

Peer-reviewed research

# Bitcoin's Environmental Impact: Examining Carbon Emission Patterns Through Price and Volume Dynamics

Charumathi Balakrishnan<sup>1a</sup>, Habeebu Rahman<sup>1</sup>

<sup>1</sup> Department of Management Studies, Pondicherry University, India

Keywords: Bitcoin, Carbon emission, Power consumption, Cryptocurrency

JEL Classifications: Q4 Energy, Q5 Environmental Economics

<https://doi.org/10.46557/001c.151204>

---

## Energy RESEARCH LETTERS

Vol. 6, Issue 6, 2025

---

We investigate the impact of bitcoin's price and trading volume on its electricity consumption, carbon emissions, and emission intensity using a Granger causality approach. The findings reveal a strong relationship between bitcoin's price and trading volume with power consumption and carbon emissions. The analysis highlights both long- and short-term relationships, while indicating that carbon emission intensity is less affected. The results of the study underscore the urgency of addressing bitcoin's carbon footprint for a sustainable future.

### I. Introduction

The primary objective of this study is to explore the impact of bitcoin prices on power consumption, carbon emissions, and carbon emission intensity of the bitcoin network, examining how bitcoin's market indicators, including price and trading volume, influence its environmental footprint amidst growing environmental concerns associated with its energy-intensive processes.

Our study's theoretical background incorporates key works in environmental economics. It includes Weitzman (1974) analysis of environmental regulation trade-offs for managing bitcoin's energy use, and Jevons (1865) exploration of the Jevons paradox, relating to increased energy consumption due to technological efficiency, to contextualize bitcoin's energy demands. These works form a framework to assess bitcoin's energy use and its sustainability implications.

The rising prominence of bitcoin has ushered in debates about its sustainability. Notably, Jiang et al. (2021) and de Vries (2020) have highlighted the substantial energy consumption associated with bitcoin, raising concerns about its long-term environmental impact. These studies set the stage for a more detailed exploration of bitcoin's environmental footprint, particularly in light of its fluctuating market dynamics.

This study uses Vector Auto-Regression (VAR) models and Granger causality tests, an approach relatively unexplored in existing literature. This methodology enables a detailed examination of how bitcoin's price and trading volume interact with its electricity consumption and carbon emissions, offering a holistic view of its environmental

consequences. Huynh et al. (2021) and Polemis and Tsionas (2021) have discussed the environmental costs of bitcoin's energy requirements, while Badea and Mungiu-Pupazan (2021) acknowledged its economic relevance. Further, Ozdurak et al. (2022) and Baur and Oll (2022) have examined bitcoin's role in investment portfolios and its implications for climate change.

Sapra and Shaikh (2023) delve into bitcoin mining and its energy demands, highlighting the influence of trading-specific variables on energy consumption. Their insights bring to light the potential of alternative consensus mechanisms in reducing bitcoin's energy requirements. Mohsin et al. (2023) extend this discussion by analyzing the relationship between crypto-trade volume, GDP, energy use, and environmental sustainability, advocating for policy interventions to harmonize economic and environmental goals.

Hsu et al. (2023) adopt a unique approach by examining the interplay between crude oil, bitcoin, and carbon emissions, offering strategies for mitigating bitcoin's carbon footprint through energy transitions. Hong and Zhang (2023) consider bitcoin's role in emerging economies, exploring its impact on economic growth, energy use, and CO<sub>2</sub> emissions. This broader perspective underscores the complexity of bitcoin's environmental implications and the need for comprehensive, sustainable strategies.

Siddik et al. (2023) contribute a novel perspective by comparing the water and carbon footprints of cryptocurrencies and conventional currencies, igniting a dialogue on the broader environmental implications of bitcoin's growth and energy-intensive nature.

This study links bitcoin's economic indicators to its environmental impact, enhancing our understanding of its

**Table 1. Descriptive statistics**

| Variable    | Obs   | Mean         | Std. Dev.    | Min      | Max           |
|-------------|-------|--------------|--------------|----------|---------------|
| PRICE       | 3,099 | 13991.59     | 16065.75     | 172.3143 | 67533.82      |
| VOLUME      | 3,099 | 246000000.00 | 360000000.00 | 3.77     | 4190000000.00 |
| EMISSIONINT | 3,099 | 519.23       | 40.14        | 359.47   | 594.58        |
| POWER       | 3,099 | 6.25         | 4.90         | 0.23     | 17.30         |
| EMISSION    | 3,099 | 28.16        | 22.45        | 1.09     | 76.83         |

Note: This table presents the descriptive statistics for the variables used in the study. PRICE refers to the price of bitcoin at different time points; VOLUME indicates the trading volume of bitcoin within specified periods; EMISSIONINT represents the environmental impact of the bitcoin network's emissions; POWER denotes the energy consumed by the bitcoin network; and EMISSION indicates the emissions generated by the bitcoin network.

sustainability challenges and providing insights for policy-makers and investors. It contributes to existing knowledge and paves the way for further research on cryptocurrencies' environmental effects.

## II. Data and Results

### A. Data and Model

The present study analyzes the impact of bitcoin market indicators, namely price (PRICE) and trading volume (VOLUME) on its electricity consumption (POWER), carbon emissions (EMISSION), and carbon emission intensity (EMISSIONINT). The analysis spans nine years (December 1, 2014, to July 12, 2023), capturing both short- and long-term interactions among these variables. Data on bitcoin prices and trading volumes were obtained from [Bitcoinity.org](https://data.bitcoinity.org) (<https://data.bitcoinity.org>), while information on electricity consumption, carbon emissions, and carbon emission intensity was sourced from the Cambridge Bitcoin Electricity Consumption Index (CBECI).

This study adopts a global perspective, reflecting the decentralized and worldwide nature of bitcoin trading. The use of vector autoregression (VAR) models and Granger causality tests provides a robust framework for exploring the causal relationships between bitcoin's market behavior and its environmental impact. [Table 1](#) presents the descriptive statistics for the variables used in this study.

### B. Results

The VAR and Granger causality tests reveal a strong explanatory power for bitcoin's price, power consumption, and emissions, indicating dynamic interplays between these variables. The choice of these models was based on the flexibility and widespread use of VAR in time series analysis, particularly for forecasting financial and economic trends, as well as its ability to develop real-time equation modelling. The study also conducted a unit root test to check for data stationarity. Specifically, the Augmented Dickey-Fuller (ADF) model developed by Dickey and Fuller was used to assess the stationarity of dependent variables.

[Table 2](#) shows the (a) ADF unit root test and (b) Johansen cointegration test results. The variable PRICE has a unit root, but it does not have a unit root at first order difference (DYPRICE). VOLUME and DYVOLUME do not have a unit root. POWER has a unit root, but DYPOWER does not have a

unit root. EMISSION has a unit root, but DYEMISSION does not have a unit root. EMISSIONINT and DYEMISSIONINT do not have a unit root.

We have conducted the Johansen cointegration test (see Panel B of [Table 2](#)), and the findings suggest that these variables might share significant long-term relationships. For instance, both EMISSIONINT and POWER show positive coefficients with significant  $z$ -values and  $p$ -values close to 0.00, indicating a strong cointegrating relationship. Conversely, EMISSION shows a negative coefficient but with a similarly significant  $z$ -value and  $p$ -value. These results suggest interconnected dynamics among these variables over the long term.

[Table 3](#) presents the results of the VAR and Granger causality tests for bitcoin price. The table indicates that all equations exhibit strong explanatory power, as evidenced by high  $R$ -squared values. This suggests that PRICE, POWER, EMISSION, and EMISSIONINT are all well explained by their own lagged values.

The Granger causality test results, as shown in [Table 3](#), indicate clear directional causal relationships. Specifically, PRICE significantly influences POWER ( $\chi^2 = 13.184$ ,  $p$ -value < 0.01) and EMISSION ( $\chi^2 = 12.588$ ,  $p$ -value < 0.01), as well as EMISSIONINT ( $\chi^2 = 9.8183$ ,  $p$ -value = 0.01). Conversely, POWER and EMISSION exhibit a significant causal effect on PRICE ( $\chi^2 = 19.054$  and  $\chi^2 = 17.485$ , both  $p$ -value < 0.01, respectively), and EMISSION significantly influence POWER ( $\chi^2 = 61.449$ ,  $p$ -value < 0.01). These findings suggest a dynamic interplay between bitcoin's economic and environmental dimensions, with price changes potentially influencing environmental factors.

[Table 4](#) shows the results of the vector autoregression and Granger causality test for VOLUME. The vector autoregression results show that VOLUME has a high explanatory power for itself, with a significant  $R$ -squared value of 0.7231. This implies a strong self-influence. Similarly, EMISSIONINT, POWER, and EMISSION demonstrate significant self-explanatory power, indicated by their respective  $R$ -squared values of 0.9859, 0.9991, and 0.9991.

In the Granger causality tests, the results suggest directional causal relationships. For instance, a significant causal effect of bitcoin's VOLUME on EMISSIONINT and POWER is observed, with  $\chi^2$  values of 6.799 and 12.465, respectively, both significant at  $p$ -value < 0.05. This indicates that fluctuations in VOLUME can predict changes in EMISSIONINT and POWER. Conversely, POWER shows a signifi-

**Table 2. ADF unit root test and Johansen cointegration test**

| Panel A: ADF unit root test          |                |                      |                      |                       |                   |
|--------------------------------------|----------------|----------------------|----------------------|-----------------------|-------------------|
| Variable                             | Test Statistic | Critical Values (1%) | Critical Values (5%) | Critical Values (10%) | MacKinnon p-value |
| PRICE                                | -1.092         | -3.43                | -2.9                 | -2.57                 | 0.72              |
| DYPRICE                              | -22.674        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| VOLUME                               | -16.996        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| DYVOLUME                             | -42.811        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| POWER                                | 0.172          | -3.43                | -2.9                 | -2.57                 | 0.97              |
| DYPOWER                              | -18.052        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| EMISSION                             | -0.114         | -3.43                | -2.9                 | -2.57                 | 0.95              |
| DYEMISSION                           | -19.129        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| EMISSIONIN                           | -3.367         | -3.43                | -2.9                 | -2.57                 | 0.01              |
| DYEMISSIONINT                        | -24.848        | -3.43                | -2.9                 | -2.57                 | 0.00              |
| Panel B: Johansen cointegration test |                |                      |                      |                       |                   |
| Variable                             | Coefficient    | Std. Err.            | z                    | p > z                 |                   |
| _ce1                                 |                |                      |                      |                       |                   |
| PRICE                                | 1.00           |                      |                      |                       |                   |
| EMISSIONINT                          | 4471.67        | 1080.41              | 4.14                 | 0.00                  |                   |
| POWER                                | 332671.30      | 70065.06             | 4.75                 | 0.00                  |                   |
| EMISSION                             | -72495.78      | 15093.78             | -4.80                | 0.00                  |                   |
| _cons                                | -2384485.00    |                      |                      |                       |                   |

Note: This table presents the results of ADF unit root test performed on the variables utilized in this study, and the Johansen cointegration test in Panel A and B, respectively. All variables are defined in [Table 1](#).

**Table 3. Results of VAR and Granger causality test for bitcoin price**

| Panel A: VAR test results               |             |          |                |              |              |
|-----------------------------------------|-------------|----------|----------------|--------------|--------------|
| Equation                                | Parms       | RMSE     | R <sup>2</sup> | $\chi^2$     | p > $\chi^2$ |
| PRICE                                   | 9           | 659.553  | 0.9983         | 1839568      | 0            |
| EMISSIONINT                             | 9           | 4.77165  | 0.9859         | 216695.1     | 0            |
| POWER                                   | 9           | 0.147225 | 0.9991         | 3436499      | 0            |
| EMISSION                                | 9           | 0.674654 | 0.9991         | 3434902      | 0            |
| Panel B: Granger causality test results |             |          |                |              |              |
| Equation                                | Excluded    | $\chi^2$ | df             | p > $\chi^2$ |              |
| PRICE                                   | EMISSIONINT | 9.8183   | 2              | 0.01         |              |
| PRICE                                   | POWER       | 13.184   | 2              | 0.00         |              |
| PRICE                                   | EMISSION    | 12.588   | 2              | 0.00         |              |
| EMISSIONINT                             | PRICE       | 0.42814  | 2              | 0.81         |              |
| EMISSIONINT                             | POWER       | 1.8648   | 2              | 0.39         |              |
| EMISSIONINT                             | EMISSION    | 0.80663  | 2              | 0.67         |              |
| POWER                                   | PRICE       | 19.054   | 2              | 0.00         |              |
| POWER                                   | EMISSIONINT | 2.2236   | 2              | 0.33         |              |
| POWER                                   | EMISSION    | 7.4466   | 2              | 0.02         |              |
| EMISSION                                | PRICE       | 17.485   | 2              | 0.00         |              |
| EMISSION                                | EMISSIONINT | 817.55   | 2              | 0.00         |              |
| EMISSION                                | POWER       | 61.449   | 2              | 0.00         |              |

Note: This table provides the results of VAR and Granger causality test for bitcoin price. All variables are defined in [Table 1](#).

**Table 4. Results of VAR and Granger causality test for bitcoin volume**

| Panel A: VAR test results               |             |          |                |              |              |
|-----------------------------------------|-------------|----------|----------------|--------------|--------------|
| Equation                                | Parms       | RMSE     | R <sup>2</sup> | $\chi^2$     | p > $\chi^2$ |
| VOLUME                                  | 9           | 1.90E+08 | 0.7231         | 8086.749     | 0            |
| EMISSIONINT                             | 9           | 4.77178  | 0.9859         | 216225.6     | 0            |
| POWER                                   | 9           | 0.147599 | 0.9991         | 1737168      | 0            |
| EMISSION                                | 9           | 0.676223 | 0.9991         | 1639627      | 0            |
| Panel B: Granger causality test results |             |          |                |              |              |
| Equation                                | Excluded    | $\chi^2$ | df             | p > $\chi^2$ |              |
| VOLUME                                  | EMISSIONINT | 6.799    | 2              | 0.03         |              |
| VOLUME                                  | POWER       | 12.465   | 2              | 0.00         |              |
| VOLUME                                  | EMISSION    | 16.855   | 2              | 0.00         |              |
| EMISSIONINT                             | VOLUME      | 0.26286  | 2              | 0.88         |              |
| EMISSIONINT                             | POWER       | 1.8381   | 2              | 0.40         |              |
| EMISSIONINT                             | EMISSION    | 0.73835  | 2              | 0.69         |              |
| POWER                                   | EMISSIONINT | 4.0402   | 2              | 0.13         |              |
| POWER                                   | EMISSION    | 10.762   | 2              | 0.01         |              |
| EMISSION                                | EMISSIONINT | 816.26   | 2              | 0.00         |              |
| EMISSION                                | POWER       | 65.697   | 2              | 0.00         |              |

Note: This table provides the results of VAR and Granger causality test for bitcoin volume, price. All variables are defined in Table 1.

cant causal effect on EMISSION, with a  $\chi^2$  value of 65.697, significant at  $p$ -value < 0.01, suggesting that variations in POWER can predict changes in EMISSION.

### III. Conclusion

Our findings resonate with recent studies yet also provide unique insights. Our findings, while resonating with prior studies such as Jiang et al. (2021) and de Vries (2020), extend the understanding of bitcoin's market dynamics and their environmental impacts, suggesting policy interventions for sustainability.

Given the environmental implications of bitcoin's energy consumption and carbon emissions, this study suggests several policy interventions: a) promote the use of renewable energy in bitcoin mining operations to mitigate its carbon footprint; b) introduce carbon taxing for bitcoin mining operations to incentivize cleaner energy usage; and c) encourage investment in technologies that enhance the energy efficiency of bitcoin mining. These strategies aim to balance the economic benefits of bitcoin with environmen-

tal sustainability, aligning with the global agenda of reducing carbon emissions.

This study holds significant implications for both investors and policymakers. Investors can use these insights to assess the long-term sustainability and risk factors associated with bitcoin investments, particularly in the context of increasing environmental regulations. Policymakers can leverage these findings to develop regulations that encourage more environmentally sustainable practices in the cryptocurrency sector.

In conclusion, this study sheds light on the complex relationship between bitcoin's economic aspects and its environmental impact. The findings highlight the need for innovative strategies and policy interventions to manage the environmental consequences of bitcoin's growing popularity. Research should focus on optimizing bitcoin's energy efficiency and exploring environmentally conscious blockchain technologies more than ever before.

Submitted: August 22, 2023 AEDT. Accepted: September 14, 2024 AEDT. Published: December 20, 2025 AEDT.



This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY-SA-4.0). View this license's legal deed at <https://creativecommons.org/licenses/by-sa/4.0> and legal code at <https://creativecommons.org/licenses/by-sa/4.0/legalcode> for more information.

## References

- 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>
- Baur, D. G., & Oll, J. (2022). Bitcoin investments and climate change: A financial and carbon intensity perspective. *Finance Research Letters*, 47, 102575. <https://doi.org/10.1016/j.frl.2021.102575>
- de Vries, A. (2020). Bitcoin's energy consumption is underestimated: A market dynamics approach. *Energy Research and Social Science*, 70. <https://doi.org/10.1016/j.erss.2020.101721>
- Hong, H., & Zhang, C. (2023). Bitcoin trading, economic growth, energy use, and CO2 emissions: An advanced panel study of emerging market economies. *International Review of Economics & Finance*, 87, 519–531. <https://doi.org/10.1016/j.iref.2023.06.003>
- Hsu, T., Lien, W., & Lee, Y. (2023). Exploring relationships among crude oil, bitcoin, and carbon dioxide emissions: Quantile mediation analysis. *Processes*, 11(5), 1555. <https://doi.org/10.3390/pr11051555>
- Huynh, A. N. Q., Duong, D., Burggraf, T., Luong, H. T. T., & Bui, N. H. (2021). Energy consumption and bitcoin market. *Asia-Pacific Financial Markets*. <https://doi.org/10.1007/s10690-021-09338-4>
- Jevons, W. S. (1865). The Coal Question. *Geological Magazine*, 2(18), 550–552.
- Jiang, S., Li, Y., Lu, Q., Hong, Y., Guan, D., Xiong, Y., & Wang, S. (2021). Policy assessments for the carbon emission flows and sustainability of bitcoin blockchain operation in china. *Nature Communications*, 12(1). <https://doi.org/10.1038/s41467-021-22256-3>
- Ozdurak, C., Umut, A., & Ozay, T. (2022). The interaction of major crypto-assets, clean energy, and technology indices in diversified portfolios. *International Journal of Energy Economics and Policy*, 12(2), 480–490. <https://doi.org/10.32479/ijeep.12888>
- Polemis, M. L., & Tsionas, M. G. (2021). The environmental consequences of blockchain technology: A Bayesian quantile cointegration analysis for bitcoin. *International Journal of Finance & Economics*, 28(2), 1602–1621. <https://doi.org/10.1002/ijfe.2496>
- Sapra, N., & Shaikh, I. (2023). Impact of bitcoin mining and crypto market determinants on bitcoin-based energy consumption. *Managerial Finance*. <https://doi.org/10.1108/mf-03-2023-0179>
- Siddik, M. A., Amaya, M., & Marston, L. T. (2023). The water and carbon footprint of cryptocurrencies and conventional currencies. *Journal of Cleaner Production*, 411, 137268. <https://doi.org/10.1016/j.jclepro.2023.137268>
- Weitzman, M. L. (1974). Prices vs. Quantities. *Review of Economic Studies*, 41(4), 477–491. <https://doi.org/10.2307/2296698>