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Decoding Bitcoin: A Synthesis of Bitcoin's Relation to the Environment with a Focus on CO2

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Abstract: Since the financial crisis, bitcoin has become a pioneer among virtual currencies, and much attention has been focused on its mechanisms, market risk and expected development. Despite extensive research into these aspects, the broader significance of bitcoin's existence has gone unnoticed. A critical facet is Bitcoin mining, notorious for its substantial energy consumption and subsequent carbon emissions. This dynamic interplay with the environment and energy market is a pivotal yet understudied aspect of Bitcoin's impact. Consequently, this paper seeks to fill this research gap by synthesizing existing literature on the repercussions of bitcoin mining on energy consumption and the environment. By delving into the intricate relationship between Bitcoin mining and its environmental consequences, the paper aims to shed light on a critical yet often neglected dimension. Furthermore, the analysis extends to examining the responsiveness of prevailing government policies to address the environmental concerns associated with Bitcoin mining. This endeavor underscores the necessity for a comprehensive understanding of the broader consequences of cryptocurrency activities, particularly in the realm of energy consumption and environmental sustainability.

Keywords: carbon emission, energy price, climate change, Bitcoin price, energy policy.

1. Introduction

1.1. What is Bitcoin

Bitcoin is a peer-to-peer electronic currency system originally proposed by Satoshi Nakamoto in the Bitcoin White Paper, which implies the ability to make online payments directly from one party to another, bypassing financial intermediaries such as central banks [1]. It provides extreme privacy while maintaining a simple and straightforward network structure. The transaction history is difficult for an attacker to attack because it becomes computationally immutable very quickly, and the nodes do not require a long period of coordination to operate at the same time [1]. It is also the most popular virtual currency at the moment.

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1.2. The History of Bitcoin

Satoshi Nakamoto sent a report named "Bitcoin: A Peer-to-Peer Electronic Cash System" to the cryptocurrency mailing list metzdowd.com in 2008, amidst the world financial crisis. This marked the beginning of Bitcoin, the first cryptocurrency trading platform. Initially, the price of BTC was approximately $0.003.

On May 22, 2010, a significant event took place when Laszlo and Jercos became the first couple to engage in a real-world trade using Bitcoin. Laszlo bought two Papa John's pizzas from Jeremy Sturdivant for 10,000 BTC. At that time, Jeremy Sturdivant was only 19 years old. This event, affectionately referred to as "Pizza Day," is a significant milestone in the crypto community. In the thread, Laszlo stated that the BTC he was offering was worth about $41 USD at the time, while two pizzas would be worth $25-$30 USD. This means that the recipient of the BTC would make a significant profit on the sale. Lazslo posted this offer on BitcoinTalk. 3 ½ days after his original post, he finally found a taker. Surprisingly, he also posted his real-world address on the forum in the open as well.

On August 15, a major flaw in the protocol of the bitcoin blockchain made it necessary to fork in order to apply a correction to the protocol and undo a transaction that allowed someone to create and send more than 184 billion BTC to two addresses. This was necessary not only because of how new the bitcoin blockchain was at the time, but also because a total of 21 million BTCs is the maximum number of BTCs that can ever be mined. The bug was first noticed by BitcoinTalk user jgarzik, who drew the community's attention to the first block (#74638) in which the first transaction of more than 92 billion BTC took place. In the history of bitcoin, this was the first major hard fork.

In February 2011, Ross William Ulbricht funded the Silk Road, a website that was specifically designed with the intention of allowing the solicitation of illegal goods and services to take place without government interference. To this end, his choice of BTC as the medium of exchange was in line with this requirement. This helped cloud the legitimacy of BTC in its early years, as many believed it was something only used by criminals. In particular, it is worth noting that in the early days of Bitcoin, he sold psychedelic mushrooms on the Bitcoin Talk forum. In April, BTC crosses the $1.00 USD mark for the first time. Namecoin is launched as the first altcoin and competitor to BTC. In May, Room 77 in Kreuzberg, Berlin becomes the world's first bricks-and-mortar business to accept cryptocurrencies, accepting BTC in exchange for a beer. Unfortunately, the establishment's closure date is October 2022. June 13 Mt. Gox becomes the first cryptocurrency exchange platform hacked. From about 478 accounts, more than 25,000 BTC are siphoned off. Valued at around $40,000 USD at the time.

In 2013 June 23rd The U.S. Drug Enforcement Administration announces that it has had 11.02 BTCs in its possession. This is the first time a government agency has made such a claim. October 13 The first BTC (and cryptocurrency) ATM, a Robocoin BTC ATM, opens in a West Waves coffee shop in Vancouver, Canada. November 13th The University of Nicosia in Cyprus commences the acceptance of BTC for tuition payments. November 27th BTC reaches $1,000 USD for the first time.

In 2014 December 11th Microsoft begins accepting BTC payments for its US-based customers through its online store only.

In 2015 April 13th The Free Republic of Liberland is founded as a micronation on unclaimed land between Croatia and Serbia, with BTC as its official currency. In the meantime, it has established its own digital currency. However, it is still considered disputed, unclaimed territory by its neighbors, and is not recognized as a real country by any major nation.

On March 4, 2016, the Japanese cabinet approved a set of bills that would recognize the BTC and cryptocurrency as a financial instrument, making it the first country to do so. But that didn't happen

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until April 1, 2017, when the country acknowledged cryptocurrency as real money rather than a mere medium of exchange.

In 2017 August 17 Bitcoin Cash (BCH) was created when a hard fork was implemented on the main bitcoin blockchain to revert back to the pre-fork algorithm by a significant group of bitcoin miners who were unhappy with the Bitcoin Segregated Witness hard fork and wanted to return to the previous algorithm.

1.3. Why It's Worth to Study

Bitcoin represents the first successful implementation of a decentralized digital currency, underpinned by blockchain technology, offering revolutionary innovations. Studying Bitcoin can provide valuable insights into the potential and applications of blockchain technology. Bitcoin's emergence challenges the conventional financial system by eliminating the role of central banks and empowering users directly. Researching Bitcoin can offer insights into the potential evolution and reform of future financial systems.

However, Bitcoin mining, the process which creating Bitcoins, will impact energy finance industry. It explains about Bitcoin as follows[2]: Through the use of distributed consensus, mining adds pending transactions to the blockchain after validating them. It preserves network neutrality, guarantees chronological order on the blockchain, and permits different hosts to concur on the current state of the system. Transactions must be included into blocks that adhere to stringent cryptographic guidelines that are confirmed by the network in order for them to be validated. These guidelines forbid changing earlier blocks as doing so would render all later blocks invalid. Additionally, Yield developed a competitive lottery system that makes it difficult for anyone to consistently contribute new blocks to the blockchain. Consequently, no entity or person has the authority to decide what is put to the blockchain or alter any portion of it in order to waive costs.

As this process requires a large number of specialized computers, it generates a large amount of carbon emissions and energy using during its operation. Bitcoin is also in the spotlight for its impact on climate change, based on the American news website. The mining of bitcoin uses a lot of electricity and contributes 0.1% of greenhouse gas emissions worldwide. The Cambridge Bitcoin Consumption Index (CEBCI), published by the University of Cambridge, calculates that 67 tons of carbon dioxide are released into the atmosphere annually as a result of Bitcoin use. According to a study by the Cambridge Centre for Alternative Finance (CCAF), Bitcoin's current energy consumption is estimated to be around 110 terawatt-hours per year, which is equivalent to 0.55% of global energy production. However, the energy requirements for bitcoin mining, which stands at 100MW, have raised significant concerns regarding its environmental impact and energy costs. As the popularity of bitcoin increases, so will the amount of effort [3]. Therefore, it will be worthwhile to explore the relationship between bitcoin and energy. At the same time, the government has enacted some policies to avoid too much carbon emissions, because bitcoin will cause a certain amount of carbon emissions.

2. Energy Market

2.1. Carbon Footprint Tracking - Electricity Use and its Environmental Impacts

While Bitcoin has gained prominence in traditional finance, concerns about its environmental impact persist. The emphasis on carbon emissions and climate hazards has led to a contentious discussion regarding the electrical sources used for Bitcoin mining. Various estimates indicate the share of renewable electricity in the energy mix for Bitcoin mining, ranging from 39% to 73%.

Mining involves adding new blocks to the Bitcoin blockchain and requires specialized hardware devices to compete in a numeric guessing game. This process consumes a significant amount of electricity, with millions of devices generating quintillions of guesses per second.

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The mining crackdown in China during 2021 had a significant impact on global Bitcoin mining activity. Several Chinese provinces, citing environmental concerns, banned crypto mining. This crackdown led to a substantial reduction in crypto mining activities in China, which had previously hosted the majority of Bitcoin miners.

The commentary reveals that this mining crackdown may have resulted in an increase in the carbon intensity of Bitcoin mining. The carbon intensity of mining likely rose by 17% in August 2021 compared to the average of the previous year. This emphasizes the urgency for stakeholders in the crypto industry to address environmental, social, and governance (ESG) concerns and develop strategies to mitigate the carbon footprint of Bitcoin mining [4].

Estimating the carbon footprint of Bitcoin mining relies on analyzing the electricity sources utilized by miners. Previous studies have proposed various methods to approximate mining locations. One of these methods, employed by CCAF, involves generating a map depicting the global distribution of miners. Based on IP address data gathered from four large mining pools (BTC.com, Poolin, ViaBTC, and Foundry USA), which take together account for 44% of all Bitcoin mining activity as of October 2021, this map displays the distribution of mining activity. Mining pools allow miners to combine their computational power and share rewards, providing a stable revenue stream. However, by participating in these pools and sharing rewards, miners expose their IP addresses, enabling the establishment of their geographical locations.

Based on the estimated electric load demand of the Bitcoin network, which was recorded at 13.39 GW as of August 2021, researchers have conducted calculations using an average emission factor of 557.76 gCO2/kWh. These calculations suggest that Bitcoin mining has the potential to contribute approximately 65.4 megatonnes of CO2 (MtCO2) to annual emissions. Figure 2 illustrates the projected global carbon footprint of Bitcoin mining, which is comparable to the emissions of a country like Greece (56.6 MtCO2 in 2019) and amounts to approximately 0.19% of global emissions [4].

Estimated global carbon footprint of the Bitcoin network, as of August 2021

1. Using CCAF's mining pool data, which accounts for 44% of total Bitcoin mining activity, introduces uncertainty when estimating emissions. One-off events such as China's mining crackdown in 2021 and Kazakhstan's Internet outage in 2022 validated the representativeness of pool data.

2. Since miners use proxy services in countries hostile to crypto mining, the mining pool data may overestimate the share of computing power located in Ireland and Germany. If their share is excluded, the average emission factor increases to 573.51 g CO2 / KWH.

3. The inclusion of mining activities in Alberta, Canada, with a higher carbon intensity, would further increase the average emission factor.

4. Emission factors are a significant source of uncertainty in cryptocurrency emissions estimates, as there may be time lags in publishing updated data. Due to the increase in electricity demand, the carbon intensity of global power generation increased in 2021 after a decline in 2020.

When assessing Bitcoin emissions, it is important to use marginal emission factors rather than average emission factors. Marginal emissions specifically account for the changes in emissions resulting from shifts in electric grid load caused by mining activities. Additional power generation resources, such as idle fossil assets that can no longer yield a profit, are activated when mining activities raise the demand for electricity. For instance, in New York state, 30 fossil-fueled power plants have been reactivated to support Bitcoin mining operations. This environmental concern is not adequately captured by average emission factors, which lead to underestimating the emissions associated with Bitcoin mining in regions like New York, where the majority of electricity comes from low-carbon sources [4].

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The reactivation of stranded fossil fuel plants and the utilization of flare gas for Bitcoin mining operations generate revenue for companies in the fossil fuel industry but raise environmental concerns regarding carbon emissions.

Alex de Vries highlights the alarming increase in power consumption by bitcoin mining activities, and examines the Bitcoin network's increasing energy usage, particularly in mining operations. By estimating energy consumption using mining hardware data and the bitcoin network's hash rate, de Vries argues that the exponential growth in energy use could pose a significant environmental challenge.

Vries believes that information about the network's total computing power can be used to determine a lower bound on Bitcoin's power consumption. The publicly available Bitcoin miners have an efficiency of 0.098 joules per gigabyte, and the Bitcoin network generates 26 trillion hashes per second, finding that this lower bound should be around 2.55 gigawatts [5].

Table 1: Examples of Recent Bitcoin ASIC Miner Machine Types.

Machine	Hashrate(TH/s)	Power Use(W)	Power Efficiency(J/GH)
Antminer S9	14	1,372	0.098
Antminer T9	12.5	1,576	0.126
Antminer T9+	10.5	1,332	0.127
Anminer V9	4	1,027	0.257
Anminer S7	4.73	1,293	0.273
AvalonMiner 821	11	1,200	0.109
AvalonMiner 761	8.8	1,320	0.150
AvalonMiner 741	7.3	1,150	0.160
Bitfury B8 Black	55	5,600	0.110
Bitfury B8	47	6,400	0.130

Note: Source: Bitmain,Bitfury,and Canaan.

Since rational agents will mine when the marginal costs of this work are low, these market forces drive the industry towards equilibrium, while firms will make zero economic profit.

After combining electricity costs over a 2-year period with previous production costs, Vires finds that electricity accounts for slightly over 70% of the total lifetime expenses for an Antminer S9. Even with the more stringent lifetime assumptions, the cost of electricity is still the majority of the total lifetime expenditure of the machine, so Vires assume an future share of electricity costs of 60%. Using table 1 and assuming an electricity price of 5 cents per kWh, with 60% of the marginal product ($15.34 million) allocated to electricity in equilibrium, Vires estimates the Bitcoin network's total amount of electricity consumed at 7.67 GW [5].

Table 2: Estimated lifetime costs for an Antminer S9 under various lifetime assumptions and production cost of US$500 (assuming electricity costs 5 US cents per kilowatt-hour).

machine	Expected Lifetime (Years)	Estimated Production Costs (USS)	Lifetime Electricity Use (kWh)	Lifetime Electricity Costs (US$)	Total Lifetime Costs (US$)	Electricity Costs/Total Costs (%)
Antminer S9	2	500	24,037	1,202	1,702	70.6

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Table 2: (continued).

Antminer S9	1.5	500	18,028	901	1,401	64.3
Antminer S9	1	500	12,019	601	1,101	54.6

Bitmain has the capacity to produce around 500,000 high-efficiency bitcoin miners per month, with each 16nm wafer supplying chips for around 27-30 miners. Assuming 20,000 wafers are produced per month and 27 machines per wafer, the potential production of the Ant Miner S9 in 2018 would be as high as 6.5 million. The total power consumption of these machines would be 8.92 gigawatts, exceeding the previously estimated 7.67 gigawatts [5]. Focusing on the environmental impact of bitcoin mining, Christian Stoll, Lena Klaassen, Ulrich Gallersdörfer, and E. F. Elsasser provide an in-depth analysis of the carbon footprint of cryptocurrencies. Using a life cycle assessment approach, Christian Stoll et al. looked at the entire process of bitcoin production, including manufacturing, electricity consumption, and waste management. These findings show that cryptocurrency mining generates significant carbon emissions, and this raises concerns about its long-term sustainability [6] (see Table 2).

Participating in the validation process of the Bitcoin blockchain requires specialized hardware and substantial electricity consumption, leading to a significant carbon footprint. The authors propose a methodology to estimate the associated carbon footprint of this validation process. This estimation relies on data obtained from IPO filings, mining facility operations, pool composition, and IP address localization provided by major hardware manufacturers.The empirical analysis conducted reveals valuable insights into the environmental consequences of Bitcoin. Subsequently, utilizing IP address localization, power consumption estimates are translated into carbon emissions. A study conducted in November 2018 found that Bitcoin's annual electricity consumption was 45.8 terawatt-hours, resulting in estimated annual carbon emissions ranging from 22.0 to 22.9 megatonnes of CO2. This places Bitcoin's emissions on par with those of Jordan and Sri Lanka and comparable to those of Kansas City.Moreover, the study extends its focus to assess the external costs of Bitcoin, providing essential insights for a more comprehensive discussion on the overall costs and benefits of both Bitcoin and cryptocurrencies in general. This multifaceted approach contributes to a nuanced understanding of the environmental impact and broader implications associated with Bitcoin [6].

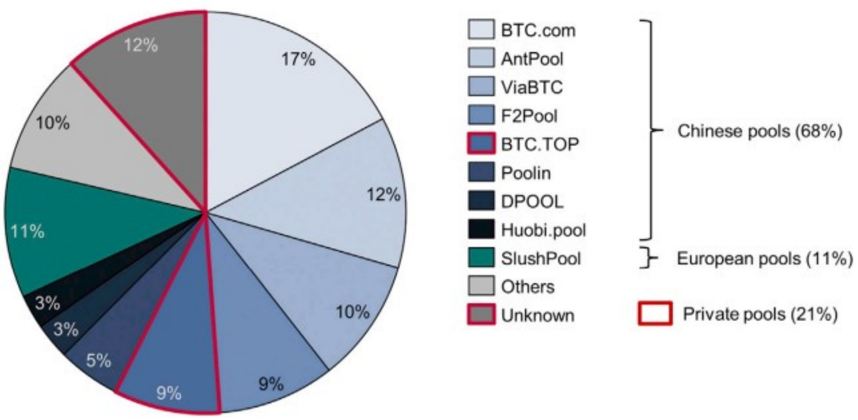

Figure 1: Bitcoin price market distribution.

Currently, the majority of participants in the network belong to public pools or privately organized pools. Chinese pools represent more than two-thirds of the computational power, while EU-registered pools account for 11 percent. Private pools, referred to as "unknown pools" by Christian Stoll et al., are categorized as such when the source of the hash rate is undisclosed. This designation arises from the fact that mining independently without joining a pool is only practical when one possesses sufficient hash power to reasonably anticipate discovering a block within a reasonable timeframe [6].

Before determining Bitcoin's actual energy consumption, the researchers began by establishing a narrow range, calculating a lower limit and an upper limit. The lower bound represents the case where all miners use efficient material, while the upper bound corresponds to the point where mining revenue equals the cost of electricity. Their more accurate estimate, shown in Figure 1, is consistent with the calculation of the lower bound, but includes the expected energy efficiency of the network, taking into account material sales and associated losses.

Figure 1 demonstrates that the upper bound of power consumption is more susceptible to fluctuations in the bitcoin price market, while the lower bound remains stable, determined by hardware efficiency and hash rates. The calculations yielded power consumption estimates of 345 MW at the end of 2016, 1,637 MW at the end of 2017, and 5,232 MW in November 2018, accounting for ancillary losses and sales of ASIC-based mining systems. The yearly power usage of 45.8 TWh was derived by Christian Stoll et al. by multiplying the power consumption as of November 2018 by 8,760 hours [6].

To gauge Bitcoin's carbon footprint, it involves assessing its overall energy consumption and where that energy is sourced geographically. This is done by multiplying the power consumed by estimating the carbon emissions associated with bitcoin in each location, using the average and marginal emission factors for electricity generation in each country. Globally, Bitcoin's yearly carbon emissions vary from 22.0 to 22.9 MtCO2, placing it in a comparable emissions range as countries such as Jordan and Sri Lanka, akin to the emissions level of a city like Kansas City. Clean surplus energy is a crucial energy source for Bitcoin. However, in regions with active mining operations, there are instances of substantial reduction in the availability of clean resources. For instance, in southwestern China, where hydropower is the predominant source of electricity, curtailment rates are significant. Conversely, mining activities are also prevalent in areas with a higher reliance on coal for power generation, like Inner Mongolia.

Different scenarios suggest that yearly emissions stemming from Bitcoin mining might reach 51.0 MtCO2 when fossil fuels contribute to the added demand. Nevertheless, a greater proportion of clean energy utilization has the potential to mitigate CO2 emissions. Calculations assume miners run their hardware uninterrupted throughout the year, and potential additional revenue sources or price volatility are not taken into account. In the long term, it is expected that Bitcoin miners will gravitate towards locations with abundant renewable energy sources, promoting the development of renewable generation resources and potentially leading to lower emission factors for the Bitcoin network compared to the current grid average [6].

2.2. Interaction of currency prices with climate and energy

Currently, there exist numerous cryptocurrencies, with blockchain serving as the underlying technology for many digital currencies. Blockchain functions as a digital transaction ledger. The process of competitively adding blocks to the blockchain is computationally intensive and demands significant energy input. In this study, Max J. Krause, Thabet Tolaymat, and Benjamin J. Buckley present a methodology to determine the minimum power prerequisites for different cryptocurrency networks and how much energy is needed to create one dollar's worth of digital assets [7].

Krause et al estimates show that mining bitcoin, ethereum, litecoin, and monero required an average of 17, 7, 7, and 14 MJ, roughly speaking, to produce one U.S. dollar from January 1, 2016,

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to June 30, 2018. In contrast, conventional mining required 122, 4, 5, 7, and 9 MJ, respectively, to produce the same value. This suggests that, except for aluminum, cryptocurrency mining typically consumed more energy compared to mineral mining for similar market value. Three out of the four digital currencies' network hashrates have continuously trended upward, showing a sustained increase in energy demands, notwithstanding the notable price swings of these coins. Based on their predictions, 3–15 million tons of CO_2 emissions were produced during this time due to the mining activity of all four cryptocurrencies [7].

Building upon previously analyzed energy consumption patterns for mining four prominent cryptocurrencies (Bitcoin, Ethereum, Litecoin, and Monero), Andrew L. Goodkind, Benjamin A. Jones, Robert P. Berrens have assessed the economic impact per coin in terms of air pollution emissions, associated human mortality, and climate effects resulting from mining these cryptocurrencies in both the US and China [8].

Their findings reveal that in 2018, the production of each $1 worth of Bitcoin contributed to approximately $0.49 in health and climate damages in the US and $0.37 in China. Interestingly, despite a significant discrepancy between the US and China regarding the estimated value of statistical life, the corresponding damages in both countries exhibit a similar magnitude. Furthermore, in the case of each cryptocurrency, the increasing electricity requirements to create a single coin may inevitably result in a reduction of overall societal gains, unless perpetual price hikes are maintained. An illustrative instance from their study (centered on Bitcoin) portrays a situation in December 2018 when the "cryptodamages" related to health and the climate almost equaled the value of every $1 worth of the coin produced. In conclusion, they emphasize the importance of considering policy implications in light of these findings [8].

Mining in the world of cryptocurrencies involves independent individuals or miner groups vying for the first spot to solve intricate algorithms and add verified transactions to the blockchain. This competition relies on brute force computing power and follows the proof-of-work (POW) process used in the original Bitcoin. Miners who succeed receive cryptocurrency units, but this procedure consumes significant electricity.The supply of cryptocurrencies is usually limited and governed by specific rules that eventually lead to diminishing new coin supply. As the competition for mining intensifies, the computing effort and electricity consumption must increase accordingly, resulting in potentially negative environmental and health impacts. These social costs related to electricity usage are not currently borne by the miners, making it crucial to assess and quantify these impacts.

To start, they collect data pertaining to the emission rates per kWh of power generation in the US and China for four main pollutants that are produced when fossil fuels are burned: sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), and fine particulate matter ($PM_{2.5}$). They then combine the kWh of power utilized and these emission rates to produce a single bitcoin coin. This enables them to ascertain the mean emissions produced in the generation of a single cryptocurrency unit, encompassing all energy origins, whatever renewable or not. Specifically, CO_2 emissions are crucial when gauging the climate-related costs associated with minting a single unit. Exposure to the other three pollutants ($PM_{2.5}$, NO_x, and SO_2) is correlated with an elevated risk of premature mortality. Consequently, they utilize these emission statistics to compute the mortality consequences of producing one unit in each country, along with the economic losses stemming from premature deaths.

To generate a single coin on a daily basis, they gauge the electricity demands by referencing the blockchain's network hashrate, which is a publicly accessible metric. The hashrate reflects the total energy consumption across the cryptocurrency network for tasks involving block mining and reward collection. Hashrates escalate in response to heightened computational competition.

A significant hurdle they face when researching cryptodamages is the absence of comprehensive data regarding the specific geographical sources of electricity used in cryptocurrency mining. While they are aware of certain concentrated production hubs, they lack aggregated information encompassing the broader distribution. Some evidence points to the concentration of mining activities in areas where electricity is both cost-effective and dependable, like the Mid-Columbia Basin region in the United States and sizable mining operations in China. Nonetheless, detailed and comprehensive data concerning electricity consumption for mining activities across various locations remain unavailable at present.

Their goal is to analyze the externalities related to the production of a coin in the United States and China. Due to the differences in power generation methods, the emission rate per kWh is significantly different. China relies heavily on coal-fired power (>60% of electricity generation), , while the proportion in the United States is more balanced (32% natural gas, 30% coal, 20% nuclear, etc.). To compute CO2 emissions per coin minted, they gathered emission rates of CO2 per kWh of electrical power produced in 2016 and coupled this data with electricity use per coin. These CO2, and then use the US federal government's social cost of carbon (SCC) emissions in 2020 and assume a discount rate of 3% to estimate climate damage.

Assessing mortality impacts from cryptocurrency generation is a complex task involving multiple steps. First, they collect data on emission rates and electricity generation for each electricity generating unit in the US and China. Next, they estimate human exposures to pollutants. Then, they estimated human exposure to the pollutants. They then used the expose-response function to translate these exposures into mortality effects. Finally, the value of statistical life (VSL) is used to turn premature death into a monetary loss. They base their estimates for the US on detailed relationships between electricity emissions and exposures, and they attempt to apply these estimates to China. They employ a model known as the Intervention Model for Air Pollution to assess the movement of emissions from electricity-generating facilities in the United States. By integrating these findings with emissions data for PM2.5, NOx, and SO2, they calculate the mortality impact for each kWh of electricity generated by these facilities. Subsequently, they distribute the emission characteristics of electricity generated at these facilities to areas where electricity consumption occurs. The combined health and climate-related costs per kWh are used to estimate the environmental expenses associated with electricity production, revealing that certain methods of electricity generation result in more substantial damages than others [8].

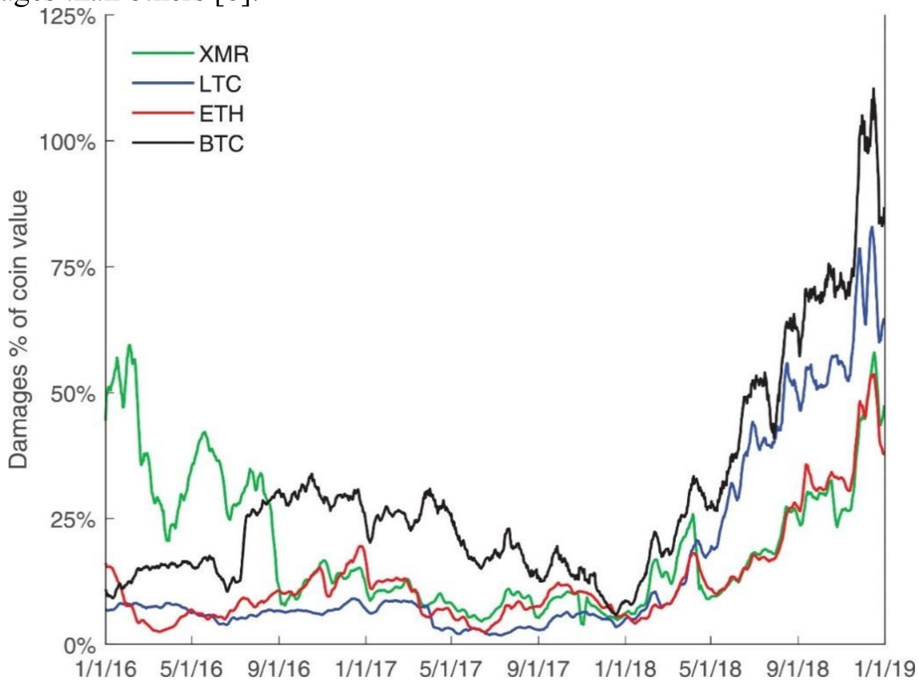

Figure 2: The damages incurred from mining a coin in the US.

The effects resulting from currency mining in the United States with an average power mix are depicted in Figure 2. However, depending on the area and fuel source used for generating, the cost and damages associated with producing electricity could range greatly. Therefore, Figure 2 analyzes the overall net social value of mining a cryptocurrency net social value of mining a cryptocurrency somewhere in the US, taking into account both the benefits and costs of generating a coin and purchasing electricity for the miner, as well as the externalities associated with electricity generation in that specific location, which are borne by society (refer to Equation (1)). For simplicity, Figure 2 focuses solely on BTC.

It is important to note that the net social value presented in Figure 2 represents the maximum value, as it excludes all other potential costs related to cryptocurrency mining, such as equipment, cooling, or opportunity costs. Figure 2 visually presents the price and electricity requirements of BTC over time, along with the net social worth of producing a coin in different places on four distinct dates:

(a) March 1, 2017: At this time, the price and electricity consumption were relatively low, resulting in moderate net benefits in several areas of the US.

(b) November 15, 2017: During this period, the price began to rise while the demand for power remained relatively low, resulting in considerable net benefits for mining in practically any region.

(c) March 15, 2018: The price of electricity began to fall, and usage grew. As a result, net gains were distributed differently across the country, with positive regions in the Northwest and Southeast and negative regions in the Midwest.

(d) July 1, 2018: By this date, the price had reduced even lower, while electricity usage had climbed dramatically, resulting in large negative net benefits in almost all regions of the US [8].

The surging prices of cryptocurrencies have spurred cryptocurrency miners to participate more actively in cryptocurrency production, leading to an increase in network hashrates and electricity usage. As network hashrates grow, it creates a more competitive environment, making it challenging for small cryptocurrency investors to keep up with the rising costs of mining hardware and electricity. Consequently, some cryptocurrency miners have transitioned into becoming investors themselves, which further contributes to the appreciation of cryptocurrency prices. However, the potential bidirectional relationship between cryptocurrency prices and electricity consumption has not been clearly identified.

To explore this relationship, Mingbo Zheng, Gen-Fu Feng, Xinxin Zhao & Chun-Ping Chang conducted a study using data from July 31, 2015, to July 12, 2019, encompassing 13 different cryptocurrencies. Their research aims to investigate the short- and long-term causal effects between cryptocurrency transactions and electricity consumption. They employed stationary analysis and comvement relationships to specifically analyze structural fractures caused by external shocks [9].

During the examined time frame, they observed that the series of cryptocurrency transactions and electricity consumption gradually returned to mean convergence after experiencing daily shocks. Additionally, cryptocurrency prices exhibited a close correlation with network hashrates. Fluctuations in cryptocurrency transactions had both temporary and lasting impacts on electricity consumption. Therefore, the computational power deployed to pursue high profits plays a crucial role in determining electricity consumption levels, highlighting the significance of transaction activities.

The results indicate that governments should monitor transaction dynamics in the cryptocurrency market due to their impact on electricity consumption and subsequent environmental costs. Additionally, investors need not adjust their strategies drastically in response to market fluctuations as external shocks are short-lived, and prices tend to revert to the equilibrium level driven by market forces [9]. In financial economics, the panel unit root test is extensively used to assess the stability of a series. In the context of the cryptocurrency market, where booms and busts are common, it is essential to account for potential structural breaks when examining the stability of transaction behaviors and electricity consumption. To address this, they employed the panel Lagrange multiplier

(LM) unit root test, which allowed to test the stationarity and determine the horizontal change during the structural mutation caused by external shocks.

During our analysis, They looked at structural breakdowns and their importance. The series have a unit root and are not stationary, according to the null hypothesis of the panel LM unit root test. By applying this test, they can gain valuable insights into the behavior of cryptocurrency transaction series and electricity consumption series during different periods affected by structural breaks [9].

$$y_{it} = \gamma_{1i} + \gamma_{2i}t + \delta_i TB_{it} + u_{it}, \tag{1}$$

The provided paragraph discusses the methodology used to analyze the concerned variables, cryptocurrency transaction behaviors, and electricity consumption. The model considers the time period represented by 't=1,...,T' and the number of cryptocurrencies denoted by 'i=1,...N.' The equation 'uit = ϕiuit-1 + εit' represents the model, where 'uit' is the concerned variable, 'ϕi' is the correlation parameter for the error term, 'uit-1' is the lagged value of the variable, and 'εit' represents the error term. The break point 'BPi' is estimated for each cryptocurrency, and 'TBit' serves as a time break indicator. The panel LM unit root test is constructed by averaging univariate LM test statistics for each cryptocurrency, and its asymptotic distribution follows a standard normal distribution.

Although the panel LM unit root test detects structural breaks in the data, the origin of this non-stationarity is not apparent. To further investigate the source of non-stationarity in transactions and electricity usage, the PANICCA test is employed. PANICCA test combines panel analysis based on principal component and cross-sectional average test. It is able to pinpoint and measure the cause of non-stationarity and break it down into the common elements of every variable as well as the influence of individual components. The data-generating process for the variable in the PANICCA model is given accordingly [9].

$$y_{it} = \phi_i' D_{t,p} + \eta_i' G_t + u_{it}, \tag{2}$$

Anh Ngoc Quang Huynh, Duy Duong, Tobias Burggraf, Hien Thi Thu Luong & Nam Huu Bui examine the connection between Bitcoin energy consumption and its market performance. Utilizing variance decomposition in conjunction with the realized semi-variance of daily data, the research highlights the noteworthy correlation among Bitcoin' s energy usage, return, and transaction volume. It is noteworthy that the volume of Bitcoin transactions has a longer-term effect on energy usage than revenue. An increase in energy consumption and connection was also a result of the second Bitcoin meltdown. The study also establishes the prediction's opposite direction and energy consumption's capacity to forecast Bitcoin returns and transaction volume. The research findings highlight the difficulties that the Bitcoin ecosystem has in fostering sustainable innovation and lowering its carbon footprint overall [10].

3. Policy

Nowadays various policies are introduced to limit carbon emission. There are several typical examples. First of all, the European Union was the first major economy to put a price on carbon emissions and adopt market-based trading. The European Union Emissions Trading System (EU ETS) employing a cap-and-trade mechanism is a policy which is implemented by European Union in 2005 to decrease carbon emission. Greenhouse gases which can be discharged by specific industries and power plants have a setting cap. Companies and factories own emission allowances, each representing one ton of CO_2, which can be bought, sold, or traded. When a company emits more carbon dioxide than given quota, it must trade to get excess allowances from the market or has to pay fine. Besides the EU has also implemented a carbon tax to cover key industries with carbon emissions.

What's more, although there isn't a national carbon market in the United States, states have jointly established regional programs to reduce emissions, notably the Regional Greenhouse Gas Initiative

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(RGGI), the Western Initiative (WCI), and the Transportation and Climate Initiative Program (TCI-P). Among these examples, RGGI is the nation's first mandatory, market-based greenhouse gas emissions reduction program for the electricity sector. Much of the RGGI process is similar to that of the European Union, in that each state receives a certain amount of allowances that are allocated to different industries within the state, but there are some differences in that companies in the RGGI program are required to have mandatory CO2 emissions tracking systems.

In addition, The Korea Emissions Trading Scheme (K-ETS) was established in January 2015 as Asia's first national carbon market. By the end of 2021 K-ETS covers 684 large companies from Waste, Domestic Aviation, Transport, Buildings, Industry, Power, accounting for about 73.5% of the country's carbon emissions and six greenhouse gases. Allowances for EITE sectors must be auctioned at least 10% of the time, with free allocations based on benchmarks for production costs and trade intensity. Domestic financial intermediaries and other third parties have been able to participate in exchanges since 2021.

These carbon-emission reduction policies for various industries have achieved certain results. In order to avoid inhibiting the development of specific industries, we also agree that the Government should implement industry-wide carbon reduction policies. In the case of Bitcoin, we believe that the following carbon reduction policies can be proposed by the government at the moment to deal with Bitcoin's massive carbon emissions. It may be segmented into carbon reduction, zero carbon, and negative carbon categories based on the emission reduction process. Carbon reduction technology mainly refers to energy-saving and emission reduction technology, which is mostly applied to realize the effect of high efficiency, low emission, low energy consumption and low pollution in the process of production, consumption and use. It can be used to optimize bitcoin mining technology, improve bitcoin mining efficiency, and develop more efficient and low-consumption bitcoin mining tools. Decarbonization technologies mainly refer to clean energy technologies that are (almost) decarbonized, including wind energy, photovoltaics, decarbonized hydrogen, nuclear energy and other technologies, as well as the creation and development of technologies for energy storage systems. Governments can encourage individuals or businesses that mine Bitcoin to use clean energy by, for example, giving subsidies to organizations or individuals that mine Bitcoin using clean energy. Carbon negative technologies, or negative emission technologies (NETs), are mainly applied to capture, sequester, actively utilize, and treat carbon dioxide from the atmosphere. The carbon dioxide emitted as a result of Bitcoin mining can be used to increase ecological carbon sinks that can be further utilized for other purposes such as soil improvement. These large amounts of CO2 can also be captured and utilized for resource utilization.

4. Conclusion

We summarize 8 papers on the climate and Bitcoin-related literature and propose policies that can be adopted for governments regarding the control of Bitcoin's negative externalities. We describe the literature in two parts, the first centered around calculations related to carbon emissions, and the second centered around the interplay between the price of Bitcoin and climate. However, there is a cap of 2,100 bitcoins, and the current mining progress is already over 60%, and when the progress is complete bitcoin mining will no longer have an impact on the environment. Simultaneous, the difficulty of mining is decreasing, and higher costs will reduce the demand for mining and slow down the mining process, which in turn will prolong the time that bitcoin mining will affect the environment. Overall, Bitcoin mining accounts for only 0.1% of total carbon emissions, and the need for regulation is debatable.

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