

Journal of Scientech Research and Development Volume 6, Issue 1, June 2024 P-ISSN 2715-6974

E-ISSN 2715-5846

Open Access at: https://idm.or.id/JSCR/index.php/JSCR

ENVIRONMENTAL IMPACT OF CRYPTOCURRENCY MINING: SUSTAINABILITY CHALLENGES AND SOLUTIONS

Hugo Prasetyo Winotoatmojo¹, Samuel Yesua Lazuardy², Fabian Arland³, Antonius Ary Setyawan⁴

^{1,2,3}Finance Program, Accounting Department, School of Accounting, Bina Nusantara University, Jakarta 11480, Indonesia
⁴Information System, Sekolah Tinggi Ilmu Komputer Yos Sudarso Purwokerto, Purwokerto, Jawa Tengah, 53144, Indonesia
Email: <u>hugo.prasetyo@binus.ac.id</u>

ARTICLE INFO

ABSTRACT

Keywords:

Cryptocurrency, Crypto Mining, Environmental Impact, Sustainability, Solution. The rapid growth of cryptocurrencies over the past 14 years has led to increased deep-level mining activities. This research aims to explore the environmental impacts resulting from the surge in crypto mining and proposed solutions to mitigate these impacts. Cryptocurrencies, gaining popularity as alternative investments and global payment tools, have significantly boosted crypto mining activities. However, the increasing number of transactions requiring computer validation has resulted in adverse consequences for the environment, particularly in terms of substantial energy consumption. Literature review and systematic analysis were conducted to comprehend the environmental impact of crypto mining, focusing on major cryptocurrencies such as Bitcoin, Ethereum, and others. The analysis highlights that crypto mining, especially Bitcoin, requires a significant amount of electricity, leading to a substantial carbon footprint and broad environmental repercussions. Proposed solutions to address the environmental impact of crypto mining include the use of renewable energy sources such as solar and wind power, enhancing the efficiency of specialized mining devices (ASICs), and exploring more energy-efficient consensus mechanisms like Proof of Stake (PoS) compared to the currently utilized Proof of Work (PoW). Reducing redundancy in blockchain technology has also been identified as a crucial step in minimizing unnecessary energy consumption. However, this research has limitations concerning data consistency, a comprehensive understanding of overall environmental impacts, and continuous technological changes in the crypto world. Therefore, future research should focus on developing more efficient consensus mechanisms, effective policy frameworks and governance, as well as real-world implementation studies to evaluate the sustainability solutions proposed.

Copyright © 2024 JSR. All rights reserved.

INTRODUCTION

Cryptocurrency has had an immense growth over the past 14 years. Especially with the COVID-19 outbreak which led to the application of online payments worldwide (Goel & Mittal, 2020). With the pandemic outbreak happening all over the world, people who lost their job sought into another option to gain earnings without the needs of having lots of base capital to start with and without the needs to go outside. Combined with the potential people see in cryptocurrency being an online currency that can be used worldwide, people began investing in it. Thus how cryptocurrency could earn the value of \$230 billion in total worldwide (Panda, 2020)

Cryptocurrency itself was first introduced in 2009 as a virtual currency named bitcoin created by Satoshi Nakamoto. Where it first was priced at a flat \$0.1, contrary to the present where they are valued at \$16,605 US at the start of 2023. This value is contracted by the number of supply and demand of the cryptocurrency. Whereas the more people demand by buying, the higher the value becomes.

With the rise in cryptocurrency, more people started to look upon cryptocurrency, the potential within cryptocurrency, the needs to adapt, and the risks that come alongside the rise. As a virtual currency that is traded online, people started to identify the risks of cryptocurrency, including its damages to the environment. Trading cryptocurrency requires a substantial electricity to power computers that are needed to validate the transactions done (Erdogan et al., 2022) The energy needed for this, could then pose an impact as a new source in contributing to the global environmental problem that is global warming. The emergence of this problem would then led to people searching for a solution to mitigate or even counter, the environmental risks of cryptocurrency.

Within this paper, we will discuss the environmental impact posed by the rise of cryptocurrency mining and the solution proposed to mitigate the impact.

The article "Analyzing asymmetric effects of cryptocurrency demand on environmental sustainability" examines the causal effect of cryptocurrency by examining three cryptocurrencies that is Bitcoin, Ethereum, and XRP on environmental degradation. The test was employed using a standard and asymmetric causality methods. The results from this examination is that there are both symmetric and asymmetric causal effect between cryptocurrency on environmental degradation. Where the growth of cryptocurrency mining and transactions effects environmental degradation as can be seen with Bitcoin's growth (Erdogan et al., 2022).

"Impact of Bitcoin mining and crypto market determinants on Bitcoin-based energy consumption" This study explores how Bitcoin's energy use is influenced by factors like Crypto Index and Ethereum prices. It looks at data from December 2018 to January 2023 to see how changes in these factors affect the electricity used and carbon emissions produced by Bitcoin mining and trading. The findings show that when the Crypto Index and Ethereum prices go up, Bitcoin's energy consumption and carbon

emissions also increase. This suggests that some environmentally conscious investors might start favoring cryptocurrencies that use different methods, not like Bitcoin's energy-intensive approach. The study proposes that Ethereum could be seen as an alternative to Bitcoin because they seem to have a relationship in the long term. This research gives ideas for investors who care about the environment and policymakers to lessen Bitcoin's impact on nature due to its huge energy use. It also highlights the need to explore other ways of managing cryptocurrencies that are less harmful to the environment than Bitcoin's current method (Sapra & Shaikh, 2023).

METHOD

This paper uses systematic literature review to analyze and synthesize the outcome of the analysis. Systematic literature review is a method of research done by gathering relevant literatures, reviewing them, and then coming out with a summary based on the analysis or providing new theory (Xiao & Watson, 2019). The paper used for the review includes a minimum of 10 papers from a well-known publisher, that is Scopus, with the keywords of cryptocurrency, sustainability, and environment. Papers selected are the ones from the last 5 years and have relevance to the relation between cryptocurrency and environment.

LITERATURE REVIEW

Cryptocurrency

Cryptocurrency (crypto for short) is a form of digital currency, which is protected by encryption algorithms (cryptography). A digital currency means that it is only available electronically, unlike regular currencies of any country in the world which has a physical form (cash). Some examples of cryptocurrency available today are Bitcoin, Ethereum, XRP, Polygon, and etc. Cryptocurrency uses a decentralized system of recording and verifying transactions. This means that every transaction using crypto are not managed or insured by central banks or any other third party (Watorek et al., 2021). Instead, it is regulated using blockchain, a decentralized digital system that "keeps an eye" on every transaction made on the Blockchain itself. Blockchain works for example, there's a person who wants to send crypto or any other digital assets to a recipient. The blockchain detects this request for transaction and represents that single transaction as a block. That block will then be announced to every computer present in the network, and they will approve the transaction. After it is approved, the block will then be recorded in the chain (database) and is considered as valid. This chain is transparent, so anyone can see the transaction records. However, no one can tamper it because messages (transaction) sent are encrypted by cryptography which is impossible to hack through. Finally, the block is received by the recipient. This shows how secure and open the blockchain technology is (Wu et al., 2021)

These digital currencies are stored online too. They are stored in what's called as a digital wallet. There are a lot of variety where one can store their crypto: web-based, desktop, mobile, or other hardware specialized to store crypto. Even though the method of transaction has top tier security, the wallets aren't. It might even be the weakest link in the whole crypto system, as it is still prone to hackers if not chosen wisely. Just like a regular wallet, if someone manages to get a hold of a person's digital wallet, then all of its contents are no longer protected and can be stolen. So, it is important to always pick the most trustworthy digital wallet application when using your own computer as your wallet.

One of the biggest drawbacks that can be found in cryptocurrencies is that not all type of crypto can be converted into fiat currencies such as USD or Euros. Only some countries and companies in the world can directly accept crypto as a method of payment. For example, only a few large companies like Microsoft, Starbucks, and AT&T accept Bitcoin as payment.

Cryptocurrency Mining

Cryptocurrency mining is a process in which the transactions of cryptocurrencies are verified and added to the blockchain (Li et al., 2019) Mining is also a way for new cryptocurrencies to be added. Considering that mining is a process that verifies cryptocurrency transactions, mining is central for cryptocurrencies' security. Where different from banks and country currency where people have to trust other organizations, cryptocurrency investor puts their trust in technology.

Cryptocurrency mining is done by miners. These miners will update the transactions on the digital ledger to prevent double spending of the digital currency. By being responsible for preventing double-spending, miners will be rewarded with new coins. To ensure the miners are credible, a proof-of-work (PoW) consensus protocol will be put into place.

RESULTS AND DISCUSSION

Environmental Impact

Cryptocurrency is defined as a peer-to-peer version of electronic cash, enabling online payments to be sent directly from one party to another without going through financial institutions. (Badea & Mungiu-Pupazan, 2021), Due to its electronic nature, the cryptocurrency undoubtedly involves use of substantial energy consumption.(Kumari et al., 2024) Bitcoin mining started growing, raising concerns about CO2 and natural gas emissions resulting from its exploitation. The estimated energy consumption for a single Bitcoin transaction is over 600 kilowatt-hours (KWh), equivalent to more than 300,000 contactless payment transactions or the power consumption of an average household for over 22 days (Yousaf et al., 2024).

The current hybrid PoW and PoW/PoS schemes are utilized for Bitcoin mining. All calculations within these schemes, including Bitcoin mining processes and system maintenance, involve energy-intensive electronic devices. The high computational power required by the Bitcoin network initially involved CPU and GPU usage (2009-2011), followed by FPGA (2011-2013), and then transitioning to ASICs (since 2013) (Alfian, 2022).

Bitcoin mining operates in 58 countries, with a majority of miners operating in the United States. The U.S., with 37.84%, holds the most energy-intensive Bitcoin mining activity globally. However, the environmental impact of this technology transcends beyond the borders of the U.S. During the 2020-2021 period, the global Bitcoin mining network consumed 173.42 Terawatt-hours of electricity. This implies that if Bitcoin were a country, its energy consumption would rank it 27th globally, surpassing countries like Pakistan, with a population of over 230 million people. The resulting carbon footprint is equivalent to burning 84 billion pounds of coal or running 190 natural gas power plants (Chamanara et al., 2023).

During this period, Bitcoin's water footprint was comparable to the amount of water required to fill over 660,000 Olympic-sized swimming pools, sufficient to meet the current domestic water needs for over 300 million people in rural sub-Saharan Africa. The land footprint from global Bitcoin mining activities during this period was 1.4 times the size of Los Angeles.

UN scientists reported that Bitcoin mining heavily relies on fossil energy sources, with coal contributing 45% to Bitcoin's energy supply mix, followed by natural gas (21%). Hydropower, a renewable energy source with significant water and environmental impacts, is the most significant renewable energy source for the Bitcoin mining network, fulfilling 16% of its electricity demand. Nuclear energy accounts for a substantial 9% share in Bitcoin's energy supply mix, while renewables like solar and wind only provide 2% and 5%, respectively, of the total electricity used by Bitcoin.

Among all cryptocurrencies, Bitcoin consumes the most energy. Bitcoin uses about 2/3 of the total energy consumption used by all studied cryptocurrencies. Meanwhile, lesser-studied cryptocurrencies contribute around 1/3 of the remaining energy needs. Thus, these lesser-studied cryptocurrencies add about 50% to Bitcoin's energy requirements, which already cause considerable environmental damage (Gallersdörfer et al., 2020).

The sustainability index of countries in cryptocurrency mining activities ranks Denmark at the top with a score of 87, followed by Germany (82.3) and Sweden (78.3). On the other end of the spectrum, countries like Bolivia (9.3), Suriname (9.4), and Libya (10.0) rank lowest in cryptocurrency mining sustainability (Náñez Alonso et al., 2021).

Solutions

Renewable energy

Several studies indicate that utilizing renewable energy sources such as solar and wind power can reduce CO2 emissions from crypto mining. These studies advocate for a shift from fossil fuels to more environmentally friendly energy sources, implementing sustainable production processes, embracing green trading, enhancing education, and raising awareness about environmental issues.

When considering crypto mining locations, legal aspects, sustainability, and the cost of electricity supply are key factors. Research suggests that wind and solar energy are the best choices for operating blockchain networks.

Therefore, it's suggested that countries with high levels of crypto mining allocate investment in renewable energy. This step is expected to mitigate the environmental impact caused by high energy consumption in PoW crypto systems. (Gallersdörfer et al., 2020)

Mining device choice

The process of Bitcoin mining involves utilizing high computational power to solve complex mathematical algorithms. This process is also known as "Proof-of-Work." (Zhang et al., 2023). In the Proof of Work (PoW) system, the importance of employing efficient devices is crucial in reducing energy costs. If PoW is maintained, the use of specialized devices like ASICs (Application-Specific Integrated Circuits) becomes highly necessary. According to data from, devices based on ASICs consume the least energy per hash and boast the highest computational power, achieving a hash rate of up to 40,000 GH/s at a rate of 0.05 J/GH. In the Proof of Work (PoW) system, the importance of employing efficient devices is crucial in reducing energy costs. If PoW is maintained, the use of specialized devices like ASICs (Application-Specific Integrated Circuits) becomes highly necessary. According to data from a source, devices based on ASICs consume the least energy per hash and boast the highest computational power, achieving a hash rate of up to 40,000 GH/s at a rate of 0.05 J/GH. Research has shown that utilizing ASIC-based devices, as implemented in facilities like KnCMiner in Boden, Sweden, could significantly reduce global mining energy consumption to 1.46 TWh.

Consensus mechanism

The most significant issue with cryptocurrency energy consumption lies in the consensus mechanisms used, particularly in cryptocurrencies employing Proof of Work (PoW). One feasible option to reduce energy consumption involves exploring alternative consensus mechanisms more energy-efficient than PoW.

A promising alternative to PoW is the Proof of Stake (PoS) consensus mechanism, initially utilized in Peercoin as an energy-saving alternative. It is also proposed in Ethereum 2.0. In PoS, proof originates from staking, the miner's contribution to the

blockchain, rather than computational power. This eliminates the computational race involved in PoW, thereby reducing energy consumption and CO2 emissions during the mining process.

Proof of Activity (PoA) extends PoW by using PoS, reducing network communication and storage requirements without compromising security. Another energy-efficient consensus mechanism is Proof of Burn (PoB), where miners reach consensus by 'burning' coins and removing them from circulation.

Additionally, consensus mechanisms like Hash graph in Hedera, efficient ecologically due to their gossip protocol, and Probabilistic Consensus (FPC) in IOTA, an efficient and secure binary voting protocol, exist. Similarly, XRP Consensus, based on trust, doesn't require high computational power and consumes significantly less energy than PoW. (Zhang et al., 2023)

Several storage-based consensus mechanisms have been proposed, such as Proof of Rretrievability (PoR), Proof of SpaceTime (PoST), and Proof of Space (PoSpace). PoST and PoSpace utilize minimal computational power and can operate on computers with disk space and free internet connectivity.

There are also recommendations to adopt Proof of Useful Work (uPoW) and Resource Efficient Mining (REM) utilizing trusted hardware like Intel SGX. These mechanisms transform unproductive work in PoW into useful work without reducing the difficulty level. REM utilizes trusted hardware and has developed SGXblockchain implementation with low computational overhead.

Redundancy reduction technique

Reducing redundancy in storage and operations within the blockchain network is crucial. One promising method is sharding, dividing the network into small parts called shards based on consensus mechanisms, allowing transaction updates in each shard. Several studies propose stable sharding techniques with low failure rates. Sharding is also proposed for Ethereum 2.0, dividing the blockchain network into shards, albeit challenging due to decentralized computational power in PoW. However, this method can be executed based on staking and storage proportions in PoS and PoSpace.

In addition to sharding, Elastic Chain is another method that reduces redundancy. In ElasticChain, nodes in the chain store parts of the ledger based on a duplicate ratio regulation algorithm. This research demonstrates stability, security, fault tolerance, and improved storage scalability.

Another approach, such as Semantic Differential Transaction (SDT) as proposed in [88], suggests a method to reduce redundancy in integrating Building Information Modeling (BIM) and blockchain. SDT reduces redundancy in the BIM-blockchain system by recording local changes in information models as BIM Change Contracts (BCC), which are only 0.02% of the size of Industry Foundation Classes (IFC). (Kohli et al., 2023)k

Moreover, Zero-Knowledge Proofs (ZKP) like SNARKS represent another category of methods proposed to reduce operational redundancy in blockchain. ZKP enhances user privacy by avoiding the disclosure of personal information, ensuring security while improving the scalability and throughput of cryptocurrency networks, making them more energy-efficient. Other research employs ZKP to expedite the proof and verification process of large sequential computations compared to current ZKP implementations. All of these efforts aim to decrease redundancy in blockchain storage and operations.

Limitations

- 1. Data Consistency Challenges: Sometimes, it's tough to get reliable and consistent data about how much energy different cryptocurrencies use. The way people report this info can vary, and some data might be missing, which could affect how accurate our research is.
- 2. Understanding the Full Impact: We looked at how mining cryptocurrencies affect the environment, mainly focusing on how much energy they use and their carbon footprint. But there might be other ways they affect the environment, like how they handle electronic waste or use land and water, which we didn't explore enough.
- 3. Technology Keeps Changing: Cryptocurrencies and the technology behind them are always changing. This means our findings might become old-fashioned because new ways of doing things might come along, making our research less useful in the future.
- 4. Not Covering Everything: Our study might concentrate too much on specific cryptocurrencies or how they're mined. This could mean our conclusions might not apply to all cryptocurrencies because there are lots of different ones out there.
- 5. Government Rules and Policies: We might not have looked closely enough at how rules made by governments affect how people mine cryptocurrencies. These rules could have a big impact on how environmentally friendly mining is.

Future Work

- 1. Advanced Energy-Efficient Consensus: Further research can explore the development and implementation of more energy-efficient consensus mechanisms or improvements in existing mechanisms, considering the evolving nature of blockchain technology.
- 2. Policy and Governance Frameworks: Research can focus on evaluating and proposing effective policies, incentives, or governance models that encourage eco-friendly practices within the cryptocurrency industry.
- 3. Real-World Implementation Studies: Field trials or case studies in regions with significant mining operations can validate the practicality and scalability of proposed sustainability solutions in actual mining scenarios.

- 4. Social and Economic Impact Studies: Future work can explore the broader social and economic implications of transitioning to sustainable mining practices, considering aspects such as employment, community development, and socio-economic inequalities.
- 5. Cross-Comparison Studies: Comparative analyses across different cryptocurrencies or mining methodologies can offer insights into the relative environmental impacts and efficiencies of various blockchain networks.
- 6. Monitoring and Adaptation Strategies: Develop monitoring frameworks and adaptive strategies to continuously evaluate and enhance the effectiveness of implemented solutions over time.

CONCLUSION

This research has unveiled that the rapid growth of cryptocurrency mining, especially Bitcoin, has resulted in serious environmental consequences. The high energy consumption from crypto mining has led to a significant increase in carbon emissions, exacerbating the impacts of climate change. In recent years, the Bitcoin mining network alone has consumed electricity comparable to that of several major countries worldwide. Additionally, its impacts on water resources and land cannot be overlooked.

However, the proposed solutions offer positive aspects in addressing these environmental issues. Implementation of renewable energy sources such as solar and wind at mining locations, utilization of more efficient mining devices, and exploring environmentally friendly consensus mechanisms like Proof of Stake (PoS) have garnered attention as potential ways to mitigate these negative impacts.

Nevertheless, there are challenges in gathering consistent data, obtaining a comprehensive understanding of various aspects of environmental impacts, and coping with the constant changes in cryptocurrency technology. Therefore, further research should focus on developing more efficient consensus mechanisms, establishing adequate policy frameworks, and conducting real-world implementation studies to evaluate the sustainability of the proposed solutions.

REFERENCES

- Alfian, A. (2022). Bitcoin Di Indonesia: Selain Haram, Ancamankah Terhadap Lingkungan? *Journal of Sharia Economics*, 3(2), 121–134. chttps://doi.org/10.22373/jose.v3i2.1898
- Badea, L., & Mungiu-Pupazan, M. C. (2021). The Economic and Environmental Impact of Bitcoin. *IEEE Access*, 9, 48091–48104. https://doi.org/10.1109/ACCESS.2021.3068636

- Chamanara, S., Ghaffarizadeh, S. A., & Madani, K. (2023). The Environmental Footprint of Bitcoin Mining Across the Globe: Call for Urgent Action. *Earth's Future*, 11(10). https://doi.org/10.1029/2023EF003871
- Erdogan, S., Ahmed, M. Y., & Sarkodie, S. A. (2022). Analyzing asymmetric effects of cryptocurrency demand on environmental sustainability. *Environmental Science and Pollution Research*, 29(21), 31723–31733. https://doi.org/10.1007/s11356-021-17998-y
- Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2020). Energy Consumption of Cryptocurrencies Beyond Bitcoin. *Joule*, 4(9), 1843–1846. https://doi.org/10.1016/j.joule.2020.07.013
- Goel, S., & Mittal, H. (2020). Economic, legal and financial perspectives on cryptocurrencies: a review on cryptocurrency growth, opportunities and future prospects. World Review of Entrepreneurship, Management and Sustainable Development, 16(6), 611. https://doi.org/10.1504/WREMSD.2020.111391
- Kohli, V., Chakravarty, S., Chamola, V., Sangwan, K. S., & Zeadally, S. (2023). An analysis of energy consumption and carbon footprints of cryptocurrencies and possible solutions. *Digital Communications and Networks*, 9(1), 79–89. https://doi.org/10.1016/J.DCAN.2022.06.017
- Kumari, P., Mamidala, V., Chavali, K., & Behl, A. (2024). The changing dynamics of crypto mining and environmental impact. *International Review of Economics & Finance*, 89, 940–953. https://doi.org/10.1016/j.iref.2023.08.004
- Li, J., Li, N., Peng, J., Cui, H., & Wu, Z. (2019). Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. *Energy*, 168, 160–168. https://doi.org/10.1016/J.ENERGY.2018.11.046
- Náñez Alonso, S. L., Jorge-Vázquez, J., Echarte Fernández, M. Á., & Reier Forradellas, R. F. (2021). Cryptocurrency Mining from an Economic and Environmental Perspective. Analysis of the Most and Least Sustainable Countries. *Energies*, 14(14), 4254. https://doi.org/10.3390/en14144254
- Panda, P. C. (2020). *Growth of Cryptocurrency and Illegal Activities Nisarg Jani. November* 2019, 0–19.
- Sapra, N., & Shaikh, I. (2023). Impact of Bitcoin mining and crypto market determinants on Bitcoin-based energy consumption. *Managerial Finance*, 49(11), 1828–1846. https://doi.org/10.1108/MF-03-2023-0179
- Wątorek, M., Drożdż, S., Kwapień, J., Minati, L., Oświęcimka, P., & Stanuszek, M. (2021). Multiscale characteristics of the emerging global cryptocurrency market. *Physics Reports*, 901, 1–82. https://doi.org/10.1016/j.physrep.2020.10.005

- Wu, J., Liu, J., Zhao, Y., & Zheng, Z. (2021). Analysis of cryptocurrency transactions from a network perspective: An overview. *Journal of Network and Computer Applications*, 190, 103139. https://doi.org/10.1016/J.JNCA.2021.103139
- Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. Journal of Planning Education and Research, 39(1), 93–112. https://doi.org/10.1177/0739456X17723971
- Yousaf, I., Abrar, A., Yousaf, U. Bin, & Goodell, J. W. (2024). Environmental attention and uncertainties of cryptocurrency market: Examining linkages with cryptomining stocks. *Finance Research Letters*, 59, 104672. https://doi.org/10.1016/j.frl.2023.104672
- Zhang, D., Chen, X. H., Lau, C. K. M., & Xu, B. (2023). Implications of cryptocurrency energy usage on climate change. *Technological Forecasting and Social Change*, 187, 122219. https://doi.org/10.1016/J.TECHFORE.2022.122219