REGION
The Journal of ERSA
Powered by WU

Volume 10, Number 3, 2023, 83–104
DOI: 10.18335/region.v10i3.468
journal homepage: region.ersa.org
ISSN: 2409-5370

The Rise of Bitcoin, Economic Inequality and the Ecology

Gal Benshushan[1]

[1] Swansea University, Swansea, United Kingdom

Received: 8 December 2022/Accepted: 9 October 2023

Abstract. What do we know about the interrelations between economic inequality, ecology and the increased use of Bitcoin? The aim of the paper was to empirically test the relationship between economic and ecological effects related to the increase in Bitcoin's network hashrate in a selection of countries that have the highest influx of crypto-mining. To test these three hypotheses, I collected a dataset concerning Bitcoin indicators, economic indicators and ecological indicators that were obtained from multiple trustworthy sources: OECD, World Bank, Fred Data, World Inequality Database (WID). Handling the data challenges, I used this unique panel dataset to explore the relationship between Bitcoin's hashrate and two types of outcomes: (i) economic outcomes where inequalities may emerge or direct measures of inequality (such as the GDP, income inequality (GINI) and the share of people with top 1% of income and 1% of wealth), and (ii) ecological outcomes (such as carbon emissions, carbon footprint and electronic waste). I found that the Bitcoin currency is associated with a certain redistribution of wealth but, it itself remains concentrated in the wealth of the top 1%. Also, there is evidence for certain nonlinearities in the relationships with the ecological degradation, echoing the concept of the Kuznets curve.

Key words: bitcoin, ecology, hashrate, inequality, productivity

1 Introduction

The advancement of digital currencies over the last decade has contributed to a huge increase in the popularity of trading and mining them in the crypto space all around the world. Cryptocurrencies are digital currencies that can be exchanged between people without the need of any third-party intervention from an organisation such as a central bank. The rise of cryptocurrencies became prominent in recent years due to the accessibility of the blockchain and its anonymity. The rise of the cryptocurrency market came along over a decade ago with the creation of Bitcoin in 2009, with many more following in its footsteps, creating what is now a huge platform of digital currencies which can be created, traded and used to purchase valuables. But how much do we know about the interrelations between economic inequality, ecology and the increased use of Bitcoin?

What we know is that the Bitcoin network alongside most other cryptocurrencies operates via the 'proof of work' mechanism, which was created as a way to secure the network and does so in a very effective manner. This mechanism is used to protect the network from attacks and fraudulent users, by users needing to complete proof of work to validate transactions to be added to the blockchain for all to see. In doing this some users, called miners, are rewarded a portion of the digital currency, and thus generate the coins, but at a cost, because to do this effectively the miner requires a very powerful computer system. Since Bitcoins popularity spiked, the network saw a huge influx of users, which raised questions about Bitcoin's sustainability due to its current mechanism being highly energy intensive (Di Febo et al. 2021).

So, the crypto space operates with an incredibly high demand for electrical energy, due to its current operational mechanism. This intense need for a lot of energy is a very relevant topic, from the perspective of ecological degradation, which has been a growing concern over the last decades. This is particularly concerning as not all the energy to be supplied is from renewable sources, but instead from scarce and incredibly damaging fossil fuels, which emit an unsustainable amount of greenhouse gases into the environment. In 2015, the Paris Agreement was signed by several countries in strive to avoid climate change by pushing global warming below 2°C, but the rise of the digital currency era could prevent this from happening. There is also a great amount of electronic waste being disposed of in relation to Bitcoin mining, which again has a damaging effect on the environment that the world is striving to eliminate (Di Febo et al. 2021).

Another very relevant area within this topic, which is discussed in this study, is whether or not these cryptocurrencies will help with wealth and income inequality. Many sources suggest that the crypto space has helped with the world's income inequality, I will explore whether the blockchain is actually run by the wealthiest and whether it is not just a new method of driving the wealth of the already wealthy up, whilst the poorer will not enjoy much benefit in the long run. This is very relevant today as world inequality is still very high and there are many efforts to push for equality, but this new digital age could help worsen the current economic situation around the world.

The aim of this paper is to assess which are the different factors that affect the digital currency world with focus on Bitcoin, in order to shed light on how and why they operate and to disentangle the possible economic and ecological outcomes of their use. To achieve this, the current paper compiles a unique panel dataset, informed about the Bitcoin networks, their main determinants with economic and social nature, as well as information about the ecological degradation in the countries included in the dataset. This information allows us to explore the trends in Bitcoin usage and the ecological damage in a country and the relationship between them.

The rest of this paper is structured as follows. Section 2 will offer the literature review on how Bitcoin was developed and how it works, the economic outcomes in relation to Bitcoin's development, the ecological impacts from its development and finally a dive into the non-linearities in these relationships, in line with what we know about the economic and statistical meaning of the Kuznets curve. Section 3 will present the empirical part of this study, this will include the description of data and estimation strategy, followed by the results and their analysis. Section 4 will offer some concluding remarks, with discussion on the importance of the findings presented here and some ideas for further research.

2 Literature review

2.1 The history of the blockchain technology

During the 2008 financial crisis, a paper was released called 'Bitcoin: A Peer-to-Peer Electronic Cash System', by a pseudonymous individual named Satoshi Nakamoto. This paper illustrated that the current financial system had some major weaknesses, which stemmed from the trust model (Nakamoto 2008). The current financial model we are familiar with is almost completely reliant on a third-party, this third party is a financial institute such as a central bank or governing body. Nakamoto goes on elaborates that the current system "cannot avoid mediating disputes" (Nakamoto 2008, p. 1) and that there no way to currently have "completely non-reversible transactions" (Nakamoto 2008, p. 1), this is mainly due to trust between the individual parties. This trust factor can lead to fraud and is very common and thus creates an unwanted hostility between a merchant and a buyer (Vranken 2017).

This hostility seems to stem from the system being able to reverse transactions and at the time there was no way of protecting a seller from being vulnerable to fraud. However, this uncertainty in payments and costs of mediation can be avoided by a buyer using physical payments such as cash but this isn't sufficient in the growing digital age. So, Nakamoto proposed a computational system to make payments without the need of involvement from a financial system, so peer to peer transactions can occur directly without trust needing to be placed on the third party (Chohan 2021). This would be done by having a system where there is a timestamp of proof of transactions in a chronological order, to create a safe space to buy and sell via a digital currency without the worry of a fraudulent individual attempting to 'double spend' (Nakamoto 2008).

Although Satoshi Nakamoto put the blockchain technology on the map it wasn't him who first established this technology, in fact this technology wasn't initially created for cryptocurrencies. David Lee Chaum, a cryptographer who published a dissertation in 1982 named 'Computer Systems Established, Maintained and Trusted by Mutually Suspicious Groups', describes the first instance of a blockchain system. The blockchain is a simply a distributed, decentralised ledger that records and stores data such as transactions. As the name suggests the data is first recorded and stored in blocks and then the block is added to a chain thus creating a long chain of information which is all stored in a cryptographical sequence. These transactions are verified through a consensus mechanism, this information is stored for all participants to see and cannot be deleted, so every transaction can be seen and traced back to its origin (Crosby et al. 2016).

2.2 How the Blockchain works

The blockchain operates with three fundamental attributes, the first attribute is to be 'decentralised', meaning that the control of the network is not held by a singular organisation or governing body. In fact, its control is distributed among all its participants/nodes so even if one individual is corrupt the network won't fail. The second of these traits is that there is direct peer to peer transactions which entails trust between two unknown parties to interact directly to form a transaction, but this trust is built upon both users having access to proof and history of transactions. The last of these fundamental traits is that the ledger is distributed among all nodes so again if one element of data is tampered with it will not compromise the system (Chohan 2021). The data is stored on many hardware devices from many multiple nodes that are within the system. This is favourable to many people when compared to a centralised system that most are familiar with such as central banks, which can be completely compromised If the main node is corrupt or tampered with. Which can make it less safe as not everyone can or will see the corruption take place within the system, such as hackers or fraudsters as the centralised system runs on a cloud network which is very vulnerable to attacks.

In Nakamoto's paper he defines an electronic/digital coin as "a chain of digital signatures" (Nakamoto 2008, p. 2), this is done in practice when a transfer happens between two nodes on the blockchain platform. In this transaction the initial owner of the electronic coin digitally signs a hash, which is a function that meets the required inscribed demand that is needed to solve the complex blockchain calculation (Begum et al. 2020). This verification system allows for a node to see the history of ownership of the coin. However, in doing this method the second owner will not know if the first owner had double spent and this is an issue. Traditionally the financial institute will check each transaction and each payment has to go through this central authority (central bank) to be validated as not double spent.

Double spending is where a cryptocurrency is used twice or more and can occur when the transaction information within the blockchain is changed, if these modified blocks make their way into the blockchain then the person can reacquire their already spent crypto. The job of proof of work is to prevent this happening. However, unlike a centralised system where it would be easy to spot an error like this, the blockchain operates differently because it has millions of users with their own records. Double spending is very bad for a network as it can reduce the value of the coins and make it worthless.

In blockchain technology there is no mint or central authority to do this, so the method created was to make these transactions publicly known and an over consensus agreement on where the coin has been and where it arrived first. So, a proof system showing the exact time each transaction was made, with a positive number of nodes agreeing on its legitimacy. To do this there was proposed a timestamp server, which is where the hash of a block of items is and publicly announcing the hash, in doing this it shows all nodes that at that exact time the data existed (Nakamoto 2008).

2.3 The proof of work mechanism & Hashrates as a Measure for Bitcoin Use

The proof of work was the first and still is currently the leading consensus mechanism for the cryptocurrency network which was also proposed by Satoshi Nakamoto in 2008. Unlike other database systems, that would be controlled by an individual and would require them to update the system on their own, like a school or hospital database systems. The blockchain is self-governing meaning there isn't one person that can control or change the system, in fact contributions from over 60 million users worldwide that participate in the network to allow it to function accordingly. This means that people trying to commit fraud can be easily spotted, this is a huge benefit that this consensus model has. This is because instead of one person having control of the database, everyone has access to it via their own logs which are recorded and public. Proof of work is a special algorithm that uses a huge amount of effort to locate and eliminate counterfeit uses of computing power (William et al. 2022).

The proof of work mechanism is completed by users of the network called miners, these miners perform proof of work on new block to then be added to the blockchain, this works by the miner finding the winning proof of work in order to validate the transactions. In other words, the miners are running very energy demanding programs on their computer to solve these very complicated mathematical problems to be the one to guess the correct 'password' to validate the transaction and thus add the transaction to the blockchain. This method of validation is actually a hash function (Crosby et al. 2016). Upon validation the user receives a portion of the cryptocurrency as a reward for their work. So, the proof of work mechanism works similarly to Adam Back's hashcash, as it involves the scanning for a value that when hashed, with hash function SHA-256. This is a secure hash algorithm and is cryptographic, the hash algorithm creates unique hashes, and the number begins with a number of zero bits, the work required is exponential and is verified by executing a single hash. This is done by finding a nonce value that satisfies the cryptographic hash function, which means that the node has found the value that gives the block's hash the zero bits that is required (Küfeoğlu, Özkuran 2019).

So, a new block was proposed which for the Bitcoin network this set to be every 10 minutes, when this happens every active miner will have their computers continuously guessing a random nonce value, if the hash (H) with the guessed nonce (N) value is higher than the target value (T) then the computer will have to restart and guess a new nonce value until the nonce value satisfies equation 1 below (O'Dwyer, Malone 2014).

$$H(B.N) > T \tag{1}$$

When the first miner has found the correct nonce value so that the hash function is less that the target value, the block can then be added to the Bitcoin blockchain and in doing this validation the miner receives a portion of Bitcoin.

So, a Bitcoin miner goes through a process to solve the complex mathematical problem to find the nonce value so that the hash of the block containing the transaction information is smaller than the target (Kroll et al. 2013). This computational process requires an incredible amount of computational power as the CPU, GPU or ASIC devices will be constantly guessing random values. However, the more computational power the miner has the greater the amount of guesses their computer system can make per second and thus the greater the reward for that miner is. This value is called the hashrate and can be described as the computational power being used to mine and process transaction via the proof of work mechanism, so the higher the hashrate would indicate a larger number of nodes participating and thus a greater energy use overall. This is where speculations on the energy consumption of the Bitcoin network come from, as this process clearly requires a lot of energy. Due to the reward scheme integrated into the mining process, many people saw this as an opportunity to make money and the regular home computer setup was ditched for many to invest in mining rigs/farms. The more valuable Bitcoin or any other digital coin using the proof of work mechanism is, the greater the incentive for the miners to have better and more equipment (Qin et al. 2018).

Initially when Bitcoin was first released and several years after the hashrate was low, meaning that less computational power was needed for the computer to solve the problem and earn the reward. However, as the popularity of Bitcoin grew, so did its value and thus attracting more miners. As the number of miners grew, the number of attempts to validate the blocks to be added to the blockchain increased exponentially, meaning there was a greater chance of the correct hash value to be found. In the case of this technology becoming used popularly world-wide, Nakamoto had precautions put in place to make the difficulty to mine increase. Bitcoin's difficulty algorithm which was put in place to stabilise the system and maintain a 10-minute duration of finding new blocks to be validated. So, the difficulty of mining changes depending on the number of miners that are actively trying to crack the code, this difficulty is changed by increasing or decreasing the zeros in front of the target hash (O'Dwyer, Malone 2014). So, the higher the hashrate is, the more difficult the proof of work becomes. This difficulty in completing the proof of work on a block was also introduced to compensate for the expected increase in the speed for the hardware used to mine. This difficulty is what drives the energy use of Bitcoin up, as the harder it is to solve, the greater the energy needed to run these supercomputers. So intrinsically the proof of work mechanism is built to be very energy demanding as popularity increases.

The reason for this energy intensive design of the proof of work mechanism is necessary for the network's security against an attack. The most talked about is called a 51% attack, this is where attackers are able to control more of the network's hashrate than honest nodes (Ye et al. 2018). The proof of work mechanism helps to prevent this sort of attack by making it very energy demanding to control this much of the network so it wouldn't be sustainable or profitable for someone to do so (Shi 2016, Courtois et al. 2013).

2.4 Bitcoin and Economic Outcomes

Bitcoin and the blockchain technology have become very mainstream over the recent years with its value increasing significantly over the recent year. In 2018 Bitcoin's total market capitalisation was over $200,000,000,000 which is greater than the GDP of many countries in the world (Wealth 2018). Gross domestic product (GDP) is the total monetary value of all goods and services in a country, this value is usually calculated annually and can be referred to as the size of a country's economy. There are many factors and methods that go into calculating a country's GDP such as money spent, money earned or the value added to the economy, so when looking at Bitcoin's contribution it comes with great difficulty. For example, a Bitcoin miners contribution comes from the labour and capital output but for investors in Bitcoin their contribution comes from the profit made on the asset and for the regular user of the Bitcoin network it is the actual currency itself (Wealth 2018).

In a paper called "Role of Bitcoin on Economy", it can be seen that in Dubai the GDP increased by nearly 10% from 2009 to 2011, which was expressed to be due to the Bitcoin technology helping online trading and retail industries to boom. The Bitcoin technology allows for faster transactions in a more efficient way that there has been before. Bitcoin is also universal, meaning that there is no need for exchange rates which would be necessary in the conventional use of money (Singhal, Rafiuddin 2014). Another study that has shown Bitcoin's effect on GDP, showed that Bitcoin has a very significant effect on GDP, with each unit change of Bitcoin having an effect of increasing or decreasing GDP by a coefficient of 2924749 with a negative relationship (Utomo 2016). It has also been found that an increase in the use of crypto trading with Bitcoin being the dominant currency has led to enhanced GDP and globalisation (Miśkiewicz et al. 2022).

In the recent years of the uprising of the Bitcoin network, many speculations on the wealth distribution of the currency have risen. In theory a new currency that allows for anonymity with free and easy access, could help drive down wealth and income inequality.

However, many argue that Bitcoin's circulation has landed with the wealthiest, and the average user will not reap the benefits of the network compared to a user who was wealthy previous to Bitcoin's creation. In the light of the Bitcoin network, inequality can be increased by many individuals and organisations who can't compete with miners in countries where the electrical energy cost is high. We see a movement of their mining facilities to areas of the world where the cost of electricity is much less, meaning the profits for the miners are higher in countries where this energy cost is low. This means the poorer areas being exposed to more ecological pollution which is a great downfall of the current system (Dilek, Furuncu 2019).

It has been estimated by Credit Suisse, a large financial company in America, that a large sum of Bitcoins wealth is only distributed to a small minority of addresses, with the top 4% of users owning 97% of its wealth (Novak 2019). Another paper calculated that approximately in 2015 12 million Bitcoin was in circulation with 47 users holding over 28% of this value showing an incredible amount of inequality in the distribution of the Bitcoin network (Wolfson 2015).

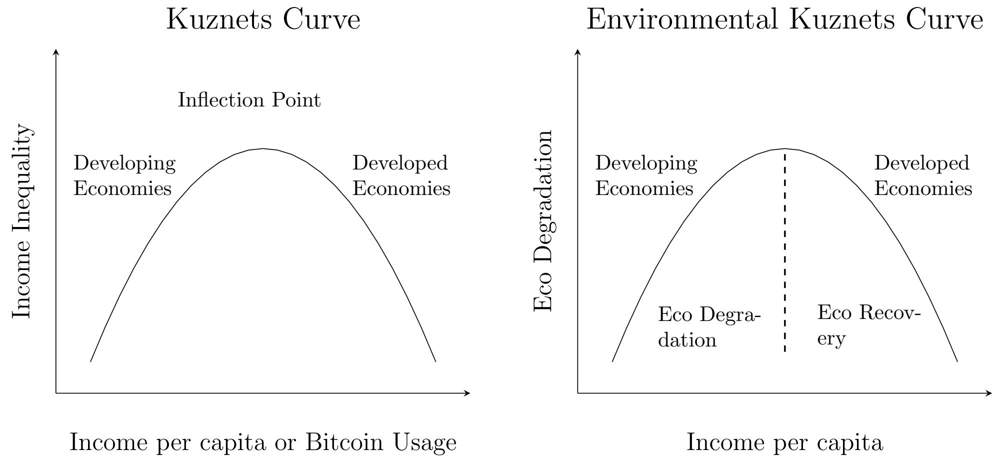
Another way to look at the wealth inequality of the Bitcoin network is to use the Gini index. The Gini index is a coefficient used as a measure of inequality across a certain population of people. The value of this coefficient is between 0-100 or 0-1, with a higher value indicating that the distribution of wealth is very low hence a higher inequality. Yet a lower value would indicate a more equal distribution of the wealth within the population. For Bitcoin this value started very low but by late 2009 early 2010 the value of this coefficient shot up to nearly 0.9 (or 90). However, this value was estimated to have reduced to 0.67 when looking at the top 10000 network addresses (Weymans 2022).

As we can see from the graph above the Gini coefficient has been declining for Bitcoin which shows the inequality of its wealth distribution is getting better over time. However, using the Gini coefficient has its limitations where a few users on either of the extreme ends of the wealth can change the statistic in a significant way.

The Kuznets Curve proposed and developed by Russian American economist Simon Kuznets uses this Gini index to show how income inequality behaves for a developing economy. An inverted 'U' shaped relationship exists between the income inequality and the growth of an economy represented as income per capita. The relationship that Kuznets discovered is very interesting as it shows that as an economy begins to develop, we see an increase in the income inequality that is measured by the Gini coefficient. In between the origin of the graph and the point labelled 'Developing economies' describes an economy at low levels of development, where the majority of the population will have a low income, and at this level the income inequality is relatively low. However, as the economy becomes more developed a minority of the population will gain higher income which then widens the income gap in the population which can be seen on the first graph from the point labelled 'Developing economies' to the point labelled 'Turning Point Income', in this region the income inequality is very high and is related to these few members experiencing a greater reward from the growing economy. As the economy keeps developing, we see a drop in the income inequality which the area between the peak of the graph and the point labelled 'Developed Economies', in this region appears the middle class. This is due a higher income experiencing a larger tax on their income which is used as investment on public goods and social welfare (Kuznets 1955).

The Kuznets curve was also developed to show how the development of an economy can also display the same shape for environmental degradation. This is to do with a developing economy having increased industrialisation, with a continuous increase in the capital stock, which means pollution increases and damages the environment. This can be shown on the second graph on Figure 1 which displays the environmental Kuznets curve, and once again we see that the pollution of a developing country increase initially and worsens the environment but again there is a turning point where the economy has developed and this environmental degradation begins to decrease and the environment will head towards its fruitfulness which was displayed before the development of the economy (Grossman, Krueger 1993, Dasgupta et al. 2002).

As discussed before Bitcoin's inequality coefficient, Gini, started at a very low value and then had a dramatic rise and now this value is declining as the wealth distribution



Notes: The above presented image is a well-known relationship. It is quoted in many studies, see for example Matthews (2018)

Figure 1: Economic and Environmental Kuznets Curve

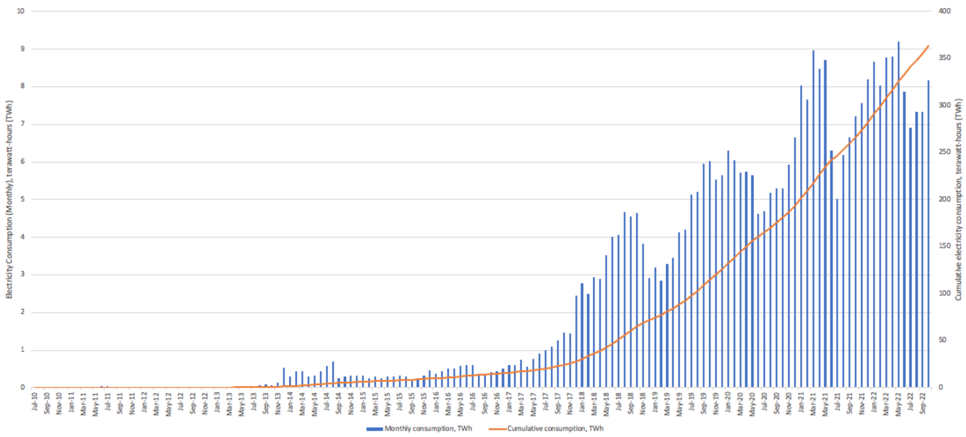
is being more spread out. This could be interpreted that Bitcoin is also experiencing a Kuznets curve due to its quick economic growth. However, the pollution caused by Bitcoin is still rising but this is due to it being in its development stage, and there is curiosity on whether or not it will also be subject to an environmental Kuznets curve, so once it has fully developed could we see a decrease in the environmental degradation. This will be explored throughout this paper as rich literature on its nature is not yet available.

2.5 Bitcoin and Ecological Outcome

Although there are many positive attributes of cryptocurrencies and the blockchain upon their creation, that initially gave rise to many people and organisations around the world seeing this new decentralised ledger as positive change away from a government-controlled economy. However, as of recent years many studies about the platform have unfolded the major negative impacts on the climate that this platform is causing due to its overwhelming energy use, which is purposefully built into its design (Truby 2018). This energy use links to an ever-increasing amount of carbon dioxide being released into the atmosphere which many experts have stated is not sustainable. Sustainability is essential for this digital platform in this day and age, as the world is currently suffering from a lack of care towards the environment. If these issues are left undealt with, it could not only cause a collapse to the digital currency platform itself but also cause permanent negative damage to the environment which this sector does not want on their hands.

As stated previously Bitcoin and other cryptocurrencies have a very energy intensive mechanism that becomes more energy demanding with time, which results in the network having an exponentially increasing energy consumption. In order for the current mechanism to work there needs to be miners. As discussed before miners use their computational power to solve a complex mathematical problem which finds a specific hash value to validate a block and then the block can be added to the blockchain (Egiyi, Ofoegbu 2020). The incentive to do this is because on completing this task the miner is rewarded an amount of that coin. However, this is where the extreme power usage comes from, as many people around the world saw this as a means to earn a lot of money.

Initially when cryptocurrencies first came into popularity there weren't many new transactions being added to the ledger and the currencies weren't worth a lot, so the steaks weren't very high. This meant the computer power and associated energy needed to mine wasn't that intensive, which meant most crypto miners were able to work from their own computers at home. Due to the difficulty increase of Bitcoin mining discussed in section 2.3, meant that the average miner was upgrading from their home computer to



Source: Data is obtained from Cambridge Bitcoin Electricity Consumption Index (CBECI) Database

Figure 2: Total Bitcoin Electricity Consumption

mining warehouses which is where the most financially successful mining operations are held. These mining warehouses are huge facilities that are running thousands of power intensive computers. This meant that there was a switch from CPU's and GPU's to mine the Bitcoin to ASIC's (Application-Specific Integrated Circuit) (Taylor 2017). These ASIC rigs are running constantly throughout the day attempting to find the right hash value, ASIC's can also produce more guesses of the hash value every second resulting in a greater competition among miners (Sutherland 2019). ASICs are purely mining devices and they serve little other purpose meaning as soon as their used until their no longer as fast as they were originally, they become electronic waste (De Vries 2019). Along with the power to run these computers there also needs to be cooling devices such as huge industrial fans which are also running at all times and thus requiring even more power is needed to keep this huge number of computers cooled and running (Stoll et al. 2019).

The power consumption gets worse with the increased incentive that the miner could have the potential to be very profitable with the ever-increasing value of Bitcoin. The value of Bitcoin was recorded to be $0.07 in 2010, at this time not many were invested into the network. However, this value rose quickly, with its value reaching $960 at the start of 2017 but this value quickly rose near the end of 2017 where it was recorded at highs of $20000 per coin and exceed a value of over $40000 in 2021 (Dilek, Furuncu 2019, De Vries 2021).

This increasing price created a huge increase in the number of miners on the network and caused the demand for energy to supply these mining facilities to increase drastically. Digiconomist have estimated that Bitcoin alone will use more that 120 terawatt-hours of electricity annually, which in comparison is a greater energy consumption that the whole of Norway annually (Digiconomist 2022). This is more than a 40% increase in electrical energy consumption when compared to last year's energy consumption. In an even more recent study, we saw the estimated energy consumption of Bitcoin increase to over 130 TWh, which was based on the consumption in July 2022 and means that per transaction the network will require 1455.8 kWh of electricity, which means for every transaction enough energy is used to power the home of an average American household for nearly 50 days (Reiff 2021).

Over the years Bitcoin's energy consumption has been compared to the energy consumption of many countries annually and has been reported to have exceeded the annual energy consumption of over 150 countries in 2017 (Dilek, Furuncu 2019).

As we can see from Figure 2, Bitcoin's total electricity consumption is constantly rising, there are dips in the monthly data (Grey bars) however this is due to the unpredictability of the network, but as a general trend we see that over the year's Bitcoin is consuming more and more electricity. The issue behind this energy use is where this electrical energy is coming from, in a recent study by the University of Cambridge it found that 40% of the mining power comes from coal (Smith 2022). The use of fossil fuels in such a large amount is not great for the environment as the CO2 that is produced is unprecedented with latest data showing that Bitcoin produces 22 million metric tons of carbon dioxide emissions in just a year, which is roughly the same amount produced by over 2.7 million homes (Smith 2022). Although the Bitcoin network is using renewables, it is not enough for their continuous system, as renewables aren't as reliable as a steady flow of electricity from a coal mine (Digiconomist 2022, Onat et al. 2021).

The growing energy consumption has led many to believe if nothing is done in the near future, we could see cataclysmic climate events that could cause devastating effects on the human population and the planet. Another study on the pollution emissions of Bitcoin mining from the University of Hawaii Manoa, estimated that the carbon dioxide emissions in 2017 was upwards of 69 million metric tonnes (Egiyi, Ofoegbu 2020). It was also calculated that due to the difficulty increase that the Bitcoin network intrinsically has as discussed in the end of section 2, we saw that per transaction the energy requirement increased from 6.09 kWh to 493.77 kWh and the associated carbon emissions from 4.53 kg of emissions to 430.92 kg of emissions in just 6 years from 2015 to 2021. This value is set to keep rising at a spectacular rate due to the increased popularity, and complexity of the Bitcoin network (Onat et al. 2021).

There is also a selection of non-renewable sources being used to power the Bitcoin network mining procedures, however there is still a large portion of energy being supplied from fossil fuels. Many are concerned that this continuous use of fossil fuels could push global warming over the 2°C limit (Goodkind et al. 2020). These increasing air pollutants can cause major issues to human health alongside damaging the planet (Clark, Greenley 2019). In a study in 2018 looking at the Bitcoin mining network it was reported that Bitcoin mining was receiving 77.6% of its energy from renewable sources (Bendiksen, Gibbons 2018), however in another study in 2018 it estimated this value to be closer to 28% (Rauchs et al. 2018). This uncorrelation in the value of Bitcoin's use of renewables is concerning but with the studies discussed on the carbon emissions it suggests the value is lower than estimated by many.

In an article by Christian Stoll called 'The Carbon Footprint of Bitcoin' he discusses that Bitcoin mining would produce nearly 500 grams of carbon dioxide emissions per kWh of energy consumed (Stoll et al. 2019). If we assume this value to stay constant for Bitcoin, and using the yearly energy estimated previously of 120TWh, we could see Bitcoin carbon emissions to be upwards of 60 million metric tonnes. Due to the disparity of what energy sources Bitcoin uses, this value could be less, however, many mining operations have moved to many fossil fuel reliant countries such as Iran and China which would mean this value could be rising (De Vries 2021).

Alongside Bitcoin's energy consumption leading to carbon dioxide emissions that are harming the environment there is also the issue of electronic waste (E-waste). This electronic waste is due to the intensive nature of the proof of work mechanism and with these ASIC mining rigs constantly running, there leads to malware of the devices. This is an often occurrence and replacement of these devices is done regularly. However, the number of people doing this leads to a heap of electronic devices being thrown away and they end up as e-waste that doesn't get recycled. In China which hosts a majority of the big Bitcoin mining operations, only 16% of all electronic waste is collected and in other countries like Iran, Malaysia and Kazakhstan there are even fewer e-waste regulations as these countries are all comparatively low-income countries. This clear lack of attention towards the growing e-waste problem can cause devastating effects to both human and ecological health (De Vries, Stoll 2021, Jana et al. 2021).

Electronic waste from Bitcoin mining has also shown evidence of bacteria growth in soil with bio-remediation properties. This increase in electronic waste can be very hazardous to the environment if nothing is done (Jana et al. 2022). The amount of electronic waste created by Bitcoin mining in 2019 was nearly the same amount of waste produced in Luxemburg annually and is only set to rise as more users join the growing network (Lang et al. 2019).

The literature on Bitcoin focuses enthusiastically on its benefits and ability to affect inequality in a positive manner. However, the economic literature knows about important nonlinearities in the relationship between productivity and ecology and income, known generally under the Kuznets curve and environmental Kuznets curve labels. Hence, I think a gap exists in terms of the lack of details around the relationship between Bitcoin, inequality and ecology in terms of nuances of the measurement of the main notions and in terms of non-linearities in their dependencies. I will try to shed some light on this gap with the further explorations below.

3 Empirical Analysis

3.1 Data

In this research on the economic and environmental effects of Bitcoin I collected data from multiple sources (see Appendix A). This data was over various years and for multiple countries, although not all data was in the same scale. I found data on the monthly hashrate for Bitcoin from Cambridge Bitcoin Electricity consumption index (CBECI), the hashrate data was for 9 countries (China, Russian Federation, U.S.A, Canada, Malaysia, Kazakhstan, Iran Islamic Republic, Ireland and Germany), this hashrate was in two parts, the average monthly hashrate percentage and the average absolute hashrate over the year 2019-2022. Hashrate is described as the computational power used by a Proof of Work (PoW) cryptocurrency network, it can also relate to the number of active miners that are attempting to solve hash puzzles (CCAF 2023), it is measured in Exahashes per second (Eh/s) and can give us a direct assumption on the energy consumption as a higher hashrate links to a greater energy consumption and a lower hashrate is linked to a lower energy consumption (Financial 2022).

The next set of data I collected was the GDP for all the same countries as mentioned above. GDP is the Gross domestic product and is essentially a monetary measure of the size and health of the economy of a country over a certain period of time, for the research I am conducting, it is each year. I found this value via multiple sources such as OECD, Statista and the Federal Reserve Bank of St. Louis (FRED database). The GDP can be used to estimate the size and growth rate of an economy and was measured in billion dollars. The values I found were for the year 2019-2022.

I then found the Gini index/coefficient for the same countries, this value as well as the GDP was a yearly value. I gathered the data for the Gini index again from multiple sources, such as OECD, FRED data and Statista. The Gini index is a measure of the distribution of income and related to the wealth inequality of a country. A high Gini index represents a high level of wealth inequality and a low Gini value means the wealth is more evenly distributed, the scale for the Gini I have used is from 0-100, other scales may be from 0-1 but both serve the same purpose (Hayes 2022).

The last of the economic variables were income inequality and wealth inequality of the top 1%. I use the renowned Piketty's database – World Inequality Database (WID) to inform these indicators. These indicators are two alternative proxies for economic inequality, but the literature suggests that wealth would be more significant than income in the context of this research (Novak 2019).

Alongside the economic variables I also collected 3 ecological variables. These 3 variables are the carbon emissions, electronic waste and carbon footprint for the top 10% of carbon emitters. I found this data using the OECD database, e-waste monitor, ITU, Statista and world inequality database. Carbon emissions were measured in Megatons (Mt) and is the amount of Co2 that is emitted into the environment from each country, each year. The electronic waste is the number of electronic devices thrown away to landfill each year as waste and was collected in million tonnes. The carbon footprint is the total amount of all greenhouse gases produced by our actions this variable was for the top 10%

Descriptive statistics for all variables in the dataset used for this analysis are available in Appendix B.

3.2 Methodology

For the variables I have collected, I have panel data as it is observing how the different parameters behave over a period of time in different places. Within this time component, I had months and years and I used an OLS regression with the years and countries employing fixed effects for time and location, as these variables were constant across all the data and I had months detrending. Yet the results with and without month detrending did not differ too much because some of the values were already available only on yearly level. Yet, I preserved the monthly level of the observations to gain degrees of freedom for the estimations.

H01: The economic factors affect the level of Bitcoin's network hashrate.

H02: The ecological factors are affected by the level of Bitcoin network hashrate.

H03: Bitcoin's network hashrate is associated with a non-linearity in the economic factor, in line with an-inequality-Kuznets-curve tendency.

3.3 Operational Models

To operationalize this **H01**, I use the following operational model:

$$\text{Bitcoin Hashrate} = \text{Economic variables} + \text{Error} \tag{2}$$

To operationalize this **H02**, I rely on the following operational model:

$$\text{Ecological variables} = \text{Bitcoin Hashrate} + \text{Error} \tag{3}$$

To operationalize this **H03**, I will use operational model:

$$\text{Bitcoin hashrate} = \text{Kuznets curve} + \text{Error} \tag{4}$$

I will test the operational models using different proxies, to show and compare the results across the different specifications. The proxies for Bitcoin are the hashrate percentage and the hashrate absolute. The proxies for economic factor are the GDP productivity, GINI, income inequality for top 1% and wealth inequality for top 1%. The proxies for the ecology are the carbon emissions, the electronic waste and the carbon footprint. I will do this to test these hypotheses with the different proxies of the main components of the hypotheses in this study in order to make sure I have consistency across the different specifications. Put differently, this is a way to triangulate these results within the econometric methodology.

4 Results and Analysis

Table 1 shows the estimations for the association between Bitcoin and the economic factor. When GDP increases, we have a strong correlation that hashrate decreases, this holds true both for hashrate percentage and absolute hashrate. It could be interesting to see which of the determinants of GDP are most responsible for this association between GDP and Bitcoin as this will further extend our understanding of this relationship. However, it is still a very interesting result as it shows that Bitcoin was redistributed towards less wealthy countries. Yet, it is also true that an increase in the use of Bitcoin would in theory create more circulation of money thus increasing GDP for a country. So, this might seem as very positive news about Bitcoin and its propensity to decrease the economic inequality in the world. If we take a look at the next economic variable, this positive news seems to be further confirmed, as we see that the lower the Gini coefficient is, the higher the hashrate tends to be. As the Gini is a direct measure of inequality, this finding means that the wealth of Bitcoin is getting more distributed and this would mean more wealth distribution outside of the network. The Gini value association is only detectable for the hashrate percentage and not the absolute hashrate. However, looking at the last two variables we start to see some complexities, previously

Table 1: Economic variables effect on Bitcoin Hashrate

	hashrate_perc				hashrate_absolute			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
gdp_productivity	-0.008***				-0.005***			
	(0.001)				(0.001)			
GINI		-1.621***				-0.383		
		(0.491)				(0.605)		
Income_1perc_ppl			-1,567.067				1,618.109	
			(5,146.791)				(6,069.827)	
Wealth_1perc_ppl				-1,182.202***				-1,031.962***
				(188.539)				(230.809)
country FE	YES	YES	YES	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES	YES	YES
month_detrended	YES	YES	YES	YES	YES	YES	YES	YES
Constant	171.666***	123.084***	270.767	408.437***	139.545***	74.573***	-169.285	369.189***
	(14.222)	(21.923)	(720.999)	(57.046)	(18.830)	(27.008)	(850.305)	(69.836)
Observations	261	216	252	252	261	216	252	252
R-squared	0.795	0.749	0.745	0.782	0.762	0.747	0.759	0.778

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; OLS with fixed effects for country and year, month detrended data; Specification (1) to (4) use outcome variable: hashrate, and Specifications from (5) to (8) regard outcome variable hashrate_aboslute.

Table 2: Ecological effects due to Bitcoin's Hashrate

Variables	(1) carbon_-emissions	(2) carbon_-footprint	(3) e_waste	(4) carbon_-emissions	(5) carbon_-footprint	(6) e_waste
hashrate_perc	134.510***	-0.000	0.005***			
	(8.506)	(0.000)	(0.001)			
hashrate_absolute				87.776***	-0.000	0.004***
				(8.981)	(0.000)	(0.001)
country FE	YES	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES
month_detrended	YES	YES	YES	YES	YES	YES
Constant	-503.091	36.000	9.515***	1,474.036*	36.000	9.545***
	(632.310)	(0.000)	(0.101)	(764.699)	(0.000)	(0.099)
Observations	204	252	183	204	252	183
R-squared	0.850	1.000	0.998	0.766	1.000	0.998

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; OLS with fixed effects for country and year, month detrended data; Specification (1) and (4) use outcome variables: Carbon emissions, Specifications (2) and (5) regard outcome variable Carbon footprint and Specifications (3) and (6) regard outcome variable e-waste.

not known. Namely, the income for the top 1% is not correlated with Bitcoin hashrate, but the wealth of the top 1% is significantly associated. The wealth of the top 1% seems here to be decreasing with an increase in hashrate. This means that the top 1% are getting worse off. This however is strangely juxtaposed to the existing literature that finds that the top 1% are profiting off an increased use of the Bitcoin network and the 'Bitcoin inequality' where the wealth distribution although getting more distributed is still heavily located with the more wealthy (Wolfson 2015, Weymans 2022). But in a way, it is logical that if re-distribution increases, then those who were previously dominant in the inequality will appear to be losing. Hence, actually there is consistency here between us and the literature, but it needs to look at the economic meaning of the statistical sign more closely.

In Table 2, we have the ecological pollution as an outcome (measured through alternative proxies), and we explore its relationship with the Bitcoin use as a determinant factor. Looking at the carbon emissions we see that there is a strong association between the carbon emissions increases and the increasing use of Bitcoin (both when measured with hashrate percentage or absolute hashrate). This finding is completely consistent with the literature. An increase in the hashrate tells us that there is an influx of users undergoing the proof of work mechanism which increases the energy use, and this is directly correlated to an increase in the carbon emissions. The carbon footprint has no correlation with the hashrate in this model which could be as a result of lack of controls for this variable as it takes into account more than just the carbon emissions (such as cars and other modes of transport). For the electronic waste variable, we see that there is also a strong association with an increased hashrate. This also is a convincing finding, as the higher the hashrate is, the more computers are being used to mine data, which in turn would lead to more computers being used up and replaced, in the replacement process these computers are disposed of as electronic waste.

In Table 3, we can see that the hashrate percentage and hashrate absolute do have a non-linear relationship with economic prosperity, which can be called a Bitcoin-Kuznets curve, in line with previous literature labelling nonlinear relationship with economic wealth in this manner (Weymans 2022). As seen from Table 3, the impact from wealth on Bitcoin is first positive but then declines with the further increase in wealth. The same occurs for the carbon emissions as it starts off increasing then a decreasing relationship appears, and the carbon footprint is not significant in this table. However, something quite interesting happens with regard to what the data reports about inequality increases in terms of wealth concentration and the nonlinear relationship of this indicator with GDP. For this variable we see in the table that the opposite occurs, at first it is decreasing and then increasing, so as the wealth of the top 1% is increasing. But this also occurs

Table 3: Bitcoin Kuznets Curve in Wealth Inequality

Variables	(1) gdp_productivity	(2) carbon_emissions	(3) carbon_footprint	(4) e_waste	(5) hashrate_perc	(6) hashrate_absolute
Wealth_1perc_ppl	-848,682***	2,820,585***	0.0	-122**	8,789***	7,070***
	(113,842)	(376,207)	(0.0)	(48)	(1,818)	(2,307)
Wealth_1perc_sq	1,501,659***	-5,386,515***	-0.0	175**	-17,136***	-13,923***
	(194,708)	(635,261)	(0.0)	(83)	(3,111)	(3,947)
Constant	134,930***	-353,690***	36.0	30.8***	-1,039***	-807**
	(16,788)	(56,069)	(0.0)	(7.1)	(268)	(340)
country FE	YES	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES
month_detrended	YES	YES	YES	YES	YES	YES
Observations	252	204	252	183	252	252
R-squared	0.996	0.833	1.000	0.998	0.807	0.789

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; OLS with fixed effects for country and year, month detrended data; Specification (1) uses outcome variable: GDP, Specification (2) regards outcome variable: Carbon emissions, Specifications (3) regards outcome variable: Carbon footprint, Specification (4) uses outcome variable: e-waste, Specification (5) regards outcome variable: Hashrate and Specification (6) regards outcome variable: Absolute Hashrate.

Table 4: Bitcoin Kuznets Curve in GDP

Variables	(1) GINI	(2) carbon_emissions	(3) carbon_footprint	(4) e_waste	(5) hashrate_perc	(6) hashrate_absolute
gdp_productivity	0.001	-7.9***	-0.0	-0.001***	-0.033***	-0.037***
	(0.001)	(0.5)	(0.0)	(0.000)	(0.003)	(0.004)
gdp_sq	0.0	0.0***	0.0	0.0***	0.0***	0.0***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Constant	32.8***	90,644***	36.0	16.8***	395.876***	414.7***
	(5.9)	(4,187)	(0.0)	(0.8)	(29.757)	(40.2)
Observations	216	204	252	183	261	261
R-squared	0.968	0.924	1.000	0.999	0.841	0.808

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; OLS with fixed effects for country and year, month detrended data; Specification (1) uses outcome variable: Gini, Specifications (2) regards outcome variable: Carbon emissions, Specifications (3) regards outcome variable: Carbon footprint, Specification (4) regards outcome variable: E-waste, Specification (5) regards outcome variable: Hashrate, Specification (6) regards outcome variable: Absolute Hashrate.

for the electronic waste variable as we can see on the graph initially is it decreasing and then increasing. Firstly, this means that when wealth concentrates in a few, it might bring more productivity, but will also associate it with more harmful behaviour to the environment. Second, in spite of the different signs and directions across specifications, it still is always evident that non-linearity exists in the relationship of this variables employed. This important to note because the relationship which is already known to exist between GDP productivity, inequality and carbon footprint has been destabilised and is now present in the relationship between inequality and the Bitcoin hashrate. Some path dependence but also some changes and complexities seem to have occurred and need better data and more attention.

In results Table 4, these results use different proxies for the economic wealth (GDP rather than the top 1% of wealth as it was in Table 3). The only difference is that specification 1 uses GINI as an outcome measure for the local inequality. And we see that GINI has a linear relationship with GDP that disappears when we add a square value of GDP, and it does not provide any useful information for us as well as carbon footprint again. Otherwise, our specifications are the same as in Table 3 and they report consistent results with Table 3.

5 Conclusion

The exploration in this study regards the extent of the economic and ecological effects associated with the rise of the Bitcoin network. To explore the relationship between these effects, I compiled a unique dataset with a wealth of economic and ecological variables (such as: GDP, Gini, income and wealth inequality of the top 1%, carbon emissions, electronic waste and carbon footprint). The literature review offered an overview of the descriptive facts known about Bitcoin, the economy and the ecology, and the empirical explorations help to shed some further light on this relationship, factoring in also some aspects of nonlinearity.

The empirical analysis in this study shows that GDP has an inverse effect on the use of Bitcoin, with a rising GDP being associated with a lower hashrate. The Gini coefficient has the same relationship, which is in line with the reviewed literature, that claims that over time the Bitcoin-wealth is getting more evenly distributed among all users (Weymans 2022). The relationship of Bitcoin-wealth with the income and wealth of the top 1% however differs. For the income of the top 1% it showed an inverse relationship, while the wealth of the top 1% shows a positive relationship with Bitcoin. The interpretation of these findings can be done (in line with the existing literature on the top 1%) that Bitcoin-wealth gets more evenly distributed, however Bitcoin is in the hands of the wealthier 1%. Put differently, the redistribution in Bitcoin doesn't really mean an improved objective economic inequality – the Bitcoin-wealth seems still to be enriching the rich.

For the ecological variables available in the dataset used for this study, I find a consistent trend with both carbon emissions and electronic waste. These two variables both increased with the increase of hashrate. Which makes complete intuitive sense and is consistent with the literature, as an increased hashrate would indicate more active miners. Thus, an increased energy consumption is expected. In addition, increased number of hashrates indicates that the miners are probably using the previously discussed most efficient ASIC devices for mining, and the higher rate of using these ASICs leads to the generation of more electronic waste in time, since they wear out in higher numbers within the same time in comparison to the old devices. For the carbon footprint variables, there were no significant values that would indicate a relationship with an increase or decrease in hashrate. This makes us reflect on the statistical and ecological meaning of the footprint variable as a good measure for ecological aftermaths. That's particularly relevant, and apparently rather alarming, since such aftermaths are consistently detectable with the measures of emissions and e-waste, but invisible with the footprint variable.

The results in this study are obtained, using a personally compiled panel database, which contains more information, efficiency and variability than both cross-section and time-series data could offer and allows me to extract more statistical meaning from the raw data. Using the panel data, I completed an OLS regression with fixed effects for time and location. This is motivated by the fact that while this dataset is unique and previously not addressed for empirical exploration, still part of the data needed to be computed or was available at different levels. Thus, the most sparing and simple OLS with fixed effects allows me to extract the most without over-reliance on what might be sensitive to the pitfalls due to data availability.

Regarding the first hypothesis, I found that it cannot be falsified, i.e. the economic variables did have an effect on the Bitcoin variable, although the relationship was not as expected. Across the different specifications, the results were generally consistent. I found a significant relationship between the economic factors and the Bitcoin hashrate. Yet, the use of different proxies helped to identify some nuances about this relationship. While the use of GINI showed results consistent with the existing literature, namely decreasing inequality with the increase of Bitcoin, the use of the other variables depicted the picture in further details, as follows. GDP reported a negative relationship with Bitcoin, which might agree with the assumption that poorer countries started to mine. Yet, when we focus on the richest 1% of the population, the relationship of Bitcoin with income is not at all present, and it seems that the presence of Bitcoin is strongly associated with the richest 1% of the populations across the world.

Regarding the second hypothesis, I also found that it cannot be rejected, namely, the change in the Bitcoin variable did have an effect on two out of the three specifications tested.

The final third hypothesis was that Bitcoin was associated with a Kuznets curve type of nonlinearity that is typical for economic and ecological inequality. To cross check this, I explored the relationship between economic productivity and its square term on the one side and on the other side I used three alternative outcomes: (i) the economic inequality (to operationalize the classical Kuznets curve), (ii) the ecological pollution (operationalizing the ecological Kuznets curve) and (iii) the Bitcoin hashrate, as an outcome variable. When I used GDP as a measure of economic productivity and its square, the results obtained differed in direction from the findings when I used the 1% of the wealthy population. However, in both cases the expected nonlinearity was present. The difference in direction is also consistent with my previous findings that Bitcoin spreads across less wealthy countries but remains locked within the wealthier 1% of the population. This, more generally, gives the general novel insight, that the nonlinearities from ecology and economic development seem to have transferred in the field of the use of Bitcoin. Yet, the Bitcoin world has replicated in some complex ways the existing inequalities previously known in the literature.

While the above results shed some light on complexities in the relationship of inequality and ecology, that might be of high importance, still this work has some limitations which stem from the data availability which makes the use of more robust methods inaccessible at this point. Therefore, this research paper's main contribution entails raising some important flags for where attention might be due when better data becomes available in the future. Namely, during the collection of this data, I faced the challenge that there were multiple missing values in many of the data sources. For this electronic waste data, it was very hard to find many values, as some countries hadn't had a specific statistic in place for the measurement. Thus, I gathered most of the data I could and for the data that was not available, I used a 10% increase each year which was in-line with the data assumption from previous studies about China that the electronic waste was increasing by 10% each year. The data I gathered for the Bitcoin variables was monthly data, however monthly data was not available at some cases, and this meant that I had to use the yearly value to fill in the missing points, yet this led to some loss of variability.

Despite the limitations of the data, which meant that I had to use also the most conservative methods, the results in this study are still important in two ways: (i) they are validated with external consistency with the literature and (ii) they offer novel insights that report internal consistency between the findings of the current study. Thus, even with the existing data challenges, I still managed to show some significant and complex relationships of the Bitcoin hashrate and the economic and ecological variables. My results indicate that further work is worth to be done in the same direction, especially in order to confirm and further disentangle how the complex transfer of the economic inequalities has happened in the world of Bitcoin, and to delve further in the differences in terms of country and individual redistribution of income and wealth.

References

Begum A, Tareq A, Sultana M, Sohel M, Rahman T, Sarwar A (2020) Blockchain attacks analysis and a model to solve double spending attack. *International Journal of Machine Learning and Computing* 10: 352–357

Bendiksen C, Gibbons S (2018) The bitcoin mining network: Trends, composition, average creation cost, electricity consumption & sources. CoinShares Research, Whitepaper

CCAF – Cambridge Center for Alternative Finance (2023) Cambridge bitcoin electricity consumption index, 2022. Cambridge Centre for Alternative Finance. https://ccaf.io/cbnsi/cbeci

Chohan UW (2021) The double spending problem and cryptocurrencies. Available at SSRN 3090174. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3090174

Clark CE, Greenley HL (2019) Bitcoin, blockchain, and the energy sector. Congressional Research Service, Washington, DC. https://crsreports.congress.gov/product/pdf/R/R45863

Courtois NT, Grajek M, Naik R (2013) The unreasonable fundamental incertitudes behind bitcoin mining. arXiv preprint arXiv:1310.7935

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

Dasgupta S, Laplante B, Wang H, Wheeler D (2002) Confronting the environmental Kuznets curve. *Journal of economic perspectives* 16: 147–168. CrossRef

De Vries A (2019) Renewable energy will not solve bitcoin's sustainability problem. *Joule* 3: 893–898. CrossRef

De Vries A (2021) Bitcoin boom: What rising prices mean for the network's energy consumption. *Joule* 5: 509–513. CrossRef

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

Di Febo E, Ortolano A, Foglia M, Leone M, Angelini E (2021) From Bitcoin to carbon allowances: An asymmetric extreme risk spillover. *Journal of Environmental Management* 298: 113384. CrossRef

Digiconomist (2022) Bitcoin energy consumption index. Retrieved from https://digiconomist.net/bitcoin-energy-consumption/

Dilek S, Furuncu Y (2019) Bitcoin mining and its environmental effects. *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi* 33: 91–106

Egiyi MA, Ofoegbu GN (2020) Cryptocurrency and climate change: An overview. *International Journal of Mechanical Engineering and Technology* 11: 15–22. CrossRef

Financial R (2022) Bitcoin's energy consumption. Retrieved from https://river.com/learn/bitcoins-energy-consumption/

Goodkind AL, Jones BA, Berrens RP (2020) Cryptodamages: Monetary value estimates of the air pollution and human health impacts of cryptocurrency mining. *Energy Research & Social Science* 59: 101281. CrossRef

Grossman GM, Krueger A (1993) Environment impacts of a North American Free Trade Agreement. NBER working paper series, 3914, National Bureau of Economic Research, Cambridge MA. CrossRef

Hayes A (2022) Gini index explained and gini coefficients around the world. Investopia. Retrieved from https://www.investopedia.com/terms/g/gini-index.asp

Jana RK, Ghosh I, Das D, Dutta A (2021) Determinants of electronic waste generation in Bitcoin network: Evidence from the machine learning approach. *Technological Forecasting and Social Change* 173: 121101. CrossRef

Jana RK, Ghosh I, Wallin MW (2022) Taming energy and electronic waste generation in bitcoin mining: Insights from facebook prophet and deep neural network. *Technological Forecasting and Social Change* 178: 121584. CrossRef

Kroll JA, Davey IC, Felten EW (2013) The economics of Bitcoin mining, or Bitcoin in the presence of adversaries. Proceedings of WEIS (vol. 2013, no. 11)

Kuznets S (1955) Economic growth and income inequality. *The American economic review* 45: 1–28

Küfeoğlu S, Özkuran M (2019) Energy consumption of bitcoin mining. Cambridge Working Papers in Economics 1948, Faculty of Economics, University of Cambridge

Lang C, Hu Y, Oxley L, Hou Y (2019) The sustainability and profitability of Bitcoin mining: A time-varying Granger causality approach. Available at SSRN 3448837. CrossRef

Matthews R (2018) The illusion of growth and the fallacy of Kuznets curve. Retrieved from https://thegreenmarketoracle.com/2018/04/23/the-illusion-of-growth-and-fallacy-of/

Miśkiewicz R, Matan K, Karnowski J (2022) The role of crypto trading in the economy, renewable energy consumption and ecological degradation. *Energies* 15: 3805. CrossRef

Nakamoto S (2008) Bitcoin: A peer-to-peer electronic cash system. *Decentralized business review*

Novak M (2019) The implications of blockchain for income inequality. In: Swan M, Potts J, Takagi S, Witte F, Tasca P (eds), *Blockchain economics: implications of distributed ledgers-markets, communications networks, and algorithmic reality*. World Scientific, Singapore, 235–250. CrossRef

O'Dwyer KJ, Malone D (2014) Bitcoin mining and its energy footprint. Hamilton Institute, National University of Ireland Maynooth, http://karlodwyer.com/publications/pdf/bitcoin_KJOD_2014.pdf

Onat N, Jabbar R, Kucukvar M, Fetais N (2021) Bitcoin and global climate change: Emissions beyond borders. Preprint, available on Research Square. CrossRef

Qin R, Yuan Y, Wang S, Wang FY (2018) Economic issues in bitcoin mining and blockchain research. 2018 IEEE Intelligent Vehicles Symposium (IV), pp. 268-273. CrossRef

Rauchs M, Blandin A, Klein K, Pieters G, Recanatini M, Zhang B (2018) 2nd global cryptoasset benchmarking study. Available at SSRN 3306125. CrossRef

Reiff N (2021) What's the environmental impact of cryptocurrency. Investopedia. last updated: December, 21, 2022, https://www.investopedia.com/tech/whats-environmental-impact-cryptocurrency/

Shi N (2016) A new proof-of-work mechanism for bitcoin. *Financial Innovation* 2: 1–8. CrossRef

Singhal A, Rafiuddin A (2014) Role of Bitcoin on economy. Proceedings of the World Congress on Engineering and Computer Science (Vol. 2). https://www.researchgate.net/publication/286598305_Role_of_Bitcoin_on_Economy

Smith N (2022) Crypto woes: Cryptocurrency and climate change, from coal to e-waste. Retrieved from https://www.colorado.edu/ecenter/2022/02/07/crypto-woes-cryptocurrency-and-climate-change-coal-e-waste

Stoll C, Klaaßen L, Gallersdörfer U (2019) The carbon footprint of bitcoin. *Joule* 3: 1647–1661. CrossRef

Sutherland BR (2019) Blockchain's first consensus implementation is unsustainable. *Joule* 3: 917–919. CrossRef

Taylor MB (2017) The evolution of bitcoin hardware. *Computer* 50: 58–66. CrossRef

Truby J (2018) Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of blockchain technologies and digital currencies. *Energy research & social science* 44: 399–410. CrossRef

Utomo GOT (2016) The influences of cryptocurrency on economic growth: Case study of Bitcoin in 5 Asian countries 2011-2016 period. *Jurnal Ilmiah Mahasiswa FEB* 6

Vranken H (2017) Sustainability of bitcoin and blockchains. *Current opinion in environmental sustainability* 28: 1–9. CrossRef

Wealth O (2018) Bitcoin's contribution to gross domestic product (GDP). Retrieved from https://medium.com/@ObsidianWealth/bitcoins-contribution-to-gross-domestic-product-gdp-181fcd7e0f67

Weymans M (2022) Bitcoin wealth is becoming more evenly distributed over time 3/4. ecommerce Institut Köln, Cologne, Germany. https://ecommerceinstitut.de/bitcoin-wealth-is-becoming-more-evenly-distributed-over-time-3-4-2/

William P, Jadhav D, Cholke P, Jawale MA, Pawar AB (2022) Framework for product anti-counterfeiting using blockchain technology. 2022 international conference on sustainable computing and data communication systems (ICSCDS), IEEE, pp. 1254-1258. CrossRef

Wolfson SN (2015) Bitcoin: the early market. *Journal of Business & Economics Research* 13: 201–214. CrossRef

Ye C, Li G, Cai H, Gu Y, Fukuda A (2018) Analysis of security in blockchain: Case study in 51%-attack detecting. 2018 5th international conference on dependable systems and their applications (DSA), IEEE, pp. 15-24. CrossRef

A Appendix: Data Sources

Country	Data Source Link
China	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/MKTGDPCNA646NWDB
	https://wid.world/data/
	https://www.statista.com/statistics/263770/gross-domestic-product-gdp-of-china/#: :text=Gross domestic product (GDP) of China 1985-2028&text=In 2022, the gross domestic,in the world GDP ranking.
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/
Russian Federation	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/MKTGDPCNA646NWDB
	https://wid.world/data/
	https://www.statista.com/statistics/263772/gross-domestic-product-gdp-in-russia/#: :text=In 2021, the GDP in,around 1.84 trillion U.S. dollars.&text=The Russian economy is primarily,private sector and the state.
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE
U.S.A	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/GDP
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/188105/annual-gdp-of-the-united-states-since-1990/
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE
Canada	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/NGDPRSAXDCCAQ
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/650869/real-gdp-canada/
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining˙map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE
Malaysia	
	https://fred.stlouisfed.org/series/MKTGDPMYA646NWDB
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/319024/gross-domestic-product-gdp-in-malaysia/#: :text=The gross domestic product in,a new peak in 2028.
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://www.statista.com/statistics/1394260/malaysia-co2-emissions-from-energy-use/#: :text=In 2022, the amount of,highest in that same year.
	https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/
Kazakhstan	
	https://fred.stlouisfed.org/series/MKTGDPKZA646NWDB
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/436130/gross-domestic-product-gdp-per-capita-in-kazakhstan/#: :text=Gross domestic product (GDP) per capita in Kazakhstan 2028&text=The gross domestic product per,U.S. dollars (+29.89 percent).
	https://ccaf.io/cbnsi/cbeci/mining_map

Continued on next page

Table A.1 – continued from previous page

Country	Data Source Link
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://www.statista.com/statistics/1320969/energy-related-co-2-emissions-kazakhstan/
	https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/
Iran Islamic Republic	
	https://fred.stlouisfed.org/series/MKTGDPIRA646NWDB
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/294245/iran-gross-domestic-product-gdp-per-capita/#: :text=The gross domestic product per,year to 4,996.57 U.S. dollars.
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://www.statista.com/statistics/1302695/iran-emissions-per-capita-from-electricity-generation/
	https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/
Ireland	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/CLVMNACSAB1GQIE
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/377002/gross-domestic-product-gdp-per-capita-in-ireland/#: :text=The gross domestic product per,a new peak in 2028.
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE
Germany	
	https://data.oecd.org/gdp/gross-domestic-product-gdp.htm
	https://fred.stlouisfed.org/series/CPMNACSCAB1GQDE
	https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators
	https://wid.world/data/
	https://www.statista.com/statistics/295444/germany-gross-domestic-product/#: :text=GDP of Germany 2022&text=In 2022, Germany's gross domestic,in the world GDP ranking.
	https://data.oecd.org/inequality/income-inequality.htm
	https://ccaf.io/cbnsi/cbeci/mining_map
	https://www.statista.com/forecasts/1171540/gini-index-by-country
	https://data.oecd.org/air/air-and-ghg-emissions.htm
	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE

B Appendix: Main Variables and Their Descriptive Statistics

Variables	Definition	Source	Obs.	Mean	Std.Dev.	Min	Max
gdp_productivity	Gross Domestic Product	OECD, World Bank, Statista,FRED	261	5246.3	7581.7	171.1	22996.1
GINI	Income Inequaltiy Coefficient	OECD, World Bank, Statista	216	37.5	7.2	26.9	48.9
Income_1perc	Income of the Top 1%	World Inequality Database	252	0.2	0.0	0.1	0.2
Wealth_1perc	Wealth of the Top 1%	World Inequality Database	252	0.3	0.1	0.2	0.5
carbon_emissions	Co2 Emissions	OECD, World Bank, Statista	204	1865.9	2769.4	11.9	10081.3
carbon_footprint	Carbon Footprint	World Inequality Database	252	45.4	13.4	34.0	75.0
e_waste	Electronic Waste	OECD, World Bank, Statista	183	3.5	3.8	0.1	10.2
hashrate_perc	Bitcoin Network Hashrate % share	CBECI	261	10.4	17.1	0	75.5
hashrate_abs	Bitcoin Network Hashrate Absolute	CBECI	261	13.3	21.0	0	91.1