Innovation and Green Development 2 (2023) 100048

Contents lists available at ScienceDirect

Innovation and Green Development

journal homepage: www.journals.elsevier.com/innovation-and-green-development

Full Length Article

# Asymmetric effects of climate policy uncertainty and energy prices on bitcoin prices

Provash Kumer Sarker[a,b,*], Chi Keung Marco Lau[c], Ashis Kumar Pradhan[d]

[a] School of Economics and Management, Wuhan University, Hubei, China
[b] Bangladesh Bank, Dhaka, 1000, Bangladesh
[c] Department of Economics and Finance, The Hang Seng University of Hong Kong, China
[d] Department of Humanities and Social Sciences, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India

A R T I C L E I N F O

*JEL classification:*
G12
Q43
Q54

*Keywords:*
Climate policy uncertainty
Bitcoin
Global energy prices
NARDL

A B S T R A C T

This paper investigates the asymmetric effects of climate policy uncertainty (CPU) and the global price of energy index (GPEI) on Bitcoin prices. It applies the nonlinear ARDL method and the Granger causality test to examine how changes in climate policy uncertainty and energy prices influence Bitcoin prices. Using the monthly data of CPU, GPEI, and BTC from 2013M10–2021M12, the findings show that CPU's increases and GPEI's decreases positively affect BTC in the short term. Specifically, CPU and GPEI's increase and decrease show significantly higher effects on BTC in the long term. The causality result shows bidirectional causality between BTC and CPU's increases/decreases, while unidirectional causality runs from GPEI's increases/decreases to BTC. These findings suggest that Bitcoin investors should be aware of the risks associated with climate policy uncertainty and fluctuations in energy prices, as these factors can significantly asymmetrically impact Bitcoin prices.

## 1. Introduction

The growing use of cryptocurrency, particularly Bitcoin[1], as a currency and a financial asset has enormous climate and energy effects. However, estimating the catastrophic impacts of climate change is cumbersome but crucial in dealing with climate uncertainties related to financial investment, technological change, carbon cycle, and energy-intensive industries. Although green innovation and policymaking have evolved to minimize such uncertainties, the looming threat of energy transition and future carbon prices threaten fuel-driven industries. Such uncertainties will influence renewable energy, fasten the energy transition process supporting green investments, and substantially affect global energy prices. Climate uncertainties may also affect cryptocurrencies as they consume a large amount of energy to operate, eventually aggravating environmental degradation. For example, a single Bitcoin transaction takes around 619 kW, equal to the power usage of a single US household over 20.92 days (Corbet, Lucey, & Yarovaya, 2021a; 2021b). Likewise, other major cryptocurrencies like Ethereum (ETH) and XRP also consume a massive amount of energy to operate, which emits CO2 and affects the environment. For instance, the Monero mining in China may consume 30.34 GWh and contribute to 19.12–19.42 thousand tons of carbon emissions from April to December 2018. Thus, the high electricity consumption-level hashing is a significant environmental concern, specifically in China, which dominates coal-based electricity production. The Cambridge Bitcoin Electricity Consumption Index (CBECI) estimates Bitcoin's annual electricity consumption in crypto-mining at around 115[2] TWHs. The aggregate electricity consumption of all major cryptos is far more than that of Bitcoin. From an environmental perspective, such high energy consumption is a grave concern. Afjal and Sajeev (2022) reveal that Bitcoin's trading volume has greater effects on energy than on returns in the long run. Sarkodie et al. (2022) find that the Bitcoin trade is positively related to energy consumption and carbon footprint, affecting the climate. Thus, cryptocurrency's growing energy use may adversely affect climate uncertainty globally.

However, the recent climate crisis worldwide has intensified investors' consciousness of climate risks (Fahmy, 2022; Krueger et al., 2020) and the adverse ecological effects of fossil fuels (Lauri et al., 2014). Besides, the price volatilities in the energy markets, such as oil and gas, trigger the demand for alternative energy and facilitate the energy transition (Zhao, 2020). Naeem and Karim (2021) explored the

* Corresponding author. School of Economics and Management, Wuhan University, Hubei, China.
*E-mail addresses:* provash.sarker@whu.edu.cn (P.K. Sarker), marcolau@hsu.edu.hk (C.K.M. Lau), ashiskumarprdhn@gmail.com (A.K. Pradhan).

[1] Refer https://ccaf.io/cbeci/index to gain more insights about Bitcoin.
[2] The Cambridge Bitcoin Electricity Consumption Index as on June 1st, 2021, retrieved from https://ccaf.io/cbeci/index.

https://doi.org/10.1016/j.igd.2023.100048
Received 13 January 2023; Received in revised form 9 March 2023; Accepted 10 March 2023
Available online 22 March 2023

dependence between green stocks and Bitcoin, revealing that green stocks do not affect Bitcoin prices. Recently, a few studies have linked CPU with finance and investment (Bouri et al., 2022; Fried et al., 2021). Bouri et al. (2022) find that the impacts of CPU on green energy stock are significantly positive. Wu et al. (2022) forecast the CPU's effects on the European Union Allowance Futures (EUAF) and show that the CPU negatively affects the volatility of EUAF. Ren et al. (2022) investigated the nonlinear effects of CPU on investment decisions and found a nonlinear association between CPU and Chinese energy firms' investment decisions.

The economic relationship between Bitcoin and climate policy uncertainty is closely linked. Bitcoin mining and transactions require a significant amount of energy, a significant portion of which comes from fossil fuels. Therefore, the more uncertain the climate policy is, the more likely it is that Bitcoin will continue to rely on these non-renewable sources of energy. Climate policy uncertainty can also create regulatory risk for Bitcoin. Furthermore, as climate concerns become more pressing, the negative perception of Bitcoin's energy consumption and carbon footprint could reduce demand and value. Investors and consumers may shift towards more environmentally-friendly alternatives, which could lead to a decline in Bitcoin's market share.

On the other hand, with a clear policy direction toward clean energy and sustainability, Bitcoin mining could become more environment-friendly, and the demand for Bitcoin may increase as investors seek sustainable investment opportunities (Lee, Wang, et al., 2022a,b). The economic relationship between Bitcoin and climate policy uncertainty is complex and multi-faceted. As governments worldwide continue to develop climate policies and regulations, it will be interesting to see how this affects the Bitcoin market and its energy consumption.

We hypothesize that CPU and GPEI asymmetrically affect cryptocurrency prices. There are several ways CPU, Bitcoin, and energy prices can interact. First, climate policy uncertainty can create a lack of incentives to switch to renewable energy sources for Bitcoin mining, as there may be no clear policy direction toward clean energy. Therefore, Bitcoin mining could continue to rely on fossil fuels. Second, climate policy uncertainty could lead to negative perceptions of Bitcoin's energy consumption and carbon footprint. As climate concerns become more pressing, investors and consumers may shift towards more eco-friendly alternatives, which could lead to a decline in Bitcoin's market share. Third, Climate policy can also drive technology innovation. A clear policy direction towards clean energy and sustainability could create incentives to develop more energy-efficient Bitcoin mining technologies that rely on renewable energy sources.

In summary, Bitcoin's high energy consumption jeopardizes the climate through the carbon footprint, a significant climate policy input. With Bitcoin's growing popularity, its trade is increasing, emitting more carbon on the planet, which increases climate policy uncertainty. Thus, carbon-aware investors may react differently when the CPU increases and decreases, leading to CPU's asymmetric effects on cryptocurrencies. Since Bitcoin is energy-intensive, investors' expectations may differ when GPEI increases and decreases. However, no studies have investigated the asymmetric effects of CPU and GPEI on BTC. The findings may involve financial and climate policy implications for policymakers and investors.

The paper's novelty is that it is the first to examine CPU and GPEI on BTC and provides the first-ever evidence of CPU's and GPEI's asymmetric effects on Bitcoin prices. This paper has three unique contributions. First, the study examines the asymmetric effects of climate policy uncertainty and energy prices on Bitcoin prices, which is a unique contribution. While previous studies have looked at the relationship between Bitcoin prices and energy prices, this study goes further by examining how climate policy uncertainty impacts this relationship. Second, unlike other studies, this article considers the impact of climate policy uncertainty on Bitcoin prices. Climate policy is an emerging field, and the study is the first to examine how it affects the Bitcoin market. This is important because the global shift towards low-carbon economies and the growing concern about climate change may significantly impact Bitcoin prices. Third, the article employs advanced econometric techniques to examine the asymmetric effects of climate policy uncertainty and energy prices on Bitcoin prices. These techniques allow for a more precise analysis of the relationship between these variables and Bitcoin prices. Specifically, the study uses the Nonlinear ARDL(NARDL) model to capture the asymmetric effects.

The paper is structured into five sections. The 2 section outlines the empirical methodology, while the 3section provides information on the data used in the study. The 4 section presents and discusses the empirical findings. Lastly, the paper is concluded in Section 5.

## 2. Related studies

### 2.1. Bitcoin and climate policy uncertainty

Bitcoin mining requires a lot of energy, and a significant amount comes from fossil fuels. The more uncertain the climate policy is, the less incentive it is for bitcoin miners to switch to renewable energy sources. In other words, if there is no clear policy direction toward clean energy, bitcoin mining will likely continue relying on fossil fuels.in addition, if bitcoin continues to be associated with high energy consumption and carbon emissions, it may become increasingly unpopular with consumers and investors concerned about climate change. This could reduce demand for bitcoin and make it less valuable. Cryptocurrency mining necessitates abundant power consumption, which is increasing rapidly. A plethora of literature discusses the possible association between the mining of cryptocurrencies and its climatic consequences. For instance, Goodkind et al. (2020) empirically investigated the climatic and health damage associated with mining cryptocurrencies. The authors employ the data of four popular cryptocurrencies and found that a $1 value in Bitcoin was responsible for $0.49 and $0.37 deterioration in climatic and health conditions in the US and China, respectively. Similarly, past research raised concerns related to climatic changes and argued that carbon emissions concomitant to the mining of Bitcoin could alone increase the global temperature by over 2 °C (Camilo, 2018); an increase in Bitcoin's carbon footprint and negative environmental externalities (Stoll et al., 2019), cryptocurrencies mining and its unsustainable impact on smart cities (Fadeyi et al., 2019). Therefore, the development of virtual currencies has alarmed the attention of researchers and policymakers for the looming threats to the environment, raising questions about its sustainability and carbon neutrality (Yahya & Lee, 2023). Several studies have concluded that excessive crypto assets mining might multiply future energy needs, raise industries' energy intensity, harm the natural environment, and subsequently cause uncertain climatic conditions if the mining of cryptocurrencies is sustained.

Overall, previous literature lacks empirical foundations as they are based upon simplistic estimations of energy consumption focusing upon forecasting future trends of CO2 emissions relating to rising cryptocurrency mining or mining of metals and its comparisons with cryptocurrency mining. Therefore, a broader scope of research intervention is exploring the possible energy-environment-crypto assets nexus.

### 2.2. Bitcoin and energy prices

Bitcoin mining, the process by which new bitcoins are created and transactions are verified on the blockchain network, requires a significant amount of energy. The energy consumption of Bitcoin mining comes primarily from the computing power needed to solve complex mathematical equations to verify transactions and add new blocks to the blockchain. As a result, the energy cost is a major factor in the profitability of Bitcoin mining operations. When energy prices are high, it becomes more expensive to mine Bitcoin, reducing the profitability of mining and potentially decreasing the amount of Bitcoin being produced. On the other hand, the high energy consumption associated with Bitcoin mining can also contribute to increased demand for energy, which can drive up energy prices in certain areas.

In some cases, Bitcoin miners may even seek out areas with lower energy prices or subsidies to reduce costs and increase profitability. According to the bitcoin electricity consumption index published by the University of Cambridge, as of January 2017, the total monthly bitcoin electricity consumption stands at 1.79 TW-hours (TWh), which surged to the tune of 15.05 TW-hours by July 2022. Other studies, such as Goodkind et al. (2020) and Krause and Tolaymat (2018), pointed out that 1 million bitcoins were mined, consuming 2.5 billion kWh units of power in 2016. Albeit a marginal drop in bitcoin mining to 700,000 compared to 1 million in 2016, the power usage rose to 47.9 billion kWh in 2018. According to the Cambridge Center for Alternative Finance (CCAF), bitcoin mining is expected to increase the annual power usage by approximately 110 TWh, equivalent to 0.55% of the global and annual electricity consumption of small countries as Malaysia or Sweden (Cuen, 2021). Karmakar et al. (2021) used the daily electricity load of Bitcoin and found an increase in volatility over time, especially during the COVID-19-related lockdown enforced to contain the virus spread in the US.

Similarly, Corbet, Lucey, and Yarovaya (2021a, 2021b) find a significant nexus between volatility in cryptocurrency markets and power utility companies. Further, the authors show a surge in the appreciation of Bitcoin's price in late 2017, influencing the profitability of power companies. Therefore, previous studies indicate a close connection between cryptocurrency mining and its underlying dynamics on energy markets influencing the prices of energy and the performance of the energy generation sector. In summary, the relationship between Bitcoin and global energy prices can vary depending on several factors, including energy cost, the efficiency of mining operations, and the demand for Bitcoin itself.

## 3. Methods

We employ the NARDL method, as data series are nonlinear shown in Table 2. The choice of the model is based on the NARDL method's advantage over other linear econometric methods because it can account for both short- and long-term asymmetries by modeling asymmetric cointegration (Mensi et al., 2016; Demir et al., 2021). Also, the problem of multicollinearity is avoided by selecting the appropriate lag order for the included variables (Shin et al., 2014). This method can catch each independent variable's asymmetric short- and long-term impact on the dependent variable. Besides, NARDL can analyze the presence of any asymmetry of non-stationary variables in a single equation. Most price series are usually non-stationary; therefore, NARDL is suitable for exploring and establishing the relationship between green bond prices and WTI oil prices (Chattopadhyay & Mitra, 2015). The NARDL has been applied to study the asymmetric climatic effects on crops (Mujtaba et al., 2022) and financial markets (Naifar, 2022; Sarker et al., 2022; Tang et al., 2023). This method decomposes the CPU and GPEI into positive and negative partial sums of increases and decreases.

$$CPU_t^+ = \sum\nolimits_{j=1}^{t} \Delta CPU_j^+ = \sum\nolimits_{j=1}^{t} \max\left(\Delta CPU_j, 0\right) \quad (1)$$

$$CPU_t^- = \sum\nolimits_{j=1}^{t} \Delta CPU_j^- = \sum\nolimits_{j=1}^{t} \min\left(\Delta CPU_j, 0\right) \quad (2)$$

and

$$GPEI_t^+ = \sum\nolimits_{j=1}^{t} \Delta GPEI_j^+ = \sum\nolimits_{j=1}^{t} \max\left(\Delta GPEI, 0\right) \quad (3)$$

$$GPEI_t^- = \sum\nolimits_{j=1}^{t} \Delta GPEI_j^- = \sum\nolimits_{j=1}^{t} \min\left(\Delta GPEI_j, 0\right) \quad (4)$$

Following Shin et al. (2014), we specify the NARDL error correction model as the following:

$$\Delta BTC_t = \alpha_1 + \alpha_2 BTC_{t-1} + \beta_1 CPU_{t-1}^+ + \beta_2 CPU_{t-1}^- + \sum_{i=0}^{r}\left(\lambda_t^+ \Delta CPU_{t-i}^+ + \lambda_t^- \Delta CPU_{t-i}^-\right) + \mu_t \quad (5)$$

$$\Delta BTC_t = \alpha_1 + \alpha_2 BTC_{t-1} + \beta_1 GPEI_{t-1}^+ + \beta_2 GPEI_{t-1}^- + \sum_{i=0}^{n}\left(\lambda_t^+ \Delta GPEI_{t-i}^+ + \lambda_t^- \Delta GPEI_{t-i}^-\right) + \mu_t \quad (6)$$

The symbols (p, m) and (r, n) indicate the respective lag lengths for BTC and CPU, GPEI, respectively. If $\lambda_i^+ = \lambda_i^-$ for all $i = 0, \ldots, r$, then we find short-term symmetric effects. Similarly, if $\beta_1 = \beta_2$, We found some long-term symmetric effects.

## 4. Data

We use the monthly time-series data of BTC, CPU, and GPEI from 2013M10–2021M12. The CPU, recently developed by (Gavriilidis, 2021), was downloaded from www.economicpolicyuncertainty.com/. We use Bitcoin because Bitcoin is a leading crypto asset with a market capitalization of US$318.50.78 billion as of November 2022. We extracted Bitcoin data from www.investing.com/ and GPEI from https://fred.stlouisfed.org/.

The results (Table 1) show that the variables are first-differenced stationary at a 1% significance level. The series should be stationary at I(0), or I(1), or a mix but should not be I(2) (Shin et al., 2014). Thus, the requirement for applying the NARDL model is met. In addition, we performed the Brock–Dechert–Scheinkma (BDS) test of Brock et al. (1996), which confirms that the variables are nonlinear.

The BDS test statistics show that the Bitcoin prices, global energy price index, and climate policy uncertainty are nonlinear.

## 5. Results and discussion

Table 3 shows the NARDL estimation results. The results show that the $F_{PSS}$- and $^{t}$BDM statistics are significant at 1% and 10% levels, confirming that the CPU and GPEI are cointegrated. Short-term estimates show that the CPU's increase shows a higher negative impact on BTC. In general, an increase in climate policy uncertainty could potentially have a negative effect on Bitcoin prices in the short term, as it could impact the cost of energy, increase volatility in the energy markets, and lead to increased regulatory scrutiny of cryptocurrencies. This finding is consistent with (Bouri et al., 2022). This indicates that investors decrease

**Table 1**
Descriptive statistics and data stationarity.

| | BTC | CPU | GPEI |
|---|---|---|---|
| Mean | 7.9334 | 4.8500 | 4.9108 |
| Std. Dev. | 1.7374 | 0.6313 | 0.3225 |
| Skewness | 0.0788 | −0.1232 | 0.0002 |
| Kurtosis | 1.7238 | 2.6022 | 2.9071 |
| Jarque-Bera | 6.8204 | 0.9029[a] | 0.0355[a] |
| ADF, I(0) | −0.7100 | −1.7264 | −2.2285 |
| ADF, I(1) | −12.715[a] | −4.3211[a] | −6.4934[a] |
| PP, I(0) | −0.7064 | −4.2383[b] | −1.6843 |
| PP, I(1) | −11.970[a] | −17.6102[a] | −6.1527[a] |

Notes: Superscripts “a" “b" indicate 1% and 5% significance levels.

**Table 2**
BDS test for nonlinearity.

| m | BTC | GEPI | CPU |
|---|---|---|---|
| 2 | 0.169105[a] | 0.023103[a] | 0.192290[a] |
| 3 | 0.288272[a] | 0.034755[a] | 0.323998[a] |
| 4 | 0.369104[a] | 0.042169[a] | 0.414113[a] |
| 5 | 0.423254[a] | 0.045248[a] | 0.475130[a] |
| 6 | 0.458289[a] | 0.042847[a] | 0.516072[a] |

Note: Superscript “a" indicates significance at 1% level.

**Table 3**
Asymmetric effects of CPU and GPEI on BTC.

| Variables | CPU's effect on BTC | | Variables | GPEI's effects on BTC | |
|---|---|---|---|---|---|
| | Coefficients | Std. Error | | Coefficients | Std. Error |
| Short-term estimates | | | | | |
| $\Delta LCPU^{+}$ (-1) | −0.1337[c] | 0.0766 | $\Delta LGPEI^{+}$ | −0.0021 | 0.9253 |
| $\Delta LCPU^{+}$ (-2) | −0.1823[a] | 0.0684 | | | |
| $\Delta LCPU^{+}$ (-3) | −0.1235[c] | 0.0675 | | | |
| $\Delta LCPU^{-}$ | 0.0153[a] | 0.0206 | $\Delta LGPEI^{-}$ | 0.0610[b] | 0.3146 |
| Long-term estimates | | | | | |
| $LCPU^{+}$ (-1) | −0.2001[a] | 0.0492 | $LGPEI^{+}$ | −0.0572[a] | 0.0148 |
| $LCPU^{-}$ (-1) | 0.1898[a] | 0.0536 | $LGPEI^{-}$(-1) | 0.1920[a] | 0.0728 |
| Bounds tests | | | | | |
| $F_{PSS}$ | 7.3136[a] | | 5.9238[a] | | |
| $t_{BDM}$ | −5.5432[a] | | −3.0921[c] | | |
| Asymmetries | | | | | |
| $W_{SR}$ | 3.8538 | [0.0528] | $W_{SR}$ | 5.1468 | [0.0569] |
| $W_{LR}$ | 6.0173 | [0.0741] | $W_{LR}$ | 6.8954 | [0.0616] |
| Diagnostic tests | | | | | |
| ECM (-1) | −0.0757 | [0.0000] | ECM (−1) | −0.0644 | [0.0000] |
| $R^2$ | 0.8087 | | $R^2$ | 0.9582 | |
| $\chi^2_{HET}$ | 0.5957 | [0.4367] | $\chi^2_{HET}$ | 0.0759 | [0.7829] |
| $\chi^2_{SC}$ | 0.4895 | [0.5781] | $\chi^2_{SC}$ | 0.3022 | [0.7236] |
| $\chi^2_{NOR}$ | 0.2180 | [0.8967] | $\chi^2_{NOR}$ | 1.9644 | [0.3744] |
| Cusum sq | Stable | | Cusum sq | Stable | |

Notes: Superscripts “a”, “b”, and “c" indicate significance at 1%, 5%, and 10% levels, respectively. The superscripts "+" and "-" imply positive and negative cumulative sums. $W_{SR}$ and $W_{LR}$ are short-term and long-term Wald-test results. $\chi 2_{HETR}$, $\chi 2_{SC,}$ and $\chi^2_{NOR}$ represent heteroskedasticity, serial correlation, and normality tests. Empty cells mean the absent variables in the model. Values in [] are p-values.

its use and investment when the CPU increases, leading to a fall in Bitcoin demand and price. For example, Bitcoin mining requires a significant amount of energy, which has been criticized for its potential negative impact on the environment. If there is uncertainty around climate policy, such as changes in regulations or taxes on carbon emissions, this could potentially increase the cost of energy and make Bitcoin mining less profitable. This could lead to a decrease in the overall hash rate of the Bitcoin network, which could negatively impact the security and reliability of the network and potentially lead to a decrease in demand for Bitcoin. GPEI's decrease positively affects BTC, suggesting that a unit fall in energy prices would increase Bitcoin price by 0.76%. This implies that a decrease in energy prices would make Bitcoin mining and operation cheaper, and thus, investors increase Bitcoin investment and its use. When energy costs decrease, it becomes less expensive for Bitcoin miners to operate, as electricity is one of the most significant expenses for mining operations. This can lead to increased profitability for miners, who may need to spend less money to generate the same amount of Bitcoin. As a result, they may choose to hold onto their Bitcoin holdings instead of selling them, which can reduce the supply of Bitcoin on the market and potentially lead to an increase in prices.

Additionally, a decrease in global energy prices can increase the overall hash rate of the Bitcoin network. This is because some miners may choose to expand their operations due to the lower cost of electricity or may switch from other, less profitable cryptocurrencies to Bitcoin. An increase in the hash rate can positively impact the security and reliability of the Bitcoin network, potentially leading to an increase in demand for Bitcoin and a subsequent increase in prices. However, factors such as investor sentiment, regulatory developments, and macroeconomic conditions can all play a role in determining the short-term price movements of Bitcoin. Therefore, a decrease in global energy prices is one of many potential factors that can impact the price of Bitcoin in the short term.

In the long term, CPU's increases have significantly greater effects (−0.2001) on BTC than decreases (0.1898) and are supported by (Lee, Wang, et al., 2022a,b). A potential explanation can be that an increase in climate policy uncertainty could also potentially lead to increased regulatory scrutiny of Bitcoin and other cryptocurrencies. This could lead to increased restrictions on using and trading cryptocurrencies, negatively impacting demand and decreasing Bitcoin prices. Declines in GPEI have significantly higher impacts (0.1920) on BTC than increases (−0.05), implying that a reduction in energy prices increases demand for and price of Bitcoin and is supported by (Ren et al., 2022; Sarkodie et al., 2022; Sokhanvar & Lee, 2022). This can be explained by lower energy prices making Bitcoin mining more profitable and attracting more miners to the network. It can increase the hash rate, which can improve the security and reliability of the Bitcoin network, potentially making it more attractive to investors and users. A stronger and more secure network can also increase demand for Bitcoin, potentially increasing its long-term price. Furthermore, investor sentiment, technological developments, and regulatory changes can significantly shape Bitcoin's long-term price trajectory.

The short-and long-term asymmetry effects are significant, indicating inconsistent investment outlooks over different investment horizons. The significant and negative estimates of ECM (−1), i.e., (−0.0757, −0.0644), are low, confirming that the correction speed following the shocks from CPU and GPEI are slow, in which CPU and GPEI are essential for predicting the BTC fluctuations. The diagnostic results show that the models are homoscedastic, serially uncorrelated, and follow a normal distribution.

Fig. 1 shows that the blue lines remain within the red lines, indicating the stability of all coefficients in the NARDL models.

### 5.1. Nonlinear granger causality test

A nonlinear Granger causality test determines whether one time series has a causal effect on another time series, considering any nonlinear relationships between them. Nonlinear Granger causality is used in various fields, including economics, and finance, to understand the causal relationships between complex systems that may exhibit nonlinear behavior. It is a powerful tool for identifying hidden causal relationships that may not be apparent through linear analysis. Following (Diks & Panchenko, 2006), we test the nonlinear Granger causality to examine whether increases/decreases in CPU and GEPI can predict the BTC. In this case, the null hypothesis is that the past values of time series CPU do not Granger-cause the future values of time series BTC nonlinearly. If the p-value associated with the test statistic is less than the chosen significance level (0.05), the null hypothesis is rejected, indicating evidence of

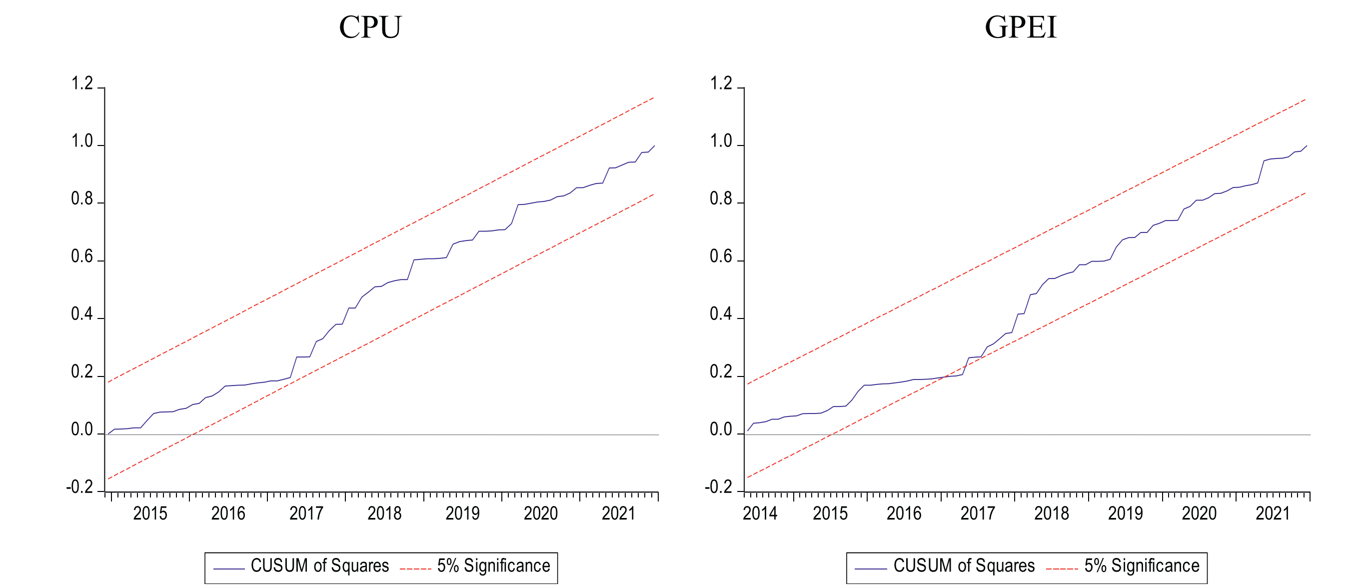


**Fig. 1.** Cumulative sum of squares (CPU and GPEI).

**Table 4**
Nonlinear Granger causality test results.

| Series | CPU→BTC | BTC→CPU | Series | GPEI→BTC | BTC→GPEI |
|---|---|---|---|---|---|
| $LCPU^{+}$ | 1.790[b] | 1.515[c] | $LGPEI^{+}$ | 1.851[b] | 0.895 |
| $LCPU^{-}$ | 2.077[b] | 2.19[b] | $LGPEI^{-}$ | 1.652[b] | 0.566 |

Notes: 1). $lx = ly = 1.2$). Superscripts b and c indicate the significance of the t-statistic at 5% and 10% levels, respectively. 3). "→" indicates the null hypothesis of granger non-causality.

nonlinear Granger causality from time series CPU to time series BTC.

The results from (Table 4) show significant bidirectional nonlinear granger causality between the increase and decrease in CPU and BTC. This is explained by investor sentiment/perception about energy consumption or technological developments, which may also influence changes in Bitcoin prices. Climate policy uncertainty could lead to negative perceptions of Bitcoin's energy consumption and carbon footprint. As climate concerns become more pressing, investors and consumers may shift towards more environmentally-friendly alternatives, which could lead to a decline in Bitcoin's market share. In contrast, climate policy can also drive technology innovation. Any policy towards clean energy can create incentives to develop more energy-efficient Bitcoin mining technologies and create demand for Bitcoin.

On the other hand, the increase and decrease in GPEI unidirectionally granger cause BTC. The energy consumption of Bitcoin mining comes primarily from the computing power needed to solve complex mathematical equations to verify transactions and add new blocks to the blockchain. As a result, the energy cost is a major factor in the profitability of Bitcoin mining operations. When energy prices are high, it becomes more expensive to mine Bitcoin, reducing the profitability of mining and potentially decreasing the amount of Bitcoin being produced. On the other hand, the high energy consumption associated with Bitcoin mining can also contribute to increased demand for energy, which can drive up energy prices in certain areas. These findings signify that the asymmetry effects have a causal relationship with BTC.

## 6. Conclusion ad policy implications

This study investigated the asymmetric effects of CPU and GPEI on BTC using the NARDL model and nonlinear Granger causality tests. The findings show the short- and long-term asymmetry effects, indicating that the positive impact of CPU and GPEI are unique from the adverse effects on BTC in both short-and long-term equilibrium. Besides, causality results show a bidirectional nonlinear causality between BTC and CPU's increases/decreases, while unidirectional causality from GPEI's increases/decreases to BTC.

The findings suggest that when investors are uncertain about the future regulatory environment for Bitcoin mining and its impact on the environment, they may become hesitant to invest in Bitcoin, leading to a decline in Bitcoin prices. Bitcoin mining requires a significant amount of energy, and as energy prices increase, so does the cost of mining Bitcoin. This can create a scarcity effect, making Bitcoin more valuable and increasing its price.

Given these findings, Bitcoin investors should be aware of the potential impact of climate policy uncertainty and energy prices on Bitcoin prices. Increased uncertainty around Bitcoin mining regulations or a significant increase in energy prices could lead to a decline in Bitcoin prices. On the other hand, if energy prices remain low and stable, this could create a positive environment for Bitcoin investors, as it may become more profitable to mine Bitcoin, driving up its value. Specifically, investors can hedge BTC with a GPEI's decrease when CPU increases. Investors can also predict Bitcoin's price behavior for CPU and GPEI's increase and decrease. Therefore, investors should monitor these factors and make informed investment decisions based on their market analysis.

## Data availability statement

The data are publicly available online.

## Funding

This research received no funding.

## Declaration of competing interest

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.

## References

Afjal, M., & Sajeev, K. C. (2022). Interconnection between cryptocurrency and energy market: An analysis of volatility spillover. *Opec Energy Review*. https://doi.org/10.1111/opec.12227
Bouri, E., Iqbal, N., & Klein, T. (2022). Climate policy uncertainty and the price dynamics of green and brown energy stocks. *Finance Research Letters, 47*. https://doi.org/10.1016/j.frl.2022.102740

Brock, W. A., Dechert, W. D., Scheinkman, J. A., & LeBaron, B. (1996). A test for independence based on the correlation dimension. *Econometric Reviews, 15*(3), 197–235.

Camilo Mora, R. L. (2018). Bitcoin emissions alone could push global warming above 2°C. *Nature Climate Change*. https://www.nature.com/articles/s41558-018-0321-8?source=content_type%3Areact%7Cfirst_level_url%3Aarticle%7Csection%3Amain_content%7Cbutton%3Abody_link.

Corbet, S., Lucey, B., & Yarovaya, L. (2021a). Bitcoin-energy markets interrelationships - new evidence. *Resources Policy, 70*. https://doi.org/10.1016/j.resourpol.2020.101916. March 2021.

Corbet, S., Lucey, B., & Yarovaya, L. (2021b). Bitcoin-energy markets interrelationships - new evidence. *Resources Policy, 70*. https://doi.org/10.1016/j.resourpol.2020.101916

Cuen, L. (2021). The debate about cryptocurrency and energy consumption. https://techcrunch.com/2021/03/21/the-debate-about-cryptocurrency-and-energy-consumption/.

Demir, E., Simonyan, S., García-Gómez, C.-D., & Lau, C. K. (2021). The asymmetric effect of bitcoin on altcoins: Evidence from the nonlinear autoregressive distributed lag (NARDL) model. *Finance Research Letters, 40*. https://doi.org/10.1016/j.frl.2020.101754. May 2021.

Diks, C., & Panchenko, V. (2006). A new statistic and practical guidelines for nonparametric Granger causality testing. *Journal of Economic Dynamics and Control, 30*(9–10), 1647–1669. https://doi.org/10.1016/j.jedc.2005.08.008

Fadeyi, O., Krejcar, O., & Petra Maresova, K. K. (2019). Opinions on sustainability of smart cities in the context of energy challenges posed by cryptocurrency mining. *Sustainability*. https://www.mdpi.com/2071-1050/12/1/169.

Fahmy, H. (2022). The rise in investors' awareness of climate risks after the Paris Agreement and the clean energy-oil-technology prices nexus. *Energy Economics, 106*. https://doi.org/10.1016/j.eneco.2021.105738, 2022.

Fried, S., Novan, K. M., & Peterman, W. (2021). The macro effects of climate policy uncertainty. *FEDS Working Paper No. 2021-018* https://dx.doi.org/10.17016/FEDS.2021.018.

Gavriilidis, K. (2021). *Measuring climate policy uncertainty*. SSRN E J.. Retrieved from https://ssrn.com/abstract=3847388.

Goodkind, A. L., Jones, B. A., & Berrens, R. P. (2020). Cryptodamages: Monetary value estimates of the air pollution and human health impacts of cryptocurrency mining. *Energy Research & Social Science*. https://doi.org/10.1016/j.erss.2019.101281

Karmakar, S., Demirer, R., & Gupta, R. (2021). Bitcoin mining activity and volatility dynamics in the power market. *Economics Letters*. https://doi.org/10.1016/j.econlet.2021.110111

Krause, M., & Tolaymat, T. (2018). Quantification of energy and carbon costs for mining cryptocurrencies. *Nature Sustainability*. https://doi.org/10.1038/s41893-018-0152-7

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. *Review of Financial Studies, 33*(3), 1067–1111. https://doi.org/10.1093/rfs/hhz137

Lauri, P., Havlík, P., Kindermann, G., Forsell, N., Böttcher, H., & Obersteiner, M. (2014). Woody biomass energy potential in 2050. *Energy Policy, 66*(2014), 19–31. https://doi.org/10.1016/j.enpol.2013.11.033

Lee, C.-C., Wang, C.-W., Thinh, B. T., & Xu, Z.-T. (2022a). Climate risk and bank liquidity creation: International evidence. *International Review of Financial Analysis, 82*. https://doi.org/10.1016/j.irfa.2022.102198. July 2022.

Lee, C.-C., Yuan, Z., Lee, C.-C., & Chang, Y.-F. (2022b). The impact of renewable energy technology innovation on energy poverty: Does climate risk matter? *Energy Economics, 116*. https://doi.org/10.1016/j.eneco.2022.106427

Mensi, W., Hammoudeh, S., Yoon, S.-M., & Nguyen, D. K. (2016). Asymmetric linkages between BRICS stock returns and country risk ratings: Evidence from dynamic panel threshold models. *Revew of International Economics, 24*(1), 1–19. https://doi.org/10.1111/roie.12201

Mujtaba, A., Pawar, S., Joshi, D. P., & Gopinathan, R. (2022). Examining asymmetric impact of climatic factors on crop yields in India. *Applied Economics Letters*. https://doi.org/10.1080/13504851.2022.2064416

Naeem, M. A., & Karim, S. (2021). Tail dependence between bitcoin and green financial assets. *Economics Letters, 208*. https://doi.org/10.1016/j.econlet.2021.110068, 2021.

Naifar, N. (2022). Sukuk returns dynamics under bullish and bearish market conditions: Do COVID-19 related news and government measures matter? *Applied Economics Letters*. https://doi.org/10.1080/13504851.2022.2027860

Ren, X., Shi, Y., & Jin, C. (2022). Climate policy uncertainty and corporate investment: Evidence from the Chinese energy industry. *Carbon Neutrality, 1*(14). https://doi.org/10.1007/s43979-022-00008-6

Sarker, P. K., Bouri, E., & Marco, C. K. (2022). Asymmetric effects of climate policy uncertainty, geopolitical risk, and crude oil prices on clean energy prices. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-23020-w

Sarkodie, S. A., Ahmed, M. Y., & Leirvik, T. (2022). Trade volume affects bitcoin energy consumption and carbon footprint. *Finance Research Letters, 48*. https://doi.org/10.1016/j.frl.2022.102977, 2022.

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). In R. H. Sickles (Ed.), *Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework*. New York, NY: Springer. https://doi.org/10.1007/978-1-4899-8008-3_9.

Sokhanvar, A., & Lee, C.-C. (2022). How do energy price hikes affect exchange rates during the war in Ukraine? *Empirical Economics*. https://doi.org/10.1007/s00181-022-02320-7

Stoll, C., Klaaßen, L., & Gallersdörfer, U. (2019). The carbon footprint of bitcoin. *Joule, 3*(7), 1647–1661. https://doi.org/10.1016/j.joule.2019.05.012

Tang, Y., Chen, X. H., Sarker, P. K., & Baroudi, S. (2023). Asymmetric effects of geopolitical risks and uncertainties on green bond markets. *Technological Forecasting and Social Change, 189*. https://doi.org/10.1016/j.techfore.2023.122348. April, 2023.

Wu, X., Yin, X., & Mei, X. (2022). Forecasting the volatility of European union allowance futures with climate policy uncertainty using the EGARCH-MIDAS model. *Sustainability, 14*(7). https://doi.org/10.3390/su14074306

Yahya, F., & Lee, C.-C. (2023). The asymmetric effect of agriculturalization toward climate neutrality targets. *Journal of Environmental Management, 328*. https://doi.org/10.1016/j.jenvman.2022.116995

Zhao, X. (2020). Do the stock returns of clean energy corporations respond to oil price shocks and policy uncertainty? *J. Econ. Struct., 9*(53). https://doi.org/10.1186/s40008-020-00229-x