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Comparative Analysis of Bitcoin Mining Machines and Their Global Environmental Impact

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Abstract

The amount of power required to mine one Bitcoin (BTC) can vary significantly depending on several factors, including the type of mining hardware being used, its efficiency, the cost of electricity, and the overall network difficulty at any given time. Mining BTC involves solving complex mathematical problems to validate transactions on the blockchain network, which requires significant computational power. This research paper focuses on dedicated mining machines, combining essential data and information into a singular comparison evaluation of these machines.

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1. Introduction

In the earlier days of BTC, it was possible to mine BTCs using a regular central processing unit (CPU) on a personal computer. However, as the network difficulty increased and more people started mining, specialised mining hardware called application-specific integrated circuits (ASICs) became necessary for profitable mining.

Mining hardware's power consumption is typically measured in watts (W) or kilowatts (kW) [9, 59]. Today's high-end ASIC miners are much more efficient than older models, with power consumption ranging from a few hundred watts to a few thousand watts [4, 45].

To estimate the power consumption required to mine one BTC, it is essential to consider the specific mining hardware planned for use, its power efficiency, and the current network difficulty. Additionally, electricity costs vary depending on the location of the mining operation, so factoring in the price of electricity is necessary to calculate the total expenses [74].

It is important to note that the BTC network's difficulty level adjusts approximately every two weeks to maintain a consistent block time, making it harder or easier to mine BTCs based on the total computational power in the network. Therefore, the amount of power required to mine one BTC is not a fixed value and can change over time [4, 51].

This paper, a Comparison Review of BTC Mining Machines, includes support summaries and resources. We accomplished this by carefully evaluating collected works, which allowed us to identify various BTC mining machines, strategies and characteristics. Therefore, the paper's objective is a comparative analysis of the advantages and disadvantages of 4 BTC mining machines, such as the S9, S19, S19+ and the S19j Pro, which are synonymous in the BTC Mining world.

Additionally, the Comparison Review of BTC Mining Machines will focus on how much power is required to mine one BTC and understand the global effects of pollution and agriculture.

This paper provides a comprehensive comparative analysis of various Bitcoin mining machines, evaluates their global environmental impacts, and explores their indirect effects on agriculture. It also proposes mitigation strategies to address these issues and presents a detailed methodology for assessing mining machine performance and profitability. The remainder

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of this paper is structured as follows: Section 2, Background, introduces the BTC mining machines and their overall features and resources, specifically based on the information cited but not limited to Table 1. Section 3 describes our methodology, while Section 4 discusses the global effects caused by BTC mining, including pollution and damage to agriculture. Finally, Section 5 concludes the work and presents a direction for future developments. *EAI Endorsed Transactions*.

1.1. Key Contributions

This paper makes several key contributions to the understanding of Bitcoin mining and its broader implications:

Firstly, it presents a comparative analysis of Bitcoin mining machines, focusing on their hashing power, energy consumption, and efficiency. This analysis provides valuable insights into different mining models' performance and operational costs, specifically the S9, S19, S19+, and S19j Pro.

Secondly, the paper examines the global environmental impact of Bitcoin mining, quantifying its carbon footprint and emphasising the urgent need for sustainable practices. By comparing Bitcoin mining's carbon emissions to other industrial activities, the research highlights the significant environmental degradation caused by these operations.

Thirdly, the research explores the indirect effects of Bitcoin mining on agriculture. It discusses how the high energy consumption and pollution from mining activities can impact land use, water resources, and soil quality, ultimately affecting agricultural productivity.

Fourthly, the paper proposes potential mitigation strategies to address Bitcoin mining's environmental impact. These strategies include transitioning to renewable energy sources, strategic site selection to avoid agricultural land, and collaborative initiatives between the cryptocurrency industry and agricultural stakeholders to develop sustainable solutions.

Finally, the methodology section comprehensively evaluates the mining machines' performance and efficiency. It includes detailed calculations for profitability and energy costs, offering a clear framework for assessing the viability of different mining models in various geographic locations.

2. Background

A new BTC block is created every 10 minutes, yielding 6.25 BTCs. At the current mining rate, 328,725 BTCs (6.25 * 365.25 * 24 * 60 / 10) are generated annually. To mine one BTC annually, 1/328,725 of the current BTC hash rate is required. Consequently, 501 Tera Hashes (TH) per second are necessary [16, 20].

The BTC network uses approximately 96 terawatt-hours (TWh) annually. However, power consumption fluctuates for various reasons, such as changes in mining difficulty and the production of sufficient hardware with greater energy efficiency, including mining activity [4, 18].

Other arguments from "The BTC Mining Network: Trends, Marginal Creation Cost, Electricity Consumption Sources" were released by the digital asset management company CoinShares in June 2019. According to the analysis, the yearly energy usage for BTC mining is anticipated to be around 41 TWh, or almost 4.7 GW [4, 9].

Furthermore, Life Cycle Assessments of BTC Mining studied the environmental impact of mining BTC and concluded similar results [51]. This adds to the debate about the technology's alleged high energy use and carbon footprint. The paper focused on establishing a Life Cycle Assessment of past and future environmental impacts. Contrary to earlier research, it was discovered that the service life and end-of-life production had a negligible overall impact [4, 51]. It was also found that while the overall hash rate is anticipated to rise, the energy usage and environmental footprint per TH mined are expected to decline [9, 20].

Estimating the precise power consumption caused by BTC mining networks is challenging [6, 9, 19, 45, 51]. However, The Cambridge Centre for Alternative Finance (CCAF) has researched cryptocurrencies extensively, including how much energy is used in BTC mining [11]. Cambridge routinely releases reports on the topic that contain the most recent data, see Figure 1, Historical Annualized Electricity Consumption [11].

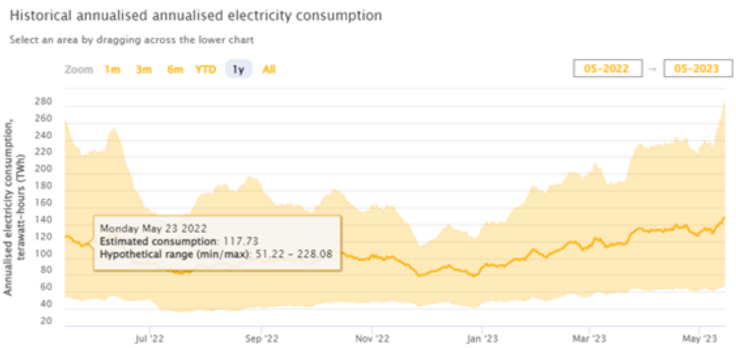

Figure 1. Historical Annualized Electricity Consumption)

The Cambridge BTC Electrical Consumption Index (CBECI) currently estimates the daily electrical load for the BTC network.

Since the precise amount of electricity consumed cannot be calculated, the CBECI offers a hypothetical range of an estimated lower bound (the floor) and an estimated upper bound (the ceiling). Suppose all miners consistently employ the most energy-efficient equipment on the market, as is the best-case scenario. In that case, the lower bound estimate corresponds to the theoretical minimal overall electricity expenditure. If all miners employ the least energy-efficient equipment to mine BTC, as is the worst-case scenario, the upper bound estimate indicates the theoretical maximum total electricity usage; see Figure 2, Total BTC Electricity.

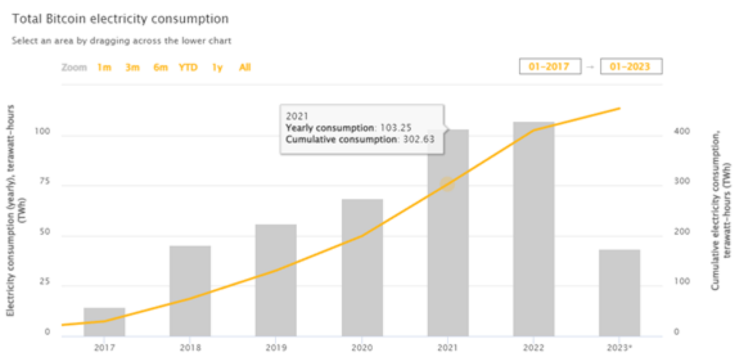

Figure 2. Total BTC Electricity Consumption

Continually, an online tool dubbed the "BTC Energy Consumption Index" is available on the Digiconomist website[19, 20]. It calculates the energy the BTC network uses; see Figure 3, BTC Energy Consumption Index and Figure 4 Annualised Total BTC Footprints.

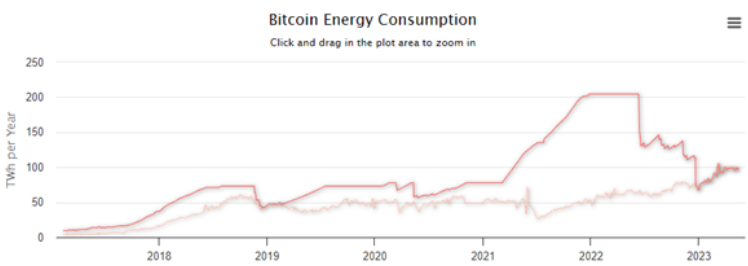

Figure 3. BTC Energy Consumption Index)

Based on the network's hash rate and the mining equipment's energy efficiency, it determines energy usage [20]. However, it should be noted that these estimates are not formal research studies [63, 64, 75].

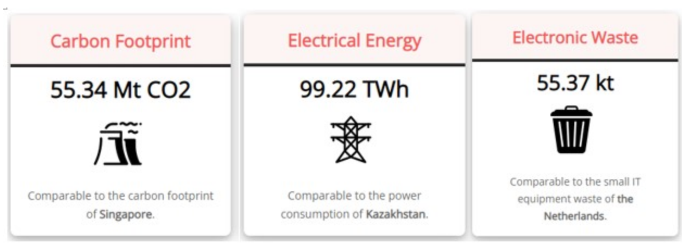

Figure 4. Annualised Total BTC Footprints

International Energy Agency (IEA): The IEA is a self-governing organisation specialising in energy policy [6]. In 2021, it released a report titled "Net Zero by 2050: A Roadmap for the Global Energy Sector." This study examined global energy usage and emphasised the need for transparency and precise statistics to evaluate the environmental impact [6]. Although there was little to no evaluation of the cause and effect of the global implications of cryptocurrencies and BTC Mining, other arguments on the Energy and Cost efficiency of BTC mining suggest that, except for rare circumstances, BTC mining is no longer a profitable endeavour [3, 4, 42, 81].

The article "Energy and Cost Efficiency of BTC Mining Endeavour" examines the impact of rising energy costs from various sources such as wind, solar, and geothermal technologies across different geographic locations. After careful consideration of several factors—including the cost of mining machines and associated components, effective repayment schemes, the network's difficulty and hash rate, BTC transaction fees, and total energy costs—the article concludes that there is a decreasing participation of miners in BTC mining and a consequent decline in their contribution to the BTC network [45].

2.1. BTC Mining Machines

The following section discusses the S9 BTC mining machines, including the S19, S19+, and S19J Pro. Each mining machine contains a table highlighting general information on the model, the date the device became available for commercial use, hardware components, noise level, power consumption/voltage, interconnectivity, temperature, and humidity. Additionally, there will be an interest in the characteristics of these mining machines, including other types of cryptocurrencies that can be mined simultaneously with BTC, enabling the crypto miner to mine several coins at once. This feature could be viewed as a means to cut costs, waste and energy [18, 52].

Some of these devices could be considered efficient due to their weight, size, hashing capability, energy consumption and overall cost to maintain the machine [18, 26, 70]. To mitigate the financial hardware and energy costs, these devices need to do more than just mining BTC; there has to be an opportunity to mine other cryptocurrencies to maximise their use case [10, 33, 52, 91].

The current power consumption and physical cost of the S9, S19, S19+ and the S19J Pro, mine as little or as high as 140 TH/s and consume 1300W of electricity, might draw the miner to more profitable and less costly endeavour involving Nodes as a Service (NaaS) [39, 68]. In this way, a crypto miner invests less for NaaS than they would do with BTC mining machines [39, 68]. For example, an individual, and not just a miner, can purchase 100 nodes with a NaaS protocol; for example, 100 Zeus nodes would cost 22,500 Zeus coins, which is the equivalent of 358 pounds that produces 5 -10 United States Dollars (USD) each day [54].

In total, investors would need to purchase, in most cases, 200 nodes to make the same equivalent financial income of a BTC mining machine of 10 USD each day, significantly reducing the energy consumption caused by BTC mining machines [39, 54, 68]. Furthermore, although not necessarily the topic of interest, it should be noted that most NaaS protocols pay in a cryptocurrency called USDC and not their native token. USDC is pegged to the USD, is classed as a stablecoin, and has the equivalent dollar value of 1 USDC equal to $1 [86].

The phrase "Node as a Service" (NaaS) describes the idea of offering a platform and infrastructure services for the deployment and management of applications built on the Node.js runtime environment [83]. Using Chrome's V8 JavaScript engine, Node.js is an open-source, event-driven JavaScript runtime. It enables web designers to create quick and scalable websites. However, it can be difficult and time-consuming to deploy and manage Node.js applications in a production environment [1, 27].

By abstracting away the infrastructure and offering a platform that manages the deployment, scaling, and administration of Node.js applications, NaaS attempts to streamline this procedure. Developers can submit their Node.js code and leave the rest to the cloud-based service it provides. NaaS solutions often offer functions like load balancing, automatic scalability, monitoring, logging, and security [39, 54, 68, 83].

Implementing NaaS offers increased development productivity, lessened operational complexity, enhanced scalability, and cost savings. Infrastructure maintenance can be delegated to a NaaS provider, freeing developers to concentrate on creating and enhancing their applications [68, 83].

Continually, bitcoin mining is the process by which new Bitcoin transactions are verified and added to the public ledger, known as the blockchain [70]. It involves solving complex mathematical problems using specialised hardware, such as ASIC miners. ASIC miners are specialised hardware devices designed specifically for mining cryptocurrencies [42, 49, 79]. Unlike general-purpose computers or graphics cards (GPUs), ASIC miners are purpose-built to perform a specific hashing algorithm with maximum efficiency [48, 80, 93].

Cryptocurrencies that use algorithms like SHA-256 (like Bitcoin) or Scrypt (like Litecoin) are frequently mined using ASIC miners [49, 80]. These methods need much processing power and are computationally demanding [17, 38]. The effectiveness and performance of ASIC miners are their main advantages. ASIC miners are much quicker and use less power than general-purpose hardware since they concentrate on a single algorithm [50, 89]. They are particularly well-suited for quick hashing computations, enhancing mining profitability.

However, ASIC miners have restrictions, they cannot simply be reprogrammed or modified to mine other cryptocurrencies that employ various algorithms because they are built for a particular algorithm [50, 56, 89]. As a result, to efficiently mine a new cryptocurrency with a unique algorithm, miners must purchase new ASICs made for that algorithm [2, 89].

ASIC miners have been essential to the growth and development of cryptocurrency mining [31, 90]. Their effectiveness has dramatically boosted the hash power of networks like Bitcoin, enhancing its security and attack resistance [69, 77]. Since purchasing and maintaining these devices can be expensive, the specialised nature of ASICs also raises questions about centralisation that may limit the ability of individual users to mine.

In short, Bitcoin transactions are created when users send or receive Bitcoin. These transactions are broadcasted to the Bitcoin network and collected into the "mempool" [65]. Miners receive a set of pending transactions from the mempool and create a new block [23, 65]. A block contains a header and a list of transactions [70]. Miners then take the block's header, which includes a reference to the previous block's hash, a timestamp, and other information, and run it through a hashing function called SHA-256 [14, 34, 53]. This produces a unique string of characters called a "hash."

The goal of mining is to find a hash that meets specific criteria set by the Bitcoin network [69, 89]. This is achieved through proof-of-work (PoW) [18, 79]. Miners repeatedly change a small part of the block's header, called the "nonce", and rehash it until they find a hash that meets the target criteria [89]. The requirement results in significant computational power, which is a resource-intensive process [31, 90].

The Bitcoin network automatically adjusts the mining difficulty every 2016 block (approximately every two weeks) [53, 65]. The difficulty measures the difficulty of finding a valid hash [34]. As more miners join the network, the difficulty increases in maintaining an average block creation time of around 10 minutes. Once a miner finds a valid hash, they announce it to the network. Other miners then verify the solution; if correct, the block is added to the blockchain [14, 34]. The miner who found the solution is rewarded with newly minted Bitcoin and any transaction fees included in the block, which incentivises miners to participate in securing the network [18].

Consequently, adding more blocks to the blockchain creates a chain of verified transactions [60]. The longest chain, which has the most accumulated computational work behind it, is considered the valid chain by the network. This consensus mechanism ensures the integrity and security of the Bitcoin network [50, 53].

The Antminer S9 (Figure 5) is designed to mine BTC and has a hashing power of 14 TH/s. It weighs 9.25 lbs—4.19kg and consumes 1,372 watts of power for the 14TH/s batch (see Table 1 S9 Antminer).

Figure 5. S9 Antminer

In the following tables, "Op Temperature" stands for Operating Temperature.

Table 1. Specifications of Bitmain Antminer S9

Manufacturer	Bitmain
Model	S9
Release	July 2017
Size	135 x 158 x 350 mm
Weight	4.19 kg (9.25lbs)
Chipboards	3
Chip name	BM1387
Chip size	16 nm
Noise level	85 dB
Cooling Fans	2
Power	1372W
Hashrate	14 TH/s
textbfWires	10 * 6 pins
Voltage	11.60 – 13.00 V
Op Temperature	0 - 40 °C
Humidity	5 – 95%

The power supply's efficiency and the surrounding temperature are just two variables that affect how much power the Antminer S9 consumes [15]. The Antminer S9 is made primarily to mine Bitcoin, which employs the SHA-256 mining algorithm [53]. It cannot be utilised with the algorithms of other cryptocurrencies like Litecoin (LTC) or Ethereum (ETH) [56, 89]. ETH employed the memory-hard Ethash algorithm for its mining process since it was a Proof-of-Work. However, this has now been switched off and moved away from Proof-of-work to Proof-of-Stake [47, 53, 76, 83]. Eth uses the Keccak-256 Algorithm, a hashing algorithm from the SHA-3 family [58, 82].

However, the Antminer S9 was highly efficient when it was first introduced. Still, due to the rapid development of mining technology and the rising cost of mining Bitcoin, it is now less lucrative than more recent and efficient mining equipment [8, 15]. Several variables affect profitability, which includes electricity costs, mining difficulty, and Bitcoin price [4, 11]. Therefore, it is crucial to remember that various cryptocurrencies employ various mining algorithms to preserve the security and reliability of their networks.

The Antminer S19 (Figure 6) has a hash rate of 82 TH/s, weighs 31.3 lbs – 14.2kg and consumes 2829 watts of power, see Table 2 S19 Antminer. The high hash rate of the Antminer S19 makes it capable of mining effectively and powerfully, making it a more efficient mining operation. As such, the improved energy efficiency helps miners save money on power [57, 90]. It uses cutting-edge semiconductor technology and an improved circuit architecture to boost mining performance while consuming less power. The S19 is constructed from high-quality materials and tested extensively to guarantee steady and dependable operation even in harsh mining environments [40].

An intuitive and user-friendly interface on the Antminer S19 makes it simpler for miners to start up and manage their mining operations. It enables miners to maximise their mining performance by giving them access to various mining statistics, settings, and monitoring tools.

Table 2. Specifications of Bitmain Antminer S19

Manufacturer	Bitmain
Model	S19
Release	May 2020
Size	400 x 195.5 x 290 mm
Weight	14.2 kg (31.3 lbs)
Chipboards	3
Chip name	BM1397
Chip size	7 nm
Noise level	75 dB
Cooling Fans	4
Power	3250 W
Hashrate	95TH/s
Voltage	200-240 V
Op Temperature	0 - 40 °C
Humidity	10 – 90%

The Antminer S19+ (Figure 7) produces up to 99 TH/s. The S19+ Antminer weighs 31.2lb / 14.2kg

Figure 6. S19

Figure 7. S19+

and consumes 3250 Watts of power for the 99TH/s batch. Besides the marginal difference in performance, resulting outcomes are similar if not distinct between the S19. Similar in size, shape and performance, both mining machines utilise the BM1397 Chip face, an improved version of its predecessor, the BM1391 chip, offering higher efficiency and better power consumption. It features a minor semiconductor process and optimised circuit architecture, allowing for increased performance and energy efficiency.

Bitmain manufactures the BM1397 chip tailored to work with the Antminer S19 series. It plays a crucial role in the mining capabilities and overall performance of the Antminer S19 miners.

The Antminer S19j Pro (Figure 8) produces 104 TH/s, weighs 29lb - 13.2kg and consumes 3068 Watts of power. Like its predecessors for hash rate, chipset and power capability, the S19j Pro has a user-friendly firmware interface that allows miners to monitor and control their mining operations [36, 57]. It offers real-time status updates, temperature monitoring, power management, and mining pool configuration.

3. Methodology

The methodology aims to comprehensively compare the mining performance and efficiency of various Antminer models, specifically the S9, S19, S19+, and S19j Pro. This comparison encompasses their capabilities, potential profitability, and environmental

Table 3. Specifications of Bitmain Antminer S19+

Manufacturer	Bitmain
Model	S19+
Release	May 2020
Size	400 x 195.5 x 290 mm
Weight	14.2 kg (31.3 lbs)
Chipboards	3
Chip name	BM1397
Chip size	7 nm
Noise level	75 dB
Cooling Fans	4
Power	3250 W
Hashrate	110 TH/s
Voltage	200-240 V
Op Temperature	0 - 40 °C
Humidity	10 – 90%

impacts. This paper presents the comparative results and tangible estimates of mining capabilities and their associated revenue potential. Additionally, the methodology includes an evaluation of the global environmental and agricultural impacts of Bitcoin mining, using metrics such as carbon emissions, energy consumption, and their effects on land and water resources.

To achieve this, we will present the comparative results in Table 5 (Comparison of BTC Mining Machines) and the data in Table 6 (Bitcoin Mining Calculations). These results will provide tangible estimates of mining capabilities and their associated

Figure 8. S19J Pro

Table 4. Specifications of Bitmain Antminer S19J Pro

Release	July 2021
Size	195 x 290 x 370 mm
Weight	13.2kg (29lb)
Chipboards	3
Chip name	BM1397
Chip size	7 nm
Noise level	75 dB
Cooling Fans	2
Power	3068 W
Hashrate	110 TH/s
Voltage	12 V
Interface	Ethernet
Op Temperature	5 - 35 °C
Humidity	5 - 95

revenue potential. This documentation will, in turn, help establish the current use case for employing Bitcoin mining machines.

It is important to note that these assessments are based on available technical specifications and performance data, which may vary depending on the batch or model being analysed. Additionally, our interpretation of the results aims to pinpoint the strengths and weaknesses inherent to each mining machine.

Each mining machine incurs electricity costs in addition to its initial purchase price. Over time, fluctuations in electricity prices can significantly impact mining revenues. Consequently, miners must evaluate their local electricity rates to ensure that mining income can adequately cover these expenses.

The efficiency of mining equipment is also crucial. Compared to earlier models like the S9, ASIC miners from the S19 series provide higher hash rates and improved energy efficiency. Enhanced energy efficiency can increase revenue, potentially offsetting higher electricity costs.

Table 5, Comparison of BTC Mining Machines, details the characteristics of these mining devices and provides additional context regarding the practical use and ongoing viability of Proof of Work (PoW) in the global market.

Table 5. Comparison of BTC Mining Machines

	S9	**S19**	**S19+**	**S19j Pro**
Hashrate (Th/s)	14	95	110	114
Power Consumption (W)	1372	2829	3250	3068
Power Efficiency (j/GH)	0.098	0.029	0.03	0.03
Electricity Cost (kW)	0.92	0.92	0.92	0.92
Pool Fee (%)	1	1	1	1
Release (year)	2017	2020	2020	2021
Size (mm)	135 x 158 x 350	400 x 195 x 290	400 x 195 x 290	195 x 290 x 370
Weight (lb / kg)	9.25 / 4.19	31.3 / 14.2	31.2 / 14.2	29 / 13.2
Noise level (db)	85	75	75	75
Fans	2	4	4	4
Interface	Ethernet	Ethernet	Ethernet	Ethernet
Op Temperature (°C)	0 - 40	5 - 45	5 - 45	5 - 35
Humidity (%)	5 – 95	5 – 95	5 – 95	5 – 95
Cost ($)	599.99	2399.99	2749.99	2649.99

Now that we have consolidated data for the S9, S19, S19+, and S19j Pro models, we can assess their viability within the United Kingdom (UK) using a profitability calculator. Referencing Table 6 for Bitcoin Mining Calculations and Figures 9, 10, 11 and 12 for Reward Estimates, it becomes evident that there is a negative downward trend in daily profitability, indicating their current impracticality within the UK. Several factors contribute to this [33, 35]. One significant factor is the considerably higher cost of electricity in the UK compared to other countries, making it a less attractive market for mining.

Table 6. Bitcoin Mining Calculations

	S9	S19	S19+	S19j Pro
Hashrate (Th/s)	14	95	100	104
Power Consumption (W)	1372	2829	3250	3068
Electricity Cost (kW)	0.37	0.37	0.37	0.37
Profit Per Day ($)	-11.17	-18.27	-21.65	-19.75

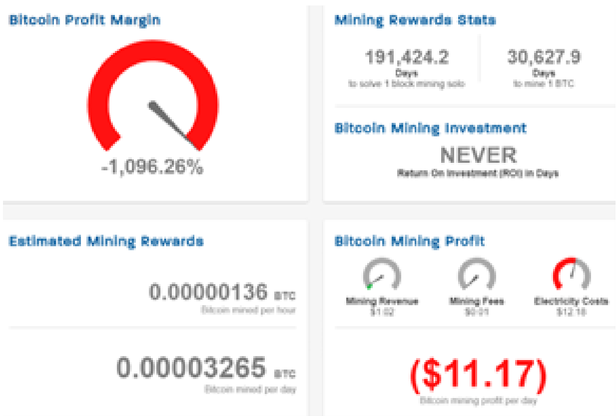

Figure 9. S9

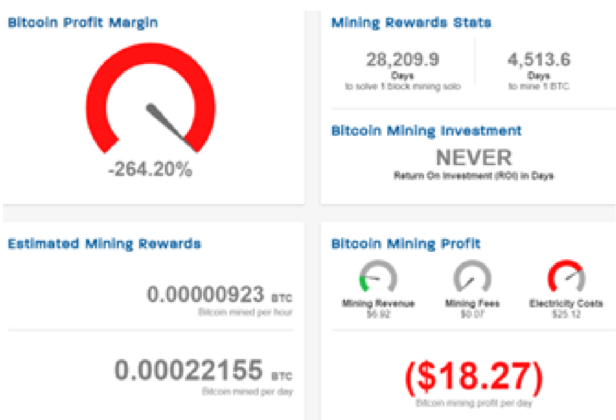

Figure 10. S19

To understand the dynamics further, it is important to recognise that the BTC network difficulty changes periodically to maintain a constant block time [41, 72, 73]. For the same amount of Bitcoin to be mined, more processing power is needed as the network difficulty rises [36]. The profitability may suffer from

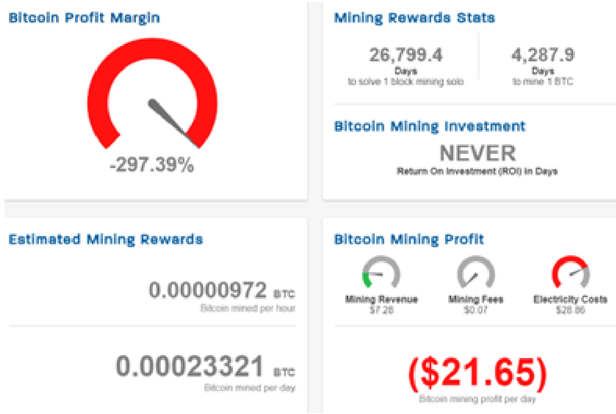

Figure 11. S19+

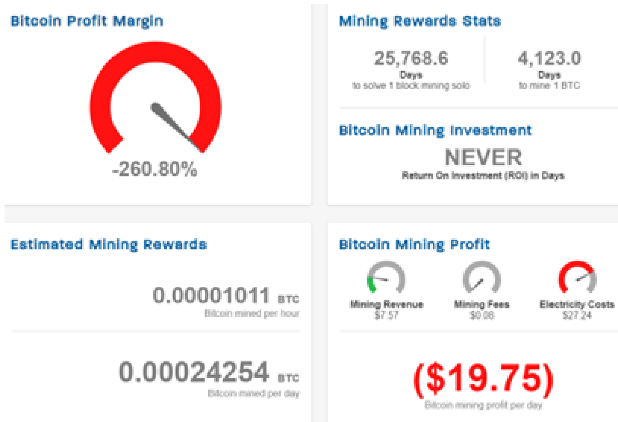

Figure 12. S19J Pro

increased difficulties and exceptionally high electricity prices. Essentially, the Bitcoin blockchain becomes more challenging to mine approximately once every four years due to an event known as the "Bitcoin halving" [12, 29]. The halving is a programmed and essential feature of the Bitcoin protocol that occurs roughly every 210,000 blocks, or approximately every four years [48, 79].

During the Bitcoin halving, the number of new bitcoins created as a reward for mining a block is cut in half [38, 93]. This means miners receive half the bitcoins for each block they successfully mine [90]. When Bitcoin was first created in 2009, the block reward was 50 bitcoins per block [70]. In 2012, it halved to 25 bitcoins per block, then 12.5 bitcoins in 2016, and finally to 6.25 bitcoins in 2020 [70].

Miners mitigate this phenomenon by joining a mining pool; miners can pool their resources and split the benefits according to the hash power they have supplied [57]. Even without free electricity, this can help spread the earnings fairly and increase the likelihood of a steady income.

Remembering that profitability can change over time in the very competitive world of Bitcoin mining is critical. Before investing in mining equipment and operations, it is advised to do extensive research, consider the market's state, and utilise mining profitability calculators to assess prospective earnings and costs [57, 59].

Miners must carefully evaluate the costs, effectiveness, and market circumstances to decide the viability of Bitcoin mining and whether it can provide revenues that outweigh the costs without free electricity. However, the current results in Tables 4, 5 and Figures 8, 9, 10 and 11 provide clear evidence that without the possibility of free electricity, BTC mining, PoW is not a viable option without considerable alternative energy sources [7, 44, 88].

4. Global effects caused by BTC mining – Pollution and Agriculture

The global effects caused by BTC or PoW can be considered catastrophic towards the environment and the plant [18, 55]. However, Bitcoin mining's global effects can be positive and damaging due to its energy-intensive nature and the scale of its operations. Here, we explore two categories: pollution, such as carbon emissions, the energy used for mining that often comes from fossil fuel-based power sources and agriculture, and the destructive nature upon the land, rivers and wildlife. However, BTC mining does not directly affect agriculture because it is code and software [21, 28, 32, 35, 55]. Instead, the environmental impact of Bitcoin mining, particularly its energy consumption and associated carbon emissions, can indirectly affect agriculture, such as land use and water resources.

4.1. Pollution

The environmental effects of Bitcoin mining, sometimes known as "Bitcoin pollution" or "Bitcoin's carbon footprint", have drawn much attention from the cryptocurrency community and other quarters [66, 91]. Due to the PoW consensus mechanism employed in the Bitcoin network, the main environmental problem with Bitcoin mining is its energy usage [55, 94].

Numerous Bitcoin mining facilities are situated in areas where coal, natural gas, and oil are the primary sources of energy generation [19, 45]. The high reliance on non-renewable energy sources is a factor in air pollution and carbon emissions [32, 33].

Bitcoin has a high carbon footprint due to the energy-intensive nature of mining and its reliance on fossil fuels. According to studies, Bitcoin produces a significant amount of carbon emissions and consumes energy on par with several small nations; see Figure 13, Bitcoin Mining Map [71, 74].

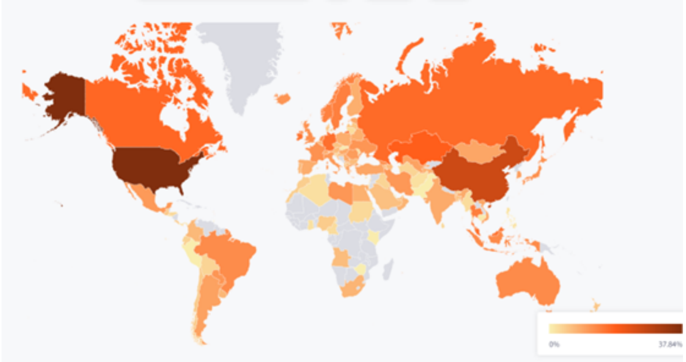

Figure 13. Bitcoin Mining Map

The Bitcoin Mining Map is based on the geolocational mining pool data, an average monthly hash rate share by country and region for the chosen period with continuous daily updates that reflect the current bitcoin mining trend [74].

The key takeaway is the 0.10% of the global emission bitcoin mining causes [74]. As seen in Figure 14, Total Greenhouse Gas (GHG) emissions. According to the University of Cambridge, Figure 14, the total GHG uses the most accurate estimate available; the daily statistics for the specified era are added to determine the total annual GHG emissions. Since the model's creation, the daily numbers have been gathered to establish the cumulative consumption, which is millions of tonnes of carbon dioxide equivalent (MtCO2e) are used to measure GHG emissions [71].

The University of Cambridge frequently mentions estimates that place the global emissions of greenhouse gases at 48.35 MtCO2e, or around 0.10%, which is equivalent to emissions from nations like Nepal (48.37 MtCO2e) and the Central African Republic (46.58 MtCO2e) [71]. Alternately, it is almost equal to the emissions of mining gold (100.4 MtCO2e) [25, 46, 87].

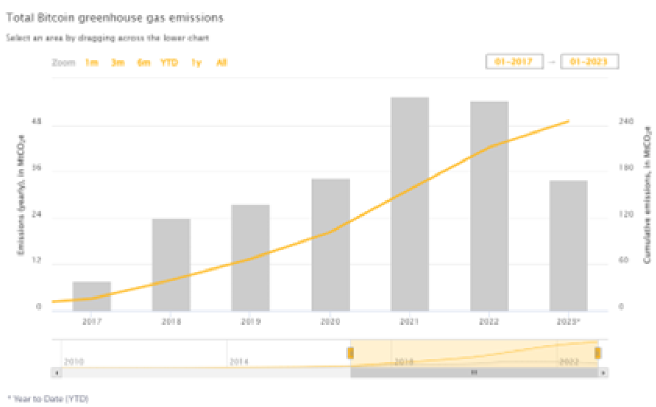

Figure 14. Total GHG emissions

Additionally, producing specialised hardware used in BTC mining machines requires extracting natural resources and using energy, contributing to environmental degradation [23, 46]. Therefore, it should be noted that other forms of pollution are indirectly caused by BTC mining, such as electrical waste (E-waste) [18, 52]. As the technology is used, BTC mining machines become outdated or obsolete; these machines are often discarded and may end up in landfills, where they can release toxic chemicals and contribute to E-waste pollution [18].

To address these concerns, certain miners have turned to renewable energy sources such as hydro, solar, and wind power to mitigate the environmental impact of their operations. Simultaneously, some manufacturers are dedicated to designing and producing more energy-efficient mining equipment [57, 58, 76, 82]. Nevertheless, the intricacies surrounding BTC mining and its environmental ramifications remain complex issues that necessitate ongoing attention and concerted efforts from the industry and governments.

Pollution and Agricultural Impacts

4.2. Agriculture

The rapid growth of Bitcoin mining operations has raised concerns about its environmental and agricultural impact. As briefly mentioned in 4.1 Pollution, the agriculture damage is detrimental [33, 46, 52, 55]. The following section delves into the effects of Bitcoin mining on agriculture, focusing on pollution (air, water, and soil) and the agricultural damage caused by building Bitcoin mining farms on green and brown belt land. Additionally, the following sections explore potential mitigation strategies to ensure a more sustainable coexistence between cryptocurrency mining and agriculture.

4.3. Air Pollution

A significant issue linked to Bitcoin mining revolves around its considerable energy consumption, predominantly sourced from fossil fuels [19]. Burning these fuels releases detrimental pollutants into the atmosphere, resulting in the deterioration of air quality [33]. These emissions encompass particulate matter, sulfur dioxide, nitrogen oxides, and volatile organic compounds, which can directly affect neighbouring agricultural regions [55, 66]. Airborne pollutants have the potential to settle on crops, leading to reduced crop yields and compromised quality [18]. Additionally, air pollution may disrupt pollinator populations, subsequently impacting crop pollination and fruit production [21].

4.4. Water Pollution

Bitcoin mining operations require substantial water for cooling and energy generation [13]. In regions with already stressed water resources, increased demand from mining activities can exacerbate water scarcity issues [21, 91]. Moreover, improper disposal of mining byproducts, such as chemicals used in cooling systems, can contaminate local water sources [28, 55]. Agricultural irrigation using polluted water can lead to soil desalinisation, reduced plant growth, and compromised crop health [18].

4.5. Soil Pollution

Disposing of electronic waste from outdated mining hardware can contribute to soil pollution [18, 21]. Heavy metals and hazardous substances contained in these components can leach into the soil, posing a threat to agricultural productivity and food safety [21, 91]. Contaminated soil may hinder plant nutrient absorption, disrupt soil microbial communities, and ultimately impact crop growth [28].

Agricultural Damage: Green and Brown Belt Land

4.6. Green Belt Land

In popular literature, Bitcoin mining operations often require vast amounts of space, leading to converting green belt land – areas designated to prevent urban sprawl and promote agriculture – into mining farms [52]. Losing arable land can disrupt local food production, reducing self-sufficiency and increasing reliance on external sources [43]. If this is true, deforestation for mining infrastructure can further fragment habitats, affecting biodiversity and ecosystem services essential for sustainable agriculture [43]. However, there is little to no evidence in the UK that Greenbelt land is being used for Bitcoin mining.

4.7. Brown Belt Land

Mining farms frequently target brown belt land, which consists of previously developed or industrial areas. While repurposing these sites may seem environmentally beneficial, it can lead to conflicts with urban agriculture initiatives [43]. Urban farming projects that aim to provide fresh produce to local communities may be displaced, undermining efforts to enhance food security in urban settings [37, 78, 92].

Mitigation Strategies and Opportunities

1. Renewable Energy Integration: Encouraging Bitcoin mining operations to transition to renewable energy sources can significantly reduce their environmental footprint. Utilising solar, wind, or hydroelectric power for mining farms can mitigate air pollution and decrease carbon emissions, positively impacting agriculture and the environment [6, 55, 94].

2. Site Selection and Design: Implementing stricter regulations on the location and design of mining farms can prevent the conversion of valuable agricultural land [3, 4]. Zoning laws prioritising agricultural preservation and limiting mining expansion in critical areas can help maintain local food production [30, 91].

3. Collaborative Initiatives: Collaboration between the cryptocurrency industry and agricultural stakeholders can foster innovative solutions. For instance, excess heat generated by mining rigs could be repurposed for greenhouse heating, promoting year-round cultivation and reducing energy waste [18, 22, 59, 84].

5. Discussion

The findings from the comparative analysis of Bitcoin mining machines have significant implications for industry stakeholders and policymakers. The performance metrics of different mining models highlight the trade-offs between energy efficiency and operational costs, informing decisions on hardware investments. Moreover, the environmental impact assessment underscores the urgent need for sustainable mining practices. The proposed mitigation strategies, including adopting renewable energy sources and strategic site selection, are critical for minimising the ecological footprint of Bitcoin mining. Collaborative initiatives between the cryptocurrency industry and agricultural stakeholders can enhance sustainability, promoting a balanced approach to technological advancement and environmental stewardship.

Furthermore, the surge in Bitcoin mining operations has brought concerns regarding its multifaceted impact on agriculture, covering pollution, land utilisation, sustainability, and energy consumption [16, 78, 92]. This discussion delves into these interconnected aspects and addresses the electricity cost and expenditure associated with specific Bitcoin mining machines, including the S9, S19, S19+, and S19J Pro.

5.1. Pollution and Environmental Stress

Bitcoin mining's substantial energy demand is a critical driver of pollution, with its reliance on energy sources often tied to emissions and environmental degradation [55, 67]. Fossil fuel-powered energy generation for mining operations contributes to air pollution, releasing pollutants that adversely affect agricultural productivity. These emissions also have broader implications for climate change, leading to altered weather patterns and potentially impacting crop yields [67].

Water pollution is another concern due to mining's significant water requirements, which might exacerbate water stress in areas with limited resources [24, 61]. Additionally, the improper disposal of electronic waste from outdated mining hardware poses risks to aquatic ecosystems and water sources vital for irrigation, potentially contaminating soil and damaging crops [5, 18, 85].

5.2. Land Use and Agricultural Disruption

Establishing Bitcoin mining farms can impinge on agricultural land, including green and brown belt areas crucial for food production [37, 62]. The conversion of these lands for mining activities can have cascading effects, displacing agricultural activities and undermining local food supply chains [43]. Furthermore, the physical infrastructure required for mining farms can disrupt soil structure and drainage systems, affecting adjacent agricultural areas.

5.3. Sustainability and Mitigation Strategies

Sustainability concerns are prompting efforts to align Bitcoin mining with more environmentally conscious practices. One avenue is adopting renewable energy sources, such as solar or wind power, to power mining operations [55, 94]. This shift can help reduce greenhouse gas emissions and the associated air pollution [18, 33, 35].

Strategic location planning for mining farms is another facet of sustainability. By choosing sites that do not encroach on agricultural lands, the conflict between mining and agriculture can be mitigated, preserving valuable resources for food production [78, 92].

Given the toxic components in mining hardware, responsible electronic waste management efforts are essential [18]. Proper recycling and disposal can help prevent soil and water contamination [5, 85].

5.4. Energy Consumption and Cost Dynamics

The energy cost of Bitcoin mining plays a pivotal role in its environmental impact. The mining process involves solving complex mathematical puzzles, a task requiring immense computational power [71, 74, 81]. Bitcoin mining machines, such as the S9, S19, S19+, and S19J Pro, vary in their energy efficiency and computational capacity. The S9, an earlier model, is less energy-efficient than the more advanced S19 series [16, 36, 40, 57].

The S19 series, including the S19+, and S19J Pro, exhibit improved energy efficiency, with higher hash rates and better performance than their predecessors [36, 40, 57]. This efficiency is crucial as it directly influences the electricity expenditure and the subsequent carbon footprint of the mining operation.

6. Conclusion and Future Work

In conclusion, this paper comprehensively analyses Bitcoin mining machines, their environmental impacts, and their implications for agriculture. The comparative review of mining hardware reveals critical insights into their efficiency and profitability. The environmental and agricultural assessments highlight the substantial impacts of mining activities, emphasising the significant need for sustainable practices. The proposed mitigation strategies offer practical solutions to reduce these impacts. Future research should focus on refining these strategies and exploring innovative approaches to enhance the sustainability of Bitcoin mining.

Energy consumption is one of the main issues with BTC mining. The mining process consumes a considerable amount of electricity. This can negatively yet significantly impact the environment by producing large amounts of GHG in areas where fossil fuels are the primary energy source. To reduce the environmental impact of mining operations, it is crucial to research and promote sustainable energy alternatives such as renewable energy sources.

The energy-intensive nature of BTC mining has also sparked concerns about how it may affect global energy consumption and sustainability objectives. This issue necessitates cooperation between industry players, legislators, and environmental specialists to balance Bitcoin technology's innovation and advantages and its environmental influence.

Concerns about centralisation within the Bitcoin network can also arise from the concentration of mining power utilising specialised hardware in specific regions, such as the United States and China. The network's long-term security and stability depend on initiatives to uphold decentralisation and encourage greater mining involvement.

Additionally, there are other economic effects of Bitcoin mining. On the one hand, it can promote economic development and job prospects in specific regions. Conversely, it might result in more rivalry for resources, especially energy, affecting regional economies and agricultural sectors.

Finding sustainable solutions that reduce the environmental impact of Bitcoin mining, support decentralisation, and consider socioeconomic considerations will ultimately determine the industry's future. As technology develops and knowledge of environmental issues rises the cryptocurrency community and governments must collaborate to create a more sustainable and just future for Bitcoin mining.

Declaration of Interests

The authors confirm there is no conflict of interest for this research paper.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data is available in this paper.

6.1. Copyright

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