Assessing the Environmental Consequences of Cryptocurrency Mining: A Comparative Study of Bitcoin, Ethereum, and Dogecoin

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Course Number: 40201391 Course Name: Computing Research Project

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1 Section One: Introduction to Environmental Impact of Digital Transformation and Introduction to Subject

In recent years, business processes, customer experiences, and cultures have all been significantly or completely disrupted by the increased incorporation of digital technologies. There are numerous ways in which we can observe this transformation being implemented, like opting for remote work, implementing artificial intelligence, relying on cloud computing, and using digital currencies.

While many positive effects can be observed like improved competitiveness, efficiency and innovation, it is our duty that we consider the environmental impact of this digital transformation in order to sustain our planet. Cloud computing, for example, is dependent on data centers, which are major energy consumers that account for 1% of global energy consumption and are frequently compared to the aviation industry [1]. In addition, with the rapid pace of change, many devices are being manufactured and replaced, resulting in an astounding amount of e-waste. This electronic waste is not only harmful to the environment but is also contributing to the depletion of natural resources.

Cryptocurrencies, a major part of digitalization, have grown rapidly in response to the demand for a more secure, private and decentralized method of making payments, as well as to store and manage digital assets. Cryptocurrency mining requires a lot of energy and has a growingly detrimental effect on the environment as it gains in popularity. Mining cryptocurrencies requires specialized software to solve difficult mathematical problems based on proof-of-work consensus procedures, which consumes a lot of energy due to the high computational demands. According to some estimates, a staggering 47 terawatt-hours of power are already used each year to mine bitcoin and Ethereum combined, and this figure is constantly rising [2]. To put this in context, Jordan's 10 million inhabitants consume nearly 16.8 terawatt-hours of energy per year [3]. Furthermore, China is home to 58% of the world's bitcoin mining operations, which are typically powered by coal-fired power plants [2]. To make the digital currency sector ecologically sustainable, in my opinion, immediate change is required.

The project will compare the environmental impact of three main cryptocurrencies bitcoin, dogecoin and Ethereum by exploring the energy consumption and carbon emissions of mining these coins. Additionally, it will examine any potential correlation between the value of cryptocurrencies and the scale of its environmental degradation. Lastly, it explores the challenges and opportunities of employing PoS (proof of stake) consensus algorithms on Bitcoin.

2 Section Two: Literature review.

Accompanied by the launch of cryptocurrencies, an increase in greenhouse gas emissions trend emerged due to the high-power consumption. To facilitate understanding the scale of the problem, it has been predicted that Bitcoin can raise the global temperatures by 2°C within the next three decades [4]. In addition, the electric load demand of just the Bitcoin network would exceed half of the estimated power demand of all global data centers combined and represent nearly half a percent of the global electrical energy consumption [5]. Table I shows the ranking of the two main cryptocurrencies namely, bitcoin and Ethereum among countries based on the yearly carbon footprint as of July 2021 as found in research paper [6]. Moreover, Table II provided by the same paper [6] compares the energy consumption of bitcoin and Ethereum and visa. While the comparison with traditional currencies isn't tackled in this paper, I think it is sensible to include this comparison to understand the full picture.

TABLE I: Ranking of Bitcoin and Ethereum among countries based on annual carbon footprint as of July 2021 [6].

Rank	Country	Population (Millions) [26]	Emission (MtCO_2)	Share (%)
0	World	7,878.2	37,077.40	100.00
1	China	1,444.9	10,060.00	27.13
2	U.S.A	332.9	5410.00	14.59
3	India	1,336.4	2,300.00	6.2
38	Nigeria	211.3	104.30	0.28
39	Czech Republic	10.7	100.80	0.27
40	Belgium	11.6	91.20	0.24
41	Bitcoin + Ethereum	N.A.	90.31	0.24
42	Kuwait	4.3	87.80	0.23
43	Qatar	2.9	87.00	0.23
49	Oman	5.2	68.80	0.18
50	Bitcoin	N.A.	64.18	0.17
51	Greece	10.3	61.60	0.16
76	Tunisia	11.94	26.20	0.07
77	Ethereum	N.A.	26.13	0.07
78	SAR	17.9	25.80	0.06

Figure 1: TABLE I

TABLE II: Comparison of energy consumption and carbon footprints per transaction for Bitcoin, Ethereum and Visa as of July 2021 [6].

Transaction method	Emission (KgCO_2)	Energy consumption (kWh)
Bitcoin [23]	844.13	1777.11
Ethereum [27]	59.55	125.36
Visa [27]	0.00045	0.0015

Figure 2: TABLE II

Existing literature on the environmental impact of cryptocurrencies have discussed many aspects, including the drivers behind the high energy consumption, potential solutions, and case studies of existing solutions attempting to reduce the size of the problem. A research paper [6] outlined the causes of cryptocurrency's high energy consumption and CO2 emissions as:

1. the Proof of Work consensus mechanism: It has been demonstrated that PoW mining has high computational requirements, imposing significant constraints on the continuous use and scalability of cryptocurrencies. [7, 8].

2. Redundancy in operation and traffic: Energy consumption from redundant operations and network traffic is particularly significant in non-PoW blockchains. [9]. Redundancy raises the overall electrical energy consumption while simultaneously decreasing the system's effectiveness [10]. This is a result of both the

quantity of nodes and the workload placed on each node, as described in [10].

3. Mining devices: The authors argued that the total energy required for mining bitcoins would be much lower, at roughly 1.46 TWh worldwide, than the current estimates of 184 TWh, 135.12 TWh, and 69.63 TWh for 2021, if all mining facilities used the highly efficient ASIC-based mining equipment.[11]
4. Energy sources: High carbon footprints result from heavy reliance on the usage of nonrenewable energy sources [12].

That same research paper [6] highlighted possible solutions:

1. Alternative Consensus Mechanisms: Consensus algorithms are used to ensure the system's data integrity and consistency by allowing multiple nodes to agree on the state of the ledger and the validity of new transactions. Earlier it was established that Proof of Work is part of the problem therefore substituting it might be part of the solution. One of the most promising substitutes for the PoW is the Proof of Stake (PoS) consensus mechanism which was first used in Peercoin [13]. This removes the computational race involved in the PoW thereby reducing energy consumption and CO2 emissions during mining [14]. The paper also discussed consensus mechanisms like Proof of Activity (PoA), Proof of Burn (PoB) and others used by smaller coins [6].
2. Redundancy Reduction Techniques: A promising method for reducing storage redundancy in blockchain networks proposed in the literature is "sharding," which involves breaking the network into subparts called "shards" based on the consensus mechanism and updating the transactions within the bounds of each shard [9].
3. Choice of Mining Device: simply opting for the most power efficient devices will help reduce energy consumption.
4. Renewable Sources of Energy: relying on renewable energy will decrease CO2 emissions however it is not currently possible due to the low amount of renewable energy used.

Policymakers and governments are urged to take action to enforce change. In this paper the first solution is discussed the most and the possibility of applying it to bitcoin is explored.

Understanding Ethereum 2.0 is a step forward to making cryptocurrencies more environmentally friendly. The goal of this version is to address the security, scalability, and sustainability challenges of Ethereum. It essentially accomplishes this by switching from the PoW consensus mechanism to the PoS, which involves far fewer mathematical calculations and thus has lower computational requirements, consuming significantly less energy. The Ethereum network likely reduced its power demand by 99.84. [5]

After conducting the literature review, I was able to identify gaps. Firstly, the correlation between the value of the cryptocurrency and the scale of the environmental degradation isn't clearly discussed in the existing literature therefore this paper will provide an analysis of this area. Furthermore, I believe that comparing the three cryptocurrencies will help make informed decisions about which ones to support and utilize. It can also help guide the development of more sustainable mining and blockchain technologies.

3 Section Three: Objective and research questions

Objective: Understand the effect of cryptocurrencies on the environment through analyzing the power consumption and carbon emissions of three main cryptocurrencies and exploring the possible correlation between the coin's value and the scale of this effect. Explore the possibility of integrating the best-known solution to coins other than Ethereum.

Questions:

1. Which of the three main cryptocurrencies bitcoin, dogecoin and Ethereum has the most impact on the environment?
2. Is there any potential correlation between the value of cryptocurrencies and the scale of its environmental degradation?
3. What are the challenges and opportunities of employing PoS (proof of stake) consensus algorithms on Bitcoin?

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4 Section Four: Methodology

Qualitative and quantitative research methodologies have varied capabilities in research and can provide complimentary insights into research questions and objectives. Non-quantitative data, such as interviews, observations, reports and research papers, are useful for investigating complex phenomena, comprehending subjective experiences, and acquiring in-depth insights. On the other hand, the quantitative approach entails gathering and analyzing numerical data to find patterns, correlations, and statistical trends which yield objective and measurable results.

I conducted a comprehensive investigation into the environmental consequences of cryptocurrency mining, utilizing both qualitative and quantitative research methods to achieve my research objective. The qualitative method was used in the form of interviews, online forums and mainly research papers to get a thorough understanding of the case study (research question 3). Moreover, the quantitative method was used by collecting data sets from the internet and using PowerBI to visualize and analyze these data to form conclusions and answer the research questions 1 and 2.

The use of qualitative approaches is consistent with the philosophical framework of interpretivism. Interpretivism stresses understanding social issues through the eyes of individuals and acknowledges the significance of subjective meanings and experiences. By carrying out the qualitative method (through analyzing existing reports and literature, conducting interview and forum analysis), I was looking to obtain a comprehensive grasp of the participants' viewpoints and investigate beyond the theoretical difficulties and opportunities of employing PoS on bitcoin.

When reading forums, I made sure to preserve representativeness by including the points of views of both the bitcoin and the Ethereum communities to obtain a sample that accurately represented the target population, hence boosting the generalizability of the findings.

Another qualitative technique employed was the in-depth interview held with the cryptocurrency expert which allowed for dynamic conversations and a deeper understanding of their perspectives on using PoS consensus for cryptocurrency mining. To add, ethical issues, such as consent, confidentiality, and bias, were carefully addressed during interviews to maintain ethical standards. Written confirmation and verbal consent were obtained.

While qualitative methods may be time-consuming and susceptible to bias, I mitigated these risks by considering all points of view, fact-checking information from forums, and ensuring my interpretation remained unbiased.

The use of quantitative approaches is consistent with positivism as a philosophical framework. Positivism places a premium on using objective, measurable evidence to understand and anticipate phenomena. The quantitative methods were used to evaluate data and uncover potential links within the acquired datasets. Statistical analysis, such as descriptive statistics (average) and regression analysis, was employed to examine relationships and test hypotheses regarding the correlation between cryptocurrency value and environmental deterioration (research question 2).

In my quantitative investigations, I relied on freely available data from various sources on the internet. To assess the energy usage of Bitcoin, I referred to the website https://digiconomist.net/, which is considered a trustworthy source providing statistics based on factors like the network's hashrate, mining hardware efficiency, and electricity costs. While this website is cited as reputable, I still followed the recommended practice of cross validating the data with other sources to enhance the reliability of my analysis. Unfortunately, due to limited data on energy usage, it was challenging to find alternative sources. However, after using the data from the website to find the average energy consumption of the three currencies I checked the values with reliable sources and found similar estimates, which increased my confidence in the data obtained.

For carbon emissions data related to Ethereum and Bitcoin, I utilized the dataset available at https://kylemcdonald.github.io/ethereum-emissions/. This dataset had been used in a published research paper, which indicates that the collection techniques and data are considered accurate and reliable.

Additionally, I incorporated a dataset from figshare, https://figshare.com/articles/dataset/Dataset_on_bitcoin_carbon_footprint_and_energy_consumption/19442933. Figshare is known as a reliable source of data sets, and since several researchers have utilized this source, I was able to critically evaluate its methodology and data collection processes.

To investigate the relationship between cryptocurrency value and environmental impact, I utilized historical cryptocurrency prices gathered from Kaggle, available at https://www.kaggle.com/datasets/sudalairajkumar/cryptocurrencypricehistory. Kaggle is widely recognized as a reliable source of data sets that adheres to ethical criteria and maintains accuracy.

Overall, to assess the goodness of data collection techniques, validity was considered to ensure accurate measurements from the websites, reliability was also considered and ensuring ethical compliance from these websites.

In terms of analysis techniques, I used statistical analysis and linear regression, both of which are highly established procedures for providing accurate results. However, it should be kept in mind that data analysis methodologies might bring biases, and assumptions, that can affect the interpretation of results.

IMAGE I: The formula used to calculate the correlation coefficient [17].

$$r = \frac{n\,(\sum xy) - (\sum x)\,(\sum y)}{\sqrt{[n^*\,(\sum x^2 - (\sum x)^2)] * [n^*\,(\sum y^2 - (\sum y)^2)]}}$$

Figure 3: IMAGE I

IMAGE II: The scale used to evaluate this value in this paper [18].

Scale of correlation coefficient	**Value**
$0 < r \leq 0.19$	Very Low Correlation
$0.2 \leq r \leq 0.39$	Low Correlation
$0.4 \leq r \leq 0.59$	Moderate Correlation
$0.6 \leq r \leq 0.79$	High Correlation
$0.8 \leq r \leq 1.0$	Very High Correlation

Figure 4: IMAGE II

It is crucial to note that correlation coefficients do not prove causation. They merely measure the degree of linear relationship between two variables.

Which is equivalent to this measure on power BI. This is an example of the equation used to find the correlation coefficient of Bitcoin.

```
Correlation Coefficient Bitcoin =
VAR __CORRELATION_TABLE = VALUES('Bitcoin'[Date])
VAR __COUNT =
   COUNTX(
      KEEPFILTERS(__CORRELATION_TABLE),
      CALCULATE(
         SUM('Bitcoin'[Close value])
            * SUM('Bitcoin'[Estimated energy consumption (TWh per Year)])
      )
   )
VAR __SUM_X =
   SUMX(
      KEEPFILTERS(__CORRELATION_TABLE),
```

```
        CALCULATE(SUM('Bitcoin'[Close value]))
    )
VAR __SUM_Y =
    SUMX(
        KEEPFILTERS(__CORRELATION_TABLE),
        CALCULATE(SUM('Bitcoin'[Estimated energy consumption (TWh per Year)]))
    )
VAR __SUM_XY =
    SUMX(
        KEEPFILTERS(__CORRELATION_TABLE),
        CALCULATE(
            SUM('Bitcoin'[Close value])
                * SUM('Bitcoin'[Estimated energy consumption (TWh per Year)]) * 1.
        )
    )
VAR __SUM_X2 =
    SUMX(
        KEEPFILTERS(__CORRELATION_TABLE),
        CALCULATE(SUM('Bitcoin'[Close value]) ^ 2)
    )
VAR __SUM_Y2 =
    SUMX(
        KEEPFILTERS(__CORRELATION_TABLE),
        CALCULATE(SUM('Bitcoin'[Estimated energy consumption (TWh per Year)]) ^ 2)
    )
RETURN
    DIVIDE(
        __COUNT * __SUM_XY - __SUM_X * __SUM_Y * 1.,
        SQRT(
            (__COUNT * __SUM_X2 - __SUM_X ^ 2)
                * (__COUNT * __SUM_Y2 - __SUM_Y ^ 2)
        )
    )
```

5 Section Five: Results and Discussion

Which of the three main cryptocurrencies bitcoin, dogecoin and Ethereum has the most impact on the environment?

I was able to gather information about the carbon emission for bitcoin and Ethereum. Below is a visualization that will demonstrate that bitcoin has a higher carbon emission.

IMAGE III: Average carbon emissions of Bitcoin and Ethereum (in KG of CO2)

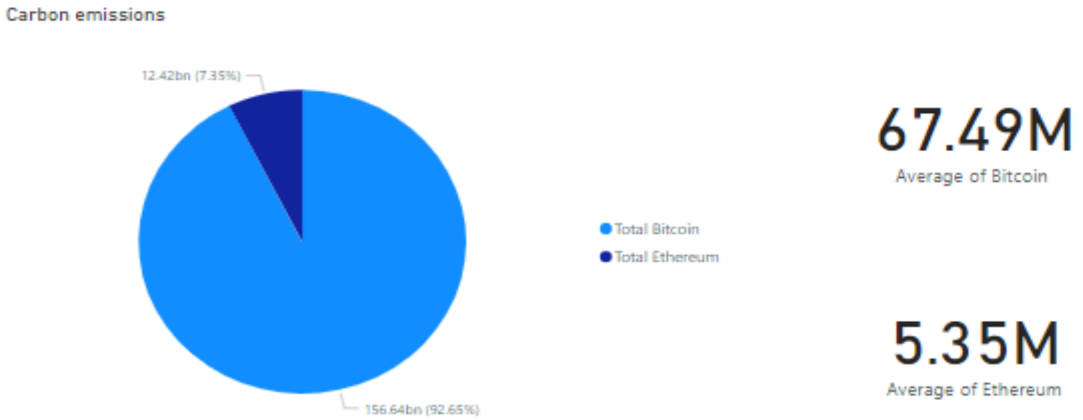

Figure 5: VISUALIZATION I

As shown above 93% of the carbon emissions from bitcoin and Ethereum were caused by Bitcoin across the documented years (July 31 2015 – December 4th 2021) sitting at 156.64 billion kg of CO2. According to the EPA (U.S. Environmental Protection Agency) [19], a passenger vehicle emits roughly 4.6 metric tons (4,600 kg) of CO2 annually. Therefore the 156.64 billion kg of CO2 can be compared to the annual emissions of almost 34 million cars. Given that it is more than the total number of registered vehicles in Australia, this figure is alarming [20].

To add, Bitcoin's daily average CO2 emissions is about 13 times higher than the carbon emissions of Ethereum (67489584.3/ 5353015 = 12.60777) without the merge. This should serve as a wake-up call to address the negative environmental effects of bitcoin mining. Creating sustainable solutions and promoting the use of greener energy sources in the mining process are essential.

IMAGE IV: Average energy consumption of Bitcoin, Ethereum, and dogecoin (in TWh)

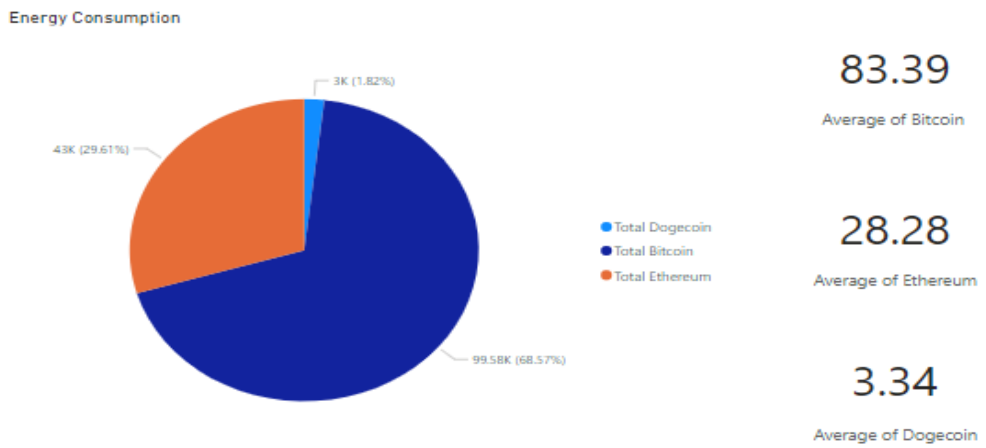

Figure 6: VISUALIZATION II

I was also able to gather the energy consumption of the three main cryptocurrencies (shown above). Once again bitcoin has a significantly higher energy consumption than Ethereum and Dogecoin (69% of the total carbon emission of Bitcoin, Dogecoin and Ethereum). The average energy consumption of bitcoin (83.39 TWh per year) is approximately equal to 228.19 GWh per day. This number is immense and to put it into perspective, the average annual electricity consumption in a typical US household consumes around 10,972 kWh (10.972 MWh) per year [21]. In this case 83.39 TWh is equivalent to powering approximately 7.6 million U.S. households for a year.

Comparing the three currencies with each other, Bitcoin consumes about 3 times more energy on average than Ethereum and 25 times more than Dogecoin.

Below is a visualization of a tree where the size is proportionate to the energy consumption and the color intensity signifies the carbon emissions intensity.

IMAGE V: Average energy consumption of Bitcoin, Ethereum, and dogecoin (in TWh)

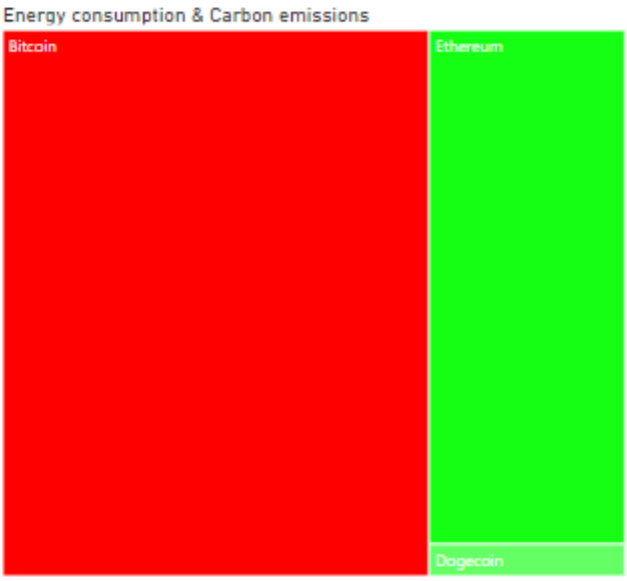

Figure 7: VISUALIZATION III

Based on the analysis, bitcoin has the most significant impact on the environment among the three main cryptocurrencies - bitcoin, dogecoin, and Ethereum - in terms of carbon emissions and energy consumption. In terms of carbon emissions, bitcoin accounts for the majority (93%) of the emissions from bitcoin and Ethereum combined. Additionally, in terms of energy consumption, bitcoin once again significantly outperforms Ethereum and dogecoin. These findings should act as a wake-up call to businesses, organizations, and individuals to address the harmful environmental effects of bitcoin mining and advocate for long-term solutions.

Overall, the research findings provide a clear answer to the research question by indicating that bitcoin has the most substantial impact on the environment among bitcoin, dogecoin, and Ethereum in terms of carbon emissions and energy consumption.

Is there any potential correlation between the value of cryptocurrencies and the scale of its environmental degradation?

When analyzing this relationship through linear regression, I noticed that the correlation coefficient varied significantly among years. First the correlation between the close value of bitcoin and the estimated energy consumption.

TABLE III: The coefficient correlation for bitcoin along years.

Year	Correlation Coefficient	Value
2017	0.95	Very high positive correlation
2018	-0.19	Low negative correlation
2019	0.96	Very high positive correlation
2021	0.13	Very low positive correlation
2022	0.78	High positive correlation
AVERAGE	0.526	Moderate positive correlation

Figure 8: TABLE III

The average correlation coefficient is moderately significant. However, when looking at each year, 2017,2019 and 2022 the correlation is highly significant. What is odd is that a pattern can be seen Where one year the correlation coefficient is significant and the year after isn't.

A strong correlation coefficient among cryptocurrencies in certain years (2017, 2019, and 2022) may be due to heightened attention from the media or public interest increasing demand from investors. As a result, the higher demand on energy-intensive cryptocurrency mining led to increased environmental destruction.

On the other hand, in those years where the correlation coefficient was not statistically significant or even showed negative values (like in 2018,2021). It implies that other factors may have had a more dominant impact on the cryptocurrency market, overshadowing the influence on the environment. For example, changes to regulations or market corrections can have a significant impact on the value of the cryptocurrency (value didn't fluctuate because of demand) causing them to deviate from any potential correlation with energy consumption.

To prove this both 2018 and 2021 were highly volatile (even late 2017 however, the volatility of 2017 October- December was observed on the value in 2018)

The following are notable, but not exclusive, events that occurred in 2018:

1. The significant price peak and subsequent market correction in late 2017 and into 2018 had a significant impact on Bitcoin's value. (The crash lasted several months) [22]
2. Greater regulatory attention and discussions about cryptocurrencies impacted Bitcoin's value. The ambiguity and possibility of harsher regulations drove market players to be cautious, which influenced investor sentiment and contributed to Bitcoin's value decrease. [23]

The following are notable, but not exclusive, events that occurred in 2021:

1. The massive price increase and setting of a new all-time high in 2021 boosted Bitcoin's value. The increased demand from institutional investors, as well as the widespread recognition of Bitcoin as a store of value, contributed to the price's upward pace.
2. Regulatory changes and pronouncements had an impact on the value of Bitcoin.[23]
3. Bitcoin's volatility and market corrections in 2021 impacted its value in the near term. [22]

The observed fluctuations in correlation coefficients throughout years imply that the relationship between cryptocurrency value and environmental degradation is complex and dependent on factors other than their intrinsic value.

Below are the graphs:

GRAPH I: Linear regression between close value and energy consumption for bitcoin in 2017.

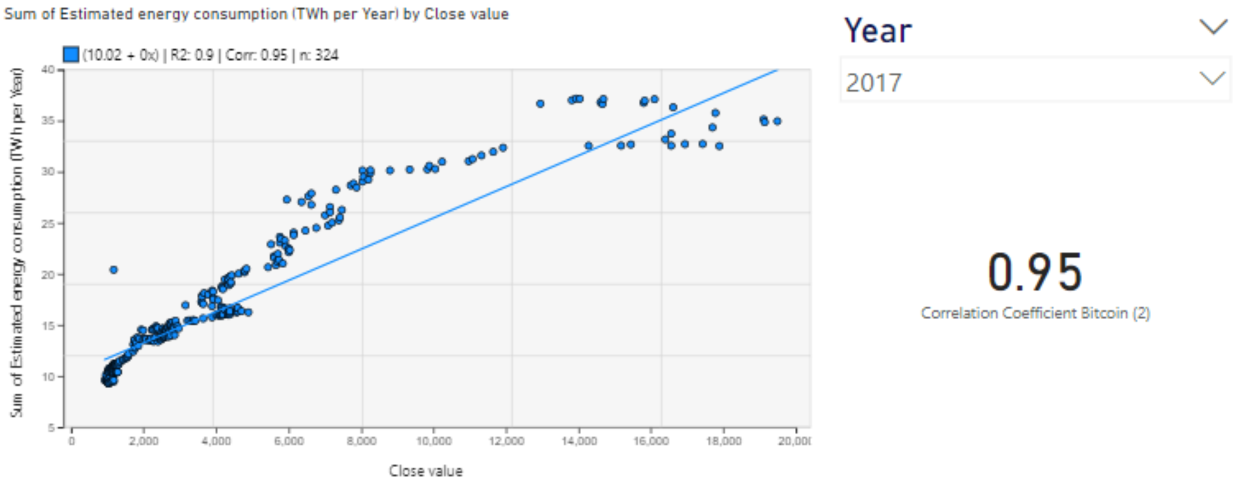

Figure 9: GRAPH I

GRAPH II: Linear regression between close value and energy consumption for bitcoin in 2018.

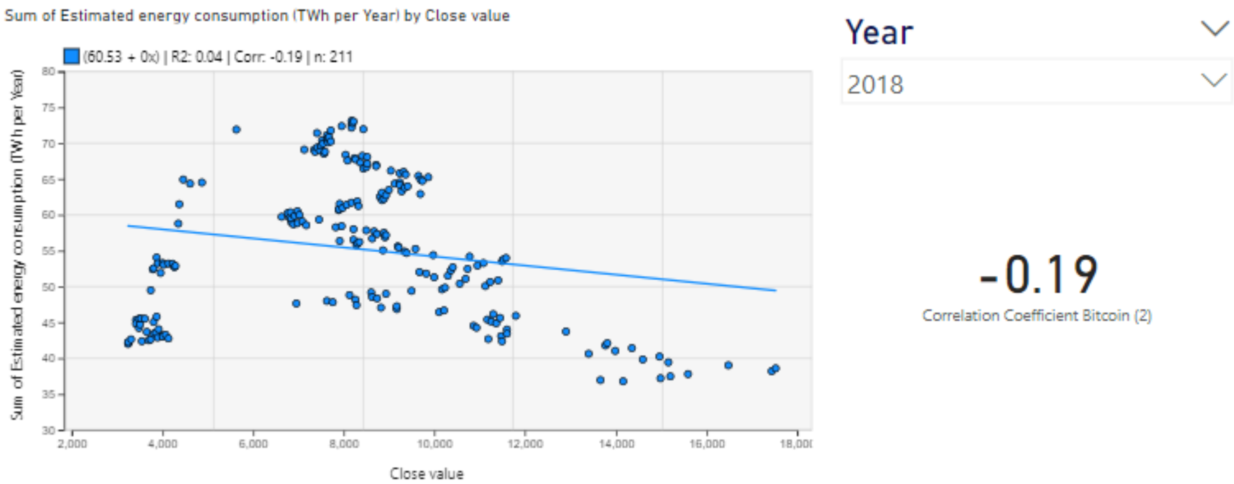

Figure 10: GRAPH II

GRAPH III: Linear regression between close value and energy consumption for bitcoin 2019.

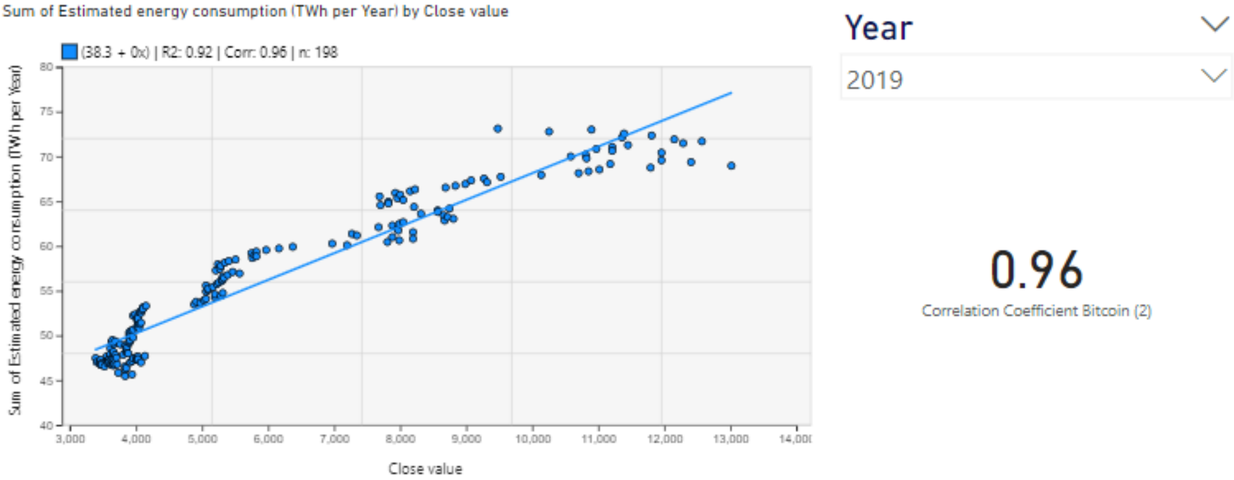

Figure 11: GRAPH III

GRAPH IV: Linear regression between close value and energy consumption for bitcoin in 2021.

Figure 12: GRAPH IV

GRAPH V: Linear regression between close value and energy consumption for bitcoin in 2022.

Figure 13: GRAPH V

GRAPH V: Linear regression between close value and energy consumption for bitcoin in 2023.

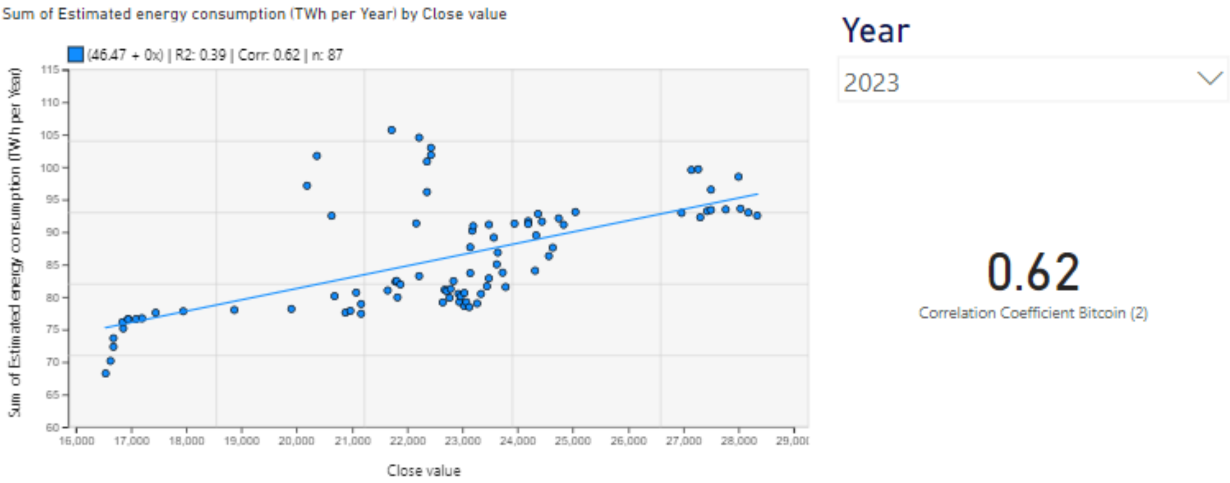

Figure 14: GRAPH V

Second the correlation between the close value of Dogecoin and the estimated energy consumption.

TABLE IV: The coefficient correlation for Dogecoin along years

Year	Correlation Coefficient	Value
2021	0.19	Very low positive correlation
2022	0.4	Moderate positive correlation
2023	0.22	Low positive correlation
AVERAGE	0.27	Low positive correlation

Figure 15: TABLE IV

The analysis of the correlation coefficient between the value of Dogecoin and the estimated energy consumption reveals that the relationship between these variables is not very strong. The average correlation coefficient of 0.27 suggests a positive but low correlation (not significant).

Overall, the correlation coefficient suggests a weak-moderate positive correlation between the value of Dogecoin and its environmental degradation. This indicates that as the value of Dogecoin increased, there was a moderate tendency for the estimated energy consumption to also increase.

Below are the graphs for dogecoin:

GRAPH VI: Linear regression between close value and energy consumption for Dogecoin in 2021.

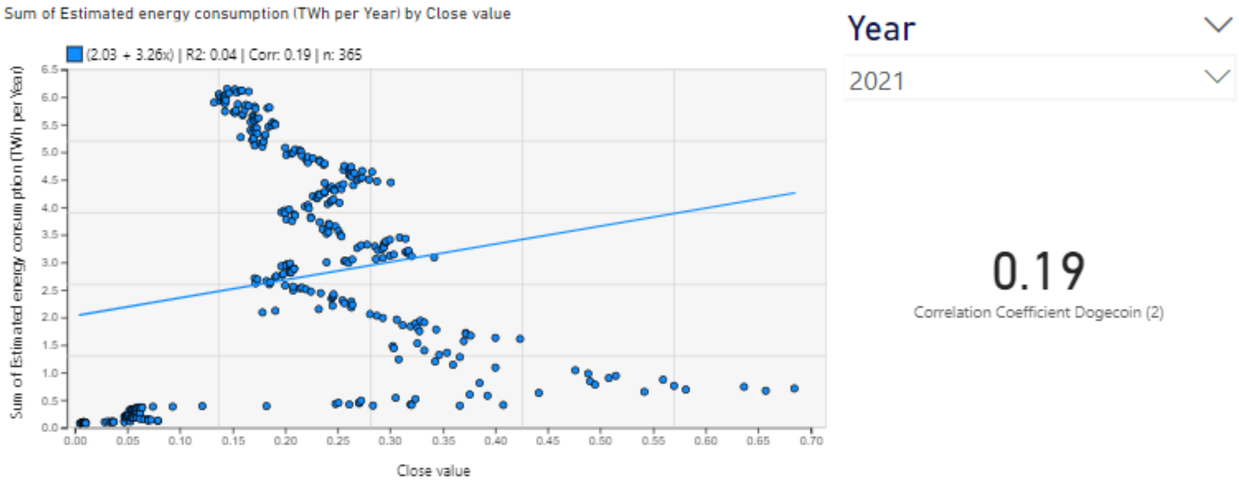

Figure 16: GRAPH VI

GRAPH VII: Linear regression between close value and energy consumption for Dogecoin in 2022.

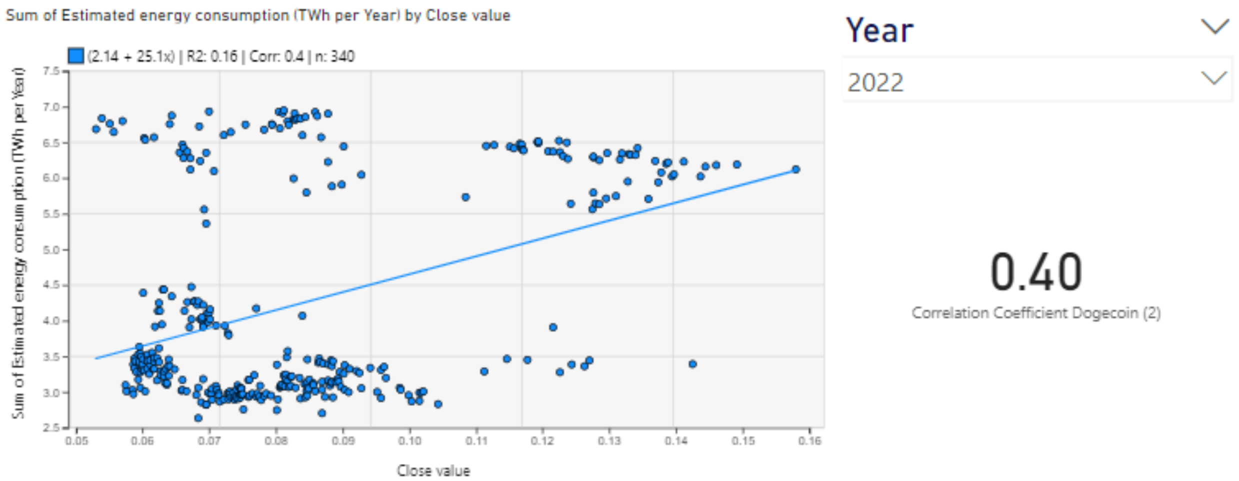

Figure 17: GRAPH VII

GRAPH VIII: Linear regression between close value and energy consumption for Dogecoin in 2023.

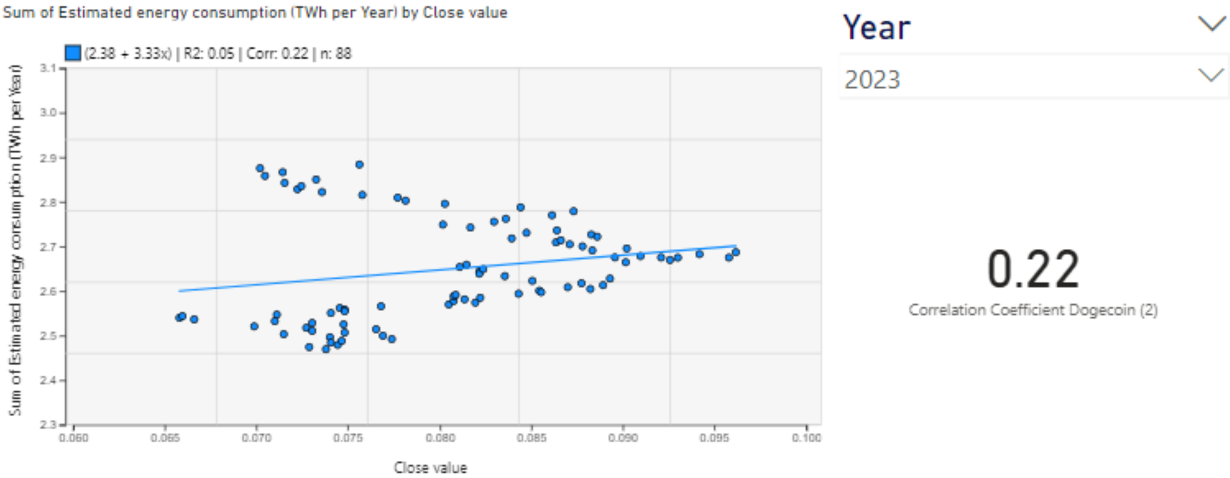

Figure 18: GRAPH VIII

Lastly, the correlation between the close value of Ethereum and the estimated energy consumption.

TABLE V: The coefficient correlation for Ethereum along years

Year	Correlation Coefficient	Value
2017	0.74	High positive correlation
2018	0.55	Moderate positive correlation
2019	0.91	Very high positive correlation
2021	0.88	Very high positive correlation
2022	0.69	High positive correlation
2023	0.53	Moderate positive correlation
AVERAGE	0.72	High positive correlation

Figure 19: TABLE V

According to the correlation coefficient research, there appears to be a positive association between Ethereum's value and the scale of its estimated consumption of energy.

The correlation coefficients for each year show a steady positive correlation between Ethereum's closing value and estimated energy use. There is a substantial positive correlation in 2017, 2022, and 2023. The correlation coefficients in 2018 and 2021 show a moderate positive correlation, indicating a comparable but somewhat weaker correlation.

Notably, 2019 has a very high positive correlation, showing a substantial association between the value of Ethereum and the magnitude of its predicted energy usage during that year.

I believe the reason why Ethereum shows a stronger positive correlation than Bitcoin is because the coin is less volatile. While both Ethereum and Bitcoin are recognized for their price volatility, Bitcoin tends to be more volatile than Ethereum. Bitcoin's market dominance, larger market capitalization, and higher trading volumes all contribute to the currency's increased volatility [24]. Furthermore, Bitcoin's status as the first and most well-known cryptocurrency frequently leads to larger price volatility caused by market emotion and speculative trading.

Below are the graphs:

GRAPH IX: Linear regression between close value and energy consumption for Ethereum in 2017.

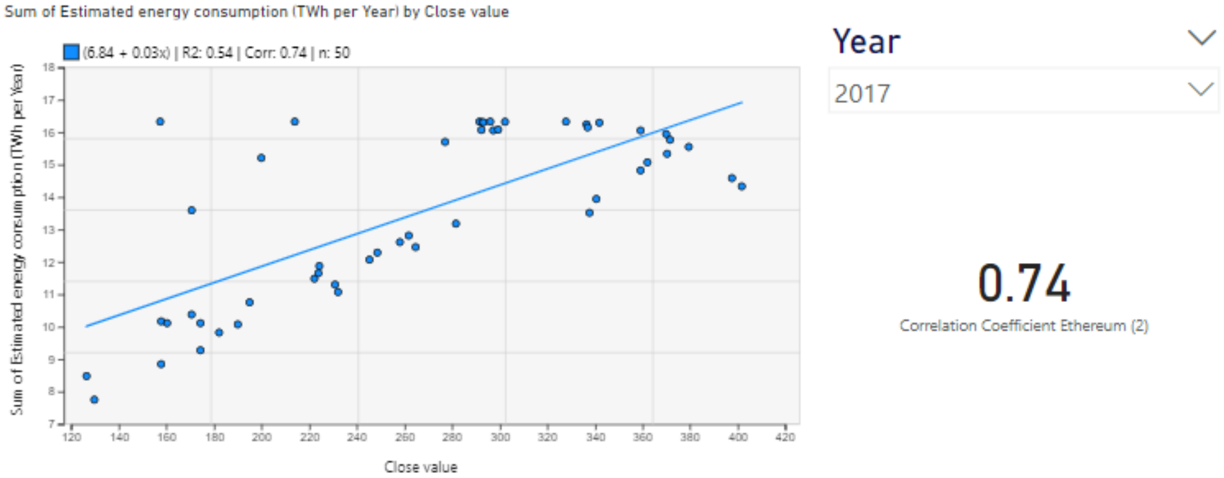

Figure 20: GRAPH IX

GRAPH X: Linear regression between close value and energy consumption for Ethereum in 2018.

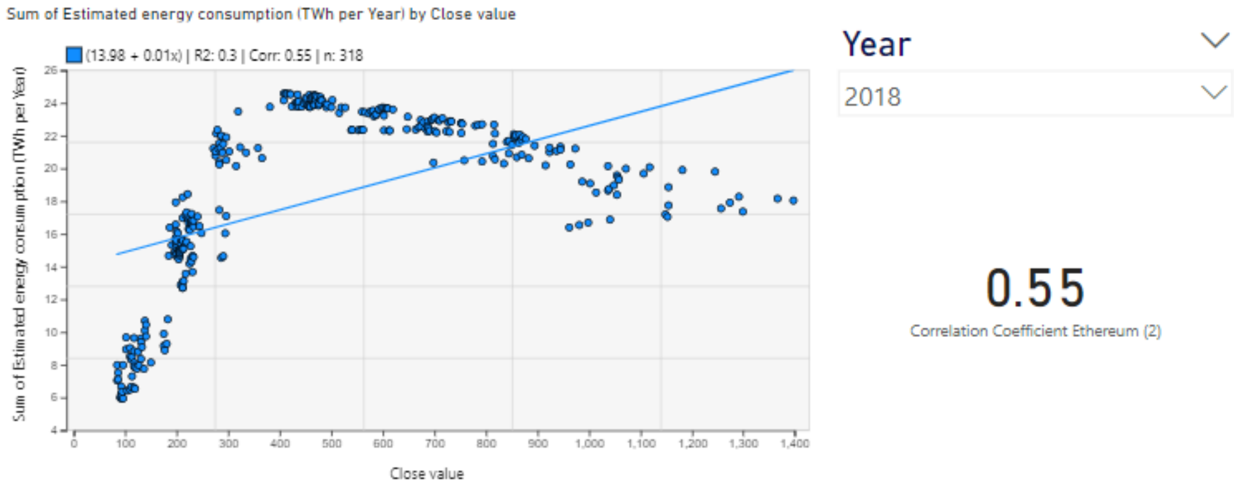

Figure 21: GRAPH X

GRAPH XI: Linear regression between close value and energy consumption for Ethereum in 2019.

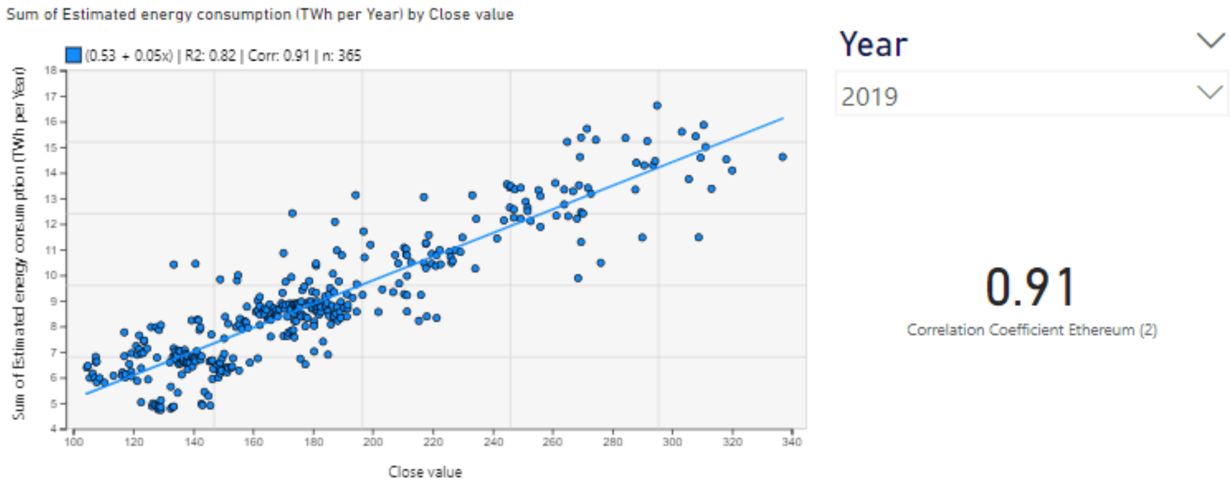

Figure 22: GRAPH XI

GRAPH XII: Linear regression between close value and energy consumption for Ethereum in 2021.

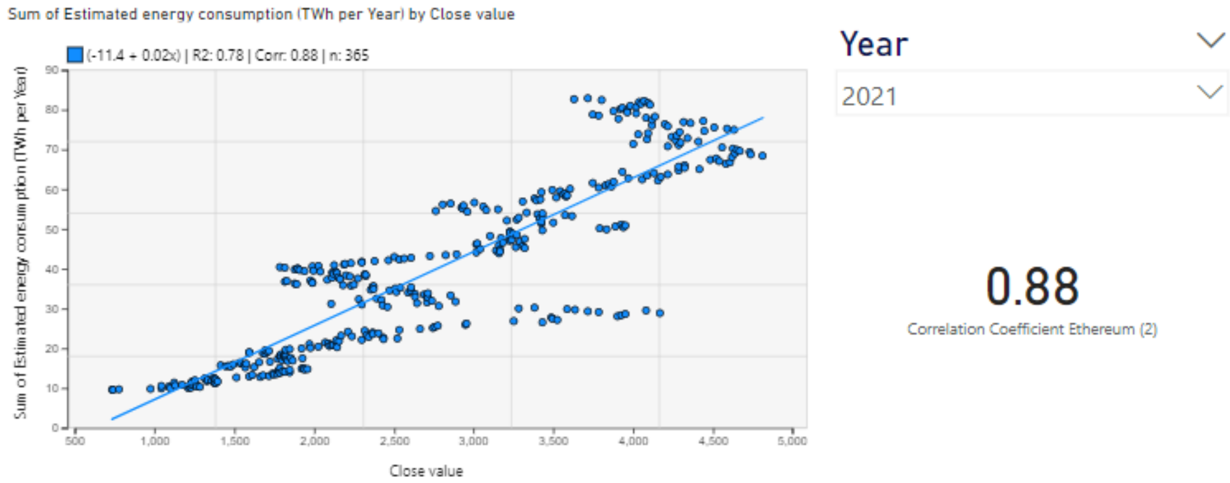

Figure 23: GRAPH XII

GRAPH XIII: Linear regression between close value and energy consumption for Ethereum in 2022.

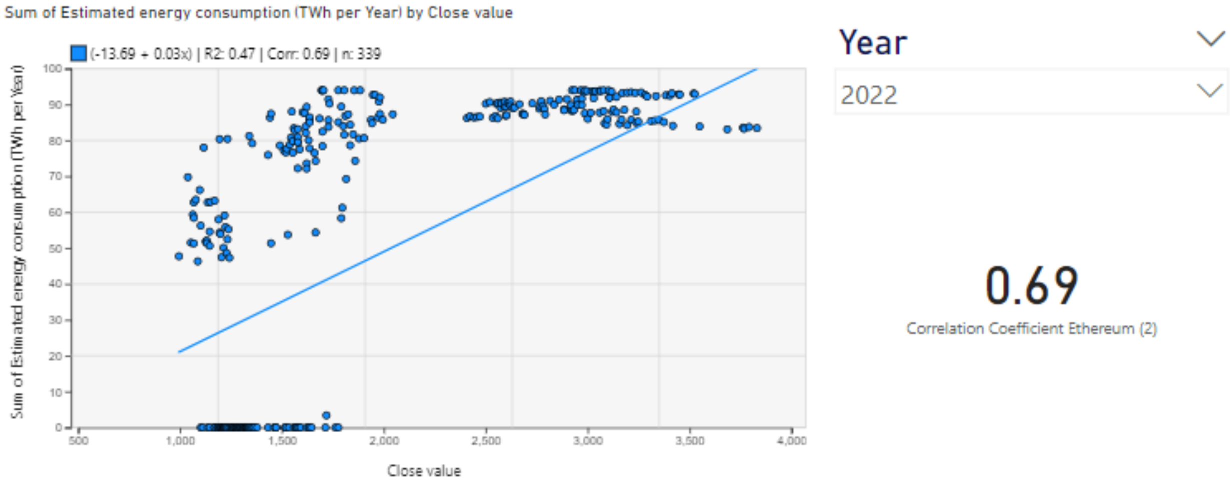

Figure 24: GRAPH XIII

GRAPH XIV: Linear regression between close value and energy consumption for Ethereum in 2023.

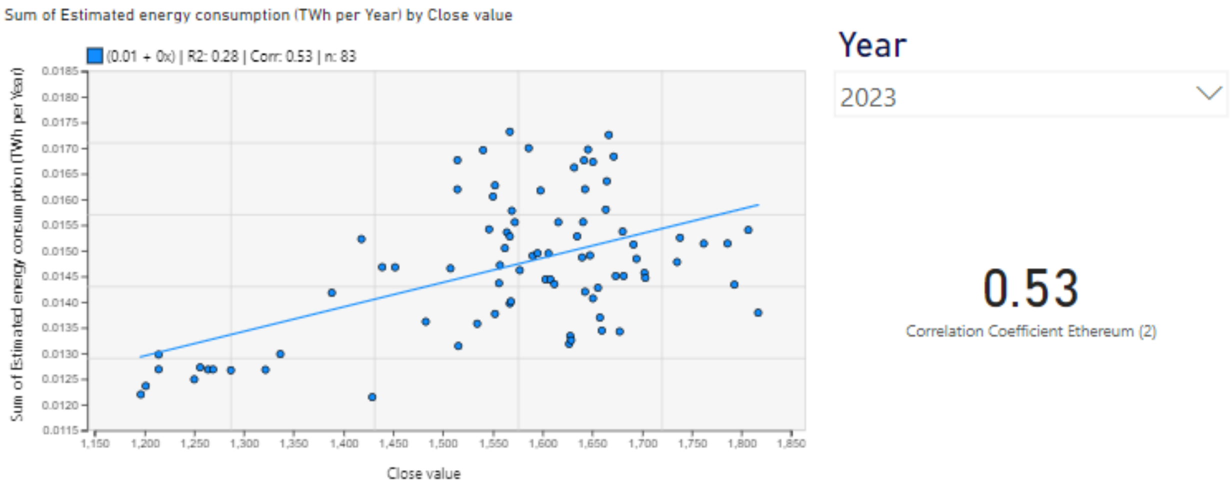

Figure 25: GRAPH XIV

Overall, while there is some correlation between cryptocurrency value and environmental deterioration, the relationship is complex and influenced by a variety of factors. The findings imply that market dynamics, regulatory changes, and investor sentiment all have a significant impact on the cryptocurrency value, influencing the link between value and energy use. It was also demonstrated that in circumstances of minimal volatility, the correlation between energy use and currency value is positive.

Exploring the Potential of Employing PoS Consensus Algorithm on Bitcoin - Replicating the Ethereum Merge

1. Introduction

1.1 Transactions validation

When someone wants to send a cryptocurrency to another person, a transaction is conducted on the network. This transaction includes information about the sender's address, recipient's address, and the amount sent [25]. After being broadcasted to the network, the transaction is validated by nodes prior to its addition on the blockchain.

A particular protocol is utilized by the consensus mechanism (eg. PoW or PoS) to verify transaction authenticity within a system. When someone validates a transaction, the block is added to the blockchain. After this, the transaction cannot be changed or reversed ensuring that the network remains safe and authentic.

1. 2 Consensus Algorithms in Cryptocurrencies

A central administrator in a centralized system, such as a database, holds the authority to add, delete, and update data to ensure the authenticity of records. However, what characterizes public blockchains is their decentralized and self-regulating nature [26]. Thus, validating new transactions and upholding the blockchain's validity among each participant in a specific cryptocurrency demands a consensus approach [27].

In other words, a consensus algorithm is a technique implemented in cryptocurrency for enabling users of a decentralized network to reach an agreement about transaction validity while also securing and preserving the network's integrity [28].

1.3 Proof of Work (PoW) Consensus

The Proof of Work (PoW) consensus algorithm requires miners to solve complex mathematical problems as a means of validating transactions and adding new blocks to a blockchain [26]. This algorithm is used by Bitcoin, the first and most widely recognized cryptocurrency [26]. The security and integrity of the blockchain get ensured through this process. However, a main concern is that PoW requires significant resources like electricity and specialized hardware to maintain security [29].

1.4 Proof of Stake (PoS) Consensus

In POS, nodes are chosen at random for transaction approval based on attributes such as age or the number of cryptocurrencies held at a specific address. To participate in building the chain, users must deposit or stake a specific number of coins. In this scenario, having more coins increases the likelihood of a node being chosen for transaction approval. Those with the correct validation will get a reward. [30]

1.5 Comparison Between PoW and PoS Consensus

PoW and POS consensus algorithms have distinct ways of ensuring network security and validating transactions. While PoW's foundation lies in resource-intensive mining using processing power, POS utilizes economic incentives by allowing users to stake their bitcoin holdings. There are concerns about centralization and security in PoS networks [31], however it is more energy-efficient and sustainable than PoW.

Ethereum 2.0 which uses PoS face the issue of centralization. According to this reference [32], two addresses were responsible for 46.15% of the nodes for storing data, processing transactions, and adding new blocks to the blockchain. However, this isn’t accurate since these two addresses are simply aggregators for the fees accrued by Lido's array of stakers and Coinbase Cloud stakers and aren't "controlling" anything.

Since those who have more resources can stake more and have more influence on validation, having a limit on staking may increase decentralization. While Ethereum doesn't have a limit on an individual stake, it is designed to give a higher reward when the total staked amount is lower. Another factor that might discourage validators from staking a large amount of ETH, is the hardware and software needed to run the node efficiently. Moreover, the minimum amount to stake is 32 ETH which is quite low allowing many validators to contribute.

2. The Ethereum Merge

As part of the larger plan called Ethereum 2.0 to improve scalability, security, and sustainability through various upgrades; The Merge holds significant importance in achieving these goals [33]. Figure 1 below outlines this roadmap.

The merge refers to the integration of Ethereum mainnet which uses PoW with the Ethereum 2.0 Beacon Chain which has been running in parallel since December 2020 and uses PoS. Not only will Ethereum 2.0 switch the consensus mechanism increasing sustainability but also it will use sharding mechanism which decreases throughput.

IMAGE VI: Ethereum's upgrade plan.

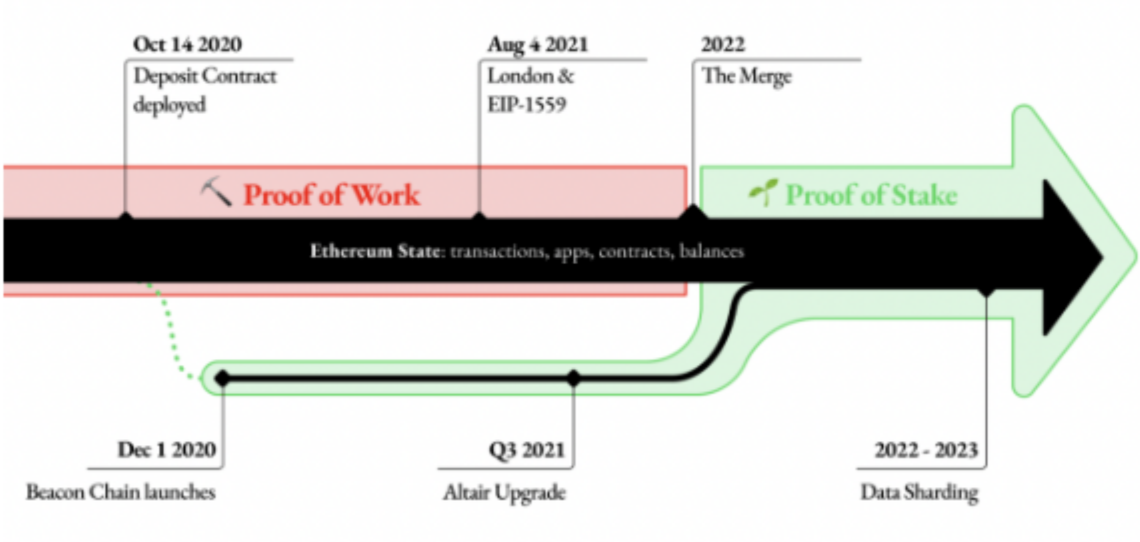

Figure 26: IMAGE VI

3. Challenges and Opportunities of Employing PoS Consensus Algorithms on Bitcoin

3.1 Opportunities

3.1.1 Energy Efficiency

Because the consensus mechanism does not necessitate the solution of complicated mathematical problems, the energy usage is significantly reduced with PoS. To back this up, when Ethereum converted to a PoS consensus method, their energy consumption was reduced by 99.98% [34].

3.1.2 PoS is better at handling a 51% attack.

PoS has mechanisms in place to prevent 51% attacks. The Ethereum network can distinguish between malicious and honest stakers, and because the attack is coming from a specific address that holds specific ETH, PoS allows the system to fork into a new chain while deleting the attacker's stake (if the attacker has 66% of the stake).

The community finds validators controlled by the attacker and agrees on whether and how to remove these validators from the active set, either by forcing them to stop staking or by totally removing these validators from the system, effectively burning the stake.
In contrast, in PoW once someone obtains 51% of the hash power, there is no mechanism to prohibit them from assaulting the chain indefinitely. [35]

3.1.3 Can make bitcoin more accessible and inclusive.

PoS has a lower barrier of entry as it doesn't require specialized hardware, expensive electricity, or technical expertise. When implemented correctly, this can increase decentralization by letting more people to participate in the validation process (no single entity having too much power over the network).

3.1.4 Potential faster block times

Since there is no block mining involved, PoS systems can support faster block times and transaction finality. This may make Bitcoin more useful for payment purposes. Furthermore, combining sharding strategies with PoS can dramatically increase Bitcoin's scalability.

3.2 Challenges

3.2.1 Fear of centralization

Significant centralization is needed during the initial transition (validators are selected based on their stake). Additionally, as larger stakeholders have more sway over the network, centralization may result if the staking reward is excessively high, proportional to the quantity staked, or uncapped.

3.2.2 Security issues

One way to look at it is that because PoS doesn't require as much computational work, the network is more susceptible to intrusions. Additionally, it is new and hasn't been well tested, so potential problems may arise.
The nothing at stake attack occurs when there is little risk to staking, allowing malicious actors to stake, validate false transactions, and compromise the network. However, Ethereum implements slashing, which takes a portion (or all) of the staked whenever a false transaction is validated. Therefore, one way to think about PoS security is "if they have $X billion, how many times can they break the chain before all their money gets slashed?"

3.2.3 Community resistance

To begin with, supercomputers and specialized hardware constructed or acquired will no longer be in use, resulting in financial losses to miners and significant environmental harm from e-waste. Additionally, Bitcoiners think that money shouldn't be created simply and that the computational difficulty of producing new Bitcoins through the mining process contributes to the currency's longevity and worth. Moreover, because the existing economic system is based on PoW, this switch will result in a change in that model, which could disrupt the network.

3.2.4 Token distribution at initialization

The most important factor when distributing initial tokens is ensuring that the process remains fair and transparent no matter what method you choose by setting up transparent processes that are open for public scrutiny while also developing clear eligibility guidelines and criteria for token allocation. Also, it's important to factor in potential long-term effects of initial distribution on network's overall health and sustainability because unequal or unbalanced distribution can lead to centralization among other issues.

3.2.5 The rich get richer
While this may be valid if the payouts were proportional to the amount staked, a counter-argument is that the delta between large and small stakers pales in contrast to the delta between large and small miners. Furthermore, PoW has been criticized for causing structural inequities between elites and the public (because of the computing powers), which is precisely the dynamic that this industry is designed to eliminate.

4. Conclusion
One prominent example of the transition from Proof of Work (PoW) to Proof of Stake (PoS) consensus algorithms is Ethereum's Merge. The possibility of introducing Ethereum Merge into Bitcoin using PoS relies heavily on the readiness of the community to adopt its opportunities along with the challenges.
It is useful to understand the process of implementing changes on the Bitcoin network. It begins with protocol researchers exploring ways to improve Bitcoin's protocol without negative trade-offs, while maintaining compatibility with the existing network. Voluntary adoption of these changes by both developers and operators of Bitcoin nodes is essential in maintaining the network's integrity and security. [36]
Despite some interest in exploring potential benefits of PoS, there is still a strong commitment to the PoW consensus mechanism amongst the Bitcoin community, and a large number of community members believe that using PoW is a secure as well as an efficient method for validating transactions while producing new blocks on the blockchain. They also assert that there isn't sufficient incentive for using PoS given its risks.
A noteworthy point is that several PoW algorithms prioritize time as opposed to consuming excessive amounts of energy thus, this might serve as a potential answer to mitigate the concerns surrounding Bitcoin's high levels of energy consumption. Furthermore, a hybrid approach that combines PoW and PoS could be a viable way to begin exploiting the benefits of PoS while retaining the security and decentralization of PoW.

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6 Section Six: Conclusion and Recommendation

The research objective was to examine the environmental consequences of cryptocurrency mining. The three questions helped examine this effect and studied the possibility of a proposed solution. To achieve this objective and answer the research questions, I employed both qualitative and quantitative research methods.
For research question 1, I used quantitative methods to gather data on carbon emissions and energy consumption of bitcoin, dogecoin, and Ethereum. The analysis I did through Power BI showed that bitcoin has the most significant impact on the environment by far among the three cryptocurrencies, contributing to a higher amount of carbon emissions and energy consumption. Ethereum had a higher impact than Dogecoin but a lower impact than bitcoin and with the merge this impact significantly dropped.
For research question 2, I conducted a linear regression correlation analysis between the value of cryptocurrencies and the environmental degradation (more specifically the energy consumption). The results varied across different years, indicating a complex relationship influenced by factors such as media attention, public interest, market corrections, and regulatory changes. While there was some positive correlation between cryptocurrency value and environmental degradation, the relationship was not consistently significant.
These results suggest that we can’t assume that the value of cryptocurrency is an indicator of how much the environment is affected since the value is affected by unexpected factors.
For research question 3, I conducted a case study on the potential of employing the Proof of

Stake (PoS) consensus algorithm on bitcoin, replicating the Ethereum merge. This qualitative investigation involved an interview and forum analysis to understand the perspectives and challenges of implementing PoS on bitcoin. The findings provided insights into the difficulties and opportunities of using PoS on bitcoin and highlighted the need for further research and exploration. The findings imply that using Proof of Stake (PoS) consensus techniques on Bitcoin is theoretically feasible. However, there are certain challenges to overcome. The Bitcoin community is firmly dedicated to the Proof of Work (PoW) consensus, and many individuals believe that PoW is a secure and efficient method of transaction validation. Furthermore, there is concern about centralization, potential security risks, initial token distribution concerns, and the idea that PoS lacks appropriate incentives. As a result, while implementing PoS on Bitcoin is technically conceivable, it would necessitate addressing these problems as well as obtaining greater acceptance and support from the Bitcoin community. Lastly, alternative solutions are proposed: using PoW algorithms that prioritize time as opposed to consuming excessive amounts of energy or implementing a hybrid approach that combines PoW and PoS.

Overall, the research met the research objectives, validated the findings through rigorous data collection and analysis, and justified the recommendations for addressing the environmental consequences of cryptocurrency mining. The findings emphasized the need for sustainable solutions and policy interventions to mitigate the negative environmental effects, particularly in the case of bitcoin mining.

It is critical to recognize that research methodology and data analysis procedures have inherent limits and potential biases that must be considered when interpreting the results. The research effort sought to mitigate these risks by considering diverse points of view, verifying facts, and assuring ethical compliance throughout the research process.

Based on the analysis and findings of the research, several recommendations can be made to address the environmental consequences of cryptocurrency mining. Several recommendations can be made based on the research's analysis and conclusions to alleviate the environmental impacts of cryptocurrency mining. First and foremost, there is a need for more awareness and education among the cryptocurrency community regarding the environmental impact of mining, particularly in the case of bitcoin. This can aid in the promotion of more ethical mining methods and the adoption of greener alternatives. Second, authorities and regulatory organizations should think about putting in place measures to incentivize and promote the use of sustainable mining techniques. Furthermore, additional research is needed to investigate and develop alternative consensus algorithms that favor energy saving while retaining network security and decentralization. This may include experimenting with hybrid approaches that combine Proof of Work and Proof of Stake, or by developing new algorithms that value time over energy use. Finally, to track accomplishment, and inform future regulatory choices, continual monitoring, and assessment of the environmental impact of cryptocurrency mining should be done.

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