	8.3	16.6		3 to 15	
Stoll et al. (2019)	-	45.8	-	-	22 to 22.9
Country Estimates* **					*in* $MtCO^2e$***
Iceland	19.2	19.8	-	3.34	3.35
New Zealand	43	43.2	-	71.45	70.71

Note: This table is for convenience of the reader only. It reflects different assumptions, methodologies, data and time periods and cannot be used for comparison.
***** Estimated figure for January of 2018 only.
******Emissions are measured in carbon dioxide equivalents (CO^2e) which includes weighted non-CO^2 gases. ******* Source: Our World In Data in ourworldindata.org

Social Impacts

Social impacts of Crypto are likely to be important but they are still not fully understood. Despite being decentralized, mining is not “placeless”, and the social impacts of each are centralized locally and may often exacerbate structural inequalities (Howson, 2019). The socio-economic benefit for the regions that suffer a cryptocurrency boom and attract high tech industries of cryptocurrency mining or data centers are moreover unclear. For example, the cryptocurrency mining in the Washington state has forced local communities to wrestle with the potential impacts of mass energy use. Crypto mining began in the Chelan County of Washington around 2010. Local authorities received a surge in requests for projects that would use 220 MW of electricity, an amount described as more than double the energy use for the entire county. In 2014, the Chelan PUD enforced a moratorium on companies or individuals applying for more than 5MW. In 2016, the county had 17 cryptocurrency mining companies. After a few compromises, the county accepted requests more than 5MW use if the users paid for all costs of construction and transmission upfront and having in hand a large enough power contract before arriving. This led to a boom in power inquiries, which led to yet another moratorium on new mining applications. Unauthorized miners started operating in residential areas, in some cases overtaxing electrical lines, and in response the Wenatchee city council banned crypto mining in residential or even mixed-use areas (Greenberg and Budgen, 2019). This, of course, is just one example. Much more research is needed to understand the local economic and social impacts of Crypto mining.

5. Other blockchain uses

Paradoxically, despite the excessive amounts of energy required by the cryptocurrencies network and the environmental damage they entail, some advocates claim that there are benefits of cryptocurrencies in fighting climate change, mostly as a carbon-incentive reduction scheme aimed at offsetting their overall carbon footprint. But most importantly, there is a growing literature on the prospective gains of the underlying blockchain technology in other industries, particularly the technological and energy sectors, that may provide efficient solutions for emission reduction schemes and the decarbonization process. While the use of cryptocurrencies does not seem to provide any benefit for the environment - on the contrary - some promising blockchain solutions take advantage of the decentralization of the network without the need for energy-intensive algorithms and provide some moments of climate change mitigation, particularly when resorting to smart-contracts that enable renewable energy transactions between the network peers. The still infant literature points to possible developments in these energy and technology sectors through blockchain systems. There should be room here for further research.

There are several areas which are said to benefit from blockchain technology. For example, it can solve security issues in the Internet of Things[21] (IoT) and future initiatives combining real life applications with the internet, or enabling the use of smart-contracts to control and configure those same IoT devices (Li et al., 2019)[22] . The decentralized technology can also facilitate machine-to-machine interactions and improve electricity use in the chemical industry (Sikorski et al., 2017). Other potential uses include optimization of automation, metering, billing processes, decentralized marketplaces and IoT developments (Andoni et al., 2019). Blockchain applications further include government record-keeping or data management projects, tracking the flow of goods and services along supply chains (Zile and Strazdina, 2018), asset registries and

[21] The Internet of Things (IoT) describes physical objects (or groups of such objects) with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.

[22] For further reference, see Khan, MA., Salah, K. 2018. IoT Security: review, blockchain solutions and open challenges. Future Generate Computational System. https://doi.org/10.1016/j.future.2017.11.022 and Huh, S., Cho, S., and Kim, S. 2017. Managing IoT devices using blockchain platform. ICACT, p. 464-7. https://doi.org/10.23919/ICACT.2017.7890132

transfer of ownership of hard asset or even applications to secure recording of intangible assets, which could range from any type of information to online voting systems (Swan, 2015).

The most prominent field of application, however, appears to be the energy sector, as reflected by the increasing number of research projects and startups surrounding the industry. According to the German Energy Agency, the decentralized nature of blockchain technology has the potential to improve the efficiency of current energy processes and provide innovation in peer-to-peer energy trading (Burger et al., 2016). Andoni et al. (2019) review over 140 blockchain uses in the energy sector and identify benefits and innovations of blockchain on creating transparent, tamper-proof and secure systems, enabling business solutions and local energy transactions, especially when combined with smart-contracts in peer-to-peer energy trading. These smart-contracts – self-executing codes that provide secure mechanisms for electronic collaboration, allow for real-time settlements and data recording of energy produced, consumed and its respective transactions in a distributed ledger (Ibid), which can be shared with network operators and energy suppliers and result in more efficient processes and traceable green energy[23].

As the renewable energy sources are variable, dependable on weather conditions and raise challenges in management and operation of electricity systems, they thus require more flexible measures – including the integration of fast acting supply, demand response and energy storage services – improved network resilience and security of supply (Andoni et al., 2019). Future energy systems must meet principles of decarbonization, decentralization, accounting for an increasing number of actors and different actions, and digitalization. The current energy market structure is inadequate to meet such goals but decentralized blockchain technology, by facilitating and developing IoT applications, enabling transactions in peer-to-peer energy trading and promoting more efficient flexibility markets, can possibly meet the required decentralization and digitalization (Ahsan and Bais, 2017). At the same time, reports show enhancements in network resilience, security of supply and transparency of the operations (Mattila, 2016). The technology can also improve practices of energy enterprises and utility companies by improving internal processes, customer services and costs (Burger et al., 2016).

An increasing number of power systems have already begun implementing smart meters in power grids, allowing a producer of energy to directly trade with a consumer or energy retail supplier (Jaradat et al., 2015). The wholesale energy market also benefits particularly from the technology, being able to reduce the third-party intermediaries, including brokers, exchanges, logistic providers, that are currently necessary for the time-consuming verification of transactions. These cost savings are not only restricted to the

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[23] Available at: https://www.sunchain.fr/sunchain#concept Last accessed June 2022.

industry, with promising solutions that intend to enable consumers and prosumers – who both produce and consume – to engage in local or consumer-centric marketplaces and support local power generation (Andoni et al., 2017; Pinson et al., 2018).

Projects using the blockchain technology to exchange energy in microgrids are expanding. Brooklyn Microgrid, for example, allows peer-to-peer energy trading between local community members. Producers sell their energy surplus to their neighbors through the use of smart-contracts, with energy surplus being measured by smart meters that handle energy measurements and subsequently transform it into energy tokens that can be transferred to end consumers through the use of the blockchain technology. The microgrid users interact with the platform by specifying their demand and willingness to pay and payments are automatically initiated by self-executed contracts, with all information being securely recorded in the ledger (Mengelkamp et al., 2018).

The idea was said to be introduced by a Brooklyn resident who promoted the first-ever blockchain based peer to peer energy transactions system, implemented with a solar panel that sells locally generated surplus solar energy to the neighborhood through an Ethereum smart contract (Marke, 2018). Currently, other types of systems are also in place, such as the Regen Network, that uses blockchain technology to monitor and verify environmental performance, share data, and facilitate payments to local land stewards. The network proposes automated remote sensors to generate reliable attestation about environmental changes in any predefined geographical area, in a project that gathers blockchain application developers, ecologists, farmers and forest communities (Booman et al., 2021; Howson, 2019).

These initiatives depict a use of the blockchain technology that appears to remove frictions from the renewable energy market, namely when resorting to the use of smart contracts, and in permissioned environments that require vast less computational power (Sedlmeir et al. 2020). The benefits are most evident for local energy and consumer oriented microgrids and marketplaces that aim to support local energy production and consumption, while meeting the flexibility the market demands (Pinson et al., 2018). Limitations of the use of the technology include scalability concerns underlying the growing distributed ledgers, costs of the infrastructure and initial investment, as well as anonymity and privacy required while still maintaining the desired properties of decentralization and security (Andoni et al., 2019)

While the innovative aspect of blockchain may be enabling some instances of effective climate-change mitigation, a rising number of projects are actively linking cryptocurrencies to these new green initiatives, in a shallow attempt to offset their carbon footprint. Mihaylov et al. (2014) considers the use of cryptocurrencies for peer-to-peer energy trading, in which the energy injected into the grid into a digital coin that enables local energy trading of producers. The coins reflect the supply and demand conditions at the time of the energy injection and can be later used to buy electricity from the grid or exchanged in the market for other cryptocurrencies. Candela Coin, another cryptocurrency, allows holders to transfer solar energy using the currency as a medium of exchange. Solar-panel owners can also sell their excess solar energy to neighbors in their community. This Washington Based company has also built a user-friendly app that acts as a solar marketplace for Candela Coin transactions, and an IoT meter to measure energy. *"This experience is perhaps trying to provide a cryptocurrency that is directly tied with energy, rather than carbon-credit based, and hopefully will encourage people to use their solar panels"* (CEO of Candela Coin, in Adam 2021). Many other cryptocurrencies developers are increasingly linking their initiatives with these potentially efficient blockchain innovations, pursuing a cryptocurrencies' incentive scheme that fosters a market with a heavy environmental toll.

Other cryptocurrencies' advocates go a step further in a clear attempt of greenwashing their environmental costs, directly tying cryptocurrencies to the carbon credits market. A Honk Kong private cryptocurrencies company, Earth's Veridium Labs, is working in partnership with IBM and connecting their payment systems with carbon credits produced from Infinite Earth's Forest reserve in Rimba Raya, Central Kalimantan. Earth Dollar, another coin, aims to link carbon credits to blockchain tokens that can later be redeemed for other types of currencies, while further claiming the issuance of blockchain tokens promotes local tree planters, to incentivize conservation in Zimbabwe's Kariba Forest. In fact, no financial compensation by Earth Dollar to forest communities of Zimbabwe has ever been made for tree conservation projects, using Earth tokens or any payment method. Some other initiatives also enable automated smart-contract payment protocols, "so that embodied carbon emissions from consumer purchases can be calculated and carbon credits purchased automatically" (Howson 2019, p.644). Ecosphere+, a natural-asset management company based in Luxembourg, is supplying carbon credits originated from the conservation efforts in Peru's Cordillera Azul National Park to investors using blockchain tokens. The credits are then provided to Ecosphere+'s blockchain partner platform Poseidon, that allows consumers and retailers to track and offset their carbon footprints using Ocean tokens[24]. The initiative gathered the support of Liverpool City Council and of Ben and Jerry's London branch.

Similarly, Evergreen Carbon Credits (ECC) has developed a unique purchasing and verification system of certified carbon credits using blockchain technology and Non-Fungible Tokens. According to ECC, a user can select the amount of carbon credits they intend to purchase and an NFT certificate of the purchased

[24] Poseidon, 2019. The Solution. Available at: https://poseidon.eco/solution.html, Last accessed March 2022.

amount of carbon credits is then delivered to a digital wallet. Cryptocurrencies can be used to purchase ECC, offering a way to offset their carbon print, accordingly to the company's CTO[25].

Several crypto businesses also joined the Crypto Climate Accord, an initiative to decarbonize cryptocurrencies by using carbon credits and alternative energy sources. Among the members are Ripple, Consensys and the XRP Ledger Foundation. *"*The accord has a goal of reaching net zero greenhouse gas emissions by 2040, net zero emissions from electricity consumption by 2030 and to develop standards and technology to support 100% renewably powered blockchains by 2025" (Adams 2021, p.8), but no plans are set in motion. Other energy reducing initiatives include the change in the consensus mechanism from Proof-of-Work to less power-hungry algorithms, although the levels of magnitude of non-PoW cryptocurrencies are of many orders more than those of conventional centralized databases (Sedlmeir et al., 2020).

Despite the growing number of initiatives, connecting carbon credits to cryptocurrencies has no offsetting impact on the environment. Even the UN architects, the initial proponents of incentive-based schemes to reduce emissions or deforestation, have concluded that "carbon offsets have been used by polluters as a free pass for inaction"[26]. Cryptocurrencies and carbon credits schemes such as the one proposed by Poisedon have no positive local impact: "Instead of reaching local host communities, income from Poseidon crypto-carbon sales are used to repay loans from Ecosphere+'s private investors*"* (Howson 2019, p. 645). As for the Climate Crypto Accord goal of having 100% renewably powered blockchains by 2025, given the resource mix presented above such scenario appears unrealistic and would moreover continue to represent a waste of scarce resources. The environmental damage this energy intensive activity entails points to its unsustainability and destructiveness, raising the question of whether cryptocurrencies bear anything else than severe costs for the environment and communities.

Cryptocurrencies: a speculative asset and illicit means of payment

Cryptocurrencies account for the most widespread use of the blockchain technology. While it is not the aim to this paper to provide an in-depth analysis of the cryptocurrencies market, there are important characteristics that are crucial to understand the role these coins can – or cannot – play in the future economy. Additionally, they describe the motivation driving the massive demand for electricity.

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[25] Evergreen Carbon Credits: Carbon Credits and Cryptocurrencies with NFT's. Available at: https://www.prnewswire.com/news-releases/evergreen-carbon-credits-carbon-credits-and-cryptocurrencies-with-nfts-301502860.html, Last accessed March 30,2022.

[26] United Nations Environmental Program, 2019. Carbon offsets are not our get-out-of-jail free card. Available at: https://www.unep.org/news-and-stories/story/carbon-offsets-are-not-our-get-out-jail-free-card, Last accessed March 2022.

The popularity of cryptocurrencies brought attention to the substantial amounts of energy required to sustain the network. In the reverse side of the coin are many millions of investors that profit from the cryptocurrencies' rapid rise in value, accumulating wealth as the market booms. This profit-driven activity relies on the speculative gains of the coin's future increase in value, which in turn depends solely on investors' confidence – as without any intrinsic value or third party claiming and backing their worth, cryptocurrencies are intrinsically worthless.

Nonetheless, investments are frantic, creating an expanding market for cryptocurrencies that hit an all-time peak of around $3 trillion in November 2021. The market's slump in June of 2022 and the downward trend since late 2021 have led prices to fall by more than 70%. Yet there are still over 20,000 different types of coins in the market, with an overall capitalization of more than $1 trillion.[27] The speculative prospects and the extreme volatility the market presents renders any attempt to categorize cryptocurrencies as a currency unfruitful, despite what the name and widespread opinion have been suggesting since the first appearance of Bitcoin. Because investors hold cryptocurrencies with the expectation that their worth will increase in the foreseeable future, these coins lack one elementary characteristic of money, that of storing value, and in fact resemble the characteristics of an extremely risky speculative asset. Economist Jorge Stolfi (2021), based on the behavior of Bitcoin, observed that investors buy in the expectation of profits, with that expectation being sustained by the profits of those that cash out. These profits have no external source, coming entirely from new investments, meanwhile the operators take away a large portion of the money. Because of this, not only do cryptocurrencies represent speculative behaviors, but are considered Ponzi schemes (Stolfi, 2021). Schemes whose losses, as opposed to what happened to a limited extent with the recent financial crises and the Ponzi original scheme of the 1920s, could not be claimed or paid back by any institution or individual. As the only way a holder of cryptocurrencies can cash out is by selling to someone else, in the advent of a crash, holders would have no claim on those who bought early and sold and "no one to pursue to recover the sum: it will simply have gone up in smoke, a social loss" (McCauley 2022)[28].

The growing size of the crypto market – with a market capitalization a little more than half that of Microsoft's[29] – exacerbates such potential loss. According to a Goldman estimate, U.S. households are said to own-one third of global crypto market, and a Pew Research survey found that 16% of U.S. adults had

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[27] Available at: https://coinmarketcap.com/ last accessed July 2022.
[28] In McCauley, Robert. 2022. Why bitcoin is worse than a Madoff-style Ponzi scheme. *Financial Times* March 1st 2022. Available at https://www.ft.com/content/83a14261-598d-4601-87fc-5dde528b33d0?shareType=nongift
[29] Available at: https://companiesmarketcap.com/assets-by-market-cap/ last accessed July 2022.

either invested, traded, or used cryptocurrencies.[30] Financial regulators are also concerned that the crypto economy poses growing financial systemic risk, as cryptocurrencies and derivative products become more embedded and disbursed through mainstream finance and the economy (Collins, 2022). El Salvador's experience with crypto is telling. The country adopted Bitcoin as a legal tender alongside the U.S. dollar in September 2021, having spent approximately $105.6 million in the hope their value would rise. The cost of purchasing, rolling out bitcoin ATMs and the appropriate software has been pointed out as at least $200 million, according to David Gerard, author of the Attack of the 50 Foot Blockchain.[31] The fallen price of Bitcoin has cut in half the value of the nation's investment, with cumulative losses on the government's holdings of about $40 million, which represents 0,5% of their nation reserve. The nation had $3.4 billion in reserves in April of 2022 and owes bondholders $382 million in interest for this year alone. The country's foreign debt tumbled around 18% this year as a result, leaving bonds due in 10- and 30-years trading "deep into distressed territory" (Oyamada and McDonald, 2022).[32] The government had plans to raise $1 billion with a Bitcoin-backed bond, but with the recent crash and having failed negotiations with the International Monetary Fund for an extended fund facility, precisely because of the adoption of Bitcoin as legal tender, the country now faces higher expectations of defaulting and lower debt ratings. The Central American country saw the largest quarterly and yearly period increase in its 5-year CDS (Credit Default Swaps) prices, rising by 66% in the last quarter of 2021 and up to 153% in 2021.[33] Amidst this, most Salvadorians households are reported to have abandoned the crypto national wallet after receiving the download bonus[34] converting it to cash, while 88% of firms report that they too cashed out of bitcoins. Now only about 5% of sales being paid for through Bitcoin (Alvarez et al., 2022).[35]

Countries under international sanctions have been also using Bitcoins. Iran, for example, is promoting mining as a workaround to the market restrictions, legalizing industrial-scale crypto mining. Flush with oil

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[30] In Perri, Andrew. 2021. 16% of Americans say they have ever invested, traded or used cryptocurrency. *Pew Research Central*, November 11, 2021.Available at: https://www.pewresearch.org/fact-tank/2021/11/11/16-of-americans-say-they-have-ever-invested-in-traded-or-used-cryptocurrency/

[31] In Talyor, Luke. 2022. What will the crypto crash mean for 'bitcoin nation' El Salvador? *NewScientist*, June 16, 2022. Available at: https://www.newscientist.com/article/2324810-what-will-the-crypto-crash-mean-for-bitcoin-nation-el-salvador/

[32] Oyamada, Aline and McDonald, Michael D., 2022. El Salvador's Bitcoin Losses Are Equal to Next Bond Payment. *Bloomberg*, May 12 2022 Available at: https://www.bloomberg.com/news/articles/2022-05-12/el-salvador-s-bitcoin-losses-are-as-big-as-its-next-bond-payment

[33] In Feliba, David. 2022. Latam Economies See CDS Spreads EBB in Q4. *S&P Global*, January 7, 2022. Available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/latam-economies-see-cds-spreads-ebb-in-q4-68317486

[34] El Salvador introduced the national digital wallet, Chivo, along with incentives for its download that included $30 in free bitcoin with each download, nearly 1 percent of average annual per capita income, alongside discounts on gasoline paid with Bitcoin (Alvarez et al., 2022)

[35] The authors conduct a nationally representative survey with 1,800 household and firms, on the adoption of Bitcoin as a legal tender since September 2021.

and gas revenues, the government provides hardware and free electricity to licensed mining operations that mine Bitcoins and sell back to the country's central bank. According to reported research from Elliptic, approximately 4.5% of the 2021 Bitcoin mining took place in Iran, with annual revenues of around $1 billion for the year.[36] 12 million Iranians are estimated to own crypto and have most likely taken a hit in the recent crash. [37] Potential implications for systemic risk grow as Bitcoins and other cryptocurrencies' use as a means of payment becomes mainstream in ordinary lives.

The use of cryptocurrencies as a means of payment, alongside their speculative prospects, are two main financial motives for the use of cryptocurrencies. These coins became popular not only because of their rapid valuation and thus rapid speculative gains, but because they allow the individual to make secure transactions without a central authority or intermediary.[38] As such, cryptocurrencies have been developed for over a decade into a means of payment and transfers of funds, where users rely on the anonymity of the network. Albeit transparent and traceable, blockchain technology increases privacy (IOCTA, 2022). The enhanced security and close to anonymity of transactions attracted criminal activity, taking advantage of the crypto landscape to conceal crimes and the origin of the assets much more easily (Bele, 2021)

Cryptocurrencies are thus being used in facilitating criminal transactions, predominantly associated with various forms fraud such as extorsion, Ponzi schemes and other investment scams, dark web payments for cybercrimes and online trade in illicit goods and services, as well as money laundering (Ibid). According to a Europol report, fraud is the most frequently identified illegal use of cryptocurrencies, but they are also particularly used within the growing number of for-profit schemes relating to child sexual abuse (Europol Spotlight, 2022). For the European Union Serious and Organized Threat Assessment, the anonymous nature of online transactions in these marketplaces reduces the risk of detection by law enforcement authorities for both vendors and buyers.[39] In 2021, Chainalysis estimated that around $8.6 billion were laundered in cryptocurrencies, a 30% increase from the 2020 figures, according to the amount of cryptocurrency sent

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[36] Elliptic, May 21, 2021: How Iran Uses Bitcoin Mining to Evade Sanctions and "Export" Millions of Barrels of Oil. Available at: https://news.bitcoin.com/up-to-12-million-iranians-own-cryptocurrency-traders-choose-local-exchanges/

[37] In Tassev, Lubomir. 2021: Up to 12 Million Iranians Own Cryptocurrency, Traders Choose Local Exchanges. *News*, November 1, 2021Available at: https://news.bitcoin.com/up-to-12-million-iranians-own-cryptocurrency-traders-choose-local-exchanges/

[38] In the blockchain configuration, miners are responsible for validating the transactions, thus representing the intermediary of such transaction. Miners get commissions for each transaction, with an average tariff of $11.42 as of January 2021. Because of this fee, cryptocurrencies are not deemed suitable for the payment of goods and services of lower value (Collins, 2022).

[39] United Nations Office on Drugs and Crime Press Release, 25 May 2017. Side Event on "Investigation of Money-Laundering and Terrorist Financing with Cryptocurrencies". Available at https://www.unodc.org/unodc/en/drug-trafficking/crimjust/news/side-event-on-investigation-of-money-laundering-and-terrorist-financing-with-cryptocurrencies.html

from illicit addresses to addresses hosted by services.[40] Consequently, many governments worldwide have been calling for the introduction of anti-money laundering regulations on cryptocurrencies and cryptocurrency-enabled organized crime that could tackle this growing phenomenon.

The overwhelming examples of cryptocurrencies, as enabler of crime and illicit activities, its extreme volatility, and the social and economic losses such speculative, unstable activity might entail, on top of its significant environmental damage, deem its use harmful if not destructive. Cryptocurrencies still account for a small share of global finance, around 1 per cent of global financial assets as of June 2022[41], but it already poses a sizeable threat. Even if the future path of blockchain is one of further regulation, de-anonymization, and policing for cryptocurrencies, these are still extremely volatile digital assets without any intrinsic value, which production requires levels of energy consumption so high, the activity alone is already worsening climate change. It is hard to conceive a future for any financial or monetary system that bases itself on cryptocurrencies.

Central Banking Digital Currencies (CBDCs)

Amidst the growing popularity of cryptocurrencies, central banks across the world have begun to develop digital tokens, Central Banking Digital Currencies (CBDCs). This new form of digital money supplements existing central bank reserves and physical currency, with the objective of improving efficiency in payments, promoting innovation in financial services and privacy. It is pegged to the value of the country's fiat currency and represents a direct claim with the central bank, which handles payments and records all transactions. CBDCs are typically based on blockchain technology, using digital wallets that store cryptographic keys for the validation of transactions and interact with a central transaction processor, run by a trusted operator. This aspect creates a central authority in the currency's ecosphere, the central bank, differentiating them from cryptocurrencies. Importantly, the system does not need energy-intensive consensus mechanisms to provide trust and security to the transactions as it operates in a permissioned environment. Nonetheless, it still faces issues regarding the inherent redundancy of blockchains, with each block containing all the information of the previous blocks. For small networks, redundancy does not add much absolute energy consumption but in large systems, the natural redundancy in a blockchain can lead to much higher energy consumption (Sedlmeir et al., 2020). However, CBDCs do not need to rely on distributed ledger technology, as other conventional centrally controlled databases can be used to develop this new digital currency, typically entailing much lesser electricity usage; in fact, applying distributed

[40] Chainalysis (2022). DeFi Takes on Bigger Role in Money Laundering But Small Group of Centralized Services Still Dominate. Available at: https://blog.chainalysis.com/reports/2022-crypto-crime-report-preview-cryptocurrency-money-laundering/ Last accessed July 2022.
[41] In Collins (2022).

ledgers to the creation of CBDCs was found to hinder its efficiency and scalability, creating for example bottleneck performance problems, as blockchains are typically very large and require more time to process transactions (Federal Reserve of Boston, 2022).

Currently, 105 countries representing roughly 95% of the world's GDP are at some level engaged with CBDCs, whether in a research phase or even at more advanced stages of implementation[42]. Out of the total, ten countries already launched their digital coins, with nine belonging to the offshore area of the Caribbean. In the Bahamas, for example, the Central Bank recently issued their CBDC, the 'sand dollar', that holds the same value as the official national currency and can be used for purchasing services and goods within the country, or even collecting (state) salaries or pensions. The People's Bank of China also adopted its CBDC, the digital renminbi, boosting 140 million individual yuan account and 150 million transactions, totaling an equivalent of $9.7 billion U.S. dollars (Collins, 2022). A 2021 survey by the Bank of International Settlement further found that 9 out of 10 Central Banks are considering their own CBDCs (Kosse and Mattei, 2022).

Even when developed with blockchain technology, the CBDC system entails a permissioned environment by the central authority – just like the wholesale lines established with a Central Bank. As previously mentioned, permissioned environments require much less amounts of energy use for the mining and validation process. However, they still require larger amounts of energy than conventional databases and have possible downturns in terms of efficiency and scalability. Because the CBDC research process is in its early stages in most jurisdictions, the architecture and design of this new form of digital currency is still open for investigation.

6. Conclusion

Since its inception, Bitcoin remains the best known use of blockchain technology. The digital coin's surge in price led to an investment boom in crypto mining that raised attention to the vast amounts of energy required to maintain the blockchain, validate its transactions and issue new cryptocurrencies. Operating in a permissionless environment, the system entails a consensus mechanism to validate the transactions that relies upon a Proof-of-Work scheme, a computationally intensive puzzle that must be solved so that new coins are issued. This in turn requires vast computational power and an increasing energy supply, since to maintain the average time of mining a new block constant and account for technological improvements and the increasing number of the miners, the difficulty of such puzzles must be continuously adjusted. Other

[42] Available at: Central Bank Digital Currency (CBDC) Tracker (cbdctracker.org) Last Accessed June 2022.

consensus mechanisms exist, such as Proof-of-Stake algorithms, that are estimated to use less than 75% of the energy necessary for PoW schemes, but are still many orders of magnitude larger than those of conventional centralized databases[43]. Even when using a non-PoW scheme, a blockchain stores data in a continuously expanding ledger, which entails a level of redundancy that represents a significant drive of energy consumption (Sedlmeir et al., 2020). Furthermore, a network using these types of alternative consensus mechanisms faces concerns regarding the security and integrity of the system, two usually defining properties of the blockchain technology.

The amounts of energy that are thus associated with the cryptocurrencies' network are found to be significant, as high as the annual consumption levels of countries such as Iceland or Angola. When deploying fossil generation resources, this increased energy demand translates into carbon emissions, with estimates pointing to an average emission of 3-15 $MtCO^2$ of only the crypto activity between 2016 and 2018 (Krause and Tolaymat, 2018). This is equivalent to the global annual CO^2 emission of countries such as Haiti or Cambodia[44].

The system also experiences high demand and limited supply, which creates an incentive to participate either actively through mining, or passively, by holding a certain number of cryptocurrencies. The question arises: how sustainable will the demand for Crypto be in the face of substantially increased volatility and price crashes? As of June 2022 there has been a drop of more than 70% of the Bitcoins' value, falling well off its 69,000$ peak in November 2021[45] threatening investors and crypto companies. The growing crypto economy threatens financial stability and increases systemic risk, as cryptocurrencies become more mainstream and embedded in the economy and global finance. Consequences of the Bitcoin crash were already felt by El Salvador, the first country to adopt it as a legal tender in September 2021. Having bought 2301 Bitcoins at a cost of approximately $105.6 million, the country lost $56 million, over 50 percent, with the devaluation of the coin[46]. Although the investment is said to represent only 0,5% of the El Salvadorian

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[43] Sedlmeir et al. (2020) estimated energy consumption between centralized and blockchain databases, and showed how a simple server can sustainably operate tens of thousands of transactions per second on office hardware while consuming less than 100 Watts, which yields about 10^-2 Joules per transaction. More complex databases such as centralized systems require an energy of 0.1J per transaction, while the levels reported for enterprise-level blockchain solutions, capable of performing 3000 transactions per second, are of 1 Joule per transaction. Public non-PoW blockchain report considerably higher levels, in the order of 10^3 joules per transaction. For reference, the order of magnitude of Bitcoin was 10^9 J per transaction.

[44] Based on reported values for 2022. In https://worldpopulationreview.com/country-rankings/carbon-footprint-by-country, last accessed June 2022

[45] In Smith, Hannah. 2022. Bitcoin crash: What's behind the crypto collapse. *The Times*. June 14, 2022. Available at: https://www.thetimes.co.uk/money-mentor/article/is-bitcoin-crash-coming/

[46] In Maki, Sidney. 2022. El Salvador's Big Bitcoin Gamble Backfires to Deepen Debt Woes. Bloomberg Europe Edition. June 15, 2022. Available at: https://www.bloomberg.com/news/articles/2022-06-15/el-salvador-s-big-bitcoin-gamble-backfires-to-deepen-debt-woes#xj4y7vzkg

National Budget, the loss aggravates the country's financial situation, with agencies such as Moody already downgrading its debt ratings.

The drop in the attractiveness of cryptocurrencies due to the Bitcoin crash may decrease the mining activity, although there is already massive investment in hardware and mining facilities in place, both by small scale and large mining operations that have attracted the attention of big corporations in the past years. These companies may continue to deploy significant efforts towards the blockchain financial driven activity.

On the plus side, the popularity of the coins also brough attention to the underlying technology and prompted multiple initiatives surrounding blockchain, with promising contributions particularly in the energy field. Advances in the sector seem to promote efficiency gains in decentralized energy trading, including the wholesale, retail and peer-to-peer energy. These energy related applications have been allowing some moments of climate change mitigation and can account for future innovations in the energy sector. The role of these types of applications should be an area for future research particularly in the technological and energy fields, allowing a better resource allocation of renewable energies while solving the still underlying limitations of security and scalability. Other uses of the blockchain technology, such as developments in automation, metering, billing, smart-devices, and the Internet of Things may also be of importance in the decarbonization process ahead, facilitating technological improvement.

At the same time, although some blockchain applications are intended to improve energy efficiency, they also highlight the ecological unsustainability of their financial counterpart: cryptocurrencies, with an underlying incentive scheme that requires vast computational power and resorts to massive energy levels, much of which from fossil generation resources. The environmental damage the activity causes is only worsened by the social and economic costs some communities are already beginning to experience given the speculative use of these assets and the underlying risks such a volatile system entail. Carbon credits or other incentive reduction schemes that resort to cryptocurrencies are worthless at best and even if changing the energy source from fossil to renewable, cryptocurrencies would continue to represent a waste of scarce resources. In this moment of climate crisis, bearing a heavy environmental, socio and economic toll, it is hard to argue that cryptomining should not be regulated out of existence. Alternatively, an adequate price on carbon may do the trick through the "magic" of the marketplace. The danger is that cryptominers, fintech companies and fossil fuel capitalists will form a powerful, unholy alliance to prevent these regulations and carbon prices from taking place, driving the social costs of crypto speculation unsustainably high.

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