



# Cryptocurrencies in a Sustainable Era: Analyzing the Influence of Environmental Innovation and US Stock Indices on Bitcoin and Ethereum Returns

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Received: 11 October 2025

Accepted: 25 January 2026

DOI: <https://doi.org/10.32479/ijeeep.22614>

## ABSTRACT

This study examines the joint influence of environmental factors and U.S. financial markets on the returns of Bitcoin (BTC) and Ethereum (ETH), shedding light on sustainability-driven crypto valuation. The analysis integrates CO<sub>2</sub> emissions, green innovations, ESG scores and financial indicators, including the S&P 500, NASDAQ, Dow Jones, gold and oil prices, using monthly data from January 2019 to February 2025. A robust econometric framework is employed to assess both the long-term cointegration and the short-term sensitivities of BTC and ETH returns. The findings suggest that BTC exhibits a strong positive correlation with environmental innovations and ESG scores, indicating an alignment with investors focused on sustainability. In contrast, ETH exhibits weaker sensitivity to environmental factors despite its adoption of a more energy-efficient Proof-of-Stake mechanism. Both cryptocurrencies respond positively to gold and oil prices, reinforcing their potential as alternative hedging assets. By jointly evaluating environmental and financial drivers, this study contributes to the fields of sustainable finance and digital asset research, bridging the gap between ESG studies and cryptocurrency market analysis.

**Keywords:** Cryptocurrency Returns, ESG Investing, Environmental Innovation, CO<sub>2</sub> Emissions, U.S. Stock Indices

**JEL Classifications:** G12, Q56, C22

## 1. INTRODUCTION

Cryptocurrencies have emerged as one of the most significant innovations in modern finance. These digital assets originate from blockchain technology and operate in a decentralised manner, functioning as a secure means of exchange through cryptographic protocols. Since the launch of Bitcoin in 2009, a continuously expanding ecosystem has emerged, now including cryptocurrencies such as Ethereum, Cardano, and Solana. They operate using complex cryptographic algorithms that ensure transparency and security without the need for a central authority.

This decentralised architecture, combined with the promise of greater financial autonomy and potentially high profitability,

has attracted a growing number of investors. However, beneath this technological innovation lies a more concerning reality: the growing environmental impact of cryptocurrencies, particularly those that use the Proof of Work (PoW) consensus mechanism. This system relies on energy-intensive computational processes to validate transactions, requiring substantial computing power and consequently high energy consumption.

PoW-based mining activates thousands of devices simultaneously, which are often hosted in data centres distributed around the world. These devices often draw electricity from fossil fuel sources, thereby increasing CO<sub>2</sub> emissions and contributing significantly to global warming. For example, recent research has shown that Bitcoin alone consumes more energy than countries such as Argentina or the Netherlands (De Vries and Stoll, 2021).

Furthermore, it could potentially contribute to a global temperature rise of over 2°C within the next three decades (Mora et al., 2018).

In response, several initiatives aimed at transitioning towards more sustainable validation mechanisms have emerged within the crypto-asset sector. One such approach is Proof of Stake (PoS), which uses the amount of cryptocurrency held by a user to validate transactions rather than computing power. Ethereum's transition to Ethereum 2.0 in 2022 reduced its energy consumption by over 99%. Other projects are exploring innovative alternatives, such as Proof of Space and Proof of Time, or hybrid algorithms that combine Proof of Work (PoW) and Proof of Stake (PoS).

Beyond environmental concerns, the performance of cryptocurrencies appears to be increasingly tied to traditional financial markets, including US stock indices such as the S&P 500, Nasdaq and Dow Jones. This growing correlation is due to increasing institutional investment in cryptocurrencies and evolving investor behaviour, with investors now being more responsive to macroeconomic indicators and financial performance metrics.

Against this backdrop, the present study investigates the joint impact of environmental factors and US financial indices on the returns of major cryptocurrencies, specifically Bitcoin (BTC) and Ethereum (ETH). The objective is to determine whether these assets, once considered independent of conventional markets, are now affected by the same global economic and environmental forces.

This analysis draws on a dataset of 74 monthly observations spanning January 2019 to February 2025. Three environmental variables are considered: CO<sub>2</sub> emissions, environmental innovation, and ESG (Environmental, Social, Governance) scores. Additionally, the study incorporates returns from the S&P 500, Dow Jones and Nasdaq indices, which were selected for their representativeness of U.S. financial markets. The choice of the US context is justified by its central role in the global crypto-asset market and the availability of reliable, detailed data.

The findings reveal a significant correlation between the performance of crypto-assets and selected environmental and financial variables. ESG scores and stock market returns are key determinants, particularly for Bitcoin. These results suggest that cryptocurrencies are no longer isolated from their broader economic and ecological context. Their value and returns now depend not only on blockchain integration, but also on a range of other factors. These results suggest that cryptocurrencies are no longer isolated from their broader economic and ecological contexts. Their value and returns now depend on both blockchain-internal mechanisms and exogenous factors, such as environmental regulations, public sentiment and financial market fluctuations.

Integrating ESG criteria and market dynamics into the analysis of cryptocurrency performance enhances our understanding of the links between digital finance, environmental sustainability, and integration with traditional markets. It also sheds light on an under-explored fact: as finance becomes increasingly digital, it

can no longer ignore sustainability requirements or the growing demand for environmental responsibility.

## 2. LITERATURE REVIEW AND RESEARCH HYPOTHESES

Analysing the performance of cryptocurrencies requires a multidisciplinary approach that combines traditional financial theories with contemporary environmental challenges. Digital assets such as Bitcoin (BTC) and Ethereum (ETH) are currently influenced by a variety of complex external factors, including sustainability trends, eco-innovative technologies, and global stock market fluctuations. This section presents a theoretical framework designed to identify the determinants of crypto-asset performance, drawing on economic, environmental and institutional theory.

Our investigation is based on three pillars: the predictability of cryptocurrency returns; the intersection between environmental concerns and financial performance; and the exposure of cryptocurrencies to traditional stock indices.

The inherent volatility of cryptocurrencies raises key questions about the nature and predictability of their returns. Several studies have emphasised the critical role of macroeconomic factors and market indicators in explaining crypto-asset price movements (Bouri et al., 2017; Corbet et al., 2018). These studies are based on the Efficient Market Hypothesis (Fama, 1970), which states that all available information is instantly reflected in asset prices. Consequently, fluctuations in indices such as the Nasdaq Composite, which is particularly sensitive to technological developments, can influence investor behaviour in crypto markets. Signal theory also provides an explanation as to why macroeconomic or technological events can act as psychological catalysts in financial markets (Spence, 1978). For instance, the announcement of large-scale blockchain adoption by a Nasdaq-listed firm could be perceived as a positive signal, thereby boosting capital inflows into crypto-assets. Empirical evidence supports this view, indicating that cryptocurrencies often react to growth indicators, interest rate changes and innovation-driven speculative bubbles.

Furthermore, behavioural finance suggests that cognitive biases, such as speculative optimism, the bandwagon effect or proximity bias, significantly influence investor choices in cryptocurrency markets. These irrational mechanisms can explain abrupt, non-fundamental price swings, particularly during periods of uncertainty or crisis.

The rise of ESG standards has brought renewed attention to the environmental impact of blockchain technologies, particularly with regard to energy consumption. Cryptocurrencies based on Proof of Work, such as Bitcoin, are often criticised for their significant energy usage and substantial contribution to global CO<sub>2</sub> emissions. This excessive consumption has become a barrier for climate-conscious institutional investors. In contrast, the development of more energy-efficient validation mechanisms, such as Proof of Stake, and the use of renewable energy in mining

processes are environmentally innovative solutions that improve the alignment of crypto-assets with sustainability goals (Sedlmeir et al., 2020).

The use of PoW in Bitcoin, for example, has attracted significant criticism due to its environmental impact, causing investors to rethink their positions. Conversely, innovations such as Ethereum's adoption of PoS have drastically reduced energy consumption (Kapengut and Mizrach, 2023).

This brings us to the second key dimension of our study: the relationship between environmental performance and cryptocurrency profitability. Bitcoin's reliance on PoW has prompted reassessments of its long-term sustainability. Studies by Stoll et al. (2019) and Mora et al. (2018) clearly demonstrate that cryptocurrency mining contributes significantly to global CO<sub>2</sub> emissions, representing a serious obstacle to its widespread adoption in an environmentally conscious world. This discussion is consistent with stakeholder theory, which emphasizes the importance of incorporating environmental, social and ethical considerations into economic decision-making processes. Similarly, legitimacy theory suggests that digital projects that align with environmental, social and governance (ESG) criteria enjoy broader market acceptance and improved financial outcomes.

Furthermore, eco-innovation theory (Rennings, 2000; Horbach et al., 2012) posits that sustainability-driven technological advances, such as proof-of-stake (PoS) or renewable-energy mining, can offer a competitive advantage. Ethereum's transition to PoS resulted in a 99.98% reduction in energy consumption (Kapengut and Mizrach, 2023) and significantly enhanced its reputation within the sustainable finance sector. This trend is supported by green finance theory, which argues that incorporating ESG criteria into investment decisions mitigates environmental risks and uncovers long-term financial opportunities (Friede et al., 2015; Fatemi et al., 2018). Recent empirical research has revealed an increasing interdependence between traditional stock markets (e.g. S&P 500, Dow Jones, Nasdaq) and major cryptocurrencies. This correlation intensifies during periods of economic stress or financial crisis, challenging the idea that cryptocurrencies can be used for diversification. Conversely, their behaviour is becoming increasingly synchronised with equity markets, which diminishes their safe-haven status in favour of a more speculative role (Bouri et al., 2017; Corbet et al., 2020).

These findings justify further empirical investigation into the interactions between the crypto and traditional markets when considering financial and environmental variables. Although originally conceived as an alternative to conventional markets, cryptocurrencies now exhibit an increasing dependency on major indices such as the S&P 500, the Dow Jones and the Nasdaq Composite. This synchronisation has become particularly evident during recent crises such as the pandemic caused by the SARS-CoV-2 virus, during which positive correlations were observed between stock and crypto market movements (Corbet et al., 2020; Bouri et al., 2020). These dynamics call into question the perception of crypto-assets as safe havens and emphasise their vulnerability to systemic shocks.

In this context, Markowitz's (1952) Modern Portfolio Theory remains essential for evaluating the role of digital assets in diversification strategies. While it was initially expected that cryptocurrencies would show weak correlations with equities, current data indicates an increasing degree of co-movement, thereby limiting their risk-reducing potential during turbulent periods. Institutional theory helps to justify the growing integration of cryptocurrencies into traditional financial systems. This theory posits that economic behaviour is shaped by both formal structures (such as regulations and financial standards) and informal ones (such as trust and investment culture). As traditional financial institutions, such as investment funds, banks and asset managers, increasingly incorporate cryptocurrencies into their strategies, these assets become more sensitive to traditional market dynamics and lose some of their initial autonomy.

Carbon dioxide emissions, particularly those produced by energy-intensive mining processes such as those used for Bitcoin, are an indicator of the environmental impact of cryptocurrencies. Several studies (Köhler and Pizzol, 2019; Wiwoho et al., 2024) have demonstrated that high-carbon cryptocurrencies are under increasing scrutiny from environmentally conscious institutional investors. The environmental consequences of cryptocurrency mining, particularly CO<sub>2</sub> emissions, are receiving increasing attention. Blockchains based on Proof of Work (PoW), such as Bitcoin or the former Ethereum model, consume large amounts of energy, mostly from non-renewable sources. This results in a significant carbon footprint, particularly in the US, where dependence on fossil fuels is high. This situation provokes negative responses from institutional investors and the public alike, thereby reducing the appeal of high-impact assets. The initial hypothesis is that an increase in CO<sub>2</sub> emissions is associated with a decrease in cryptocurrency profitability. This reasoning is consistent with the theory of pollutant asset stigmatisation (Pástor et al., 2021) and is supported by empirical studies such as those by de Vries (2018) and Stoll et al. (2019).

Gallersdörfer et al. (2021) also support this view, stating that negative environmental impacts, such as a large carbon footprint, are often considered financial risks, which can lead to the depreciation of crypto-assets in an era that is becoming increasingly focused on climate issues. In summary, rising CO<sub>2</sub> emissions in the US may reduce the market value of environmentally harmful cryptocurrencies, thus lowering their profitability. This trend illustrates how climate-related concerns are shaping investment decisions in the digital asset space. Bitcoin still operates under the energy-intensive PoW system, making it more vulnerable to environmental pressures and restrictive climate policies.

H<sub>1</sub>: CO<sub>2</sub> emissions from cryptocurrency mining significantly and negatively affect Bitcoin and Ethereum returns.

The transition to less energy-consuming validation systems, such as Proof of Stake (PoS), represents a notable ecological advancement within the cryptocurrency sector. Since its 2022 upgrade, Ethereum has exemplified this shift. As Sedlmeir et al. (2020) and Truby (2018) have highlighted, such innovation can enhance a project's market visibility and potentially boost its profitability. Innovations in cryptocurrency that are environmentally responsible, such

as switching to PoS or using renewable energy for mining, are direct responses to ecological concerns. These technological advancements improve energy efficiency and positively influence investor perception. Projects that embrace such strategies are often considered to be less risky, better governed and more sustainable. Therefore, the second hypothesis posits a positive correlation between environmental innovation and cryptocurrency performance. This is consistent with Rennings' (2000) definition of ecological innovation, as cited by Horbach et al. (2012) and Kemp and Pearson (2007).

Furthermore, environmental innovation involves integrating ESG criteria into the governance structures of blockchain-related firms. Protocols that assess and transparently report the environmental footprint of crypto projects are a significant development in managing their ecological impact. This enables investors to make informed decisions that consider financial, environmental and ethical factors, thereby enhancing the profitability of compliant projects. Green innovations improve project sustainability and attract responsible capital, potentially increasing long-term returns.

H<sub>2</sub>: Environmental innovation positively affects cryptocurrency performance.

ESG scores have become central to responsible investment decisions. Research by Friede et al. (2015) demonstrates a positive correlation between ESG performance and financial returns. Crypto projects that align with robust ESG practices are likely to attract more capital. In the US context, a high national ESG score indicates a favourable regulatory and sociopolitical environment for sustainable investment, including digital assets.

Agencies such as Sustainalytics and MSCI now provide detailed ESG ratings broken down by sector and region. These ratings directly influence investment strategies for crypto funds. Consequently, an increase in the U.S. ESG score could encourage responsible investment in sustainable cryptocurrencies. In a financial environment that prioritises social responsibility, a strong ESG score can boost returns on crypto assets by fostering investor confidence, mitigating perceived systemic risks and promoting innovation that aligns with ESG principles. ESG-aligned crypto projects enjoy better reputations and investor trust, which lowers regulatory risk and boosts perceived value.

H<sub>3</sub>: Global ESG scores positively impact cryptocurrency performance.

The S&P 500 index is a key indicator of U.S. economic health and investor sentiment. During bullish equity phases, capital often flows into cryptocurrencies in search of higher returns (Panagiotidis et al., 2018; Kurka, 2019). Recent studies (Corbet et al., 2018; Baur and Dimpfl, 2019) have highlighted a growing correlation between the S&P 500 and major cryptocurrencies, primarily caused by the institutionalization of digital assets.

VAR models and Granger causality tests confirm that S&P 500 fluctuations are increasingly responsible for the price movements of Bitcoin and Ethereum. This correlation is particularly strong during periods of monetary easing or fiscal stimulus in the US,

when abundant liquidity boosts both the equity and crypto markets. Empirical evidence supports the view that S&P 500 returns are a significant explanatory variable for crypto returns during bull markets. The S&P 500 drives crypto momentum in bullish economic contexts.

H<sub>4</sub>: The S&P 500 has a positive influence on cryptocurrency returns, reflecting an increase in market sentiment sensitivity.

The Dow Jones Industrial Average (DJIA) reflects traditional economic confidence. In times of market uncertainty, investors may either flee to safer assets or seek out high-risk assets for potential returns. Research such as that by Dyhrberg (2016) illustrates this duality. While some studies (e.g. Corbet et al., 2020) have found weak correlations between the DJIA and cryptocurrencies, the increasing presence of digital assets in institutional portfolios warrants a re-evaluation of this relationship. Complementary findings (Bouri et al., 2017) show that, while they are limited by their volatility, cryptocurrencies can partially hedge against stock market declines. This asymmetric behaviour, often fuelled by speculation, implies that investors gravitate towards traditional strategies during DJIA growth phases, but may seek alternative havens, including cryptocurrencies, during market downturns. Declines in industrial stock values may prompt investors to seek higher-risk assets such as Bitcoin.

H<sub>5</sub>: The Dow Jones has a negative influence on cryptocurrency returns.

The Nasdaq index is particularly responsive to technological innovation and speculative activity- features shared with cryptocurrency markets. This structural similarity can generate significant correlation between the two asset classes (Bouri et al., 2017; Corbet et al., 2020). The Nasdaq's focus on technology mirrors the innovation, volatility and speculation that characterise crypto markets. This connection is reinforced by novice investors attracted to these two innovative financial ecosystems. Global liquidity conditions, particularly under accommodative monetary policies, further strengthen this link as capital flows into high-risk ventures.

Financial products such as the Nasdaq Crypto Index (developed with Hashdex) aim to connect the traditional stock market with the crypto market by benchmarking the performance of digital assets using conventional market standards. However, in times of financial stress or uncertainty, capital outflows affect both the Nasdaq and the crypto markets, creating synchronised risk cycles (Corbet et al., 2019). The shared speculative and technology-driven nature of both markets reinforces their interdependence.

H<sub>6</sub>: The Nasdaq Composite exhibits a strong positive correlation with cryptocurrency performance.

### 3. METHODOLOGY

To study the effect of environmental factors and major US stock indices on cryptocurrency returns, this research takes a two-pronged methodological approach, combining an extensive literature review with rigorous empirical analysis based on real data.

### 3.1. Sample

The empirical analysis is based on a sample of 74 monthly observations, spanning six years from January 2019 to February 2025. Due to the dominance of American stock markets and the central role of the United States in the crypto-asset ecosystem, the data are limited to the U.S. context. To effectively address the research questions, the research variables are presented alongside operational indicators that measure them.

## 3.2. Measurement of Variables and Data Sources

### 3.2.1. Dependent variables

#### 3.2.1.1. Bitcoin

The world's first and most valuable cryptocurrency, Bitcoin is the primary variable considered in this study. Since its creation by Satoshi Nakamoto in 2009, it has become a key reference point in the world of digital assets. To capture Bitcoin's actual market dynamics over time, its price is measured using the monthly closing price, expressed in U.S. dollars. The final recorded price at the end of each month constitutes the monthly closing price, representing the market consensus at that exact moment. Data was collected monthly from January 2019 to February 2025, covering periods of economic expansion ("bull markets"), corrections and times of significant global instability. This timeframe enables us to evaluate Bitcoin's response to external shocks, including environmental and climate changes. The data source is Investing.com, which provides reliable historical series that are widely used in financial studies (Urquhart, 2016; Corbet et al., 2018).

#### 3.2.1.2. Ethereum

Ethereum is the second dependent variable in the study. In terms of market capitalisation, it is the second largest cryptocurrency after Bitcoin. Founded in 2015 by Vitalik Buterin, Ethereum is a key technological and financial component of the blockchain ecosystem, distinguished by its ability to execute decentralised applications and smart contracts. To enable direct comparison with Bitcoin over the same period, Ethereum's price is based on its monthly closing price in U.S. dollars from 2019 to 2025.

The monthly closing price is chosen because it accurately summarises the asset's value at the end of each cycle, while smoothing out extreme intra-month fluctuations. This method is widely used in empirical research on financial markets (Dyhrberg, 2016; Bouri et al., 2017). This measurement also helps to reveal structural trends and long-term effects, particularly those potentially caused by environmental factors such as green regulations, the energy transition and investor perceptions of ESG. Unlike Bitcoin, Ethereum transitioned to Proof of Stake (PoS) in September 2022 through "the Merge," which significantly reduced its energy consumption. This transformation makes analysing price sensitivity to environmental factors particularly relevant. Investing.com is the data source used, ensuring the consistency and reliability of the time series. Studying Ethereum as a dependent variable enables comparison between two distinct economic and technological models within the same analytical framework.

### 3.2.2. Independent variables:

#### 3.2.2.1. CO<sub>2</sub> emissions

CO<sub>2</sub> emissions are measured in thousands of tonnes generated per month, based on the estimated global electricity consumption of the Bitcoin and Ethereum networks, multiplied by an emission factor according to the energy mix (coal, gas, renewables, etc.). This methodology is employed in numerous scientific studies (de Vries, 2018; Stoll et al., 2019). Proof-of-work mining consumes substantial energy, leading to significant CO<sub>2</sub> production, particularly in countries that rely on fossil fuels for electricity generation. CO<sub>2</sub> emissions are directly influenced by the network's total computing power, mining difficulty and the type of equipment used. Bloomberg provides data on CO<sub>2</sub> emissions linked to cryptocurrency mining. This data is updated regularly and covers the entire analysis period from January 01, 2019 to February 01, 2025.

#### 3.2.2.2. Environmental innovations

In the context of the ecological transition and growing climate concerns, environmental innovations are becoming increasingly important in financial market dynamics, including cryptocurrencies. Often referred to as green or sustainable innovations, these encompass products, processes, technologies and managerial practices that aim to reduce the environmental impact of economic activity. Examples include less energy-intensive consensus mechanisms (such as Proof of Stake), the integration of eco-efficient cooling systems in data centres, the use of efficient mining equipment and the use of renewable energy sources to power mining infrastructures. According to Rennings (2000), environmental innovation encompasses technological, organisational, institutional and social changes aimed at reducing ecological damage. This definition is frequently referenced in green finance literature (Horbach et al., 2012; Kemp and Pearson, 2007) and guides our measurement of ecological innovation via the monthly consumption of green energy (in millions of cubic metres) by the Bitcoin and Ethereum blockchain networks. Data from Bloomberg reflect the renewable energy used by major mining platforms that rely on solar, hydro, wind or geothermal sources. This approach is consistent with the findings of studies by Truby (2018), Stoll et al. (2019) and Sedlmeir et al. (2020), which emphasise the significance of the use of renewable energy as an indicator of the ecological transition of cryptocurrencies. A higher share of green energy is viewed as a sign of stronger innovation. This factor is also relevant for ESG investors, who prioritise assets that are aligned with sustainable development goals (Friede et al., 2015; Krueger et al., 2020).

#### 3.2.2.3. ESG score

The ESG score evaluates the environmental (E), social (S) and governance (G) performance of a stock or entity. Though still emerging, the ESG score is becoming increasingly important in the context of cryptocurrency. It can be used to evaluate the resilience of mining protocols, blockchains, cryptographic projects and exchange-traded funds (Krueger et al., 2020). It is generally expressed as a composite index ranging from 0 to 100, with a higher score indicating better performance across the three dimensions.

### 3.2.2.4. Standard and Poor's 500 (S&P 500)

Due to its ability to accurately reflect the evolution of the US stock market, the S&P 500 index has been chosen as a significant independent variable in this study. It serves as an indicator of American economic performance, covering diverse sectors including technology, finance, healthcare, energy, industry and consumer goods. S&P 500 data is obtained from Bloomberg, which is renowned for its precise and reliable historical financial series. The index is measured in points, enabling its value changes to be tracked over time. Monthly data are used to suit economic studies on asset performance and reduce the impact of extreme daily or hourly fluctuations. The S&P 500 helps to explore the potential relationship between the dynamics of traditional financial markets and the performance of cryptocurrencies. Several empirical studies have examined the correlation between traditional stock indices and the crypto market. Increasing financial uncertainty may increase the correlation between the S&P 500 and cryptocurrencies such as Bitcoin or Ethereum (Corbet et al., 2018), while other research suggests that the decentralised nature of cryptocurrencies offers diversification benefits (Bouri et al., 2017).

### 3.2.2.5. Dow Jones Industrial Average (DJIA)

This index is included as an additional independent variable and a key indicator of the traditional stock market. Established in 1896, the DJIA is one of the oldest and most popular indices worldwide. It comprises 30 major American corporations spanning vital sectors such as consumer goods (Coca-Cola), telecommunications (Verizon), pharmaceuticals (Johnson and Johnson), finance (Goldman Sachs) and energy (ExxonMobil). According to Bouri et al. (2017), Bitcoin can act as a hedge against market fluctuations when used as an alternative asset. Corbet et al. (2020) emphasise the need to understand the channels through which traditional financial markets and cryptocurrency markets interact, particularly during times of crisis. Thus, the DJIA allows us to examine whether global stock market trends have a positive or negative influence on cryptocurrency performance.

### 3.2.2.6. Nasdaq Composite

This study incorporates the Nasdaq Composite Index as an independent variable in order to evaluate the potential influence of technology-focused stock markets on the performance of cryptocurrencies. Created in 1971, the Nasdaq Composite is a world-renowned index listing over 3,000 companies that are primarily active in technology, biotechnology, artificial intelligence (AI), telecommunications, and digital innovation. As it is weighted by market capitalisation, companies such as Apple, Microsoft, Amazon, Meta, Alphabet and Nvidia have a strong influence on index movements. Economic literature highlights behavioural similarities between cryptocurrency markets and Nasdaq-listed tech stocks. Both asset classes exhibit high volatility, continuous innovation and intense speculation, attracting risk-focused investors. Numerous empirical studies (e.g. Corbet et al., 2018; Bouri et al., 2017) have shown that the evolution of the Nasdaq can impact the price of cryptocurrencies, particularly during speculative bubbles or financial crises.

### 3.2.2.7. Gold

The gold price is used as a control variable in our model to examine the potential effect of traditional safe-haven assets on cryptocurrency returns. This variable is measured by the spot price of gold in US dollars per ounce (USD/oz). Monthly data are extracted from Bloomberg, a reliable source of updated commodity market information. Gold's inclusion is based on its historically recognised role as a refuge asset during periods of economic or geopolitical uncertainty. Several studies have demonstrated that gold can influence alternative markets, including cryptocurrencies, which are sometimes viewed as digital substitutes for traditional assets (Shahzad et al., 2020).

### 3.2.2.8. Oil

The price of crude oil is included as a control variable to capture the effect of global energy shocks on cryptocurrency returns. This is measured using Brent crude oil prices in US dollars per barrel (USD/barrel), a key international benchmark. Monthly data are obtained from Bloomberg, which is renowned for the completeness and reliability of its financial series.

$$BTC_t = \alpha + \beta_1 CO2E_t + \beta_2 EnvInv_t + \beta_3 ESGscore_t + \beta_4 S\&P500_t + \beta_5 DJIA_t + \beta_6 NASDAQ_t + \beta_7 GOLD_t + \beta_8 Petroleum_t + \varepsilon_t$$

$$ETH_t = \alpha + \beta_1 CO2E_t + \beta_2 EnvInv_t + \beta_3 ESGscore_t + \beta_4 S\&P500_t + \beta_5 DJIA_t + \beta_6 NASDAQ_t + \beta_7 GOLD_t + \beta_8 Petroleum_t + \varepsilon_t$$

Financial data on cryptocurrencies and stock indices was collected from Bloomberg and Investing.com. Environmental data were sourced from secondary databases accessible in the scientific literature, particularly the publications of Stoll et al. (2019), Wiwoho et al. (2024) and De Vries and Stoll (2021). These publications provide estimates of CO<sub>2</sub> emissions and technological innovations in the field of crypto-assets.

## 4. RESULTS AND DISCUSSION

This section analyses the empirical results obtained from econometric models designed to measure the effect of environmental factors and stock indices on the returns of cryptocurrencies, with a particular focus on Bitcoin (BTC) and Ethereum (ETH). The analysis is based on monthly data covering the period from January 2019 to February 2025.

### 4.1. Descriptive Statistics

Before undertaking the econometric analysis, it is essential to provide an overview of the variables used through descriptive statistics. These statistics enable the central tendency, dispersion and range of the data over the studied period to be observed. The following Table 1 summarizes the main descriptive measures.

In terms of descriptive statistics, the variation in BTC returns is highly dispersed, ranging from a negative value of -20,116.96 to a positive value of 26,900. Similarly, Ethereum (ETH) exhibits notable dispersion in returns, with values reaching several thousand dollars. The difference in returns between the

two cryptocurrencies can be explained by their current market values: 109,239.7 thousand dollars for BTC and 2,662.30 thousand dollars for ETH. Furthermore, the data indicate that, although the average returns of the two main cryptocurrencies studied (Bitcoin and Ethereum) are positive, they are also accompanied by high volatility, as reflected by the relatively

large standard deviation. Although more stable, stock indices also display significant variation, reflecting the period of economic uncertainty analysed.

Correlation analysis highlights several significant relationships (Table 2).

**Table 1: Descriptive statistics**

Variable	Observations	Moyenne	Écart-type	Min	Max
BTC	74	1327.25	6947.33	-20116.96	26900
ETH	74	43.27	439.42	-1008.32	1269.99
CO <sub>2</sub> E	74	75.45	16.27	44.40	110.18
EnvInv	74	141.80	17.51	114.83	182.45
ESGscore	74	98.75	0.26	98.01	99.48
S&P 500	74	4101.70	918.61	2584.59	6040.53
DJIA	74	32805.32	5442.19	21917.16	44910.65
NASDAQ	74	12731.37	3331.90	7281.74	19627.44

**Table 2: Correlation matrix**

	BTC	ETH	CO2E	EnvInv	ESGscore	S&P500	DJIA	NASDAQ	GOLD	Petroleum
BTC	1.0000									
ETH	0.7787	1.0000								
CO2E	-0.2483	-0.1766	1.0000							
EnvInv	-0.0505	0.0256	0.4065	1.0000						
ESGscore	-0.1030	-0.1516	-0.2969	-0.6697	1.0000					
S&P500	0.1870	0.0544	-0.3063	-0.7506	0.6401	1.0000				
DJIA	0.1808	0.0475	-0.2840	-0.7458	0.6275	0.9889	1.0000			
NASDAQ	0.2174	0.1066	-0.2612	-0.6998	0.5878	0.9764	0.9500	1.0000		
GOLD	0.1994	0.0240	-0.3517	-0.6971	0.5849	0.9022	0.8641	0.8975	1.0000	
Petroleum	-0.1184	-0.1527	-0.1022	-0.6391	0.4470	0.4501	0.4832	0.3311	0.2432	1.0000

**Table 3: Stationarity test after differencing**

Variable	Model	ADF Stat.	PP Stat.	Critical Value	ADF Prob.	PP Prob.	Stationary (ADF)	Stationary (PP)
BTC	Constant+Trend	-7.847	-7.821	-3.477	0.0000	0.0000	Yes	Yes
	Constant	-7.751	-7.726	-2.912	0.0000	0.0000	Yes	Yes
	None	-7.540	-7.524	-1.950	—	—	Yes	Yes
ETH	Constant+Trend	-8.542	-8.577	-3.477	0.0000	0.0000	Yes	Yes
	Constant	-8.603	-8.643	-2.912	0.0000	0.0000	Yes	Yes
	None	-8.578	-8.606	-1.950	—	—	Yes	Yes
CO <sub>2</sub> E	Constant+Trend	-4.502	-4.520	-3.477	0.0015	0.0014	Yes	Yes
	Constant	-4.196	-4.230	-2.912	0.0007	0.0006	Yes	Yes
	None	-6.843	-6.690	-1.950	—	—	Yes	Yes
EnvInv	Constant+Trend	-4.493	-4.580	-3.477	0.0016	0.0011	Yes	Yes
	Constant	-19.481	-22.785	-2.912	0.0000	0.0000	Yes	Yes
	None	-19.093	-20.729	-1.950	—	—	Yes	Yes
ESGscore	Constant+Trend	-6.200	-5.886	-3.477	0.0000	0.0000	Yes	Yes
	Constant	-8.688	-9.357	-2.912	0.0000	0.0000	Yes	Yes
	None	-8.718	-9.385	-1.950	—	—	Yes	Yes
S&P 500	Constant+Trend	-10.067	-10.163	-3.478	0.0000	0.0000	Yes	Yes
	Constant	-10.085	-10.162	-2.912	0.0000	0.0000	Yes	Yes
	None	-9.532	-9.506	-1.950	—	—	Yes	Yes
DJIA	Constant+Trend	-10.371	-10.642	-3.478	0.0000	0.0000	Yes	Yes
	Constant	-10.391	-10.633	-2.912	0.0000	0.0000	Yes	Yes
	None	1.297	1.773	-1.950	—	—	Yes	Yes
NASDAQ	Constant+Trend	-8.913	-8.918	-3.478	0.0000	0.0000	Yes	Yes
	Constant	-8.973	-8.978	-2.912	0.0000	0.0000	Yes	Yes
	None	-8.570	-8.573	-1.950	—	—	Yes	Yes
GOLD	Constant+Trend	-8.687	-8.699	-3.478	0.0000	0.0000	Yes	Yes
	Constant	-8.621	-8.623	-2.912	0.0000	0.0000	Yes	Yes
	None	-8.060	-8.074	-1.950	—	—	Yes	Yes
Petroleum	Constant+Trend	-7.320	-7.311	-3.478	0.0000	0.0000	Yes	Yes
	Constant	-7.374	-7.365	-2.912	0.0000	0.0000	Yes	Yes
	None	-7.422	-7.414	-1.950	—	—	Yes	Yes

- A strong correlation between BTC and ETH ( $r = 0.7787$ ) emphasizes their interdependence.
  - CO<sub>2</sub> emissions (CO<sub>2</sub>E) show a negative correlation with BTC ( $r = -0.2483$ ), which supports hypothesis H<sub>1</sub>.
  - Environmental innovation (EnvInv) exhibits an almost zero correlation with BTC ( $r = -0.0505$ ), which is insufficient to confirm H<sub>2</sub>.
- The ESG score shows a modest negative correlation with BTC ( $r = -0.1030$ ), contradicting H<sub>3</sub>.
  - Conversely, positive correlations are observed between BTC/ETH and the stock indices NASDAQ ( $r = 0.2174$ ) and S&P 500 ( $r = 0.1870$ ), which partially confirms H<sub>4</sub> and H<sub>6</sub>.

**4.2. Stationarity Test**

To test the stationarity of the time series used in our study, we applied the Augmented Dickey-Fuller (ADF) test. The general form of the ADF test is estimated using the following regression method:

$$\Delta y_t = \alpha + \tau + y_t - 1 + \sum_{j=1}^{\Phi} \phi_j \Delta y_{t-j} + \varepsilon_t$$

As well as the Phillips-Perron (PP) test.

The general form of the PP test is:

$$\Delta y_t = \alpha + \beta \Delta y_{t-1} + \varepsilon_t$$

The results showed that most of the variables were not stationary at their initial level, meaning their mean and variance evolved

**Table 4: Cointegration test results for BTC and ETH**

Equation	$\chi^2$	P-value	Conclusion
BTC	47.70	0.0000	Cointegration confirmed
ETH	26.08	0.0010	Cointegration confirmed

**Table 5: Estimation results of models 1 and 2 using OLS**

Explanatory variable	Bitcoin (coefficient/P-value)	Ethereum (coefficient/P-value)	Interpretation at 10% significance level
CO <sub>2</sub> Emissions (CO <sub>2</sub> E)	-8.979 (P=0.298)	-0.223 (P=0.588)	Not significant for BTC and ETH: CO <sub>2</sub> emissions do not appear to significantly influence returns.
Environmental Innovations (EnvInv)	64.478 (P=0.069)	2.332 (P=0.167)	Significant for BTC (P<0.10): green innovations favor Bitcoin. Not significant for ETH.
ESG Score (ESGscore)	15,139.8 (P=0.000)	-319.493 (P=0.070)	Strongly positive and significant for BTC. Slightly negative effect for ETH (P close to 0.07).
S&P 500 Index (SP500)	-5.778 (P=0.030)	-0.084 (P=0.503)	Significantly negative for BTC. Not significant for ETH.
Dow Jones Index (DJIA)	0.583 (P=0.084)	0.019 (P=0.232)	Weakly significant and positive for BTC. Not significant for ETH.
NASDAQ Index (NASDAQ)	-1.075 (P=0.031)	-0.091 (P=0.000)	Significantly negative for both BTC and ETH.
Gold (GOLD)	11.160 (P=0.000)	1.121 (P=0.000)	Highly significant and positive for BTC and ETH: rising gold prices support cryptocurrencies.
Oil (Petroleum)	179.145 (P=0.001)	18.495 (P=0.000)	Highly significant and positive for BTC and ETH: oil prices are positively linked to crypto returns.
Constant	-1,517,758 (P=0.000)	28,709.48 (P=0.092)	Significantly negative for BTC, marginally positive for ETH.

over time. To address this issue, we performed first differencing on the series, which made all the variables stationary (Table 3). This transformation is crucial for ensuring the stability of econometric estimates and obtaining reliable results.

**4.3. Cointegration Test Results**

Johansen’s cointegration tests demonstrate the existence of long-term relationships between cryptocurrencies and the explanatory variables (Table 4).

This means that the variables evolve jointly in the long term, and that shocks to one of the factors can lead to adjustments in cryptocurrency returns.

**4.4. Regression Model Estimation**

Multivariate Ordinary Least Squares (OLS) regressions are used to test the hypotheses with precision. The results are summarized in Table 5.

The econometric analysis revealed significant differences in the sensitivity of Bitcoin and Ethereum to the environmental and financial factors examined.

Firstly, CO<sub>2</sub> emissions appear to have no significant effect on the two cryptocurrencies. This suggests that, despite the growing focus on the carbon footprint of blockchains, these data do not seem to directly impact the short- or medium-term returns of digital assets in our sample. This may indicate that the market has not yet fully incorporated environmental costs into asset valuations, or that other factors dominate price movements.

Conversely, Bitcoin appears to be particularly sensitive to environmental innovations (EnvInv) and the ESG score. The positive and significant impact of these variables on Bitcoin underlines the market trend of valuing this asset based on its alignment with sustainability and social responsibility criteria.

This sensitivity could reflect growing investor demand to integrate extra-financial criteria into their portfolios. In contrast, Ethereum shows no significant relationship with these factors, possibly due to structural differences in how the two cryptocurrencies are perceived, or different investor profiles. As with traditional stock indices, Bitcoin reacts negatively to the S&P 500 and the NASDAQ, and positively, albeit marginally, to the Dow Jones.

This dynamic may reflect Bitcoin's status as a non-correlated, or even a safe-haven, asset during periods of stock market volatility. Ethereum, on the other hand, shows a significant association only with the NASDAQ, suggesting lower overall sensitivity to traditional stock indices. Real assets such as gold and oil have a strong and positive effect on both cryptocurrencies. These results suggest a possible correlation between these asset classes, potentially linked to investors' perceptions of commodities and certain cryptocurrencies as safe havens during periods of economic or inflationary uncertainty.

Lastly, Bitcoin's significantly negative constant could reflect an underlying downward trend not explained by the included variables, while Ethereum's marginally positive constant invites further exploration of Ethereum-specific factors.

## 5. CONCLUSION

This work highlights the complex relationship between sustainability, U.S. stock indices and cryptocurrency returns. By integrating environmental and financial variables into a single explanatory model, the study enriches our understanding of the performance of these assets. The results prompt a re-evaluation of the role of crypto-assets in modern portfolios, particularly from an ESG perspective. There are numerous implications: investors can integrate green criteria into their strategy; regulators can better oversee the sector's ecological impact; and blockchain platforms are encouraged to adopt more sustainable mechanisms. The intersection of digital and sustainable finance opens up promising avenues for research.

This study uses a comparative analysis of Bitcoin (BTC) and Ethereum (ETH) to shed light on the complex relationship between sustainability, global financial dynamics, and cryptocurrency performance. Simultaneously integrating environmental (CO<sub>2</sub> emissions, green innovations, ESG score) and financial (stock indices, commodity prices) variables into an econometric model contributes to a deeper understanding of the factors influencing crypto-asset performance.

The results reveal significant differences in how these two assets respond to the studied factors. Bitcoin stands out for its strong reactivity to sustainable innovations and ESG scores, reflecting the increased market focus on its frequently criticized ecological footprint. Although less influenced by these same criteria, Ethereum seems to benefit from its transition to the "Proof of Stake" validation mechanism, making it more aligned with the current requirements of sustainable finance.

From a financial perspective, Bitcoin exhibits negative correlations with the S&P 500 and NASDAQ indices, suggesting that it may

serve as an alternative asset during periods of stock market uncertainty. Ethereum primarily responds to NASDAQ, reflecting a closer link to the technology sector. Furthermore, the strongly positive effect of gold and oil on both cryptocurrencies reinforces their status as safe-haven assets sensitive to the macroeconomic environment.

The ETH model's excellent explanatory power, as demonstrated by its high adjusted R<sup>2</sup>, highlights the relevance of the selected variables. However, this statistical performance should be interpreted with caution, particularly given the risk of overfitting associated with highly volatile financial time series.

Beyond the statistical results, this work invites a re-evaluation of the role of cryptocurrencies in modern portfolios, particularly in the context of ESG criteria. There are multiple implications: investors can now integrate environmental and social criteria into their crypto strategy, regulators are encouraged to better frame the sector's ecological impact, and blockchain players are urged to adopt more sustainable mechanisms. The intersection of digital and sustainable finance thus opens up promising avenues for research, particularly in the areas of the extra-financial evaluation of crypto-assets, their energy governance and their resilience in the context of the global ecological transition.

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