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Blockchain in Sustainable Finance: Evidence from Cryptocurrency, Green Bonds, and Clean Energy

Sürdürülebilir Finansta Blokzincir: Kripto Para, Yeşil Tahviller ve Temiz Enerjiden Kanıtlar

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Abstract

Aim: This study explores the interaction between clean energy, sustainability, green bonds, and six blockchain indices (e.g., CBDCAI, ICEA, Bitcoin, Ethereum) from October 2017 to June 2023 to highlight sustainability issues related to recent financial innovations. The study aims to examine the extent to which sustainable equity prices are impacted by the stochastic features of Bitcoin and CBDC news across bull, bear, and normal market phases.

Method: This study utilizes the Quantile Autoregressive Distributed Lag (QARDL) method to examine the short- and long-run impacts.

Results: The QARDL results reveal a significant long-term equilibrium between blockchain variables and the green industry, with varying reactions across quantiles. Bitcoin, Ethereum, and green bonds positively impact the sustainable market index over time, especially in higher quantiles, supporting Sustainable Development Goals (SDGs).

Conclusion: The study advocates using blockchain for SDG policies and renewable energy to reduce blockchain's environmental impact and this research extends the literature by offering a deeper insight into the financial and environmental influences shaping sustainability.

Keywords

Cryptocurrency Environmental Attention, Bitcoin, Green Bonds, Sustainability, CBDC, QARDL

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Öz

Amaç: Bu çalışma, Ekim 2017'den Haziran 2023'e kadar temiz enerji, sürdürülebilirlik, yeşil tahviller ve altı blokzincir endeksi (örneğin, CBDCAI, ICEA, Bitcoin, Ethereum) arasındaki etkileşimi inceleyerek son finansal yeniliklerle ilgili sürdürülebilirlik sorunlarını vurgulamaktadır. Çalışmanın amacı, sürdürülebilir hisse senedi fiyatlarının, Bitcoin ve CBDC haberlerinin stokastik özelliklerinden boğa, ayı ve normal piyasa aşamalarında ne ölçüde etkilendiğini incelemektir.

Yöntem: Bu çalışma, kısa ve uzun vadeli etkileri incelemek için Kantil Otoregresif Dağıtılmış Gecikme (QARDL) yöntemini kullanmaktadır.

Bulgular: QARDL sonuçları, blokzincir değişkenleri ile yeşil endüstri arasında, kantiller arasında değişen tepkilerle önemli bir uzun vadeli denge ilişkisini ortaya koymaktadır. Bitcoin, Ethereum ve yeşil tahvil değişkenleri, özellikle daha yüksek kantillerde, sürdürülebilir piyasa endeksini olumlu yönde etkileyerek Sürdürülebilir Kalkınma Amaçlarını (SKA) desteklemektedir.

Sonuç: Çalışma, blokzincir teknolojisinin çevresel etkisini azaltmak için sürdürülebilir kalkınma hedefleri (SDG) politikalarını ve yenilenebilir enerjinin kullanılmasını savunuyor ve bu araştırma, sürdürülebilirliği şekillendiren finansal ve çevresel etkilere dair daha derin bir bakış açısı sunarak literatürü genişletiyor.

Anahtar Kelimeler

Kripto Para Çevresel Dikkat Endeksi, Bitcoin, Yeşil Tahviller, Sürdürülebilirlik, MBDP, QARDL

Introduction

Blockchain technology, initially designed to support cryptocurrencies, has rapidly expanded into broader applications within finance, governance, and sustainability. Its unique attributes—transparency, decentralization, and immutability—make it a potentially transformative tool for sustainable development, yet also a source of environmental concern. Recent debates highlight blockchain's dual role: on one hand, it enables financial innovation, green investment tracking, and efficient capital allocation; on the other, its high energy consumption raises questions about compatibility with environmental goals.

Sustainable Development Goals (SDGs), established by the United Nations in 2015, serve as a global framework for addressing climate change, inequality, and sustainable economic growth (United Nations, 2015). Achieving these goals requires long-term financing, liquidity provision, and mechanisms that align capital flows with low-carbon transitions. Financial innovations such as cryptocurrencies, central bank digital currencies, and green bonds represent both opportunities and challenges in this process. Green assets and sustainability-linked instruments can channel resources into renewable energy projects, while digital currencies may reshape market structures, investor sentiment, and regulatory frameworks as noted in research studies (de Oliveira, de Souza Cunha, Palazzi, Klotzle & Maçaira, 2020; Sarker, Bouri & Marco, 2023). These innovative technologies have the power to transform our approach to sustainable development and establish a more just and sustainable world for future generations. Leveraging the power of blockchain can drive sustainable development and create a better world for future generations.

Despite growing interest, the literature remains fragmented. Prior research has investigated causal linkages between sustainable equity indices, cryptocurrencies, and green bonds, but these studies often rely on linear methods and overlook nonlinear dynamics across different market phases. Furthermore, the theoretical implications of blockchain for sustainable finance remain underexplored, particularly regarding how digital asset attention and environmental awareness influence clean energy markets and sustainability-oriented indices.

This study addresses these gaps by examining the asymmetric short- and long-term relationships between blockchain-related innovations and sustainability-focused assets. Using weekly data from October 2017 to June 2023, we assess the influence of green bonds, cryptocurrency market performance, environmental attention indices, and central bank digital currency trends on the Dow

Jones World Sustainability Index and the S&P Global Clean Energy Index. By applying the quantile autoregressive distributed lag approach, we capture heterogeneous responses across bullish, bearish, and neutral market conditions.

The research is guided by the following questions:

1. Do blockchain-related innovations and green finance instruments exhibit long-run equilibrium with sustainability and clean energy indices?
2. How do short-run asymmetric shocks in digital assets and environmental attention affect sustainable finance markets?
3. What are the implications of these linkages for policymakers, investors, and sustainable finance strategies?

By addressing these questions, the study contributes to a deeper understanding of the nonlinear financial and environmental forces shaping sustainable development. It provides novel insights into how blockchain technologies and green finance interact in ways that either advance or constrain the global sustainability agenda.

The remaining parts of the study is structured as follows: The second section reviews the existing literature and the third section summarizes the conceptual foundation of the study. The fourth and fifth sections describe data and empirical methodology, respectively. The sixth section introduces empirical results and the last section gives discussions and concludes the study.

Literature Review

Recent literature has increasingly focused on the environmental implications of cryptocurrencies, particularly Bitcoin, whose energy-intensive mining process creates significant carbon emissions. Several studies highlight how Bitcoin's risks and returns are tied to energy consumption, with spillover effects on energy and carbon-related investments (Naeem & Karim, 2021; Pham, Huynh & Hanif, 2022). Consequently, Bitcoin has been examined both as a hedge and as a diversification tool in relation to traditional and sustainable investments (Karim, Lucey, Naeem & Uddin, 2022).

Despite these advances, the connection between cryptocurrencies and green bonds or sustainable financing instruments remains underexplored. This relationship is highly relevant for investors seeking to mitigate climate risks in crypto portfolios and for policymakers aiming to align blockchain technologies with climate change mitigation goals (Siddique, Nobanee, Karim & Naz, 2023).

Several contributions have examined the role of uncertainty and attention indices. For instance, Hassan et al. (2022) and Haq (2022) show that rising cryptocurrency uncertainty reduces the performance of green financial assets, while Wang, Lucey, Vigne & Yarovaya (2022) demonstrate a link between CBDC attention indices and the volatility of bond and cryptocurrency markets. These findings suggest that investor sentiment, as captured by attention indices, plays a critical role in shaping green finance dynamics. DELGADO-MOHATAR, O., Felis-Rota & Fernández-Herraiz

Other studies have focused on the green energy sector and its interaction with digital assets. Delgado-Mohatar, Felis-Rota & Fernández-Herraiz (2019) and Kristoufek (2020) discuss cryptocurrency mining profitability and electricity prices, whereas Truby (2018) and Easley, O'hara & Basu (2019) highlight its environmental costs. More recent research links blockchain adoption to social sustainability (Ronaghi & Mosakhani, 2022), while others analyze hedging properties of green bonds against Bitcoin volatility (Khalfaoui, Mefteh-Wali, Dogan & Ghosh, 2023; Huynh, Hille & Nasir, 2020). Furthermore, the relationship between carbon prices and cryptocurrencies (Yang and Hamori, 2021), the connection between electricity prices and bitcoin energy consumption in the context of bitcoin and sustainability dynamics (Krause and Tolaymat, 2018; Baur and Oll, 2019) and the impact of Bitcoin mining on the environment (Mora et al., 2018; Karatas et al., 2023) have also all received attention in a recent stream of literature.

At the same time, the growing discourse on Central Bank Digital Currencies (CBDCs) has created new avenues of inquiry. Kamal, Wohar & Kamal (2023) emphasize how regulatory uncertainty and environmental concerns around cryptocurrencies have spurred CBDC debates. Wang et al. (2022) provide evidence that CBDC uncertainty is associated with higher volatility in cryptocurrencies and traditional safe-haven assets such as gold.

Taken together, the literature establishes three main strands:

1. The environmental footprint of cryptocurrencies and their interconnectedness with energy markets.
2. The role of uncertainty and attention indices in shaping green financial asset performance.
3. The limited but emerging evidence on linkages between cryptocurrencies, green bonds, and clean energy assets.

This study builds on these strands by addressing the underexplored relationships between cryptocurrency attention indices, CBDC developments, and green financial markets, employing a QARDL approach to capture nonlinear and asymmetric effects across different market phases. In doing so, it fills an important gap in understanding the intersection of blockchain innovations, clean energy, and sustainable finance.

Conceptual Framework

The conceptual foundation of this study lies at the intersection of blockchain innovations, green finance, and sustainable development. Blockchain technology offers transparency and decentralized governance, which can enhance accountability in financial markets and facilitate capital allocation toward green investments. At the same time, concerns about its energy consumption highlight potential trade-offs for environmental sustainability.

Sustainable Development Goals (SDGs) provide the normative framework within which these innovations should be evaluated. Instruments such as green bonds and sustainability indices are designed to channel resources into renewable energy and environmentally responsible projects, while digital assets, including cryptocurrencies and central bank digital currencies (CBDCs), reshape financial structures and investor behavior. Attention indices, such as the CBDC Attention Index and the Cryptocurrency Environmental Attention Index, serve as proxies for market sentiment and regulatory awareness, capturing the interaction between financial innovation and sustainability concerns.

Building on this framework, our analysis investigates how blockchain-related assets and attention measures interact with the Dow Jones World Sustainability Index and the S&P Global Clean Energy Index. This structure allows us to explore both the supportive role of blockchain in advancing SDGs and the risks it poses through volatility and environmental costs. By integrating theoretical insights with empirical testing, the framework provides a basis for examining asymmetric, nonlinear relationships between digital finance and sustainability outcomes.

Data

This study utilized the weekly returns of green financial assets shown in Table 1 for the period from October 2017 to June 2023. The ICEA and CBDCAI are news-based novel indices constructed by Wang et al. (2022). The availability of the CBDC news indices, which were initially published at a weekly frequency and were calculated by Wang et al. (2022), determines the analysis's start date. Other indices are retrieved from the S & P Global website.

As used in various academic studies such as those by Martínez-García and Ansón (2021), and Sochneva (2021), the Dow Jones World Sustainability Index (WSUSI) has been employed as a metric for measuring Sustainable Development Goals (SDGs). These studies argue that WSUSI is a good indicator of a company's sustainability performance and helps reach the SDGs. It can be used as a standard to improve how companies handle environmental, social, and governance issues and has been widely used as a benchmark to evaluate progress toward sustainable development. Table 1 contains the specifications for the variables.

Table 1. Description of Variables

Asset/Index	Symbol	Variable Name	Structure/Description
Return on Dow Jones World Sustainability Index	WSUSI	lnwsusi	Global sustainability leaders, representing SDGs indicator
Return on S&P Global Clean Energy Index	GCLEANI	lngcleani	Global clean energy companies
S&P Green Bond Index	GBI	lngbi	The performance of globally issued green-labeled bonds
S&P Cryptocurrency Large Cap Index	CLCI	lnclci	CBDM elements with the highest market capitalization representing the altcoin market
S&P Ethereum Index (USD)	ETHI	lnethi	The performance of the digital asset Ethereum
S&P Bitcoin Index (USD)	BTCI	lnbtci	The performance of the digital asset Bitcoin
Index of Cryptocurrency Environmental Attention	ICEA	lnicea	The relative extent of media discussion around the environmental impact of cryptocurrencies
Green Cryptocurrency Asset Index	GCAI	lngcai	5 major environmentally friendly crypto assets
CBDC Attention Index	CBDCAI	lncbdcai	Tracking CBDCs' trends and variations

The time series of the raw data in our dataset is represented in Figure 1 as follows:

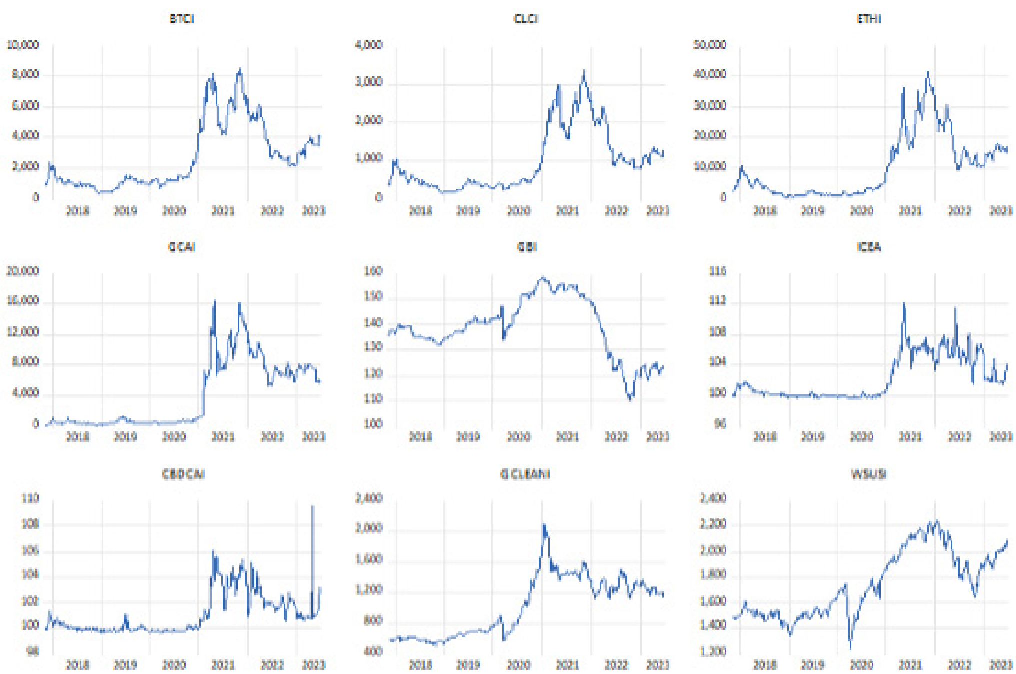

Figure 1. Graphical representations of raw data

Figure 1 illustrates the historical performance and trends of nine indices and variables related to sustainable finance, cryptocurrencies, and clean energy from 2018 to 2023. Each subplot shows how they have grown, changed, and been volatile over time. These series exhibit significant fluctuations in response to global events, policy debates, and market shocks, reflecting the complex interplay between sustainability, financial innovation, and environmental concerns.

There are times when interest levels rise because of certain events or discussions. All of these patterns show how investments that focus on sustainability, digital assets, and their links to media and environmental trends change over time. Table 2 gives the data description of the variables after taking logarithms. The most (least) volatile financial asset is GCAI (CBDCAI). The higher volatility of the assets suggests greater sensitivity to market shocks, underscoring the importance of a nonlinear modeling framework such as QARDL. The distribution of log returns is high-peaked, asymmetric, and, thus, not normal. The results via mean scores revealed that Ethereum (ETHI) has the highest mean score among all the investigated variables followed by Bitcoin (BTCI). Ethereum, green currencies (GCAI), and Bitcoin also demonstrated maximum scores compared to other variables respectively. This implies that these variables have higher trends than other studied variables.

The Jarque-Bera normality test, developed by Jarque and Bera (1980), is used to detect data anomalies. This test's null hypothesis says that the data is normal, while the alternative hypothesis states the opposite. The Jarque-Bera test's H_0 of normal distribution is simply rejected for each series at a significance level of 1%. Accordingly, the use of quantile assessment processes is deemed necessary and appropriate for the study in the wake of Godil et al. (2021) and Yan, Wang, Athari & Atıf (2022).

Table 2. Descriptive Statistics for the Dataset

Variable Name/ Statistics	LNWSUSI	LNGCLEANI	LNBTCI	LNCBDCAI	LNCLCI	LNETHI	LNGBI	LNGCAI	LNICEA
Mean	7.454153	6.845747	7.601116	4.615426	6.592621	8.689739	4.929360	7.472986	4.627703
Median	7.440616	6.941864	7.385177	4.608060	6.526305	8.660459	4.933178	6.766693	4.613293
Maximum	7.715115	7.656110	9.054057	4.696689	8.124186	10.63531	5.065818	9.709337	4.718478
Minimum	7.116402	6.229241	6.044887	4.600949	5.010035	6.626757	4.698661	4.605170	4.602370
Std. Dev.	0.145342	0.393850	0.801159	0.015879	0.803366	1.133215	0.084488	1.399913	0.027027
Skewness	0.150909	0.003737	0.122215	1.469142	0.159111	0.003137	-0.472027	0.151038	0.879588
Kurtosis	1.716285	1.463951	1.879722	5.138807	1.925952	1.577920	2.630709	1.407069	2.605721
Jarque-Bera	21.448***	29.101***	16.215***	162.898***	15.476***	24.942***	12.674***	32.420***	40.085***

Note: This table reports the statistics of each variable after segmented and logarithm is taken. In JB statistics; *** denotes statistical significance at 1% level. Source: Author's estimation.

Methodology

QARDL Model

When examining financial and macroeconomic data, the QARDL approach has a lot to offer, especially when there are complicated linkages and non-stationary variables. Unlike conventional models, QARDL evaluates the effects of independent variables at various levels of the dependent variable while combining the benefits of ARDL and quantile regression. This enables the simultaneous analysis of short- and long-term interactions (Wei, Zhou & Ren, 2021). This adaptability is particularly useful for mixed data, like price series for cryptocurrencies, which frequently contain first-order stationary variables. The QARDL model offers a more thorough and reliable analysis than the mean-focused ARDL approach because it takes into account asymmetric and nonlinear interactions across many quantiles. Additionally, it is robust against outliers, which makes it perfect for examining factors impacted by periods of extreme market volatility, such pandemics or wars.

To estimate the non-linear relation among the variables, the novel QARDL methodology instructed by Cho, Kim & Shin (2015), has been employed in this research. Firstly, the fundamental ARDL model can be used to state the equation then to take asymmetry into account, the ARDL model is then transformed into a QARDL model by applying regression across different quantiles as shown in Equation 1:

$$\begin{aligned}\text{lnwsusi}_t = a(\tau) &+ \sum_{i=1}^{p} \pi_i(\tau)\text{lnwsusi}_{t-i} + \sum_{i=0}^{q} \omega_i(\tau)\text{lnbtci}_{t-i} + \sum_{i=0}^{r} \lambda_i(\tau)\text{lncbdcai}_{t-i} \\ &+ \sum_{i=0}^{s} \theta_i(\tau)\text{lnclci}_{t-i} + \sum_{i=0}^{u} \Psi_i(\tau)\text{lnethi}_{t-i} + \sum_{i=0}^{v} \delta_i(\tau)\text{lngcai}_{t-i} \\ &+ \sum_{i=0}^{w} \gamma_i(\tau)\text{lnicea}_{t-i} + \sum_{i=0}^{y} \mu_i(\tau)\text{lngbi}_{t-i} + \mathcal{E}_t(\tau)\end{aligned} \quad (1)$$

Where *ln* represent the logarithm of the variables. $\pi\, i$, $\omega\, i$, $\lambda\, i$, $\theta\, i$, $\Psi\, i$, $\delta\, i$, $\gamma\, i$, *and* $\mu\, i$ denotes the estimation coefficients, $\mathcal{E}\, t$ is the error term and p, q, r, s, u, v, w, and y show the optimal lag order selected through SIC (Schwarz Information Criterion).

In Equation 1, the quantile is specified as $0 < \tau < 1$ (Troster, 2018). For the convenience of analysis, the quantile range sequence chosen in this work is {0.05, 0.10, 0.20, ..., 0.90, 0.95}. While $a(\tau)$, $\pi\, i(\tau)$, $\omega\, i(\tau)$, $\lambda\, i(\tau)$, $\theta\, i(\tau)$, $\Psi\, i(\tau)$, $\delta\, i(\tau)$, $\gamma\, i(\tau)$, *and* $\mu\, i(\tau)$ exhibits the coefficient values at various quantiles. The QARDL model allows us to explore the short- and long-term effects when sustainable market index is in various forms or even in extreme states, which is more significant than simple regression to the mean (Sun, Li, Tang & Wu, 2012).

In order to avoid the sequence correlation of $\mathcal{E}\, t$ in the sample, the mathematical framework is generalized to the subsequent format and after employing projections and difference methods on variables, the QARDL-ECM model is obtained in Equation 2:

$$\begin{aligned}Q_{\Delta\text{lnwsusi}_t}(\tau|.) = a(\tau) &+ \rho(\tau)(\text{lnwsusi}_{t-1} - \beta_{lnbtci}(\tau)\text{lnbtci}_{t-1} \\ &- \beta_{lncbdcai}(\tau)\text{lncbdcai}_{t-1} - \beta_{lnclci}(\tau)\text{lnclci}_{t-1} - \beta_{lnethi}(\tau)\text{lnethi}_{t-1} \\ &- \beta_{lngcai}(\tau)\text{lngcai}_{t-1} - \beta_{lnicea}(\tau)\text{lnicea}_{t-1} - \beta_{lngbi}(\tau)\text{lngbi}_{t-1}) \\ &+ \sum_{i=1}^{p-1} \pi_i(\tau)\Delta\text{lnwsusi}_{t-i} + \sum_{i=0}^{q-1} \omega_i(\tau)\Delta\text{lnbtci}_{t-i} + \sum_{i=0}^{r-1} \lambda_i(\tau)\Delta\text{lncbdcai}_{t-i} \\ &+ \sum_{i=0}^{s-1} \theta_i(\tau)\Delta\text{lnclci}_{t-i} + \sum_{i=0}^{u-1} \Psi_i(\tau)\Delta\text{lnethi}_{t-i} + \sum_{i=0}^{v-1} \delta_i(\tau)\Delta\text{lngcai}_{t-i} \\ &+ \sum_{i=0}^{w-1} \gamma_i(\tau)\Delta\text{lnicea}_{t-i} + \sum_{i=0}^{y-1} \mu_i(\tau)\Delta\text{lngbi}_{t-i} + \nu_t(\tau)\end{aligned} \quad (2)$$

where $\beta_{lnbtci} = -\frac{\beta_1}{\rho}$, $\beta_{lncbdcai} = -\frac{\beta_2}{\rho}$, $\beta_{lnclci} = -\frac{\beta_3}{\rho}$, $\beta_{lnethi} = -\frac{\beta_4}{\rho}$, $\beta_{lngcai} = -\frac{\beta_5}{\rho}$, $\beta_{lnicea} = -\frac{\beta_6}{\rho}$, $\beta_{lngbi} = -\frac{\beta_7}{\rho}$.

where the character Δ denotes the difference between the present wsusi market performance and previous period wsusi market performance, e.g. $\Delta\text{lnwsusi} = \text{lnwsusi}_t - \text{lnwsusi}_{t-1}$.

In Equation 2, the error correction coefficient ρ needs to be negative, and significant. β_{lnbtci}, $\beta_{lncbdcai}$, β_{lnclci}, β_{lnethi}, β_{lngcai}, β_{lnicea}, and β_{lngbi} parameters are long-term cointegration coefficients among WSUSI and independent variables in each quantile. $\pi* = \sum \pi_i$ are the cumulative impact of the past changes of WSUSI on the current changes of WSUSI. $\omega* = \sum \omega_i$, $\lambda* = \sum \lambda_i$, $\theta* = \sum \theta_i$, $\Psi = \sum \Psi_i$, $\delta* = \sum \delta_i$, $\gamma* = \sum \gamma_i$, and $\mu* = \sum \mu_i$ indicate the cumulative short-term influence of current and previous changes in the independent variables on the current changes of sustainable market index respectively. Following the idea of regression, the conventional delta approach is implemented to calculate the standard error of the short-term parameters.

Empirical Results

The main empirical tool in our analysis is QARDL model. Before running QARDL analysis we need to determine the degree of integration for the variable in our dataset, and then to test whether time series variables exhibit nonlinear patterns. Thus, the first step in our empirical specification starts with utilizing unit root test and then analyzing the parameter constancy.

Unit Root Test Results

This section starts with the interpretation and conversation of the empirical analysis. Firstly, it is essential to check the stationarity issues of the series. Table 3 presents the results of the unit root tests conducted to determine the stationarity properties of the variables.

The analysis employs the conventional Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, both specified with a constant and a linear trend. Furthermore, to account for potential structural breaks in the series, we utilize the two-break Lee-Strazicich (2003) test, denoted as 'LS' in the table. This test is based on Model C, which permits two endogenous breaks in both the intercept and the trend slope at 5% level. The identified break dates for the variables cluster predominantly in 2020 and early 2021. This timing strongly suggest that the COVID-19 pandemic acted as the primary structural shock, permanently altering the long-term equilibrium paths of these specific indicators.

It should be noted that not all return series are stationary in Table 3. As a result, ICEA and CBDCAI are found to be stationary, thus I(0), while other variables are non-stationary I(1). To specify both short and long-term relationships, the QARDL method can be used for time series that are either stationary, non-stationary, or a combination of the two. Thus, the results lend support to the usage of the QARDL approach. This method robustly accommodates variables of different integration orders, allowing for the estimation of a valid long-run relationship without resorting to data-distorting transformations like differencing all variables.

Table 3. Unit Root Test Results

Variable / Test	**LNWSUSI**	**LNGCLEANI**	**LNBTCI**	**LNCBDCAI**	**LNCLCI**	**LNETHI**	**LNGBI**	**LNGCAI**	**LNICEA**
ADF	-2.322	-1.377	-1.631	-3.402 [b]	-1.513	-1.446	-0.967	-1.819	-3.702 [b]
ADF **(△)**	-15.865 [a]	-17.026 [a]	-15.803 [a]	-17.375 [a]	-15.867 [a]	-16.045 [a]	-15.688 [a]	-16.172 [a]	-13.738 [a]
PP	-2.391	-1.478	-1.802	-6.319 [a]	-1.702	-1.605	-1.119	-2.213	-3.702 [b]
PP **(△)**	-15.829 [a]	-17.026 [a]	-15.832 [a]	-40.169 [a]	-15.954 [a]	-16.072 [a]	-15.760 [a]	-16.292 [a]	-22.282 [a]
LS (2003) Test Statistic (Critical Value)	-4.604 (-5.118)	-5.796 [b] (-5.043)	-3.7620 (-5.098)	-8.232 [b] (-5.007)	-3.434 (-5.118)	-3.3067 (-5.098)	-3.893 (-5.013)	-3.966 (-5.043)	-6.268 [b] (-5.007)
Break Points	5/15/2020 3/04/2022	6/19/2020 3/12/2021	3/06/2020 9/03/2021	12/25/2020 5/14/2021	3/06/2020 5/06/2022	3/13/2020 12/03/2021	9/25/2020 5/27/2022	1/31/2020 2/12/2021	11/13/2020 6/04/2021
LS (2003) **(△)** Test Statistic (Critical value)	-11.261[b] (-5.006)	-10.922 [b] (-4.955)	-15.121 [b] (-4.901)	-17.754 [b] (-4.901)	-11.513 [b] (-5.041)	-11.476 [b] (-5.117)	-10.09 [b] (-4.901)	-16.429 (-4.901)	-16.302 [b] (-4.901)

Note: **(△)** represents the stationary test of difference series. a and b denote statistical significance at 1% and 5% level. Source: Author's estimation.

QARDL Estimation Results

The QARDL model can be used to analyze the short and long-term effects of green bonds, CBDC, and cryptocurrency indices on environmental sustainability and the global clean energy market.

Tables 4 and 5 report the QARDL estimates for WSUSI and GCLEANI, revealing robust long-term equilibrium across all quantiles as indicated by the negative and significant adjustment coefficient (ρ^*). The speed of adjustment is faster in bullish states, showing that shocks dissipate more quickly when markets are strong. Three key results stand out: (i) Bitcoin and Ethereum exert a persistent positive effect on both sustainability and clean energy indices, highlighting their potential role in financing green transitions; (ii) CBDC attention has an asymmetric effect, supporting market stability during downturns but generating volatility in bullish phases; and (iii) alternative cryptocurrencies have a consistent negative impact, suggesting structural misalignment with sustainability goals. These patterns underscore not only statistical significance but also the practical implication that mainstream blockchain assets may complement green finance, while speculative altcoins could undermine it.

The QARDL results highlight several asymmetric and economically meaningful relationships between blockchain assets, green finance instruments, and sustainability indices. First, Bitcoin and Ethereum strengthen the World Sustainability Index (WSUSI) across all quantiles, but in different ways: Ethereum's impact decreases steadily from bearish to bullish markets, suggesting diminishing marginal benefits as sustainability improves, while Bitcoin exhibits a nonlinear, stronger effect at median (0.50) and upper quantiles, pointing to its role as a driver of sustainability in more developed market phases.

Second, CBDC attention shows a dual effect: in bearish conditions (0.05 to 0.20 quantiles) it provides stability and supports WSUSI, but in bullish markets (0.80 to 0.95 quantiles) it turns negative, indicating that regulatory and market overreactions may destabilize sustainability-linked assets when investor sentiment is overheated. This asymmetric effect underlines the need for careful policy design in CBDC implementation. Prior research suggests that CBDCs could advance sustainable development by promoting green finance and environmental objectives (Yang, Zheng & Wang, 2023); this finding was confirmed in this study only under bearish market conditions.

Third, altcoins (CLCI) exhibit a persistent negative relationship with WSUSI, confirming their speculative and environmentally misaligned character. This suggests that unlike BTC and ETH, altcoins may undermine the sustainable finance agenda and should be considered for stricter regulatory oversight. Fourth, green bonds (GB) are consistently and positively associated with WSUSI in the long run, but their short-term impact is insignificant. This time lag implies that structural transformation in financial markets, such as the development of liquidity and trust in green instruments, requires longer horizons before producing measurable sustainability gains. This finding is consistent with other research by Sinha, Mishra, Sharif & Yarovaya (2021), Zhao et al. (2022), Haq (2022), and Alamgir and Cheng (2023), which particularly emphasizes the cumulative rather than immediate benefits of green bonds.

From an economic perspective, these results suggest that mainstream blockchain assets (BTC, ETH) and green bonds act as complements to sustainability and clean energy markets, while altcoins pose risks. Short-term dynamics reveal that past WSUSI values significantly shape current levels, particularly at higher quantiles (0.90–0.95) at a 10% significance level, indicating a path-dependent dynamic where sustainability gains reinforce themselves. This momentum attracts investment and amplifies returns in bullish phases but can equally accelerate losses during downturns, highlighting both the resilience and fragility of sustainability markets and the need for regulatory support and diversified green instruments. Compared to the long term, in the short term, no significant link is found between green bonds and WSUSI, reflecting the time needed for raised capital to translate into sustainability outcomes. This highlights their structural role: green bonds are less sensitive to market fluctuations but gain effectiveness over longer horizons as green markets mature.

For the Global Clean Energy Index (GCLEANI), the results are equally striking: Ethereum and Bitcoin both exhibit a strong positive association across all quantiles, reinforcing the view that blockchain adoption can amplify demand for renewable energy and clean technology. These findings align with previous literature: Hung (2021), Attarzadeh and Balcilar (2022), Annamalaisamy and Jayaraman (2023). However, ICEA remains insignificant, underscoring that environmental attention in isolation does not translate into concrete market outcomes.

Overall, the analysis highlights that achieving sustainable development depends on differentiating between transformative innovations (such as BTC, ETH, and GB) and destabilizing factors (including altcoins and excessive focus on CBDCs). For policymakers, this means adopting a two-part approach: encouraging environmentally friendly blockchain finance and regulating speculative assets like altcoins to reduce sustainability risks.

Table 4. QARDL estimation results for WSUSI

Coef	Quantile levels										
	5th	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
	Long-term estim[a]tes										
Constant (α*)	-0.118	2.661	1.268	1.259	0.412	0.549	0.076	-1.443	2.609	5.461 [a]	5.838 [a]
	(-0.086)	(1.186)	(1.110)	(1.046)	(0.172)	(0.250)	(0.037)	(-0.661)	(0.871)	(3.499)	(3.539)
β1 (BTC)	0.320 [a]	0.317 [a]	0.353 [a]	0.351 [a]	0.356 [a]	0.364 [a]	0.354 [a]	0.370 [a]	0.320 [a]	0.291 [a]	0.360 [a]
	(9.318)	(8.052)	(15.120)	(13.74)	(11.567)	(12.177)	(11.603)	(11.579)	(6.112)	(4.673)	(4.504)
β2(CBDCA)	0.784 [a]	0.200	0.395 [c]	0.364	0.792	0.830	0.999	1.132	0.301	-0.419 [c]	-0.604 [a]
	(3.817)	(0.248)	(1.852)	(1.559)	(0.960)	(1.189)	(1.585)	(1.565)	(0.360)	(-1.962)	(-2.702)
β3(CLCI)	-0.506 [a]	-0.493 [a]	-0.539 [a]	-0.523 [a]	-0.509 [a]	-0.516 [a]	-0.495 [a]	-0.500 [a]	-0.312 [a]	-0.231 [b]	-0.345 [a]
	(-7.501)	(-6.623)	(-11.970)	(-12.36)	(-11.168)	(-11.388)	(-10.824)	(-9.504)	(-3.017)	(-2.438)	(-2.636)
β4(ETH)	0.238 [a]	0.220 [a]	0.220 [a]	0.203 [a]	0.195 [a]	0.192 [a]	0.183 [a]	0.173 [a]	0.082 [c]	0.048	0.088 [c]
	(6.795)	(6.013)	(9.994)	(10.852)	(10.558)	(10.529)	(9.984)	(7.554)	(1.807)	(1.421)	(1.810)
β5(GCA)	0.016	0.027 [b]	0.022 [b]	0.024 [a]	0.023 [a]	0.026 [a]	0.026 [a]	0.021 [b]	0.022 [b]	0.024 [b]	0.019 [c]
	(1.474)	(2.056)	(2.584)	(3.057)	(2.863)	(3.526)	(3.564)	(2.520)	(2.576)	(2.552)	(1.842)
β6(ICEA)	-0.041	-0.078	0.124	0.186	-0.012	-0.096	-0.136	0.116	0.206	0.325	0.305
	(-0.179)	(-0.151)	(0.742)	(1.125)	(-0.034)	(-0.314)	(-0.481)	(0.294)	(0.568)	(1.268)	(1.116)
β7(GB)	0.566 [a]	0.586 [a]	0.515 [a]	0.499 [a]	0.449 [a]	0.461 [a]	0.442 [a]	0.397 [a]	0.257 [a]	0.239 [a]	0.342 [b]
	(6.010)	(6.161)	(7.665)	(8.757)	(7.552)	(9.392)	(9.257)	(7.044)	(3.253)	(2.769)	(2.491)
	Short-term estim[a]tes										
ECM (ρ*)	-0.106 [a]	-0.111 [a]	-0.111 [a]	-0.110 [a]	-0.117 [a]	-0.144 [a]	-0.146 [a]	-0.138 [a]	-0.144 [a]	-0.152 [a]	-0.188 [a]
	(-6.247)	(-4.697)	(-3.481)	(-3.010)	(-3.048)	(-3.626)	(-3.669)	(-3.734)	(-4.385)	(-5.940)	(-7.924)
Wsus(-1)	0.079 [b]	0.088	0.102	0.111	0.125	0.150 [c]	0.149 [c]	0.144 [c]	0.123 [c]	0.146 [a]	0.131 [a]
	(2.007)	(1.602)	(1.361)	(1.315)	(1.375)	(1.779)	(1.768)	(1.941)	(1.935)	(-1.538)	(3.571)
ω0 (BTC)	-0.137 [a]	-0.135 [a]	-0.140 [b]	-0.116	0.112	0.033	0.059	0.115	0.154 [b]	0.163 [a]	0.194 [a]
	(-3.562)	(-2.647)	(-2.271)	(-1.586)	(-1.451)	(0.355)	(0.644)	(1.330)	(2.188)	(3.130)	(5.359)
ω1 (BTC)	-0.219 [a]	-0.209 [a]	-0.176 [a]	-0.170 [a]	-0.169 [a]	-0.104 [c]	-0.109 [c]	-0.089	-0.0582	0.005	0.001
	(-8.309)	(-5.895)	(-3.689)	(-3.099)	(-2.867)	(-1.662)	(-1.844)	(-1.579)	(-1.218)	(0.138)	(0.055)
λ0(CBDCA)	0.115 [b]	0.113 [c]	0.162 [b]	0.189 [b]	0.249 [b]	0.252 [b]	0.260 [b]	0.253 [b]	0.240 [b]	0.256 [a]	0.221 [a]
	(2.295)	(1.723)	(2.230)	(2.173)	(2.024)	(2.046)	(2.149)	(2.272)	(2.514)	(3.446)	(3.731)
θ0(CLCI)	0.162 [a]	0.163 [b]	0.178 [b]	0.145	0.146	-0.060	-0.092	-0.170	-0.219 [b]	-0.236 [a]	-0.274 [a]
	(3.104)	(2.352)	(2.181)	(1.483)	(1.432)	(-0.453)	(-0.710)	(-1.412)	(-2.216)	(-3.270)	(-5.423)
Ψ0(ETH)	-0.037 [b]	-0.037 [c]	-0.040 [c]	-0.032	-0.032	0.023	0.030	0.049	0.062 [b]	0.067 [a]	0.077 [a]
	(-2.496)	(-1.889)	(-1.762)	(-1.187)	(-1.152)	(0.652)	(0.857)	(1.494)	(2.211)	(3.358)	(5.387)
δ0(GCA)	-0.009 [b]	-0.008 [c]	-0.005	-0.005	-0.004	-0.001	0.001	0.002	0.007	0.007	0.008 [b]
	(-2.305)	(-1.688)	(-1.066)	(-0.885)	(-0.724)	(-0.009)	(0.165)	(0.332)	(1.100)	(1.337)	(2.236)
γ0(ICEA)	-0.152 [b]	-0.145 [c]	-0.124	-0.127	-0.145	-0.057	-0.042	-0.008	0.063	0.017	0.035
	(-2.342)	(-1.714)	(-1.160)	(-0.997)	(-1.035)	(-0.401)	(-0.299)	(-0.061)	(0.450)	(0.146)	(0.395)
μ0(GB)	0.045	0.061	0.054	0.042	0.003	0.075	0.035	0.001	-0.024	-0.099	-0.015
	(0.473)	(0.475)	(0.319)	(0.227)	(0.020)	(0.373)	(0.173)	(0.007)	(-0.153)	(-0.777)	(-0.166)
μ1(GB-1)	-0.182 [a]	-0.191 [b]	-0.196	-0.187	-0.174	-0.182	-0.181	-0.234	-0.281 [c]	-0.387 [a]	-0.474 [a]
	(-2.644)	(-2.032)	(-1.522)	(-1.247)	(-1.086)	(-0.849)	(-0.890)	(-1.354)	(-1.954)	(-3.509)	(-5.403)

Notes: t-statistics are in parentheses. a, b and c denote statistical significance at 1%, 5% and 10% level. Source: Author's estimation.

Table 5. QARDL estimation results for GCLEANI

Coef	Quantile levels										
	5th	**10th**	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**	**95th**
	Long-term estimates										
Constant (α*)	5.496	1.137	-4.362	-4.609	-5.839	3.956	4.704	6.946 [c]	10.754 [c]	6.321	8.106
	(0.770)	(0.150)	(-1.277)	(-1.263)	(-1.462)	(1.165)	(1.459)	(1.656)	(1.745)	(0.949)	(0.966)
β1 (BTC)	1.149 [a]	1.243 [a]	1.255 [a]	1.227 [a]	1.251 [a]	1.454 [a]	1.488 [a]	1.706 [a]	1.960 [a]	1.996 [a]	2.102 [a]
	(5.016)	(6.922)	(6.820)	(6.948)	(8.935)	(11.301)	(12.180)	(10.121)	(20.880)	(27.780)	(17.824)
β2(CBDCA)	-2.876	-1.839	-1.024	-1.067	-1.305	-2.797 [a]	-3.128 [a]	-3.520 [a]	-5.202 [a]	-5.652 [a]	-4.682
	(-1.243)	(-0.851)	(-1.489)	(-1.435)	(-1.583)	(-3.680)	(-4.331)	(-3.501)	(-7.287)	(-1.962)	(-1.597)
β3(CLCI)	-1.513 [a]	-1.637 [a]	-1.592 [a]	-1.619 [a]	-1.727 [a]	-1.956 [a]	-1.949 [a]	-2.198 [a]	-2.540 [a]	-2.592 [a]	-2.72 [a]
	(-4.686)	(-6.751)	(-6.908)	(-7.256)	(-8.511)	(-11.126)	(-11.87)	(-9.649)	(-17.013)	(-23.81)	(-17.56)
β4(ETH)	0.459 [a]	0.501 [a]	0.458 [a]	0.492 [a]	0.525 [a]	0.589 [a]	0.567 [a]	0.634 [a]	0.769 [a]	0.790 [a]	0.829 [a]
	(3.691)	(5.102)	(5.135)	(5.643)	(6.509)	(8.744)	(8.906)	(7.443)	(11.924)	(15.157)	(13.254)
β5(GCA)	0.088 [c]	0.071	0.058	0.063	0.077 [a]	0.072 [a]	0.063 [a]	0.034	-0.008	-0.017	-0.015
	(1.712)	(1.473)	(1.411)	(1.601)	(2.698)	(2.828)	(2.576)	(1.228)	(-0.376)	(-0.985)	(-0.920)
β6(ICEA)	0.804	0.475	1.291 [b]	1.227 [c]	1.790 [c]	1.145 [c]	1.423 [b]	1.344 [c]	1.907	3.218 [a]	1.905
	(0.530)	(0.294)	(1.996)	(1.824)	(2.135)	(1.789)	(2.256)	(1.826)	(1.577)	(2.943)	(0.597)
β7(GB)	1.487 [a]	1.68 [a]	1.298 [a]	1.463 [a]	1.442 [a]	1.354 [a]	1.248 [a]	1.163 [a]	1.341 [a]	1.431 [a]	1.335 [a]
	(3.084)	(4.591)	(4.373)	(5.028)	(5.386)	(8.183)	(8.421)	(6.830)	(8.115)	(6.682)	(3.471)
	Short-term estim[a]tes										
ECM (ρ*)	-0.056 [a]	-0.056 [a]	-0.056 [a]	-0.063 [a]	-0.060 [b]	-0.061 [b]	-0.056 [b]	-0.055 [b]	-0.051 [b]	-0.046 [a]	-0.049 [a]
	(-5.587)	(-3.983)	(-2.993)	(-2.867)	(-2.496)	(-2.481)	(-2.344)	(-2.36)	(-2.487)	(-2.984)	(-4.311)
GCLEANI (-1)	-0.023	-0.024	-0.023	-0.008	0.013	0.015	0.021	0.029	0.034	0.051	0.038
	(-0.804)	(-0.636)	(-0.449)	(-0.137)	(0.201)	(0.231)	(0.332)	(0.458)	(0.614)	(1.111)	(1.063)
ω0 (BTC)	-0.270 [a]	-0.248 [a]	-0.213 [b]	-0.186 [c]	-0.158	-0.089	0.006	0.085	0.102	0.137	0.219 [a]
	(-5.632)	(-3.928)	(-2.470)	(-1.834)	(-1.397)	(-0.687)	(0.041)	(0.544)	(0.701)	(1.176)	(2.755)
λ0(CBDCA)	-0.301 [a]	-0.296 [a]	-0.300 [b]	-0.306 [b]	-0.274	-0.268	-0.244	-0.242	-0.228	-0.199*	-0.173 [c]
	(-4.418)	(-3.050)	(-2.286)	(-2.067)	(-1.409)	(-1.329)	(-1.244)	(-1.346)	(-1.506)	(-1.706)	(-1.814)
θ0(CLCI)	0.291 [a]	0.257 [b]	0.212 [c]	0.191	0.165	0.082	-0.052	-0.169	-0.193 [b]	-0.246	-0.359 [a]
	(4.660)	(3.083)	(1.866)	(1.375)	(1.058)	(0.465)	(-0.266)	(-0.790)	(-0.969)	(-1.540)	(-3.288)
Ψ0(ETH)	-0.010	0.004	0.020	0.022	0.026	0.044	0.085	0.127 [b]	0.137 [b]	0.157 [a]	0.196 [a]
	(-0.559)	(0.161)	(0.619)	(0.551)	(0.565)	(0.904)	(1.551)	(2.044)	(2.211)	(3.226)	(5.677)
δ0(GCA)	-0.011 [c]	-0.002	-0.001	0.002	0.006	0.012	0.021	0.025	0.026 [c]	0.029 [a]	0.038 [a]
	(-1.822)	(-0.209)	(-0.072)	(0.161)	(0.418)	(0.889)	(1.462)	(1.634)	(1.944)	(2.856)	(5.756)
γ0(ICEA)	0.082	0.091	0.096	0.193	0.171	0.167	0.253	0.246	0.249	0.254 [b]	0.130
	(0.542)	(0.396)	(0.345)	(-0.924)	(0.752)	(0.729)	(1.265)	(1.308)	(1.549)	(2.061)	(1.534)
μ0(GB)	1.813 [a]	1.762 [a]	1.734	1.649 [a]	1.626 [a]	1.643 [a]	1.638 [a]	1.573 [a]	1.538 [a]	1.475 [a]	1.410 [a]
	(20.55)	(14.391)	(10.572)	(8.593)	(7.645)	(7.859)	(8.433)	(7.859)	(8.119)	(9.123)	(11.121)
μ1(GB-1)	0.013	-0.013 [b]	-0.007	-0.024	-0.084	-0.132	-0.234	-0.248	-0.272 [c]	-0.343 [a]	-0.315 [a]
	(0.147)	(-0.103)	(-0.046)	(-0.131)	(-0.420)	(-0.675)	(-1.273)	(-1.404)	(-1.745)	(-2.783)	(-3.291)

Notes: t-statistics are in parentheses. a, b and c denote statistical significance at 1%, 5% and 10% level. Source: Author's estimation.

Discussion and Conclusion

Empirical findings of this study show that BTC, ETH, and GCA returns have a positive relationship with the WSUSI in both bearish and bullish market conditions. According to the analysis, there is no significant relation between the ICEA and clean energy or financial sustainable market indices. This result is in line with the previous research conducted by Kamal and Hassan (2022).

Based on QARDL estimation results and related literature, one can express that blockchain initiatives like Bitcoin and Ethereum can improve environmental quality via energy efficiency and resource management in this way contributing sustainability. According to current study, there is a positive connection between Bitcoin, green bonds, and both sustainable financial assets and clean energy assets, while altcoins (CLCI) show a negative relationship with sustainable and renewable clean energy indices. There is also greater connectedness among variables in higher quantiles than in medium quantiles. This means that the expansion of Bitcoin and the green bond market can play a significant role in achieving sustainable development goals. As the number of investors increases, the liquidity of clean and sustainable investment instruments also increases. Consequently, this leads to an increase in the returns on green bonds, BTC, and ETH investments.

Empirical evidence supports a close link between BTC, ETH, and green bonds (Naeem, Karim & Tiwari, 2022), reinforcing the positive interaction between innovative financial instruments and sustainability-focused assets. The observed long-term cointegration between blockchain variables and green assets suggests that these instruments can serve as stable drivers of sustainable finance, aligning with findings that GB, BTC, and GCA offer diversification and hedging benefits and contribute to climate change mitigation (Haq, 2023). Economically, this suggests that blockchain-driven assets and green bonds channel capital into clean energy and sustainability projects in a persistent manner, reinforcing the structural shift toward responsible investment. However, the short-term dynamics reveal fluctuating relationships, meaning that while innovative assets can strengthen sustainability outcomes over time, they remain vulnerable to temporary volatility and shifts in market sentiment. This asymmetry highlights both the resilience and fragility of sustainability-linked finance: long-term gains are achievable, but short-term instability underscores the importance of regulatory support and robust market design to stabilize green financial instruments.

In principle, there can be several discussion paths in which Bitcoin might be converted into something that satisfies the core principles of sustainability both from the viewpoint of environmental implications and from an economic standpoint. Truby (2018) suggests a regulatory-oriented strategy, specifically by imposing fiscal efforts to confine the energy consumption of the Blockchain and therefore its environmental implications. Ziolo, Kluza & Spoz (2019) demonstrated that environmental taxes have been confirmed over time to be an effective mechanism for mitigating greenhouse gas emissions, particularly in the case of more developed countries. The use of renewable energy resources for mining and the issue of cryptocurrency especially altcoin regulation in the essence of lessening its impact on the environment should be deeply considered. Based on our analysis, it is also clear that the volatility and the performances of altcoins has a negative influence on the sustainability (WSUSI), highlighting the need for regulatory measures in the altcoin market.

There is an increase in enthusiasm for exploring more sustainable alternatives due to rising concerns about the effects of existing financial systems on the environment. One such alternative is the utilization of innovative initiatives such as Ethereum (ETH), Bitcoin (BTC), and CBDCs that are powered by renewable energy sources. By leveraging these technologies, there is an opportunity to finance the SDGs in a more efficient, cost-effective, and environmentally sustainable manner in the long-term.

Although our study aims at contributing to the literature in several ways it also has specific limitations, which provide an avenue for forthcoming analysis. Firstly, the availability of the data is time-limited. For the application of the statistical approach, weekly data was employed. Since there yet exists no concrete data for the applications of CBDC innovations; CBDC and cryptocurrency attention indices were used for the comparison. However, the more concrete the data exists, the higher the predictive power in the time series. The validity of the results should be interpreted in the light of the specific indices chosen, and the assumption that asymmetries in the QARDL framework capture nonlinearities. Future studies may extend the dataset as CBDC applications mature, employ alternative econometric approaches such as NARDL or nonlinear causality tests, and broaden the scope by integrating sectoral ESG indicators and carbon market data.

These conclusions have important implications for investors looking to decarbonize their portfolios and diversify away from concerns about climate risks and environmental issues in cryptocurrency markets. Policymakers might take a more careful approach to the facts, since environmental awareness in the digital currency market may have a negative influence on green assets. Furthermore, with the implementation and widespread use of CBDC in the future, more concrete evidence on sustainability will be feasible.

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Özet

Yeşil şirketler ve kamu otoriteleri, son zamanlarda artan enerji tüketimi ve teknolojinin ekolojik etkileri nedeniyle sürdürülebilirlik konusunda giderek daha fazla endişe duymaya başlamışlardır. Son zamanlarda Merkez Bankası Dijital Para Birimleri (CBDC) ve kripto para birimleri gibi finansal dijital yeniliklerin çevresel etkileri etrafındaki tartışmalar artmaya başlamıştır. Bu çalışma, finansal yeniliklerin çevresel etkilerini vurgulayarak; Ekim 2017'den Haziran 2023'e kadar temiz enerji,

sürdürülebilirlik, yeşil tahviller ve altı blokzincir endeksi (örneğin, CBDCAI, ICEA, Bitcoin, Ethereum) arasındaki kısa ve uzun dönem *etkileşimi incelemektedir.* Çalışmada kullanılan kantil (*QARDL) analiz sonuçları, blokzincir değişkenleri ile yeşil endüstri arasında önemli bir uzun vadeli denge olduğunu ve farklı piyasa koşulları ve farklı kantiller arasındaki bu etkilerin zamanla değiştiğini ortaya koymaktadır. Bitcoin, Ethereum ve yeşil tahvil değişkenleri, özellikle daha yüksek yüzdelik dilimlerde, sürdürülebilir piyasa endeksini zaman içinde daha olumlu yönde etkileyerek Sürdürülebilir Kalkınma Amaçlarını (SKA) desteklemektedir.* Çalışmada, sürdürülebilir kalkınma *amaçları (SKA) politikaları için blokzincir teknolojisinin kullanılması ve blokzincir teknolojisinin çevresel etkilerini azaltmak için ise yenilenebilir enerji kaynaklarının kullanılması savunulmaktadır.*

Bazı ampirik çalışmalar da BTC, ETH fiyatı ve yeşil tahviller arasında yakın bir ilişki olduğunu kanıtlamıştır. Yeşil tahvil endeksi ile temiz enerji endeksi arasındaki pozitif ilişkiye göre, blokzincir gibi inovatif finansal yeniliklerin yeşil finansal varlıklar üzerinde pozitif ve anlamlı bir etkisinin olduğu ve uzun vadeli etkinin kısa vadeli etkiden farklı olduğu söylenebilmektedir. Literatürdeki önceki bulgularla uyumlu olarak, yeşil tahviller, Bitcoin ve yeşil sürdürülebilir kripto varlıklar gibi sürdürülebilir finansal varlıklar yalnızca çeşitlendirme ve korunma faydaları sağlamakla kalmayıp aynı zamanda iklim değişikliği krizini hafifletmeye ve uzun vadede çevresel ve sosyal açıdan sorumlu yatırımlara olan artan talebi karşılamaya da katkıda bulunabilir.

Finansal sistemlerin çevresel etkilerine ilişkin artan endişeler göz önüne alındığında, daha sürdürülebilir alternatifleri keşfetmeye yönelik artan bir ilgi bulunmaktadır. Bu alternatiflerin en başında, yenilenebilir enerji kaynaklarıyla desteklenen Ethereum (ETH), Bitcoin (BTC) ve CBDC'ler gibi yenilikçi girişimlerin kullanılması gelmektedir. Araştırma sonuçlarına da paralel olarak bu teknolojilerden yararlanılarak, Sürdürülebilir Kalkınma Amaçlarının (SKA'ların) uzun vadede daha verimli, uygun maliyetli ve çevresel olarak sürdürülebilir bir şekilde finanse edilmesi mümkün görülmektedir.

Bu çalışma sonuçlarının, portföylerini karbondan arındırmak ve kripto para piyasalarındaki iklim riskleri ve çevresel sorunlar hakkındaki endişelerden uzaklaşmak isteyen yatırımcılar için önemli çıkarımlara sahip olduğu söylenebilir. Ayrıca, gelecekte CBDC'nin uygulanması ve yaygın kullanımı ile sürdürülebilirlik konusunda daha somut kanıtların ortaya çıkması ve bu konuda daha farklı çalışmaların yapılması beklenmektedir.