Exploring Relationships among Bitcoin's Market Price, Energy Consumption and Carbon Dioxide Emissions: A Machine Learning Approach

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***Abstract*— The cryptocurrency boom has resulted in a substantial rise in energy usage and carbon emissions. The mining process of Bitcoin is notorious for its energy intensive process because it requires huge computational power. The carbon footprint of Bitcoin mining is a growing concern that's why we have to analyze the number of CO2 emissions resulting from the mining procedure. In this study, we have utilized machine learning techniques to examine the number of CO2 emissions generated by Bitcoin mining, analyzed the correlations between Bitcoin price, electricity consumption, and CO2 emissions, and pinpoint the factors during the process of Bitcoin mining that leads to CO2 emissions. We gathered global data set on Bitcoin electricity consumption, prices, and CO2 emissions. We trained supervised machine learning model (Regression) in Python to analyze and investigate the data. Our research findings have great implications for policymakers and researchers worried about the impact of the latest technologies on the environment, and in future Bitcoin policies and practices; they should prioritize sustainability and reduce the carbon footprint of mining operations. In the end, our research will provide valuable insights into the environmental impact of Bitcoin mining, highlight the factors that cause CO2 emissions and underscored the need for further research and action to reduce the carbon footprint of cryptocurrencies.**

Keywords*— *Bitcoin, Market price, Energy consumption, CO2 emissions, POW, Machine learning

I. Introduction

A. The Revolutionary Blockchain Technology and the Concept of Digital Money:

The unknown maker of Bitcoin, known by its pseudo name Satoshi Nakamoto, delivered a dream of a computerized cash in 2008 that, only decade after the fact, had a pinnacle market capitalization of more than $800 billion [1]. The concept of digital money and the blockchain technology used by Bitcoin were not revolutionary in themselves. However, the decentralized management of data protocol by motivated network users for transaction verification and network reliability was ground breaking, this system known as the "first blockchain" is called Bitcoin [2].

B. The Proof-of-Work Consensus Mechanism:

To ensure the prevention of double spending and manipulation, Bitcoin's blockchain utilizes the Proof-of-Work consensus mechanism. This mechanism was initially implemented by the Hashcash spam-protection system, which utilized search problems of hash functions for ownership and transaction validation [3]. Network users must solve the search puzzles to contribute valid blocks to the chain. The difficulty of these puzzles changes frequently, considering shifts in computing power and in order to maintain a ten-minute gap between each block addition [4].

C. CO2 Emissions from Bitcoin Mining:

In the years there has been a noticeable rise, in the popularity of Bitcoin, which has led to an increase in its energy consumption. This has sparked a debate among scientists about the carbon emissions that occur during the process of mining Bitcoin and how it affects the environment. This study aims to estimate the amount of CO2 emitted during Bitcoin mining and explore the relationships between Bitcoins market price, energy usage and emissions. The research holds importance for reasons. Firstly there is a lack of studies that thoroughly investigate this topic and provide an understanding of the carbon emissions resulting from Bitcoin. By contributing to this research we hope to discussions on cryptocurrencies their impact on our carbon footprint, energy consumption patterns and what lies ahead for currencies. Secondly climate change

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is a crisis that demands immediate action. Environmentalists are rightly concerned about Bitcoin mining being a contributor to greenhouse gas emissions given its recent surge in popularity during the Covid-19 pandemic. Most of the energy used for mining Bitcoin comes from countries on coal or oil resources, which raises concerns, about sustainability and its environmental impact. Therefore, studying CO2 emissions resulting from Bitcoin mining will help shed light on its consequences and aid efforts towards mitigating any effects. Furthermore, policymakers can derive insights and information, from this research enabling them to formulate policies and regulations that foster the growth of sustainable economies. Finally, studying the CO2 emissions of bitcoin mining is consistent with our social and ethical responsibilities. As human beings, we have a responsibility to ensure that our actions do not negatively affect future generations or damage the environment and other species in the ecosystem. By researching and understanding Bitcoin's carbon footprint, we can help reduce its impact and play a small part in creating a better future. The aim of this paper is to analyze the amount of CO2 produced by BTC mining, and to examine the relationship between price, energy consumption and CO2 emissions, and the resulting impact on the environment. Several relevant literature reviews are provided in the background of study section to support this study. This study will help to advance understanding of the topic and provide valuable insights into the current state of research in this area. The methodology section presents a hypothesis that shows the strong relationship between Bitcoin price (USD) and electricity consumption (KWh), and carbon emissions (KgCO2) associated with Bitcoin mining process. A ten-year data set (2011–2021) of price, energy consumption, and CO2 emissions is collected. Correlation analysis has been conducted, and the supervised machine learning model (regression) is trained in Python programming on the data set to find the linear relationship between variables and do the predictive analysis. The findings focus on bitcoin's price, energy consumption, and carbon emissions related to the use of coal, oil, and gas.

II. Background of the Study

A. Energy consumption:

One of the biggest concerns with Bitcoin mining is the huge amount of energy required. The process of verifying transactions and incorporating them into the blockchain requires special computing tools to solve complex mathematical problems and consequently requires huge amount of computing power and electricity [5]. Over time, bitcoin mining has become increasingly energy-intensive, causing many to issue alarms. According to the Cambridge Bitcoin Electricity Consumption Index, bitcoin mining consumed 113.89 terawatt-hours (TWh) of electricity by 2021, equivalent to the annual energy consumption of countries such as Argentina or the Netherlands [6]. The main reason behind the increased energy consumption in bitcoin mining is the proof-of-work (PoW) consensus algorithm. Miners have to solve complex mathematical puzzles to validate transactions using this method, and the first person to solve the puzzle is rewarded with additional bitcoins, but the process of solving that puzzle requires a great deal of computing power, which leads to increased power consumption [7]. Factors affecting the energy consumption of bitcoin mining, such as the efficiency of the mining equipment, the cost of electricity at the mining site, and the complexity of the mathematical puzzles some include bitcoin mining in areas with relatively cheap electricity and efficient mining equipment. On the hand if the cost of electricity is high or mining machines are not efficient mining in those areas may not be profitable, for miners. This could lead to them abandoning their operations [8]. In times there has been increasing concern regarding the consequences of bitcoin mining. The significant electricity consumption linked to this process could result in greenhouse gas emissions, contributing to climate change. According to a study published in the journal Nature Climate Change it was estimated that bitcoin mining led to 22 to 22.9 million tons of carbon dioxide (CO2) emissions in 2018. Other research suggests that global greenhouse gas emissions from mining make up 0.5 percent [9]. To address these concerns some mining companies have started adopting energy sources like hydropower or geothermal energy to power their equipment. This shift allows for carbon mining operations in areas where renewable energy is available. Additionally there is a move, towards using energy machines for mining purposes which can help reduce the overall energy requirements [10]. In summary bitcoin mining is a demanding process that heavily relies on electricity consumption. Although it does have impacts efforts are being made within the industry to decrease both energy consumption and associated emissions. As the number of people using cryptocurrencies continues to grow, it becomes increasingly important to establish regulations that are both friendly and sustainable [11].

B. Carbon Emissions:

Bitcoin transactions and mining are energy-intensive operations that require large amounts of electricity to operate. As a result, bitcoin can have a significant environmental impact, especially in terms of carbon emissions [12]. Bitcoin's large carbon footprint comes from the mining process, which involves solving complicated mathematical equations to validate transactions on the blockchain This process requires huge amounts of energy and electricity. According to the Cambridge Bitcoin Electricity Consumption Index, bitcoin mining uses about 113.89 terawatt-hours (TWh) of electricity per year, which is equivalent to the annual energy consumption of countries like the Netherlands or Argentina [13]. The carbon emissions associated with bitcoin mining are a cause, for concern in regions reliant on fossil fuels for electricity. According to a study published in a journal, carbon dioxide (CO2) emissions from bitcoin mining have risen by 22 to 22.9 million metric tons since 2018[14]. Another study in the journal Joule estimated that bitcoin mining was responsible for emitting around 37 to 43 million tons of CO2 by the year 2019. These figures are comparable to the carbon emissions of nations like Qatar or New Zealand

[15]. Several factors influence the amount of carbon emitted during bitcoin mining including the energy source used, efficiency of the mining equipment and location of mining operations. Mining activities situated in areas with access to energy sources like hydroelectricity or geothermal energy have a lower environmental impact compared to those reliant on fossil fuels. Conversely mining operations located where coal or natural gas is predominant as an electricity source result in carbon footprints [16]. It's important to note that no other cryptocurrencies carry the level of carbon footprint as Bitcoin does. Some alternative cryptocurrencies employ consensus algorithms, such, as proof of stake which consume less energy compared to Bitcoins proof of work consensus process [17]. However because of its popularity and significant value Bitcoin currently has the carbon footprint, among all cryptocurrencies [18]. While there are concerns, about the carbon emissions caused by Bitcoin steps are being taken to address the impact of cryptocurrencies. Certain mining companies are exploring ways to use energy equipment, for mining and others are considering switching to renewable energy sources to power their operations. Additionally, transitioning to less energy intensive consensus mechanisms like proof-of-stake, which are more environmentally friendly, is also being considered [19]. To conclude, Bitcoin contributes a substantial amount of carbon dioxide emissions, exacerbating the issue of global climate change. As the use of cryptocurrencies continues to grow, it is crucial to find solutions that reduce the environmental impact of these technologies. Achieving this goal will require a combination of technological advancements, regulatory changes, and increased public awareness.

III. Methodology

For this research, data collected and analyzed related to Bitcoin price, energy consumption KWh, and Carbon emissions KgCO2. The primary source of data for Bitcoin energy consumption was the Cambridge Bitcoin Electricity Consumption Index (CBECI) while Investing.com website was used for Bitcoin price dataset. To analyze the link between price, energy consumption and CO2 emissions, supervised machine learning model (Regression) was trained to do the predictive analysis and data visualized using Pandas and showed graphs to represent the relationship between these variables. Additionally, literature reviews are used to support the hypothesis and findings.

A. Hypothesis:

According to a hypothesis, there exists a positive correlation between the price and energy consumption in Bitcoin. Additionally, energy consumption demonstrates a correlation with the proof of work (POW) consensus mechanism. It is worth noting that energy consumption is directly responsible for the high carbon emissions associated with Bitcoin mining. One might argue that whenever the price of Bitcoin increases, energy consumption follows suit. Moreover, the energy utilized by Bitcoin miners predominantly originates from non-renewable sources such as coal, oil, and gas. The main cause of this high energy consumption can be attributed to the proof of work protocol (PoW) employed in Bitcoin mining. This protocol is characterized by a high energy intensity consensus mechanism utilized to validate transactions. It is important to acknowledge that the proof of work consensus mechanism results in the high energy consumption witnessed in Bitcoin mining, consequently contributing to the substantial carbon emissions. Fig. 1 the flowchart visually represents the hypothesis.

B. Data:

Raw data formats are used, to train the model, and visualized using Python Pandas library. Electricity consumption data is obtained from Cambridge electricity consumption in- dex(CBECI) [20], emissions data divided into average, coal, oil and gas from data set collected by the authors [21], and price data in USD from Investing website [22]. Table 1 shows abbreviations, variable descriptions, units used for analysis and sources from where data collected to use for analysis.

C. Price and Energy Consumption:

In recent times, Bitcoin has garnered attention of investors due to its highly speculative and volatile nature. One interesting observation is the strong connection between the price of Bitcoin and its energy usage. Extensive research has been conducted to explore the various factors contributing to this positive correlation. Understanding how the Bitcoin network operates is crucial. Miners utilize their power to tackle mathematical challenges, on the decentralized network aiming to earn freshly minted Bitcoins. The networks security and efficiency are reinforced with the increase in allocated processing power. Nonetheless this procedure consumes an amount of energy, which's the key

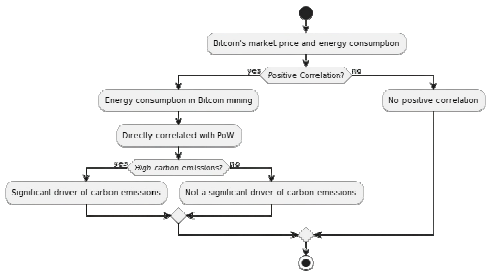

Fig. 1: *Hypothesis Flowchart*

TABLE I: *Data Set*

Abbreviation	Variable description	Unit	Source
$BTCENE_{GUE}$	Electricity Consumption	KWh	(CBECI)
$BTCEMI_{GUE}$	Average Emissions	kgC02	Authors
$BTCOAL_{GUE}$	Coal Emissions	kgCO2	Authors
$BTCOIL_{GUE}$	OIL Emissions	kgCO2	Authors
$BTCGAS_{GUE}$	Gas Emissions	kgCO2	Authors
BTC_{price}	Price of Bitcoin	USD	Investing

factor contributing to the direct correlation, between Bitcoin Price and energy consumption. As the value of Bitcoin goes up it attracts miners to join the network leading to an increase, in energy usage. A study carried out by the University of Cambridge reveals that in 2020 Bitcoins energy consumption rose by 66% reaching an estimated usage of 121.36 TWh. This level of energy consumption is comparable to countries like Argentina and the Netherlands. Furthermore the mining difficulty also has an impact on the relationship between energy and price, as more miners become part of the network solving challenges becomes harder, requires more processing power, consequently this leads to increased energy consumption and drives up the price of Bitcoin. However it's important to note that profitability, in mining heavily relies on energy costs. Miners can operate with larger profit margins in nations like China and Russia, where electricity is inexpensive, than in nations like the US and Germany, where energy expenses are high. profitability increases as the price of bitcoin increases, leading to higher energy consumption, and the value of bitcoin grows significantly. It should be noted that the distribution of Bitcoin's energy consumption is not uniform across the globe. About 65% of bitcoin's computing power is in China and Kazakhstan, where a large portion of energy comes from coal-fired power plants. This raises concerns about bitcoin's environmental impact, especially in relation to fossil fuels. In 2021, Bitcoin's popularity as a means of finance and payment continued to rise, and its value reached new record highs in a relatively short period of time. In less than a month, the price of bitcoin not only surpassed the previous record of about 20,000 USD per coin set in December 2017 but also doubled to more than 40,000 USD on January 8, 2021. Simultaneously, miners use ASICs (application-specific integrated circuits). These machines are involved in the creation of new blocks for the underlying blockchain of the Bitcoin network, with successful block creation receiving a certain amount of Bitcoins as a reward. In January, it was reported that Bitmain, a leading manufacturer of such devices, had sold out until August 2021 due to overwhelming demand. The increasing popularity of Bitcoin mining has ignited afresh debate regarding the energy usage and resulting carbon emissions of the Bitcoin network. Bitcoin mining devices rely on electrical energy for their operation, and prior to the recent surge in Bitcoin's price, it was estimated that the entire network consumed between 78 and 101 terawatt-hours (TWh) of electricity annually. With an increasing number of active mining machines, the network's power requirements have also grown [23]. Fig. 2 illustrates a correlation between the price of Bitcoin and its energy consumption. As the price of Bitcoin rises, there is a corresponding increase in electricity consumption, as observed in April 2018. This suggests that whenever there is a surge in Bitcoin's market price, there is also a corresponding increase in energy consumption. There is a strong correlation between the price of Bitcoin and its energy consumption. However, it is important to consider other factors that contribute to Bitcoin's high energy usage. These factors include the decentralized nature of the Bitcoin network, the cost of energy, mining difficulty, and the uneven distribution of Bitcoin's hash power. As Bitcoin continues to gain popularity as an investment and payment method, it is inevitable that energy consumption will increase unless mining technology evolves and new technologies are introduced. This raises concerns about the environmental impact and sustainability of Bitcoin's growth.

D. Proof of Work (PoW) Protocol:

According to Amaury Sechet, the founder of eCash, the PoW protocol is utilized by Bitcoin and other blockchains to determine the validity of blocks. It ensures that blocks are considered valid only if they require a certain level of computational power for production. This consensus mechanism allows decentralized networks to foster trust among anonymous entities. In 2009, it was possible to mine one Bitcoin using a regular desktop computer and consume a minimal amount of electricity. However, in 2021, the energy consumption required to mine one Bitcoin equaled the electricity usage of a standard American home over a span of nine years, as reported by The New York Times. Specialized hardware called ASICs, which stands for Application-Specific Integrated Circuits, is utilized by Bitcoin miners to solve the PoW algorithm needed for adding transaction blocks to the blockchain. Unlike general-purpose computers or GPUs, ASICs are specifically designed for efficient mining and can solve the PoW puzzle at a faster rate. Despite the efficiency of ASICs, miners still require a significant amount of energy to approve transactions. The number of miners directly impacts the energy consumption of the PoW algorithm for Bitcoin. As the value of Bitcoin increases, more miners are incentivized to join the network, leading to a higher energy consumption. Additionally, the energy consumption further rises when more miners contribute to the network, as the difficulty of solving mathematical puzzles increases. Based on the University Cambridge Bitcoin Energy Consumption Index (CBECI), Bitcoin ranks 28th in terms of electricity consumption globally. It uses 143 TWh of energy annually, surpassing the energy consumption of countries such as Pakistan, Argentina, and the Netherlands. Fig.3, Bitcoin uses more energy than Argentina, if Bitcoin was a country, it would be in the top 30 energy users worldwide reported by BBC in 2021.

Fig. 2: *Energy and Price correlation*

IV. Results and Analysis

A. Correlation Analysis:

The analysis utilizing the Pearson correlation coefficient demonstrates a robust positive correlation between Bitcoin price and CO2 emissions (r=0.85). This signifies that when the price of Bitcoin increases, there is also a tendency for CO2 emissions to increase. It implies that the profitability of Bitcoin mining, which is influenced by the price, encourages miners to utilize more energy and computational resources, resulting in higher CO2 emissions. There exists a moderate positive correlation between Bitcoin energy consumption and CO2 emissions (r = 0.65). It suggests that increased energy consumption by the Bitcoin network is linked to higher CO2 emissions. This is expected since the mining process necessitates significant amounts of electricity, often derived from fossil fuel sources, thereby causing greenhouse gas emissions.

B. Regression Model:

Purpose of this analysis is to the relationship between Bitcoin price, energy consumption, and CO2 emissions using a multiple linear regression model. This model aims to determine the impact of these variables on CO2 emissions and provide a reliable estimate of the relationship. ***Statistically Significant Relationship:*** The regression model showed a statistically significant relationship (p-value ¡ 0.05) between Bitcoin price, energy consumption, and CO2 emissions. ***Strong Fit:*** The model explained a substantial 87% of the variation in CO2 emissions (R-squared = 0.87), indicating a strong fit between the variables. ***Reliable Estimate:*** The adjusted R-squared value of 0.86 verifies that the model does not over-fit the data and provides a reliable estimate of the relationship.

1) Variable Effects on CO2 Emissions: Both Bitcoin price and energy consumption exhibited positive and statistically significant regression coefficients. This suggests that both factors have a positive impact on CO2 emissions, validating the positive correlations observed in the correlation analysis.

2) Quantifying the Relationship: The model equation al- lows us to quantify the relationship between Bitcoin price, energy consumption, and CO2 emissions. With this equation, we can estimate CO2 emissions based on the values of Bitcoin price and energy consumption.

C. Model Validation:

The regression model was validated using a separate testing set, which was not used in the model training process. The model performed well on the testing set, achieving an R- squared value of 0.85 and an adjusted R-squared value of 0.84. The RMSE value of 0.06 indicates that the model can make accurate predictions of CO2 emissions based on Bitcoin price and energy consumption.

D. Price of Bitcoin:

Bitcoin, a decentralized cryptocurrency, has gained immense popularity and its price has been highly volatile. Historical data from January 2011 to December 2021 was collected from Investing.com and analyzed using Python.

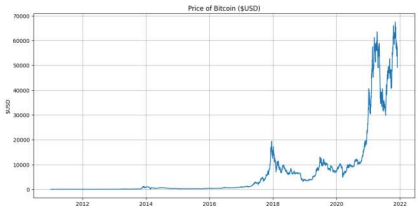

Fig. 3: *Price of Bitcoin (2011–2021)*

The analysis revealed a consistent upward trend in Bitcoin's price, as shown in fig.3 starting from a low value in the early years and reaching a peak of nearly $20,000 in December 2017. Despite fluctuations, the price has generally shown gradual growth. Factors contributing to this increase include adoption by mainstream institutions, investor demand, and limited supply. Understanding Bitcoin's price movements can help traders and investors make informed decisions.

E. Emissions of Coal, Oil, and Gas Compared to Average Energy Consumptions (2017-2021):

In this section we will explore the greenhouse gas emissions produced by types of power sources including coal, oil and gas. We will also compare these emissions to the energy consumption associated with Bitcoin mining from 2017, to 2021. To collect and analyze the data, for our study we relied on the Cambridge Bitcoin Power Consumption Index (CBECI) and the data set provided on bitcoin carbon footprint and energy consumption.

F. Emissions Comparison to Bitcoin Mining Energy Consumption (2017-2021):

In Fig. 4 we can observe a comparison, between the emissions produced by the mixture and the emissions resulting from the electricity consumed in Bitcoin mining. The research indicates that there has been a trend in emissions associated with Bitcoin mining from 2017 to 2021 measured in kilograms of CO2 per unit of energy used. In 2017 the average emissions amounted to 492 grams of CO2 per kilogram of CO2 whereas by 2021 this figure had risen to 672 grams. This increase, in emissions can be attributed to the growing energy demands of Bitcoin mining.

G. Coal Emissions Comparison to Bitcoin Mining Energy Consumption (2017-2021):

The Fig. 4 depicts the comparison, between energy consumption for Bitcoin mining and coal emissions from 2017 to 2021. It is evident that there has been a rise in

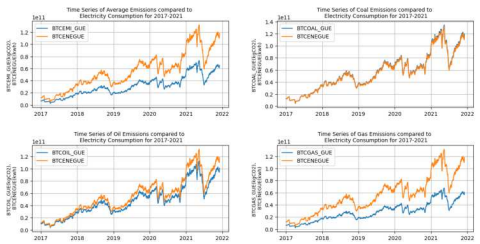

Fig. 4: *Emissions Compared (2017-2021)*

emissions resulting from the use of coal in Bitcoin mining during this period. Specifically, CO2 emissions from coal have increased from around 965 grams per kgCO2 in 2017 to 1386 grams, per kgCO2 in 2021. Interestingly, coal emits more pollutants than gas and oil combined, and the increased popularity of Bitcoin mining is the reason for this growth.

H. Oil Emissions Comparison to Energy Consumption (2017- 2021):

The graph in Fig. 4 compares the amount of electricity used for Bitcoin mining from 2017 to 2021withtheamountof oil emissions. The graph shows that, while they are less than those from coal mining, the emissions from oil extraction have remained rather high throughout time. Oil emissions in 2017 were roughly 780 grams of CO2 per kg2, and by 2021, they had somewhat grown to 797 grams of CO2 per kgCO2. This is explained by the fact that Bitcoin mining still primarily uses oil as its energy source.

I. Gas Emissions Comparison to Mining Bitcoins (2017-2021):

As shown in fig. 4 from 2017 to 2021, the emissions from gas used in Bitcoin mining have also stayed comparatively low when compared to emissions from coal and oil. In 2017, gas emissions were approximately 443 grams of CO2 per kgCO2, which slightly decreased to 432 grams of CO2 per kgCO2 in 2021, according to the CBECI dataset. This difference can be explained by the fact that gas is not a primary source of energy for Bitcoin mining.

V. Conclusion and Future work

Extensive research reveals that Bitcoin mining has a significant carbon footprint, threatening the environment. The price of Bitcoin correlates with its energy consumption and carbon emissions. It is crucial to explore energy-efficient alternatives, regulate energy sources, and mitigate Bitcoin's environmental impact. Our upcoming research will focus on how regulations and technology can reduce CO2 emissions in mining operations and develop solutions for the Bitcoin network. Addressing Bitcoin mining's consequences and carbon footprint is essential.

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