Review

Bitcoin's Carbon Footprint Revisited: Proof of Work Mining for Renewable Energy Expansion – Supporting Information

Abstract: This supporting information file contains grey literature and other media consulted for the article referenced in the title.

1. Introduction

In this section, grey literature is used to support the fact that some of the limited studies estimating Bitcoin's carbon footprint were not scientific articles (Coinshares 2022).

2. Background and Context

In this section, grey literature supports claims of slower cryptocurrency market penetration and even increased price volatility as a result of Bitcoin's public relations issues related to energy (Buckland and John 2021). It also supports indications of miners locating in parts of China, retrofitting of natural gas power plants are retrofitted for mining in the US and Canada (Coinshares 2022). It also supports the statement that there exists criticism against Bitcoin because it is argued to reduce green energy availability for other purposes (Amir 2021).

Notably, this section introduces a letter submitted to the White House Office of Science And Technology in response to a Request for Information, which casts significant doubt onto the reliance of Bitcoin on carbon-intensive energy sources (Paez and Cross 2022). One of the main sources about Bitcoin's energy consumption, the Cambridge Center for Alternative Finance, is used to support the fact that the China ban on Bitcoin has led to miners to move outside the United States (CCAF 2022). Grey literature is also used to illustrate the case of Kazakhstan (Batten 2023).

3. Bitcoin's Environmental Impact

Another response to the White House OSTP, by Global Digital Finance (GDF), is used to support the fact that Bitcoin's energy consumption and Scope 2 carbon intensity is undeniably high compared to systems like PoS (GDF 2022).

The highly-referenced site Digiconomist was consulted as the prime example of a "top-down" approach, estimating the share of miners' revenue spent on electricity (De Vries 2014). Similarly, a report by the Bitcoin Mining Council is used as a prime example of calculating the carbon intensity based on the grid mix corresponding to mining pools' IP addresses, or based on first-hand data from the miners (BMC 2022).

De Vries' index is consulted as a prime example of portraying Bitcoin's environmental impact in comparison to countries and as a share of global electricity consumption (Vries 2022). Industry reports are used to illustrate examples of comparing to industries instead (Coinshares 2022; Komando 2012; Navigant Consulting Inc 2008) and of using denominators of global CO2 and GHG emissions (Coinshares 2022).

For Table 1, grey literature provided an example of considering the entire history of past transactions as secured with every new mining event, and not just the coinage of the latest coin (Imran 2018). De Vries' index is used as an example of an index used to imply that Bitcoin's throughput can only grow at the cost of more energy consumption (Vries 2022), and grey literature provided examples of criticism of this and of the focus on value delivered per kWh (Paez and Cross 2022; Imran 2018).

Troy Cross' milestone interview in What Bitcoin Did also provided an example of different carbon accounting schools, as it brought these debates into the public knowledge (WBD 2022).

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Paez and Cross' RFI response provided an example of the claim that mining emissions will peak at 1% of global emissions at worst (Paez and Cross 2022).

Grey literature supported the existence of debates on Bitcoin's e-waste (Paez and Cross 2022; Coinshares 2022; Saylor, Carter, and Feinstein 2022), noise pollution (Nguyen Anh Hoang and Säteri 2018; Voell 2022) and intrinsic value (Paez and Cross 2022; Coinshares 2022).

4. Bitcoin Mining and RE

4.1. Limitations of RE

Another RFI response supported an industry perspective that renewable energy sources face a challenge of intermittency (Soluna Computing 2022). Other grey literature supported descriptions of the duck curve and other imbalances in energy grids (Quirk and Stabinski 2021; Paez and Cross 2022; BCEI 2021).

In Table 2, industry reports and other grey literature also supported descriptions of the buildout of transmission lines as a way to balance electricity markets and their limitations (BCEI 2021; Coinshares 2022), of the need to subsidize capacity expansion(Quirk and Stabinski 2021; BCEI 2021), of the problems of curtailment (Paez and Cross 2022; Soluna Computing 2022), of usage of batteries to mitigate imbalances (BCEI 2021), and of power-to-X solutions (KCE 2016; BCEI 2021; Paez and Cross 2022). They also supported descriptions of technical and regulatory connection queues (BCEI 2021; Rand et al. 2021; Paez and Cross 2022).

4.2. Distinctive Characteristics of PoW Mining

Industry sources also supported descriptions of the unique characteristics of Bitcoin mining (Rhodes, Deetjen, and Smith 2021; Paez and Cross 2022; BCEI 2021), including:

1. Extended time horizons (BCEI 2021; Paez and Cross 2022)
2. High interruptibility (Paez and Cross 2022; BCEI 2021) and its limitations (Freier and Ibañez 2023)
3. Bitcoin mining portability (BCEI 2021; Paez and Cross 2022; Quirk and Stabinski 2021; Imran 2018; Menati, Lee, and Xie 2022; Walton 2022; Cohn 2019; King 2022; Amir 2021)
4. Price sensitivity (Gronowska 2021; Paez and Cross 2022)
5. Scale agnosticity (Paez and Cross 2022)
6. Non-rival energy consumption (Soluna Computing 2022; Quirk and Stabinski 2021)
7. Waste heat reutilization (Nguyen Anh Hoang and Säteri 2018; Enachescu 2019; Paez and Cross 2022; Quirk and Stabinski 2021; Gronowska 2021)

4.3. Applications

Industry reports and other grey literature was also instrumental in identifying applications of Bitcoin mining with hydroelectric power (BCEI 2021), with renewable energy (King 2022; Winton, Elmandjra, and Korus 2021; ARKInvest 2021), and with waste methane (Quirk and Stabinski 2021; Carter and Stevens 2021; WB 2022). Especially relevant is the claim of Coinshares (Coinshares 2022) that carbon emissions from flare mining are already negative and equivalent to 5% of Bitcoin's global positive emissions at present.

Industry literature also pointed to the problem of negative prices with nuclear energy (Howard and Galabov 2022) and to how competition in the Bitcoin mining sector may generate positive externalities (Imran 2018).

4.4. Business Models

Industry sources pointed to business models with Bitcoin mining such as buyer of last resort (BCEI 2021), FTM and BTM mining (BCEI 2021; King 2022; Paez 2021), price-responsive mining (WB 2021). Troy Cross' milestone work on incentive offsets was also an important inspiration, as well as related industry sources (Cross and Bailey 2021; Coinshares 2022; WBD 2022; Johnson and Pingali 2021; Soluna Computing 2022; Ghaebi Panah et al. 2022).

5. Potential Impact of Mining

Numerous industry resources highlighted a possible positive effect of Bitcoin mining on renewable penetration and energy grid management (Cross and Bailey 2021; WBD 2022; Paez and Cross 2022; BCEI 2021). Certain statements stood out, such as the location of mining facilities near congested nodes (BCEI 2021; King 2022), increases in load flexibility (GCGET and Van de Graaf 2019; BCEI 2021; Paez and Cross 2022), Bitcoin as an "apex predator" of energy (Perrenod 2022) and as a tool to find a global market price for carbon (Imran 2018).

6. Challenging Trends

Industry sources were instrumental to highlighting the problem of unexpected hash rate increases (Sarkar 2022; Freier and Ibañez 2023; Frumkin 2021), supply chain disruptions (Perez 2022; Redman 2022; Frumkin 2021), the risk of regulatory intervention (Paez 2021; Coinshares 2022) and the problems with high marginal emissions (BCEI 2021; Dance 2023).

7. Challenger Technologies: Alternative Load Resources

Table 4 profited from industry sources highlighting how water desalination (BCEI 2021; Gasson 2020; L39 2022; Pearson 2018), green hydrogen and synthetic methane (BCEI 2021; Quirk and Stabinski 2021; Decker 2021; Liebreich 2020a; Liebreich 2022; Liebreich 2020b; Gupta 2021), CO2 removal (BCEI 2021), batteries (BCEI 2021; Winton, Elmandjra, and Korus 2021; Frumkin 2021; ARKInvest 2021; Paez and Cross 2022), and other flexible data centers (Radovanovic 2020; Google 2018) compare against Bitcoin mining as a flexible load resource.

8. Empirical Support for Sinergies between Bitcoin and RE

Some industry reports also provided information on specific cases of Bitcoin for remediation of ash landfills (Spence and Beard 2022)

9. Discussion and Critical Analysis

9.1. Intermittency, Profitability and Increasing Fierceness of Competition

Some grey literature had already highlighted the potential of Bitcoin to provide additional revenue to renewable energy producers (BCEI 2021), the trend of the mining market toward perfect competition (Cross and Bailey 2021; Perez 2022; McCook 2022; Öysti 2021; Braiins 2021).

9.2. Bitcoin's Potential: A Balanced Perspective

Industry sources had already highlighted the tendency of miners to go towards cheap energy sources. Notably, Imran (Imran 2018, p. 12) expects miners to act in an arbitrageur manner, first targeting "areas of energy surplus such as China, Canada, Norway [and] Iceland" and later moving into the renewable sector, looking for near-zero or even negative costs.

10. Limitations and Future Work

The point that regulatory interventions could drive miners driving miners to jurisdictions with fossil fuel subsidies, which could increase emissions had already been raised by CoinShares (Coinshares 2022, p. 18).

11. Conclusion

No grey literature was consulted in this section.

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