Future Energy
Open Access Journal
ISSN 2832-0328

May 2024| Volume 03 | Issue 02 | Pages 16-23

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.3.2.2

Future Publishing LLC

Article

Development a policy for the production of Bitcoins with renewable energy sources

Mehdi Aliehyaei[1], Ali Tofighi[2], Marc A. Rosen[3], Hamed Afshari[4]*, Solmaz Gheisari[5], Amir Safari[6]

[1]Department of Mechanical Engineering, Pardis Branch, Islamic Azad University, Pardis New City, Iran
[2]Department of Electrical Engineering, Pardis Branch, Islamic Azad University, Pardis New City, Iran
[3]Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, L1G 0C5, Canada
[4]Food Science & Engineering Department, Faculty of Civil & Earth Resources Engineering, Islamic Azad University Central Tehran Branch, Tehran, Iran
[5]Department of Computer Engineering, Pardis Branch, Islamic Azad University, Pardis, Iran
[6]Department of Science and Industry Systems, University of South-Eastern Norway (USN), Kongsberg, Norway

ARTICLE INFO

Article history:
Received 02 June 2023
Received in revised form
04 July 2023
Accepted 16 July 2023

Keywords:
Bitcoin, Energy, Policy,
Social cost of air pollution

*Corresponding author
Email address:
afshari1@gmail.com

DOI: 10.55670/fpll.fuen.3.2.2

ABSTRACT

Bitcoin, the first decentralized digital currency introduced by an anonymous person or group since 2008, has attracted worldwide attention. A significant number of economists have introduced Bitcoin as a new phenomenon in the 21st century that could reduce global inflation. Given the tens of thousands of digital currencies that have emerged since the advent of Bitcoin and its price growth trend over more than a decade, which are signs of the growth of this business. In addition to being money, Bitcoin has always been considered a tool for investing and storing value, which is why it is called digital gold. One of the most important problems in the production or extraction of Bitcoins is the high-power consumption by miners. If the energy sources of electricity generation are supplied by non-renewable energy sources, in addition to emitting air pollutant gases, it will increase greenhouse gases and consequently contribute to climate change. In this research, based on the idea of the authors, which is that the economic support of Bitcoin is energy, a strategy for producing Bitcoin from renewable energy sources is considered. First, the amount of electrical energy consumption by Bitcoin production is calculated based on statistical data, and then based on the price of electricity in different countries of the world and its global average, the base price of Bitcoin is calculated. In the following, four scenarios are proposed for the production of Bitcoin by electricity supplied from non-renewable energy sources. These scenarios include coal-fired steam power plants, natural gas-fired power plants, natural gas/oil gas-fired power plants, and dual-cycle (steam and gas cycles) natural gas-fired power plants. Based on the amount of electricity required to produce one Bitcoin, the amount of pollutants emitted to produce Bitcoin and its social costs are calculated. These costs should be added to the base cost of Bitcoin production if non-renewable energy sources are used to produce Bitcoin. Then, renewable energy sources for Bitcoin production based on the price of electricity generated by renewable energy sources are examined. Based on the analyses, how to choose the best renewable energy source to produce Bitcoin is presented as a scenario. This article briefly answers two key questions: 1. At what price of Bitcoin is it cost-effective for governments to produce it? 2. What is the best renewable energy source to produce it? These two questions can be useful in creating a roadmap and strategy for economists and governments.

1. Introduction

Blockchain is a system for recording information on a network of computer systems in a way that the information is secure, verifiable, and irrevocable. Information is recorded in a series of "blocks", each containing transactions and other key data. Each time a transaction is made, a new block containing the transaction is added. The entire stored and expanding information is called blockchain [1]. Blockchain is designed to be difficult to hack, as any change must be verified against other versions in the blockchain system. Bitcoin is the most well-known example of blockchain technology. In the Bitcoin network, validation is done by mining rigs that compete with each other to solve a general algorithm and receive financial rewards for validating correctly. Copies of the updated blockchain are then stored in distributed storage. Each new set of transactions adds to the length of the blockchain [2]. Bitcoin is a decentralized digital currency. This currency is single management and is transferred from one user to another without the need for an intermediary [3]. Transactions in a network are encrypted. In the Bitcoin mining process, the Bitcoin miner is rewarded. This mining involves consuming a lot of electricity [4, 5]. Bitcoin was invented by Satoshi Nakamoto in 2008 as a digital form of money, but no one knows who Satoshi Nakamoto is [6, 7]. It took more than a year for the first economic deal to be made. The global value of Bitcoin at that time was 4 Bitcoins per US cent. The first Bitcoin transaction took place in 2010 when a man from Florida paid 25 US$ to deliver two pizzas worth 25 US$ on May 22, 2010; At today's price, the same deal is worth 120 million dollars. In honor of this important moment, fans and supporters of digital currencies call 22 May Pizza Day [8, 9]. Bitcoin has attracted investors and the world from its simple beginnings in 2008 to its peak in 2020. For more than a decade, its price has fluctuated a lot. Bitcoin can be used to buy other currencies, products, and services. In the early days, the first Bitcoin transactions on online forums were exchanged with people who traded goods and services for Bitcoin. The value of Bitcoin was initially determined by the individual [5].

After that, Bitcoin's value grows by 200% annually. In November 2021, the price of Bitcoin reached about 68,000 US$, and its market value reached about 1.2 trillion US$. Of course, after that, it experienced many fluctuations [10]. Over the years, the Bitcoin mining process has become more complex. In 2011, a simple desktop computer could easily extract Bitcoins, but now it takes 13 years for this device to be able to extract a Bitcoin [6, 7]. It is clear that with the increasing complexity of mining, more energy is consumed to produce Bitcoins. Bitcoin energy consumption is somewhat straightforward to calculate: The amount of energy consumption is calculated based on the hash rate (total combined calculations to generate Bitcoin transactions) and the hardware energy required (miners). It is estimated that Bitcoin consumes 73.1 to 78.3 TWh of electricity per year. This amount of energy is more than the total annual electricity consumption of countries like Hongkong, Ireland, Austria, Malaysia, and Norway. It is estimated that Bitcoin consumes 707 kilowatt-hours (kilowatt-hours) of electricity per transaction [11]. The energy consumption of a Bitcoin transaction is approximately equal to the electricity consumption of a British family in two months [4, 12, 13]. The University of Cambridge has added a new indicator called the Cambridge Bitcoin Power Consumption Index (CBECI) to calculate daily power consumption by the Bitcoin network. This is an alternative to the existing Bitcoin Energy Consumption Index (BECI) [11, 12].

Research on the relationship between Bitcoin and its energy consumption can be divided into three general categories: energy consumption for Bitcoin production, its environmental effects, and the use of renewable energy sources. But the number of studies about using renewable energy resources for Bitcoin production is very limited in the third category of research. Rehman et al. [14] examined the time-frequency relationship between the price of Bitcoin and Bitcoin mining during the period from January 2013 to October 2018. Three sources of energy were considered: oil, coal, and gas. They showed that the production time of Bitcoins for oil and gas from mid-2014 to 2016 was about 64 to 128 days. Das and Dutta [15] examined the relationship between Bitcoin energy consumption and miner revenue. In their view, the relationship between the two is contradictory. They concluded that, due to the increase in costs and energy consumption for Bitcoin production along with the downward trend of the market, Bitcoin mining will not reach the endpoint that exits the market. As a result, cost-effective Bitcoin mining depends on low-cost energy sources and efficient hardware. Li et al. [16] statistically analyzed data on the Monero currency code. They estimate that, in 2018, Monero mining could consume 645.62 GWh of electricity worldwide. The mine also consumes about 30.34 GWh of electricity in China and emitted 19.12 to 19.42 thousand tons of carbon from April to December 2018. Similar observations have been reported in the literature, which shows that mining Bitcoin consumes a high amount of energy [11, 17-20]. Sarkodie and Owusu [21] have studied the effects of pollution produced on Bitcoin production. The study was based on 4158 statistical data points acquired during the period July 7, 2010, to December 4, 2021. The 12 variables of the study include the maximum and minimum and the annual carbon footprint trend from three non-renewable sources (oil, gas, and coal). The annual carbon footprint trend in this study is measured and calculated based on the carbon dioxide produced and based on the method provided by the International Energy Agency [21].

Stroll et al. [22] proposed a method for estimating the energy consumption of Bitcoin production. Based on the localization of IP addresses, the annual power consumption of Bitcoin production up to November 2018 was equal to 45.8 TWh, with annual carbon emissions between 22.0 and 22.9 Mt. This annual amount of carbon dioxide production is equal to the annual production of carbon dioxide by Jordan and Sri Lanka. Krause and Tolaymat [23] provided a way to calculate the minimum energy requirements of several digital currencies and their dollar value. The review period was from January 1, 2016, to June 30, 2018. Calculations showed that Bitcoin, Atrium, Light Coin, and Monroe mining consumed about 17, 7, 7, and 14 MJ of energy, respectively, to produce one USD. In comparison, the extraction of aluminum, copper, gold, platinum, and rare earth oxides, respectively, consumed 122, 4, 5, 7, and 9 MJ of energy to produce one US dollar, respectively. This comparison shows that, except for aluminum, cryptocurrency extraction consumes more energy than the extraction of minerals. The data also show that the network calculations for the four digital cryptocurrencies are constantly increasing. It is also estimated that the production of four currency codes emits 3 to 15 million tons of carbon dioxide. Similar studies have concluded that, due to high energy consumption, digital currency markets can be an important source of carbon dioxide production [23, 24]. Vries and Stoll [25] examined the increase in e-waste through the increase in hardware for Bitcoin production. According to the method presented, about 30.7 tons of toxic chemical waste

and heavy metals are buried in the soil annually, which is equivalent to the annual e-waste in the Netherlands. Vries [26] concluded that renewable energy is not the answer to Bitcoin sustainability. He suggested other alternatives to Bitcoin mining, including a Proof-of-Stake mechanism. In this mechanism, the participating machines do not have to use their computing power. Malfuzi et al. [27] studied the thermodynamics and economics of a Bitcoin mining system that is powered by a solid oxide fuel cell. The fuel source of this system was natural gas or biogas. In that study, different scenarios related to Bitcoin price and extraction difficulty were proposed. The system was studied based on the economic conditions of different countries. The results showed that Iran, Russia, and China are the best countries to extract Bitcoin using grid electricity. Iran, Canada, and Russia are also the best countries to extract Bitcoins from the solid oxide fuel cell (SOFC) system with natural gas. In general, in the mentioned countries, the profitability of SOFC mining is less than that of grid mining. But the SOFC has better sustainability and lower environmental costs. Lei et al. [28] reviewed and analyzed the energy consumption of blockchain technologies and proposed policies in this regard. Due to the expansion of the digital currency market and its growing popularity, and the high level of energy consumption and environmental issues, the production of Bitcoins by non-renewable energy sources is impacting the environment and energy security. Therefore, the use of renewable energy sources can be considered an alternative.

In this article, the amount of electricity consumed by miners to produce a Bitcoin is calculated based on statistical data. Based on the amount of electricity consumed and the price of electricity in different regions, and its global average, a model is proposed to calculate the base price of Bitcoin. Various scenarios for the production of Bitcoins with renewable and non-renewable energy sources from an energy, economic, and environmental perspective are presented. Finally, a conceptual policy for Bitcoin production is proposed. The main objectives of this article are as follows:

- Provision of the theory that Bitcoin value is supported by energy.
- Calculation of the base price of Bitcoin based on the price of electricity in different countries and regions and based on the theory presented in this article (above objective).
- Calculation the amount of air pollutants to extract Bitcoin if the energy source of power plants is non-renewable energy.
- Calculation of the social costs of air pollutants based on the amount of electricity used to produce Bitcoin and the associated pollutants for which the cost should be added to the base price of Bitcoin.
- Development of a strategy to produce Bitcoin from renewable energy resources based on the price of electricity from systems that use renewable energy resources.

2. Calculation of electricity consumption for Bitcoin production

An application-specific integrated circuit (ASIC) is an integrated circuit chip designed and built for a specific purpose. Miner ASIC refers to the hardware used to extract a particular type of digital currency. Therefore, an ASIC Bitcoin miner is only for Bitcoin mining. The extraction process means solving a complex mathematical problem using hash functions associated with blocks containing transaction data. The first miner to solve the puzzle can authorize the transaction or add Bitcoins to the block. Each winner of Bitcoin mining receives a prize (a certain amount of Bitcoin). This bonus includes all transaction fees. To calculate the amount of electricity required to produce Bitcoin, the entire network must be considered. It should be noted that the amount of energy required for electricity depends on the miner model, its efficiency, and the difficulty of extracting Bitcoins [5, 23, 29-31]. According to data published in the reference [32], a Bitcoin is currently produced at 122,000 Terra hash per second for 24 hours. Note that hash rate or hash power is a measure of the performance of a miner device. In other words, a hash rate indicates the rate at which a miner succeeds in solving a hash to receive a reward. In the Bitcoin extraction process, blocks containing approved transactions must be hashed before being added to the blockchain. The process of hashing blocks is also called hashing [32]. The number of ASICs required can be written as follows:

$$N_{ASIC} = \frac{122000}{N_{HR}} \quad (1)$$

Here, N denotes the number, and subscript HR means hash rate.

The electrical energy required for one Bitcoin production is calculated by [9, 33]:

$$E = 24 \times N_{ASIC} \times \dot{W}_{ASIC} \quad (2)$$

where $\dot{W}_{ASIC}$ denotes electrical power consumption by one ASIC (kW).

As an example, considering equations 1 and 2, the S19 Pro 110 Miner needs 86,509 kWh of electricity to generate a Bitcoin [5, 23, 29-31]. The whole market does not use the above model. For this purpose, market share and different types of miner models are considered. This model was presented for the first time in reference [23]. So, the top Bitcoin miner models that have the largest market share are considered [34]. Table 1 shows the specifications of those miners. Because the market share of those miners is almost in the same range, equal market share is considered for them.

Table 1. Top Bitcoin miner models [34]

Miner model	N_{HR} (TH/s)	$\dot{W}_{ASIC}$ (kW)
Antminer S19 Pro	110	3.25
Antminer T19	84	3.15
AvalonMiner A1166 Pro	81	3.4
WhatsMiner M30S++	112	3.472
AvalonMiner 1246	90	3.42
WhatsMiner M32-62T	62	3.536
Ebang EBIT E11++	44	1.98
Ebit 12+	50	2.44

According to equations 1 and 2 and the data in Table 1, the amount of electrical energy required to produce a Bitcoin is equal to 120,360.2 kWh.

3. Developing a methodology for calculating the base price of Bitcoin

The support of the currencies of countries is a certain amount of gold or other precious metals and foreign exchange reserves. According to the authors of this article, Bitcoin is financially supported by energy.

Figure 1 shows the production or extraction cycle of Bitcoins. In this process, electricity is generated by power plants that use renewable or non-renewable energy sources. If non-renewable sources are used to generate electricity, the initial cost of equipment, installation, commissioning, and maintenance of the power plant along with the price of fuel is taken into account to calculate the price of electricity. But, if renewable energy sources are used, the cost of fuel is eliminated, but other costs still exist. In both cases, the generated electricity has a value and price that is consumed by the miners to produce Bitcoins. Thus, the value and price of Bitcoin are inherently supported by the price of energy consumed to produce and extract it. So, the base price of Bitcoin can be considered based on the price of electricity consumed to produce it. Of course, at certain times, due to economic issues, the price of Bitcoin can be more or less than its base, which is due to economic issues such as buyers' or sellers' power, injecting money into the market, expansionary or contractionary economic policies of governments, etc. Then, the value and price of Bitcoin can be evaluated from an economic point of view in two ways: technical and fundamental. But Bitcoin's digital currency still has an intrinsic value that stems from the amount of electricity consumed to generate or extract it. Except for specific periods, this value has been on the rise for more than two decades due to the increasing complexity of its extraction and production and the increase in the number of hash rates for its production or extraction. Table 2 shows the electricity cost and base price of Bitcoin in 2022 in different countries and its average global price. The electricity cost is taken from Ref. [35]. Based on the consumption of 120,360.2 kWh of electricity to produce a Bitcoin, as described earlier in this article, the base price of a Bitcoin is determined based on the price of this amount of electricity.

Table 2. Electricity cost and base price of Bitcoin in 2022 in different countries and its average global price

No.	Countries	Electricity cost (US$/kWh) [35]	Bitcoin basic cost (US$)
1	Belgium	0.32	38515.4
2	Chile	0.17	20461.3
3	China	0.09	10832.4
4	Denmark	0.36	43329.8
5	France	0.2	24072.1
6	Germany	0.35	42126.2
7	India	0.08	9628.8
8	Italy	0.23	27682.9
9	Japan	0.24	28886.5
10	Kenya	0.22	26479.3
11	Mexico	0.09	10832.4
12	New Zealand	0.21	25275.7
13	Qatar	0.03	3610.8
14	Russia	0.06	7221.6
15	Saudi Arabia	0.05	6018.0
16	Singapore	0.18	21664.9
17	Turkey	0.06	7221.6
18	United Kingdom	0.28	33700.9
19	United States	0.16	19257.7
20	World	0.135	16248.7

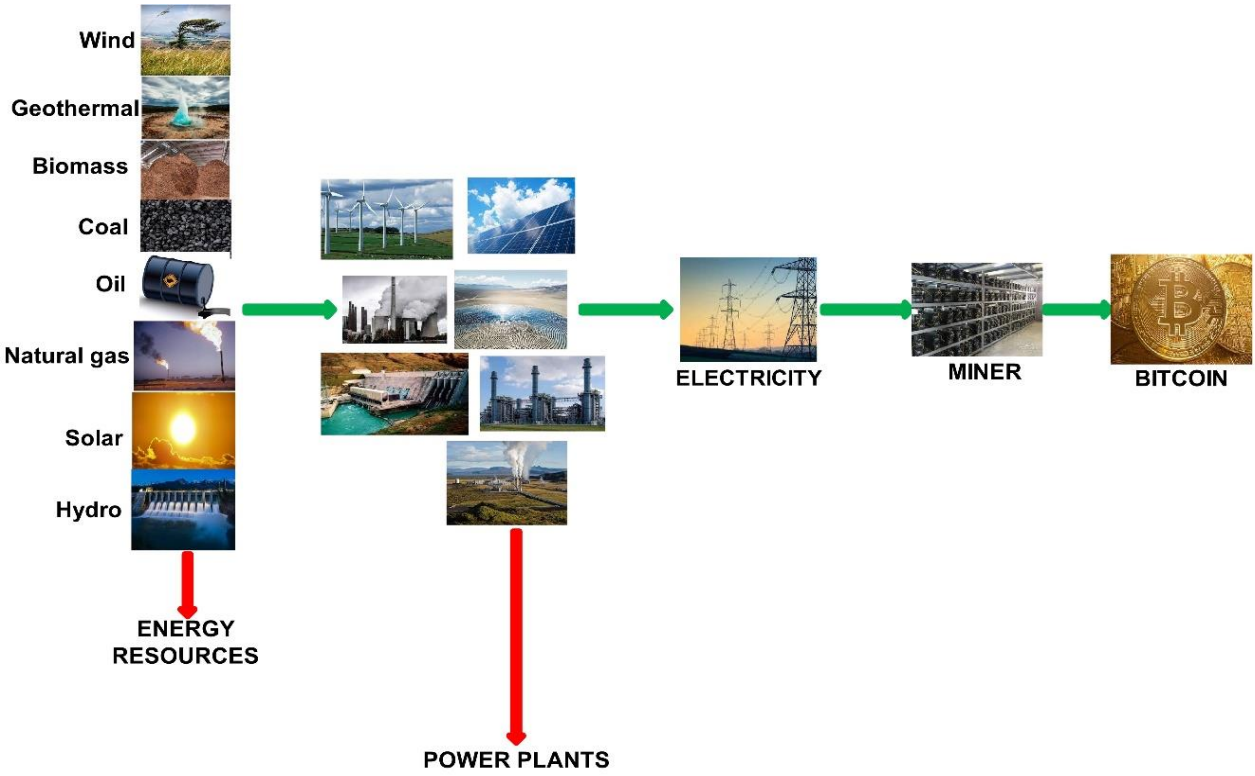

Figure 1. Production or extraction process for Bitcoins

The base price of Bitcoin shows the real value of Bitcoin in a country or its global average. The change in the price of Bitcoin higher or lower than its base price is due to market influences and is related to influential economic parameters. In connection with the subject of this article, if the price of Bitcoin in the economic market grows above the base price, the production of Bitcoin in that country is cost-effective. otherwise, it is not cost-effective. Of course, special attention should be paid to whether the price of electricity in a country is its real value or whether the government subsidizes it. From Table 2 and according to the price of electricity, the highest base price of Bitcoin is for Denmark and Germany and the lowest is for Qatar and Saudi Arabia. For example, the base price of Bitcoin in Qatar is 3610.8 US$, while in Denmark it is 43,329.5 US$, which is about 14 times more. It can also be seen in Table 2 that the highest electricity prices and consequently the base prices of Bitcoin are related to continental Europe and the cheapest are related to the Middle East region due to abundant sources of fossil fuels. Also, the average global electricity price is 0.135 US$ and the base Bitcoin price is 16248.7 US$.

4. Analysis of the production of Bitcoin by non-renewable energy sources

To generate Bitcoin from non-renewable energy sources, the following four scenarios are considered:

- Scenario 1: Electricity is generated by a coal-fired steam power plant.
- Scenario 2: Electricity is generated by a gas power plant that is fueled by natural gas.
- Scenario 3: Electricity is generated by a gas power plant whose fuel is gas with gas oil.
- Scenario 4: Electricity is generated by a combined cycle power plant that includes a gas power plant, steam turbine, and heat recovery steam generation (HRSG), and is fueled by natural gas.

Table 3 shows the unit amount of selected pollutants for the four scenarios [35]. In Table 3, the pollutants considered are CO_2, NO_x, and SO_2. Note that power plants emit other air pollutants, as well as wastes that enter the soil and water. In this article, only selected air pollutants during operation are considered.

Table 3. Amount of pollutants produced for four scenarios for generating Bitcoin from non-renewable energy sources

Scenario	CO_2 (g/kWh)	NO_x (g/kWh)	SO_2 (g/kWh)
1	930	2.1	8.8
2	800	1.6	1.4
3	610	1.1	0
4	510	0.9	0

Figures 2 to 4 show the production of CO_2, NO_x, and SO_2 for four scenarios, for the production of one Bitcoin. The highest amount of pollutants are related to Scenario 1 due to burning coal in the steam power plant and the lowest is related to Scenario 4, due to the recovery of gas turbine exhaust hot gas in HRSG for efficiency and to the use of natural gas as the fuel. To create a link between the economy and the environment, the social costs of environmental pollutants are considered. The social costs of environmental pollutants are considered here to be the costs that are indirectly imposed on people in the community due to environmental degradation.

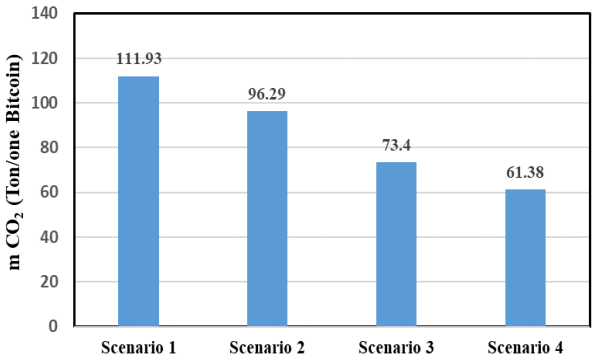

Figure 2. Quantities of CO_2 generated per Bitcoin produced, for four scenarios

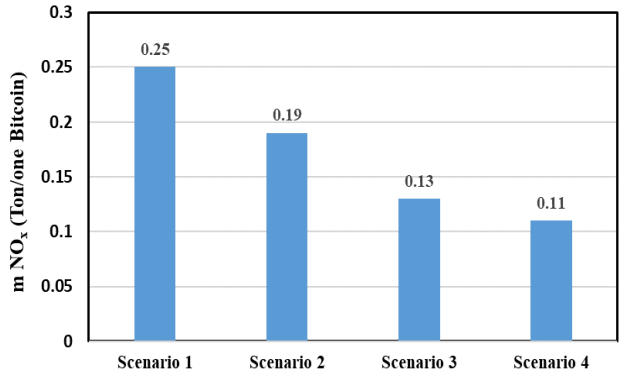

Figure 3. Quantities of NO_x generated per Bitcoin produced, for four scenarios

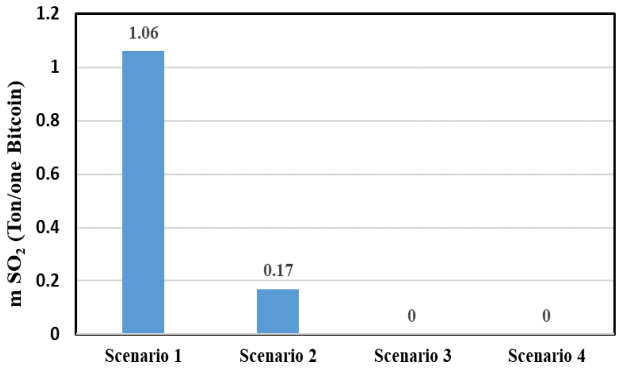

Figure 4. Quantities of SO_2 generated per Bitcoin produced, for four scenarios

These costs include reduced productivity, illness, and death in the community. These costs depend on the living conditions of the community, the local location, and the type of environmental degradation. Table 4 shows the social costs of CO_2, NO_x, and SO_2 pollutants [36, 37]. According to the data in Tables 3 and 4 and Figures 2 to 4, the social costs of air pollutants for the production of a Bitcoin are 13384 US$, 6696 US$, 4050 US$, and 3368 US$, respectively, for scenarios 1 to 4. Therefore, if any of scenarios 1 to 4 are used to generate electricity and, subsequently, Bitcoin, the costs mentioned should be added to the base price of Bitcoin (Table 2).

Table 4. Social costs of CO_2, NO_x, and SO_2 pollutants [36, 37]

Air pollution	Values (US$/kg)
CO_2	0.042
NO_x	7.3
SO_2	7.4

5. Investigation of the production of Bitcoin by renewable energy sources

The main types of renewable energy sources considered here are geothermal, solar, biogas, wind, and hydro. The maximum, mean, and minimum levelized cost of electricity (LCOE) for various renewable energy resources are shown in Table 5 [38-40]. The variation of LCOE from maximum to minimum depends on the potential of that country or region for that renewable energy source, import and export taxes, and other factors.

Table 5. Maximum, mean, and minimum LCOE for various renewable energy resources

Type of renewable energy resource	Sub-division	LCOE (US$/kWh)		
		Max	Ave	Min
Wind	On-shore	0.14	0.05	0.029
	Off-shore	0.2	0.088	0.049
Solar PV	Utility-scale	0.172	0.056	0.034
	Commercial	0.14	0.094	0.074
	Residential	0.223	0.126	0.108
Solar thermal	-	0.13	0.121	0.112
Hydro	Reservoir (≥ 5 MW)	0.142	0.072	0.039
Hydro	Run of river ((≥ 5 MW)	0.104	0.068	0.046
Geothermal	-	0.12	0.099	0.078
Biomass	-	0.182	0.118	0.053

5.1 Case study

A detailed case study is now considered. The price of electricity and the base price of Bitcoin in Denmark are 0.36 US$/kWh and 43,329.8 US$, respectively. Considering the high potential of wind energy in that country, the shore-wind turbine is selected to produce electricity. Considering the data in Table 5, the average cost of electricity is 0.05 US$/kWh. According to the price of electricity in Denmark (Table 2: 0.366 US$/kWh), the profit per kilowatt hour of electricity is 0.31 US$/kWh. According to the calculations in this article, 120360.2 kWh of electricity is required per Bitcoin produced. Now, if this amount of electricity is sold to the electricity grid instead of producing Bitcoins, the profit will be equal to 37,311,662 US$. If we consider that Bitcoin is generated by this system, and according to the price of electricity generated by this system (0.05 US$/kWh), the cost of producing a Bitcoin is equal to 6018 US$. Considering the current price of Bitcoin (2 June 2022: 31,700 US$), the profit is 25,682 US$. To reach the tipping point, the profit from the sale of electricity is 37311.6 US$ should be added to the base price of Bitcoin by non-renewable energy sources (6018 US$), which is 43329.7 US$, which is the same as the base price of Bitcoin shown in Table 2.

Note that if the electricity used to produce Bitcoin is replaced by power plants that use fossil fuels, the social costs of environmental pollutants (part 4 of the article) should be added to the base price. Also, in the case of Bitcoin production by renewable energy sources, miners can be placed next to the power generator, thus the cost of electrical power transmission and distribution is eliminated. Due to the new digital currency market, price changes for digital currencies are very sharp. In 2021, for example, the price of digital currencies fluctuated from about 34,000 to 61,000 US$. So the question is, if it is cost-effective to produce Bitcoin in one period and not in another, is there an alternative way to use the electricity allocated to produce Bitcoin?

The answer to this question depends on various factors such as the needs of a region or country, the number of its natural resources, the level of the social and economic welfare of society, etc. There are several ways to consume electricity generated at a time when it is not cost-effective to produce Bitcoins. For example, in a cold or hot region or country, heating and cooling loads for residential, commercial, and office buildings can be provided. In regions and countries that have a shortage of drinking water resources and in the vicinity of the sea or ocean, drinking water can be produced by reverse osmosis system, or in countries that have a shortage of fuel and have sufficient water resources, electricity can be used to split water via electrolysis to produce hydrogen as a clean fuel. Along with all these solutions, we can continue to produce Bitcoin and look at it as a long-term investment.

6. Proposing a strategy to produce Bitcoin by renewable energy resource

In this part of the article, the following strategy is proposed for the production of Bitcoin by renewable energy sources:

- Step 1: The potential of renewable energy sources in that region or country is examined and, according to the potential of these resources, and their availability and usability, the priorities of these resources are selected.
- Step 2: The price of electricity produced by power generation systems with renewable energy sources selected in the first step is calculated. To calculate the price of electricity generated, two modes are considered: with and without considering the transmission and distribution electrical network.
- Step 3: Power generators in the country or region considered are examined. If the energy sources of power generation systems are non-renewable sources, the social costs of environmental pollutants (similar to scenarios 1 to 4 of Part 4 of the article are added to the base price of electricity (Table 2 of the article).
- Step 4: If the price of generated electricity by renewable energy resource system (considering the costs of electricity transmission and distribution) is less than the price of electricity without government subsidies and the price of Bitcoin is less than the base price of Bitcoin (Table 2), electricity generation is neglected by the selected system in steps 1 and 2.
- Step 5: If the price of Bitcoin is lower than the Bitcoin base price shown in Table 2 and the price of electricity generated by the proposed system of electricity generation with renewable energy sources is lower (taking into account the costs of transmission and distribution of electricity) than the price of electricity in that area or country, the generated electricity is sold to the electricity grid.

- Step 6: If the price of Bitcoin is higher than the base price of Bitcoin shown in Table 2, the production of Bitcoin by the system is recommended. In this case, Bitcoin production miners can be placed next to the power generation system, which eliminates the cost of electricity transmission and distribution.

7. Conclusion and policy implications

Bitcoin, the first decentralized digital currency introduced by an anonymous person or group since 2008, has attracted worldwide attention. A significant number of economists have introduced Bitcoin as a new phenomenon in the 21st century that could reduce global inflation. Given the tens of thousands of digital currencies that have emerged since the advent of Bitcoin and its price growth trend over more than a decade, which are signs of the growth of this business. In addition to being money, Bitcoin has always been considered a tool for investing and storing value, which is why it is called digital gold. One of the most important problems in the production or extraction of Bitcoins is the high-power consumption by miners. If the energy sources of electricity generation are supplied by non-renewable energy sources, in addition to emitting air pollutant gases, it will increase greenhouse gases and consequently contribute to climate change. In the following, four scenarios are proposed for the production of Bitcoin by electricity supplied from non-renewable energy sources. These scenarios include coal-fired steam power plants, natural gas-fired power plants, natural gas/oil gas-fired power plants, and dual-cycle (steam and gas cycles) natural gas-fired power plants. Based on the amount of electricity required to produce one Bitcoin, the amount of pollutants emitted to produce Bitcoin and its social costs are calculated. These costs should be added to the base cost of Bitcoin production if non-renewable energy sources are used to produce Bitcoin. If renewable energy sources are used to produce electricity that reaches the consumption of bitcoin production, in addition to solving the problems mentioned above, it can be an income-generating factor for countries, especially developing countries where the price of electricity is low. In this article, based on the price of electricity in different countries and regions, the base price of Bitcoin is calculated, and a strategy is presented based on which price of Bitcoin is cost-effective to produce for that country, considering the price of electricity.

Nomenclature

HR: Hash rate
N: Number
$\dot{W}$: Electrical power consumption

Subscripts

ASIC: Application-specific integrated circuit

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] Atlam, H.F. and G.B. Wills, Technical aspects of blockchain and IoT, in Advances in computers. 2019, Elsevier. p. 1-39.

[2] Sawa, T., Blockchain technology outline and its application to field of power and energy system. Electrical Engineering in Japan, 2019. 206(2): p. 11-15.

[3] Abbaspour, H., et al., Energy, exergy, economic, exergoenvironmental and environmental (5E) analyses of the cogeneration plant to produce electrical power and urea. Energy Conversion and Management, 2021. 235: p. 113951.

[4] Dogan, E., Majeed, Muhammad Tariq, Luni, Tania, Are clean energy and carbon emission allowances caused by bitcoin? A novel time-varying method. Journal of Cleaner Production, 2022. 347: p. 131089.

[5] Gallersdörfer, U., Klaaßen, Lena, Stoll, Christian, Energy consumption of cryptocurrencies beyond Bitcoin. Joule, 2020. 4(9): p. 1843-1846.

[6] Lemieux, P., Who is satoshi nakamoto? Regulation, 2013. 36(3): p. 14-16.

[7] Born, B., International regulatory responses to derivative crises: The role of the US commodity futures trading commission. International Journal Of Law and Buisiness, 2000. 21: p. 607-615.

[8] Farber, M. This billionaire just called Bitcoin a 'Pyramid Scheme' See: https://fortune.com/2017/07/27/howard-marks-bitcoin-pyramid-scheme/ [Accessed 7 March 2022]. Available from: https://fortune.com/2017/07/27/howard-marks-bitcoin-pyramid-scheme/ [Accessed 2022].

[9] Paul, V.a.M., C, The age of crytocurrency: How Bitcoin and digital currency are challenging the global economic order. Vol. 1. 2016, USA: New York, NY : St. Martin's Press. 368.

[10] Sarkodie, S.A., Ahmed, Maruf Yakubu, Leirvik, Thomas, Trade volume affects bitcoin energy consumption and carbon footprint. Finance Research Letters, 2022. 48: p. 102977.

[11] de Vries, A., Bitcoin's growing energy problem. Joule, 2018. 2(5): p. 801-805.

[12] Knapton, S. Bitcoin using more electricity per transaction than a British household in two months See: https://www.telegraph.co.uk [Accessed 3 April 2022]. Available from: https://www.telegraph.co.uk [Access 3 April 2022].

[13] Corbet, S., Lucey, Brian, Yarovaya, Larisa, Bitcoin-energy markets interrelationships - New evidence. Resources Policy, 2021. 70: p. 101916.

[14] Rehman, M.U. and S.H. Kang, A time–frequency comovement and causality relationship between Bitcoin hashrate and energy commodity markets. Global Finance Journal, 2021. 49: p. 100576.

[15] Das, D. and A. Dutta, Bitcoin's energy consumption: Is it the Achilles heel to miner's revenue? Economics Letters, 2020. 186: p. 108530.

[16] Li, J., et al., Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. Energy, 2019. 168: p. 160-168.

[17] Vranken, H., Sustainability of bitcoin and blockchains. Current Opinion in Environmental Sustainability, 2017. 28: p. 1-9.
[18] Bevand, M. Electricity consumption of Bitcoin: a market-based and technical analysis See: http://blog. zorinaq. com/bitcoin-electricity-consumption [Accessed 3 May 2022] Available from: http://blog. zorinaq. com/bitcoin-electricity-consumption [Access 3 May 2022].
[19] Digiconomist. Bitcoin energy consumption index See: https://digiconomist.net/bitcoin-energy-consumption/ [Accessed 15 January 2021]. Available from: https://digiconomist.net/bitcoin-energy-consumption/ [Access 15 January 2021].
[20] de Vries, A., Bitcoin's energy consumption is underestimated: A market dynamics approach. Energy Research & Social Science, 2020. 70: p. 101721.
[21] Sarkodie, S.A., Owusu, Phebe Asantewaa, Dataset on bitcoin carbon footprint and energy consumption. Data in Brief, 2022. 42: p. 108252.
[22] Stoll, C., Klaaßen, Lena, Gallersdörfer, Ulrich, The carbon footprint of Bitcoin. Joule, 2019. 3(7): p. 1647-1661.
[23] Krause, M.J. and T. Tolaymat, Quantification of energy and carbon costs for mining cryptocurrencies. Nature Sustainability, 2018. 1(11): p. 711-718.
[24] Mora, C., et al., Bitcoin emissions alone could push global warming above 2 C. Nature Climate Change, 2018. 8(11): p. 931-933.
[25] de Vries, A. and C. Stoll, Bitcoin's growing e-waste problem. Resources, Conservation and Recycling, 2021. 175: p. 105901.
[26] de Vries, A., Renewable Energy Will Not Solve Bitcoin's Sustainability Problem. Joule, 2019. 3(4): p. 893-898.
[27] Malfuzi, A., et al., Economic viability of bitcoin mining using a renewable-based SOFC power system to supply the electrical power demand. Energy, 2020. 203: p. 117843.
[28] Lei, N., E. Masanet, and J. Koomey, Best practices for analyzing the direct energy use of blockchain technology systems: Review and policy recommendations. Energy Policy, 2021. 156: p. 112422.
[29] McQuillan, B., et al., High efficiency generation of hydrogen fuels using solar thermo-chemical splitting of water (solar thermo-chemical splitting for H2), in Prepared under Solar Thermochemical Hydrogen Grant No. DE-FG36-03G013062 2010: University of Nevada Las Vegas Research Foundation, USA.
[30] de Vries, A., Bitcoin boom: What rising prices mean for the network's energy consumption. Joule, 2021. 5(3): p. 509-513.
[31] Fujii, K., et al., Hydrogen production by the magnesium–iodine process. Advances in Hydrogen Energy, 1982. 3: p. 553-6.
[32] Bitcoin miner beats 1 in 1.3 million odds to mine a BTC block See:https://www.theblockcrypto.com/post/129894/bitcoin-miner-beats-1-in-1-3-million-odds-to-mine-a-btc-block [Accessed 30 Apr 2022]. [cited 2022; Available from: https://www.theblockcrypto.com/post/129894/bitcoin-miner-beats-1-in-1-3-million-odds-to-mine-a-btc-block [Access 2022].
[33] Kamiya, G., Bitcoin energy use-mined the gap. 2019. https://www.iea.org/commentaries/bitcoin-energy-use-mined-the-gap
[34] Top 10 Bitcoin Mining Hardware [2022 Updated List] See: https://www.softwaretestinghelp.com/bitcoin-mining-hardware/ [Accessed 5 May 2022]. [cited 2022; Available from: https://www.softwaretestinghelp.com/bitcoin-mining-hardware/ [Accessed 5 May 2022].
[35] Combined Heat and Power (CHP) Developers Guides 2009, United Kingdom Government Department of Energy & Climate Change
[36] David Birchby, J.S., Sally Whiting, Michel Vedrenne, Air Quality damage cost update 2019. 2019. p. 1-54.
[37] Karkour, S., Ichisugi, Yuki, Abeynayaka, Amila, Itsubo, Norihiro, External-cost estimation of electricity generation in G20 countries: case study using a global life-cycle impact-assessment method. Sustainability, 2020. 12(5): p. 2002.
[38] Projected costs of generating electricity 2020 See: https://www.iea.org/reports/projected-costs-of-generating-electricity-2020 [Accessed 3 May 2022]. Available from: https://www.iea.org/reports/projected-costs-of-generating-electricity-2020 [Accessed 3 May 2022].
[39] Average renewable electricity generation cost globally in 2020, by energy source See: https://www.statista.com/statistics/478049/global-utility-scale-electricity-generation-cost-by-resource/ [Accessed 17 May 2022]. Available from: https://www.statista.com/statistics/478049/global-utility-scale-electricity-generation-cost-by-resource/ [Access 2022].
[40] Renewable power generation costs in 2020 See: https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020 [Accessed 17 May 2022]. Available from: https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020 [Access 2022].