International Journal of Economics, Management and Accounting 33, no. 1 (2025): 1-21

RELATIONSHIP BETWEEN CRYPTO CURRENCIES AND CLIMATE CHANGE

Ismail Bekcı[a], Eda Kose[b*] and Esra Aksoy Erzurumlu[c]

[a]*Department of Business Administration, Suleyman Demirel University Eastern Campus Cunur, 32260 Isparta, Türkiye. (Email: ismailbekci@sdu.edu.tr)*

[b]*Department of Business Administration, Hacı Bektas Veli University, 50300 Nevsehir, Türkiye (Email:edakose@nevsehir.edu.tr)*

[c]*Department of Finance and Banking, Suleyman Demirel University Eastern Campus Cunur, 32260 Isparta, Türkiye. (Email: esraaksoy@sdu.edu.tr)*

ABSTRACT

Since the emergence of cryptocurrencies in 2008 to the present day, the volatility of bitcoin prices has generated a surge of interest among investors, as it provides an opportunity to profit from excessive price increases. Industry observers refer to it as a "growing energy problem" as bitcoin mining consumes more energy than most countries in recent times. This research study examines the causality relationship between the cryptocurrencies involved in Bitcoin mining and the amount of carbon emissions that lead to climate change. In the research study, the total energy consumption estimates and the predicted trend global CO_2 emission values of Bitcoin and Ethereum cryptocurrencies are discussed. The data used in the research study are the daily time-series data over the period 05.20.2017 - 04.08.2022. The analysis was conducted by performing the Toda-Yamamoto causality test. A bilateral causal relationship was found between Bitcoin and CO_2 emissions; whereas no significant connection existed between Ethereum and CO_2 emissions. In conclusion, the high energy consumption of cryptocurrencies and the resulting CO_2 emissions pose significant environmental challenges, bringing the sustainability of cryptocurrencies into question. In this context, efforts to increase the share of renewable energy in energy consumption of cryptocurrencies need to be accelerated. Additionally, this study will contribute to the development of theoretical foundations in this field.

JEL Classification: Q540, Q430, Q560

Keywords: Climate change, Bitcoin, Ethereum, Toda-Yamamoto Causality Analysis

*Corresponding author: edakose@nevsehir.edu.tr

Submitted: 28/03/2023 Accepted: 26/02/2024 Published: 28/06/2025

1. INTRODUCTION

Global climate change is a long-term change in the temperature and weather patterns of our world. These changes are not only natural but also arise from human activities affecting worldwide climate change (Trenberth, 2018). Human activities have caused the atmosphere to become filled with carbon dioxide and other heat-trapping substances (Hao et al., 2008). This temperature rise has caused melting of glaciers, rising sea levels, forest fires, floods and excessive precipitation (Kompas, Pham, and Che, 2018). In addition to such natural events, factors such as agriculture, energy use and public health negatively affect our lives (Tol, 2009). In fact, climate change is a long-term problem affecting all areas of human life. For example, as global warming increases following climate change, assets and substructure will be destroyed, productivity will decrease, and mass migrations and security threats will emerge. This situation will create many problems worldwide (Wade, 2016). This study explores the relationship between cryptocurrency production and climate change.

Before introducing how cryptocurrency mining affects the environment through energy consumption, some background on climate change is presented. Geographical features have changed several times around the world, from the existence of humanity until today. Periodically, the natural balance between the elements of the earth has been disturbed for various reasons. Depending on these deteriorations, there have been great climate changes. Especially since the beginning of the "Industrial Revolution", the amount of greenhouse gases in the atmosphere has increased. Since then, pollution and global temperature has been increasing, leading to climate change. Thus, the negative effects of climate change are gradually manifesting themselves. The human-induced impact of climate change has continued to increase in recent years.

The common view of climate scientists is that the climate change that will continue in the future will arise from global warming caused by the increase in greenhouse gas emissions in the atmosphere. If immediate steps are not taken to slow down acceleration of global warming, the Earth will experience unimaginable disruptions in every aspect of human life by 2050. Since the Industrial Revolution, the average surface temperature has risen by 0.8 °C due to past and ongoing human-induced greenhouse gas emissions caused by burning fossil fuels. Environmentalists warn that global warming would accelerate by

1.5°C by 2050, and catastrophic consequences of climate change may occur if no measures are taken to combat climate change within the next decade (Taskinsoy, 2019). To prevent such a disaster, the objectives of the “Paris Agreement” regarding climate change must be implemented within the given timeframe. Besides, new solutions are needed to get climate change under control. Emerging technologies such as blockchain have been developing new methods to prevent climate change. Blockchain is not only the technology utilized for cryptocurrency units but also serves as an independent instrument that can be used for various purposes.

Blockchain technology has become indispensable, particularly for financial systems, maintaining its popularity in recent years. Cryptocurrencies that have been developed using “Blockchain technology” provide users with various advantages such as being available for investment, being used as a medium of exchange, and having ease of storage. Many types of cryptocurrencies serve different purposes such as online payment, exchange in internet games and so forth. The uses of cryptocurrencies are increasing day by day. The most basic feature of cryptocurrencies is that they are not issued and managed by a central mechanism. The level of blockchain technology usage has been increasing considerably since 2018. The use of cryptocurrency units, which are products of developing technology, has raised energy consumption problems. People in the cryptocurrency system use a high amount of electrical energy to mine and distribute the currency. A high amount of energy consumption will increase costs. The returns of the processors in the system may decrease in parallel with this situation because they need to have a larger capacity operating system in order to do more scraping, and this comes across as an extra cost. On the other hand, in order to meet the increasing demand for cryptocurrencies over time, more excavation is made and thus energy consumption increases.

Considering Bitcoin's share in global electricity consumption, the importance of this consumption share is quite remarkable. Various studies have estimated the consumption that cannot be calculated clearly. Bitcoin production is carried out in the computer environment and by the processors making complex calculations. Increased value of Bitcoin in the last few years has led to more users producing Bitcoin. Cryptocurrencies result in huge demand for energy systems, but it is also thought to increase carbon emissions that affect global warming. In other words, cryptocurrency mining utilizes a significant amount of energy by including new blocks in the chain. Therefore, due to the amount of CO_2 emissions released to the natural environment, both the global ecosystem and human life are being endangered. These developments raised concerns regarding their environmental impacts. Such concerns, which have been frequently expressed recently, draw attention to the environmental impacts of cryptocurrencies and enhanced energy consumption.

As of 2021, governments, firms, media commentators, and economists have expressed their concerns regarding the environmental impacts of cryptocurrencies (Stoll, Klaaßen, and Gallersdörfer, 2019; De Vries, 2018). Some researchers have argued that cryptocurrencies, especially the very old Bitcoin, served as "economic batteries" in sustainable energy markets, and therefore, assumed importance (Bitcoin Clean Energy Initiative, 2021; Carter, 2020; Bendiksen and Gibbons, 2019). Bitcoin, "on the other hand, is defined as a decentralized inter-account electronic cash system that provides online payment without the intervention of any bank, government, or central authority" (Nakamoto, 2008). Although Bitcoin emerged in 2008, it is being preferred by investors due to its excessive price increase. The value of Bitcoin fluctuated between US$500 and US$1.200.000.000 over the period January-September 2021, generating more than 50% of the market cap of all cryptocurrencies combined (CoinMarketCap, 2021). There is a growing reaction to environmental issues for other cryptocurrencies, especially Bitcoin, whose value is increasing for investors (Cambridge Center for Alternative Finance, 2021). Industry observers have stated that it would have emerged with a "growing energy problem" as cryptocurrency networks consumed more electricity than most countries (De Vries, 2018). In support of this situation, the total annual energy cost of Bitcoin mining alone as of the year 2014 was calculated as equal to the total annual energy consumption of Ireland. In February 2021, research studies conducted by Cambridge University asserted that the annual energy consumption of bitcoin mining was approximately 121 terawatts per hour (https://www.bbc.com/ news/technology-56012952). According to these results, if cryptocurrencies were countries, they would be among the countries that consume the most energy in the world. It is aimed that society would be completely cash-free in the future, and therefore, although cryptocurrencies would gain value after a point, their ecological impacts that would lead to an environmental crisis should not be ignored (Walsh, 2021).

Predictions of the carbon footprint of cryptocurrencies are attracting enormous attention in both academic and public discussions. Nevertheless, cross-country comparison shows that crypto networks tend to concentrate more on emissions (Howson, 2019; Stoll et al., 2019). Binding relative measures on carbon emissions regarding cryptocurrencies, however, still do not constitute an important portion of the discussion. The financial aspect of cryptocurrencies, in general, has been researched in favor of investors. Nonetheless, in the case of merely dealing with cryptocurrencies financially and ignoring carbon emissions, misleading results would be obtained in terms of investment and portfolios.

Besides, criticism of the negative impact of cryptocurrencies on the climate is increasing today. Recently, Roeck and Drennen (2022), Badea and Mungiu-Pupazan (2021), Jiang et al. (2021) focused on the carbon dioxide emissions of cryptocurrency mining. Roeck and Drennen (2022) explored the environmental impact of bitcoin mining in New York. They used global warming, smoke generation, acidification, and pollutant emissions as environmental variables. The research revealed that Bitcoin mining not only hinders national climate measures, but also threatens local programs related to climate change. Panah et al. (2022) emphasized integrating regulatory practices into markets to reduce greenhouse gas emissions globally. They suggested reducing greenhouse gas emissions by investing in green hydrogen production in research. The idea that cryptocurrency mining would become profitable by doing this was discussed. At the same time, a crypto tax should be levied by correlating hydrogen costs with the bitcoin market. Erdogan, Ahmed, and Sarkodie (2022) investigated the asymmetric relationship between cryptocurrency demand and environmental sustainability/ Their findings suggest that demand for cryptocurrencies such as “Bitcoin (BTC), Ethereum (ETH) or Ripple (XRP)” results in environmental degradation. Badea and Mungiu-Pupazan (2021) conducted a comprehensive analysis covering energy consumption and carbon dioxide emissions with bitcoin data mining to reduce its negative impact on climate and environment. Their research highlights how energy is used in bitcoin transactions and bitcoin is used intensively by investors, although it harms the environment.

At the same time, although there are accusations about bitcoin usage, its use rate is increasing in many countries and it has gained credibility as a currency. In their research, Othman and Dob (2022) explored the relationship between bitcoin data mining and energy use and global carbon emissions between 2012-2021. The research findings show that before 2013, bitcoin mining was correlated between energy use and the global carbon emission index at different frequencies and time periods. After 2013, it shows that there is no relationship between bitcoin mining and energy consumption and the global carbon emission index. De Vries (2021) reveals that as bitcoin prices rise, the environmetal damage increases. It was determined that there was a high level of energy consumption as a result of the Bitcoin price breaking a record at the beginning of 2021. Hence it could result in a carbon footprint comparable to London. Accordingly, the causal relationship between Bitcoin and Ethereum and carbon dioxide (CO_2) emissions are to be examined in this research study. The research study concentrates on the causal relationship between climate change and the Bitcoin and Ethereum digital currencies presented by technology.

2. LITERATURE REVIEW

Almost all of the money used in the world has started to be digitalized. Especially with the pandemic, electronic payment methods have replaced paper payment methods. Many countries will become cashless societies in future. In the last two decades, certain alternative methods have been on the rise as all traditional money and banking transactions have shifted to the electronic field. These various forms of digital currencies or cryptocurrencies are online assets unlike our traditional notions of money. The first and best known of these is Bitcoin. Thousands of cryptocurrencies exist such as LiteCoin, NameCoin, PeerCoin and Ethereum, with new ones appearing every day (Walsh, 2021). As the cryptocurrency market continues to evolve, it will create some important problems in the future as well as its expected benefits. In particular, the energy use of bitcoin mining has increased to 4.8 Terrawatt hour (Twh) 73.12 Twh in the last two years. The energy footprint per Bitcoin transaction is estimated at 619 Kwt, which equates to the average US household's electricity consumption for 20.92 days. Considering its energy usage, bitcoin in its current form can be considered as an expensive and inefficient transmission mechanism. In addition, most bitcoin mining is located in China. The main fuel for these networks, the energy for each operation comes from coal-fired power stations (Corbet, Lucey, and Yarovaya, 2021). Cryptocurrency mining is getting more complex as the network of encrypted assets continues to grow. Bitcoin data mining machines will need more energy to operate and generate computing power requirements (Yan, Mirza, and Umar, 2022). In this situation, the concern regarding environmental damage caused by cryptocurrency mining is not surprising (Huynh, Hille, and Nasir, 2020).

At the same time, the "Cambridge Bitcoin Electricity Consumption Index (CBECI)" estimated Bitcoin's energy consumption to be around 100 TWh per year. It is more complicated to calculate the carbon footprint, which is required to know the power resources used by the total miner network, while calculating the energy consumption can be determined without error. Bitcoin also uses data models to make estimates of energy consumption in carbon footprint calculations, and estimates are made from this model to measure fossil fuel use of the mining network. These calculated estimates, however, contradict industry reports that claim to use data directly from data miners and arrive at very low estimates (Rennie, 2022).

The concept of “social licence” emerges in relation to Bitcoin and energy. This concept explains that strategies to own and maintain reputation capital are associated with the actions of people seeking legitimacy. In fact, this concept causes a loss of reputation by the public, mostly because disasters such as chemical spills threaten business activities (Moffat et. al., 2016). Like legitimacy, social licence acknowledges that social arrangements can come first (Jenkins, 2018; Gehman, Lefsrud, and Fast, 2017).

As of today, the frequently expressed concern about cryptocurrencies includes the environmental impacts associated with increased energy consumption and mining pollution. Upon considering the studies in this field, it is seen that such a concern is frequently raised along with the uncertainty it has created. Egiyi and Ofoegbu (2020) emphasized that although the impacts of Bitcoin are difficult to predict within the near future, it is predictable that the acceleration of its adoption could generate enough emissions for its electricity demand to produce emissions resulting in more than 2°C of global warming in a few decades. Nonetheless, they suggested that objectives are required to reduce demand for power to avoid potential demoralizing consequences of further cryptocurrency development. Browne (2021) stated that bitcoin mining can generate up to 36.95 megatonnes of CO_2 emissions per year. This rate is equivalent to New Zealand's per capita carbon footprint and more.

Undoubtedly, Bitcoin requires a large amount of energy as it has a significant market share (Corbet et al., 2019). Dilek and Furuncu (2019) studied Bitcoin mining and blockchain technology. The high amount of energy consumed by Bitcoin and its environmental aspects were discussed. With the increase in Bitcoin mining, the energy consumed has increased, and accelerated effects such as global warming and climate change, leading to environmental and social consequences. Krause and Tolaymat (2018) raised the question of the relationship between cryptocurrency mining and environmental damage. The current literature, research results have shown that people need more energy every year for bitcoin mining. For example, while 1005 kWh of electricity was used in January 2016, 60,461 kWH electricity was used in June 2018 (Krause and Tolaymat, 2018). Although there are existing studies on energy consumption and economics (Dey and Tareque, 2019), an in-depth understanding of the relationship between the mechanism of cryptocurrencies and the amount of energy is a fascinating subject. Greenberg and Bugden (2019) examined the energy consumption of US local communities from using crypto mining. The results obtained covered the following: (1) the effect of covariates between energy supplies and prices, (2) uncertainty in socioeconomic benefits, (3) illegal cryptocurrencies, (4) environmental problems resulting from increased electricity use, and (5) separation from the national heritage and the community economic identity.

Mohsin (2021) noted that concerns existed about the long-term impacts of widespread cryptocurrency usage. He emphasized that these included the increased CO_2 emissions due to energy consumption in cryptocurrency mining. Goodkind, Jones and Berrens (2020) estimated the economic losses of air pollution emissions and related human deaths as well as climate impacts of cryptocurrency mining per coin both in the USA and China, and found that the value of every US$1 worth of Bitcoin generated in 2018 accounted for US$0.49 and US$0.37 worth of health and climate damage in the USA and China, respectively. Gallersdörfer, Klaaßen, and Stoll (2020) made predictions about currency units, regardless of the uncertainty in assessing the demand for energy and associated greenhouse gas emissions of cryptocurrencies. Based on the underlying algorithms and suitable mining devices, they concluded that Bitcoin accounted for two-thirds of the total energy consumption, whereas the remaining cryptocurrencies accounted for one-third. Also, it was emphasized that understudied currencies would add about 50% to the energy impact of Bitcoin, which alone could cause a significant level of environmental damage.

Wang et al. (2022) developed a new index of cryptocurrency environmental attention to address the concerns regarding sustainable growth in cryptocurrency markets. It was determined that the index had a significantly positive relationship with the "volatility index (VIX)", Brent crude oil, and Bitcoin. Moreover the advanced index had a significant negative relationship with global economic policy uncertainty and global temperature uncertainty. Furthermore, the index had a significant and positive relationship with industrial production in the short run, but a significant and negative relationship in the long-run. Zhang et al. (2023) explored the environmental impacts of Cryptocurrency energy consumption on climate change. They highlighted the need to foster technological advances in developing energy efficient decentralized finance consensus algorithms to transform the cryptocurrency market into a climate-friendly one. The results will provide policy implications, emphasizing the importance of decarbonizing the cryptocurrency ecosystem in addressing environmental concerns. In addition, according to Truby et al. (2022), the Art industry wanted to draw attention to the impact of NFT operations on climate change. It has commercialized and popularized non-fungible tokens (NFTs), as NFT transactions rapidly grew to about US$10 billion in the third quarter of 2021. The surge in NFT transactions has drawn the attention of the art market to the carbon emissions from the verification of transactions on proof-of-work blockchains that support NFT transactions. Along with the CO2-related deaths attributable to NFT transactions, social pressure from the art market has helped advance the shift from deliberately polluting proof-of-work blockchains to more sustainable consensus protocols. Many popular types of blockchains, however, have resisted pressure to reduce their environmental impact, including Bitcoin, whose 2021 annual emissions will produce emissions responsible for future deaths. Recent global policy interventions have used legal and financial tools to reduce the carbon impact of some or all blockchain types. By associating the damage caused by proof-of-work blockchains with climate change and human deaths, they examined recent policy interventions designed to motivate miners' energy efficiency to reduce environmental damage and effect change in blockchain consensus protocols.

In the present study, we focused on the causality relationship between the increase in global CO_2 emission values that cause climate change and the total energy consumption of the cryptocurrencies Bitcoin and Ethereum. The hypothesis of our study is:

H0: Total energy consumption of Bitcoin and Ethereum is not the cause of the increase in $C0_2$ emissions.

H1: Total energy consumption of Bitcoin and Ethereum is the cause of the increase in $C0_2$ emissions.

3. METHODOLOGY, DATASET, AND ANALYSIS

In this part, a brief description of the methodology used in the research study is made and the dataset and analysis phases are introduced in compliance with the study objective.

3.1 METHODOLOGY

In the research study, the relationship between Bitcoin and Ethereum and carbon dioxide (CO_2) emissions is investigated by performing the Toda-Yamamoto causality test. The omission of the stationarity of the series or the existence of a cointegration relationship in the analysis accounts for the preference for the Toda-Yamamoto test. In the conventional Granger (1969) causality test, on the other hand, it is necessary to ensure that the series is stationary and contains a cointegration relationship (Mecik and Koyuncu, 2020). Additionally, in our study, only causal analysis has been preferred. This is because regression analysis entails the dependency of one variable on another. However, this dependency does not imply causality. No matter how strong, a statistical relationship may not inherently indicate causality. Causality is established through theoretical examination. In our study, we focused on the causal relationship. We constructed a model based on the premise that the increase in global CO_2 emissions, caused by climate change, may be related to the total energy consumption of cryptocurrencies such as Bitcoin and Ethereum.

The fact that the series is stationary/cointegrated to the same degree according to the Toda-Yamamoto causality test does not hamper the test validity. This situation is not valid in the Granger causality test and may cause data loss by rendering the series stationary by taking the first difference.

In order to perform the Toda-Yamamoto causality test, the Vector Autoregressive (VAR) model is established first. The lag length (k) is determined with the established VAR model. Then, the highest degree of cointegration (d_{max}), is included in the obtained lag length (Mecik and Koyuncu, 2020). Here, unit root tests are performed to determine the stationarity degrees of the series (Ata and Yucel, 2003). The Dickey-Fuller (1979) (DF) test is one of the most widely used and oldest unit root tests. The DF test is based on the assumption that the error terms are statistically independent and have constant variance. The Augmented Dickey-Fuller (ADF) was proposed in 1981 for avoiding the autocorrelation problem that can be encountered in error terms upon performing the DF tests (Izolluoglu, 2019). The ADF is performed as the unit root test in the analysis part of the research study.

3.2 DATASET AND ANALYSIS

Recently, research studies suggesting that Bitcoin mining increases carbon emissions along with energy use have been attracting attention.

This situation accompanies the negative impacts of climate change (Iklim, 2018). In this context, this research study aims at investigating the causal relationship between the cryptocurrencies involved in Bitcoin mining and the level of carbon emissions that cause climate change. The total energy consumption predictions for Bitcoin and Ethereum, as well as the predicted trend of global CO_2 emission values, are discussed. The data used in the research study are the daily time-series data obtained over the period 20.05.2017- 04.08.2022. The beginning date of the obtained data is determined as 20.05.2017 since the earliest data on cryptocurrencies and carbon emissions that are the topics of the research have been simultaneously accessed on this date. CO_2 emission values are obtained from the Global Monitoring Laboratory (NOAA) (gml.noaa.gov). The latest predictions of the total energy consumption of the networks of Bitcoin and Ethereum are obtained from the website called digiconomist, which presents the data under the titles of “Bitcoin Energy Consumption Index” and “Ethereum Energy Consumption Index” (https://digiconomist.net/). During the analysis phase, Bitcoin is denoted by “BIT”, Ethereum by “ETH”, and carbon dioxide emission values by “CO_2”. Toda-Yamamoto's (1995) Causality Test is preferred for analysis. Firstly, the ADF unit root tests are performed to determine the highest stationarity levels (d_{max}) of the data. Then, the optimal lag lengths are determined. Using the obtained information, the Toda-Yamamoto causality analysis is conducted. According to the analysis results, the relationships among the variables are determined. In this regard, the analysis results are presented as next. Before analysis, descriptive statistics for the variables are given in Table 1.

TABLE 1
Descriptive Statistics of Variables

	CO_2	BIT	ETH
Mean	411.0472	81.5866	25.0844
Standard Error	0.0818	1.1769	0.7121
Median	411.1900	73.1215	10.6450
Mode	405.2800	73.1215	11.7130
Standard Deviation	3.4483	49.6379	30.0360
Sample Variance	11.8910	2463.9202	902.1615
Kurtosis	-1.2135	0.9246	2.1265
Skewness	-0.0127	1.2653	1.8416
Count		1779	

4. RESULTS

4.1 UNIT ROOT TESTS

The existence of unit roots for the variables is determined by performing the ADF unit root tests. The hypotheses for the ADF unit root tests are as follows:

H0: Series is not stationary.

H1: Series is stationary.

In Tables 2, 3, and 4 presented below, the degrees of stationarity (d_{max}) of the series are examined. In Table 2, the stationarity of the variables is examined. ADF Unit root test is used to calculate the stationarity of the variables. "CO_2", "BIT" and "ETH" values are not stable at the level. The analysis is continued in order to determine the stationarity levels of the variables. Variables are reanalyzed by taking the 1st degree difference with the ADF unit root test.

Table 3 shows the ADF unit root test results. The stationarity of the variables at the 1st difference is determined. According to the results, "BIT" and "ETC" variables are stationary at the first difference.

The analysis is continued in order to determine the stability level of the "CO_2" variable.

The results of the second-order stationarity test of the "CO_2" variable are shown in Table 4. Looking at the ADF unit root test results, the "CO_2" variable became stationary at the second difference.

As can be seen from the tables above, according to the ADF unit root test results, the "*BIT*" and "*ETH*" series are stationary at the first difference. Again, according to the unit root test results, the "CO_2" series is determined as stationary at the second difference.

4.1.1 DETERMINATION OF LAG LENGTH

The optimal lag length in the VAR model is tested at the 5% significance level. The optimal lag length (k) indicated by the majority of the information criteria is chosen for the model. The test results for determining the optimal lag lengths by the VAR model are shown in Table 5.

As can be seen from Table 5, the optimal lag length is determined to be 8 according to the VAR model.

TABLE 2
ADF Unit Root Tests (At Level)

At Level	Constant		Constant with Trend		Non-Constant without Trend	
Variables	t-statistic	Prob. value	t-statistic	Prob. Value	t-statistic	Prob. Value
$C0_2$	0.3089	0.9788	-2.5343	0.3113	2.3354	0.9957
BIT	1.7042	0.9997	0.1317	0.9976	4.0888	1.0000
ETH	2.4863	1.0000	-0.8475	0.9998	3.4362	0.9990
Critical values at 1%, 5%, and 10% levels, respectively.	-3.43, -2.86, -2.56		-3.96, -3.41, -3.12		-2.56, -1.94, -1.61	

TABLE 3
ADF Unit Root Tests (1st Difference)

1st Difference	Constant		Constant with Trend		Non-Constant without Trend	
Variables	t-statistic	Prob. value	t-statistic	Prob. Value	t-statistic	Prob. Value
$C0_2$	-2.2262	0.1971	-2.2063	0.4852	0.6924	0.8650
BIT	12.6653	0.0000	-12.8272	0.0000	-12.0483	0.0000
ETH	-6.1405	0.000	-6.8688	0.0000	-5.6093	0.0000
Critical values at 1%, 5%, and 10% levels, respectively.	-3.43, -2.86, -2.56		-3.96, -3,41, -3,12		-2,56, -1,94, -1,61.	

TABLE 4
ADF Unit Root Tests (2nd Difference)

2nd Difference	Constant		Constant with Trend		Non-Constant without Trend	
Variables	t-statistic	Prob. value	t-statistic	Prob. Value	t-statistic	Prob. Value
$C0_2$	-19.6349	0.0000	-19.6365	0.0000	-19.6124	0.0000
BIT	-	-	-	-	-	-
ETH	-	-	-	-	-	-
Critical values at 1%, 5%, and 10% levels, respectively	-3.43, -2.86, -2.56		-3.96, -3,41, -3,12		-2,56, -1,94, -1,61	

TABLE 5
Optimal Lag Length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-19215.740	NA	535095.0	21.70383	21.7131	21.7073
1	6446.155	51207.870	1.40e-07	-7.2661	-7.2290	-7.2524
2	7387.081	1874.415	4.90e-08	-8.3185	-8.2535	-8.2945
3	7647.169	517.238	3.69e-08	-8.6021	-8.5093	-8.5678
4	7776.068	255.905	3.22e-08	-8.7375	-8.6168	-8.6929
5	7804.813	56.970	3.15e-08	-8.7598	-8.6113	-8.7049
6	7853.011	95.363	3.01e-08	-8.8041	-8.6277*	-8.7389
7	7879.075	51.480	2.96e-08	-8.8233	-8.6191	-8.7479
8	7903.566	48.289*	2.90e-08*	-8.8408*	-8.6088	-8.7551*

* Optimal lag length of the Information Criteria

4.1.2 TODA-YAMAMOTO CAUSALITY ANALYSIS

The causal relationship among the series in the analysis is investigated bilaterally. To this end, the Toda-Yamamoto causality test is performed along with the established models. Subsequently, the optimal lag length (k) is determined as eight. As a result of the analysis, the maximum stationarity level is determined as two. The hypotheses established to investigate the relationship among the variables are as follows:

H0: Independent variable does not cause the dependent variable.

H1: Independent variable causes dependent variable.

The results of the Toda-Yamamoto causality analysis conducted to determine the possible causal relationships between the CO_2 emission values and the energy consumption values of Bitcoin and Ethereum are presented in the following Table 6.

TABLE 6
Test Results

Hypothesis Models Dependent Variable - Independent Variable	$k+d_{max}$	Chi-Sq.Test Statistic	P-value	RESULTS
CO_2-BIT	10	14.0424	0.0807**	Related
BIT-CO_2	10	13.4884	0.0961**	Related
CO_2- ETH	10	10.1998	0.2513	Not related
ETH-CO_2	10	10.9429	0.2050	Not related
BIT-ETH	10	111.3593	0.0000*	Related
EHT-BIT	10	45.3443	0.0000*	Related

Probability values are statistically significant at the 1%* and 10%** significance levels. The optimal lag length is indicated by the majority of the information criteria. d_{max} = the maximum stationarity level according to the ADF unit root test results, k = VAR lag length.

Upon considering Table 6, the Chi-square test statistic p-probability values are determined by two analysis results in which the H_0 hypothesis is rejected at the 1% level, and two analysis results in which the H_0 hypothesis is rejected at the 10% level. As a result of the analysis, a bilateral causal relationship is found between Bitcoin and

CO_2 emissions at the 10% significance level. With this obtained result, it is possible to claim that Bitcoin and CO_2 emissions cause each other. Correspondingly, a bilateral causal relationship is detected between Bitcoin and Ethereum at the 1% significance level. With this obtained result, it is possible to claim that Bitcoin and Ethereum cause each other. As a result of the analysis, however, no statistically significant causality relationship is detected between CO_2 emissions and Ethereum.

5. CONCLUSION

In this study, the extent of the relationship between cryptocurrencies and carbon emissions is investigated. Based on recent frequently expressed concerns, the findings of this study support this relationship. According to the analysis results, a bilateral causal relationship is found between Bitcoin and CO_2 emissions. A bilateral causal relationship is detected between Bitcoin and Ethereum, whereas no causal relationship is found between Ethereum and CO_2 emissions. Nonetheless, detecting a causal relationship running from Ethereum to Bitcoin would indirectly lead to a causal relationship from Ethereum to CO_2 emissions, since a causal relationship exists from Bitcoin to CO_2 emissions. The results of this study concerning the causal relationship running from Bitcoin (and indirectly from Ethereum) to CO_2 emissions align with the results of similar studies in the literature. For instance; Goodkind et al. (2020) mentioned the environmental impacts of cryptocurrencies by emphasizing that each US$1 worth of Bitcoin value generated in the increasing Bitcoin market accounts for US$0.49 and US$0.37 worth of health and climate damage in the USA and China, respectively. Similarly, Gallersdörfer et al. (2020), who yielded similar results, reported that cryptocurrency energy consumption could generate negative environmental impact. Wang et al. (2022) developed a new index of cryptocurrency environmental attention toward the sustainability concerns of the growth of cryptocurrency markets. They observed that the index had a significantly positive relationship with Bitcoin, whereas it has a significantly negative relationship with global temperature uncertainty.

It is thought that there may be studies conducted in compliance with the increasing concerns with the environmental pollution that cryptocurrencies may cause along with energy consumption in the findings of a causal relationship running from CO_2 emission to Bitcoin. In the presence of such a remarkable concern, efforts are being made to fulfill the energy needs in mining activities using renewable energy resources instead of fossil fuels. In this context, the Bitcoin Mining

Council is promoting renewable energy usage to mitigate the environmental damage during cryptocurrency production. Moreover, it is stated that cryptocurrency miners increase the volume of renewable energy usage, and this rate is over 70% (Yenilenebilir Enerji Kripto", 2021). Within these improvements, while the share of renewable energy consumption of cryptocurrencies in total energy consumption is quite crucial, the amount of energy consumed by cryptocurrencies in the total energy consumption that causes CO_2 emission is also critically important.

As a result, the high energy consumption of cryptocurrencies, which has great potential, and the CO_2 emission pollution problems question sustainability of cryptocurrencies. Furthermore, it is expected that more studies on the environmental impacts of Blockchain technology would be conducted, and it would be possible to benefit from taking measures concentrated on sustainable development. In this regard, efforts should accelerate to increase the share of renewable energy usage in the energy consumed by cryptocurrencies.

This research study contributes to formation of the theoretical infrastructure in the relevant field. Considering the results of the research study, ideas are offered to policymakers to highlight cryptocurrency projects or technologies that reduce energy consumption or provide renewable energy usage. In the long term, the extent to which the adverse impacts of cryptocurrencies which are crucial investment instruments in the financial market would be reflected in the prices of cryptocurrencies is critical. Although it is observed that more research studies are needed in this field, such research studies would guide policymakers, researchers, environmentalists, and investors.

REFERENCES

Ata, A.Y., and F. Yucel. "Eş Bütünleşme Ve Nedensellik Testleri Altında Ikiz Açıklar Hipotezi: Türkiye Uygulaması." *Çukurova Üniversitesi Sosyal Bilimler Enstitüsü Dergisi* 12, no. 12 (2003): 97-110.

Badea, L., and M.C. Mungiu-Pupăzan. "The Economic And Environmental Impact Of Bitcoin." *IEEE Access* no. 9 (2021): 48091-8104.

Bendiksen, C., and S. Gibbons. "The Bitcoin Mining Network: Trends, Average Creation Costs, Electricity Consumption & Source." CoinShares Research, 2019. https://coinshares.com/assets/resources/Research/bitcoin-mining-network-december-2019.pdf

Bitcoin Clean Energy Initiative. "Bitcoin is Key to an Abundant, Clean Energy Future." Square. 2021. https://tinyurl.com/BitcoinCleanEnergyInitiative

Browne, R. "Bitcoin's Wild Ride Renews Worries about its Massive Carbon Footprint." [online] CNBC, 2021. https://www.cnbc.com/2021/02/05/Bitcoin-btc-surge-renews-worries-about-its-massive-carbon-footprint.html

Cambridge Centre for Alternative Finance. "Cambridge Bitcoin Energy Consumption Index. FAQ: Is Bitcoin Mining an Environmental Disaster?" 2021. www.cbeci.org/about/faq

Carter, N. "The Last Word On Bitcoin's Energy Consumption." 2020. https://www.coindesk.com/the-last-word-on-bitcoins-energy-consumption

CoinMarketCap. "Today's Cryptocurrency Prices by Market Cap." 2021. www.coinmarketcap.com

Corbet, S., B.M. Lucey, and L. Yarovaya. "The Financial Market Effects Of Cryptocurrency Energy Usage." 2019. https://ssrn.com/abstract=3412194

______. "Bitcoin-Energy Markets Interrelationships-New Evidence." *Resources Policy* 70 (2021): 1-12.

De Vries, A. "Bitcoin's Growing Energy Problem." *Joule* 2: no. 5 (2018): 801-05.

______. "Bitcoin Boom: What Rising Prices Mean for the Network's Energy Consumption." *Joule* 5, no. 3 (2021): 509-13.

Dey, S.R., and M. Tareque. "Electricity Consumption and GDP Nexus in Bangladesh: A Time Series Investigation." *Journal of Asian Business and Economic Studies* 27, no. 1 (2019): 35-48.

Dilek, Ş., and Y. Furuncu. "Bitcoin Mining and its Environmental Effects." *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi* 33, no. 1 (2019): 91-105.

Egiyi, M. A., and G.N. Ofoegbu. "Cryptocurrency and Climate Change: An Overview." *International Journal of Mechanical Engineering and Technology (IJMET)* 11, no. 3 (2020): 15-22.

Erdogan, S., M.Y. Ahmed, and S.A. Sarkodie. "Analyzing Asymmetric Effects of Cryptocurrency Demand on Environmental Sustainability." *Environmental Science and Pollution Research* 29, no. 21 (2022): 31723-733.

Gallersdörfer, U., L. Klaaßen, and C. Stoll. "Energy Consumption of Cryptocurrencies Beyond Bitcoin." *Joule* 4, no. 9 (2020): 1843-846.

Gehman J., L.M. Lefsrud, and S. Fast. “Social License To Operate: Legitimacy By Another Name?” *Canadian Public Administration* 60, no. 2 (2017): 293-317.

Global Monitoring Laboratory Earth System Research Laboratories. https://gml.noaa.gov/ccgg/trends/gl_data.html

Goodkind, A.L., B.A. Jones, and R.P. Berrens. “Cryptodamages: Monetary Value Estimates of The Air Pollution and Human Health Impacts Of Cryptocurrency Mining.” *Energy Research & Social Science* 59 (2020): 101281.

Greenberg, P., and D. Bugden. “Energy Consumption Boomtowns in The United States: Community Responses to a Cryptocurrency Boom.” *Energy Research and Social Science* 50 (2019): 162-67.

Hao, X., Y. Chen, C. Xu, and W. Li. “Impacts of Climate Change and Human Activities on The Surface Runoff in The Tarim River Basin Over The Last Fifty Years.” *Water Resources Management* 22, no. 9 (2008): 1159-171.

Howson, P. “Tackling Climate Change with Blockchain.” *National Climate Change* 9 (2019): 644-645.

Huynh, T.L.D., E. Hille, and M.A. Nasir. “Diversification in The Age Of The 4th Industrial Revolution: The Role of Artificial Intelligence, Green Bonds and Cryptocurrencies Technol.” *Forecast. Social Change* 159 (2020): 120188.

Izolluoglu, C. “Zaman Serisi Birim Kök Testleri Ve Bir Uygulama.” Master’s Thesis, Department of Econometrics, Institute of Social Sciences, University of Inonu, Izmir, 2019.

Iklim Haber. Bitcoin Madenciliği İklim Değişikliğini Tetikliyor mu?, 2018. https://www.iklimhaber.org/bitcoin-madenciligi-iklim-degisikligini-tetikliyor-mu/

Jenkins, K. “Can I See Your Social License Please?” *Policy Quarterly* 14, no. 4 (2018): 27-35.

Jiang, S., Y. Li, Q. Lu, Y. Hong, D. Guan, Y. Xiong, and S. Wang. “Policy Assessments For The Carbon Emission Flows And Sustainability Of Bitcoin Blockchain Operation in China.” *Nature Communications* 12, no. 1 (2021): 1-10.

Kompas, T., V.H. Pham, and T.N. Che. “The Effects Of Climate Change On GDP By Country And The Global Economic Gains From Complying With The Paris Climate Accord.” *Earth's Future* 6, no. 8 (2018): 1153-173.

Krause, M.J., and T. Tolaymat. “Quantification of Energy And Carbon Costs For Mining Cryptocurrencies.” *Nature Sustainability* 1, no. 11 (2018): 7-11.

Mecik, O., and T. Koyuncu. “Türkiye’de Göç ve Ekonomik Büyüme İlişkisi: Toda-Yamamoto Nedensellik Testi.” *İnsan ve Toplum Bilimleri Araştırmaları Dergisi* 9, no. 3 (2020): 2618-635.

Moffat, K., J. Lacey, A. Zhang, and S. Leipold. “The Social Licence to Operate: A Critical Review.” *Forestry: An International Journal of Forest Research* 89, no. 5 (2016): 477-88.

Mohsin, K. “Cryptocurrency & its Impact on Environment.” *Int. J. Cryp. Curr. Research* 1, no. 1 (2021): 1-4.

Nakamoto, S. “Bitcoin: A Peer-to-Peer Electronic Cash System.” 2008. https://bitcoin.org/bitcoin. pdf

Othman, A., and A.B. Dob. “Bitcoin Mining's Energy Consumption and Global Carbon Dioxide Emissions: Wavelet Coherence Analysis.” Arab Monetary Fund, 2022. https://www.amf.org.ae/sites/default/files/publications/2022-06/Bitcoin%20Minings%20Energy%20Consumption%20final.pdf

Panah, P.G., M. Bornapour, X. Cui, and J.M. Guerrero. “Investment Opportunities: Hydrogen Production or BTC Mining?” *International Journal of Hydrogen Energy* 47, no. 9 (2022): 5733-744.

Rennie, E. “Climate Change and the Legitimacy of Bitcoin.” Working Paper, 2022. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3961105

Roeck, M., and T. Drennen. “Life Cycle Assessment Of Behind-The-Meter Bitcoin Mining At US Power Plant.” *The International Journal of Life Cycle Assessment* 27, no. 3 (2022): 355-65.

Stoll, C., L. Klaaßen, and U. Gallersdörfer. “The Carbon Footprint Of Bitcoin.” *Joule* 7 (2019): 1647-661.

Taskinsoy, J. “Blockchain: An Unorthodox Solution to Reduce Global Warming.” 2019. https://ssrn.com/abstract=3475144

Tol, R.S. “The Economic Effects of Climate Change.” *Journal Of Economic Perspectives* 23, no. 2 (2009): 29-51.

Trenberth, K.E. “Climate Change Caused by Human Activities is Happening, and it Already has Major Consequences.” *Journal of Energy and Natural Resources Law* 36, no. 4 (2018): 463-81.

Truby, J., R.D. Brown, A. Dahdal, and I. Ibrahim. “Blockchain, Climate Damage, And Death: Policy Interventions to Reduce The Carbon Emissions, Mortality, and Net-Zero Implications Of Non-Fungible Tokens And Bitcoin” *Energy Research & Social Science* 88 (2022): 102499.

Wade, K. “The Impact of Climate Change on The Global Economy. Schroders”. 2016. https://prod.schroders.com/en/SysGlobalAssets/digital/us/pdfs/the-impact-of-climate-change.pdf

Walsh, M. “Bitcoin Cryptocurrencies and The Climate Crisis. The Regulatory Review.” *Irish Marxist Review* 10, no. 30 (2021): 80-9.

Wang, Y., B. Lucey, S. A. Vigne, and L. Yarovaya. “An Index Of Cryptocurrency Environmental Attention (ICEA).” *China Finance Review International* 12, no. 3 (2022): 378-414.

Yan, L., N. Mirza, and M. Umar. “The Cryptocurrency Uncertainties And Investment Transitions: Evidence from High and Low Carbon Energy Funds in China.” *Technological Forecasting and Social Change* 175 (2022): 121326

Yenilenebilir Enerji Kripto Paranın Hızına Yetişmeye Çalışıyor, 2021. https://www.milliyet.com.tr/ekonomi/yenilenebilir-enerji-kripto-paranin-hizina-yetismeye -calisiyor-6541288

Zhang, D., X.H. Chen, C.K.M. Lau, and B. Xu. “Implications of Cryptocurrency Energy Usage on Climate Change.” *Forthcoming, Technological Forecasting & Social Change* 187 (2023): 122219.