Policy Recommendations for the Environmental Efficiency of Bitcoin

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Importance of the Study

Cryptocurrencies are digital currencies characterized by decentralization and cryptographic protocols. Bitcoin (BTC) is the most prominent cryptocurrency in terms of adoption rate, market capitalization, and market dominance. However, Bitcoin mining requires substantial amounts of electricity. When this energy is predominantly sourced from fossil fuels, significant carbon emissions result, has intensified debates about the environmental impact of BTC. Consequently, studies focusing on the environmental efficiency of BTC mining are of increasing importance.

Purpose of the Study

The proof-of-work mechanism, a critical component of Bitcoin's transaction validation process, also regulates the supply of the digital currency. Commonly known as “mining”, this process involves performing complex computational tasks to verify and record transactions, thereby ensuring the integrity and security of the Bitcoin network. The process of Bitcoin mining is conducted in numerous countries worldwide. In fact, the electricity consumed by BTC mining often exceeds the total electricity consumption of several individual nations. Therefore, a comprehensive analysis of the CO2 emissions generated by this electricity use is imperative. To mitigate the negative environmental externalities of BTC mining in the future, governments will need to introduce regulatory interventions and provide public incentives that steer the industry toward technology-based systemic solutions (Oğhan, 2022). In this context, the findings of this study can inform the design of public policy measures concerning BTC mining.

Literature

Mora et al. (2018) contended that Bitcoin's carbon footprint in 2017 was equivalent to 69 million metric tons of CO2 equivalent, which, in isolation, could potentially trigger a 2°C rise in global temperatures. Schinckus et al. (2020) identified a positive correlation between Bitcoin's transaction volume and its energy demand. Sarkodie et al. (2022) emphasized that an increase in Bitcoin trading volume results in an expansion of its long-term carbon and energy footprints. Evidence of a two-way causal link between Bitcoin prices and its energy use was reported by Söylemez and Gürsoy (2022). In contrast, Felek et al. (2023) detected a unidirectional causality from Bitcoin activity to carbon emissions. In a similar vein, Koçak and Uçan (2023) observed that cryptocurrency transactions have been shown to exacerbate CO2 emissions. In a recent study, Çelik and Özırmak (2025)

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demonstrated that an increase in Bitcoin electricity consumption, when combined with climate policy uncertainty, has a negative effect on greenhouse gas emissions. Magdalena et al. (2025) reached the conclusion that BTC mining has a detrimental effect on energy consumption and environmental sustainability.

Design and Methodology

The present analysis focuses on identifying the factors that shape Bitcoin's benefit–cost ratio. In accordance with the work of Goodkind et al. (2019), who introduced the concept of "cryptodamages" by establishing a correlation between miners' direct economic gains and Bitcoin's environmental costs, the value generated per unit of carbon was calculated. Consequently, the Bitcoin Carbon & Environmental Efficiency Index (BCEE) was developed to capture miner-level dynamics. In order to assess the impact of additional variables on the index, a time-series model was constructed by incorporating relevant factors. The objective of this model is to analyze the determinants of the environmental efficiency ratio, defined as the relationship between miners' revenues and the carbon costs associated with Bitcoin mining over time. The ARDL bounds testing approach was applied, using monthly data from January 2019 to October 2024. The dependent variable is BCEE (bcee), while the explanatory variables include the BTC hashrate (hash), BTC price (price), BTC market dominance (dom), and the global share of renewable energy (renew). All variables are expressed in their natural logarithmic form.

$$\ln(bcee)_t = \beta_0 + \beta_1 \ln(hash)_t + \beta_2 \ln(price)_t + \beta_3 \ln(dom)_t + \beta_4 \ln(renew)_t + \epsilon_t$$

The dataset was created by accessing data on the variables through official databases. The null hypothesis states that none of the explanatory variables have a significant effect on BCEE, while the alternative hypothesis states that at least one explanatory variable has a statistically significant effect on BCEE. Sub-hypotheses were established to determine the significance of each explanatory variable's relationship with BCEE.

Findings and Discussion

According to the results of the ARDL model, there are significant long-term relationships between the BCEE and the key determinants in the model. The findings indicate that the environmental impact of Bitcoin mining is predominantly influenced by hashrate, price, and market dominance. While hashrate exerts a negative effect on environmental efficiency, increases in price and dominance have been demonstrated to have a positive effect. The share of renewable energy was not found to be statistically significant in the long term. The short-term dynamics were examined using an error correction model (ECM). According to this, the Bitcoin price and the share of renewable energy contribute positively and significantly to environmental efficiency Granger causality tests were applied to more precisely determine the direction of relationships among the variables. The results indicate that hashrate, price, and dominance are Granger causes of BCEE. The diagnostic tests further substantiate the model's validity and reliability. Overall, the findings provide a robust framework that can be applied in both academic and policy-making contexts.

Conclusion and Recommendations

The empirical findings have several implications for environmental policies and regulations on crypto asset systems, particularly in the context of Bitcoin mining's environmental efficiency. The adverse effect of rising hashrates on environmental efficiency highlights the the importance of incentives to enhance the energy efficiency of mining technologies. The short-term positive impact of using renewable energy underscores the strategic role of renewable energy sources in reducing the carbon intensity of crypto mining. The positive effects of price and market dominance on environmental efficiency imply that crypto markets require regulation not only in financial but also in environmental terms. In this regard, carbon pricing could be an effective tool for internalizing the environmental costs of the crypto mining sector The results of the study underscore the need to implement policies that promote energy efficiency improvements, carbon pricing mechanisms, and renewable energy incentives within the framework of internationally coordinated policy measures.

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