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Unveiling the quantile connectedness between cryptocurrency market and Shari'ah-based sustainability indices

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Abstract

Purpose – This study aims to examine the quantile connectedness of Islamic cryptocurrencies compared to conventional cryptocurrencies with Shari'ah-based sustainability indices.

Design/methodology/approach – For baseline results, the authors use a novel econometric method, the method of moments quantile regression (MMQR), to estimate coefficients across heterogeneous quantiles under bearish and bullish market trends. The main empirical investigation uses daily data of two Islamic cryptocurrencies, two conventional cryptocurrencies and two Shari'ah-based sustainability indices from January 3, 2022, to September 30, 2024. For robustness tests, the authors extend the sample to five Islamic cryptocurrencies and the top five conventional and green cryptocurrencies, ranked by market capitalization, alongside four Shari'ah-based sustainability indices. The quantile VAR (QVAR) connectedness approach is used as an alternative method to validate the main findings.

Findings – Islamic cryptocurrencies show stronger quantile connectedness with Shari'ah-based sustainability indices compared to conventional cryptocurrencies. Positive connectedness dominates in bullish markets, supporting growth-oriented strategies, while negative connectedness emerges in bearish markets, indicating potential for portfolio diversification and hedging.

Practical implications – Overall, this study findings are significant for both diversification-seeking investors, who may prefer negative connectedness, and growth-oriented investors, who may benefit more from positive connectedness driven by market integration.

Originality/value – This study investigates the quantile connectedness of Islamic cryptocurrencies with Shari'ah-based sustainability indices, including a robustness check with an extended crypto sample and an alternative QVAR connectedness methodology.

Keywords Conventional cryptocurrencies, Islamic cryptocurrencies, Method of moments quantile regression, Quantile VAR connectedness, Shari'ah-based sustainability indices

Paper type Research paper

1. Introduction

The integration and diversification of technological advancements within the business sector, especially in areas related to environmental and social responsibility, are essential for achieving sustainability goals. The unique characteristics of blockchain technology have spurred significant interest in the development of cryptocurrencies, drawing the attention of various stakeholders, including researchers, investors and policymakers (Meria *et al.*, 2024). The drive to adopt advanced technological systems extends beyond business entities, as

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governments and international institutions recognize its impact on economic and social security (Zhang and Zhang, 2024; Shine, 2024). This global momentum toward blockchain technology is justified with the World Economic Forum forecasting that by 2027, 10% of global GDP will be stored on blockchain networks (World Economic Forum, 2015). Recently, the Securities and Exchange Commission (SEC) approved the first Bitcoin spot exchange-traded products (ETPs), marking a milestone for cryptocurrency and emphasizing the need for enhanced regulatory oversight (SEC, 2024).

As awareness grows among investors regarding the risks of climate and environmental change, and with the global push for regulations aimed at fostering more sustainable practices, there has been a rise in green projects and initiatives that embrace environmentally friendly approaches (Sakariyahu *et al.*, 2024; De Vries *et al.*, 2022). Green blockchain networks consume far less energy and produce fewer carbon emissions than the Bitcoin network (Alzoubi and Mishra, 2023; Aibai *et al.*, 2024; Howson and De Vries, 2022). It is important to note that Ethereum recently underwent a major strategic change by switching from a proof-of-work mechanism to a proof-of-stake mechanism, which led to a huge decrease of up to 99.99% in energy consumption, which could represent a radical shift in the cryptocurrency market (Newkeen, 2024).

Climate policy uncertainty increases regulatory challenges and costs for tech companies, including cryptocurrency, by making future expenses unpredictable, particularly for energy-intensive mining operations (Su *et al.*, 2023). It can also cause market volatility, reduce investment in cryptocurrencies and shift capital toward more sustainable assets (Gürsoy *et al.*, 2024; Guo *et al.*, 2024). Additionally, unclear policies can delay the adoption of green technologies and hinder investment in renewable energy for mining (Menati *et al.*, 2023). This uncertainty may harm public and regulatory perceptions, leading to stricter regulations and reputational risks for companies not aligning with green standards (Huang *et al.*, 2023; Wang *et al.*, 2023). Furthermore, energy supply risks and delayed sustainability investments highlight the need for proactive strategies in navigating climate policy challenges (Ni *et al.*, 2023).

The integration of renewable energy significantly benefits technological companies, including those in the cryptocurrency market, by reducing operational costs and enhancing sustainability (Nepal *et al.*, 2022; Gunarathna *et al.*, 2022). This shift improves energy efficiency, aligns with global sustainability goals and meets consumer demand for greener practices (Bekun *et al.*, 2019). In the cryptocurrency sector, renewable energy adoption is fostering the development of sustainable blockchain technologies and green cryptocurrencies (Saquib *et al.*, 2023; Anandhabalaji *et al.*, 2024). Neglecting renewable energy adoption can have negative consequences. Reliance on fossil fuels exposes companies to volatile energy prices, rising operational costs and environmental harm, particularly in energy-intensive activities like cryptocurrency mining (Sahoo and Timmann, 2023; Siddique *et al.*, 2023). In the cryptocurrency market, the carbon footprint of mining operations may deter eco-conscious users and investors (Lv, 2023).

The rise of Islamic crypto assets, powered by blockchain technology, introduces a unique dimension to Islamic finance, particularly in developing and emerging economies (Abdeldayem and Aldulaimi, 2024). Islamic crypto assets, like gold-backed OneGram Coin and X8XToken and MRHB DeFi, show lower volatility and minimal correlations, positioning them as potential safe havens in Islamic stock markets (Aloui et al, 2021; Ali *et al.*, 2022; Zaman *et al.*, 2025; Rizvi and Ali, 2022). Media coverage significantly influences investor attitudes and behavior, especially in the cryptocurrency market (Youssef and Waked, 2022; Lee and Jeong, 2023). The Cryptocurrency Environmental Concern Index (ICEA) has shaped investor trends, highlighting the impact of carbon footprints, and energy use (Kamal and Hassan, 2022; Wang *et al.*, 2022).

Islamic stocks respond to investor attitudes and behavior, emphasizing their role in portfolio risk management and the need for policies to reduce volatility in Shariah-compliant markets (Bossman *et al.*, 2024). In this context, Shari'ah-based sustainability indices reflect the intersection of Islamic ethical finance and contemporary sustainability goals. These indices are specifically designed for investors who aim to align their financial activities with both Shari'ah principles and environmental, social and governance (ESG) standards (Jan *et al.*, 2023).

It is crucial for the Islamic financial industry to keep pace with technological developments to remain competitive and meet evolving customer needs while maintaining a strong focus on sustainability, an essential principle of Islamic finance. Shari'ah-compliant investors have shown a growing interest in cryptocurrency investments, leading to the creation of gold-backed cryptocurrencies (Lahmiri and Bekiros, 2019). Given their substantial gold reserves, many Islamic countries have the potential to develop and issue their own Islamic gold-backed cryptocurrencies in the future (Yousaf and Yarovaya, 2022). In 2019, the central banks of Saudi Arabia and the UAE jointly launched a pilot cryptocurrency project named "Aber," aiming to explore the feasibility of a shared digital currency for cross-border payments between the two nations (SAMA, 2019). In January 2024, the United Arab Emirates (UAE) completed its inaugural cross-border payment using the Digital Dirham, transferring AED 50 million (approximately $13.6m) to China (CBUAE, 2024). In parallel with these technological initiatives, the top priority remains to maintain the basics of sustainability in its various aspects and ensure compliance with the Sharia standards that are supposed to govern the transactions of these countries.

The interconnectedness between the cryptocurrency market and Shari'ah-based sustainability indices is a critical area for research, as it bridges the rapidly evolving landscape of digital finance with the principles of ethical and sustainable investing. Cryptocurrencies, powered by blockchain technology, are reshaping global financial systems, yet their environmental and social implications remain underexplored, especially in the context of Shari'ah compliance. With increasing investor awareness of climate risks and the growing demand for sustainable financial instruments, understanding this relationship can provide valuable insights into aligning technological innovation with ethical and environmental imperatives. Furthermore, the emergence of Islamic crypto assets and Shari'ah-based sustainability indices reflects a unique opportunity to develop financial tools that address the needs of socially responsible investors while adhering to Islamic principles.

Our findings indicate that the quantile connectedness between Islamic cryptocurrencies and Shari'ah-compliant sustainability indices is more pronounced than that of conventional cryptocurrencies during both bearish and bullish market conditions. Therefore, this research offers important insights for policymakers, investors and regulators, fostering a more inclusive and sustainable financial ecosystem that balances technological advancements with ethical considerations.

The remainder of the study is organized as follows. The next section provides a literature review and identifies the research gap. Section 3 presents the data and empirical strategy. Section 4 discusses the empirical results, and finally, Section 5 concludes.

2. Literature review

The cryptocurrency market has evolved from an experimental technology to a significant financial ecosystem, influencing global finance, investment and innovation. Its rapid expansion, however, has raised concerns about regulatory oversight (Hendrickson and Luther, 2017; Griffith and Clancey-Shang, 2023), extreme volatility (Yi *et al.*, 2018; Katsiampa, 2019; Hansen *et al.*, 2024) and environmental impact (Zhang *et al.*, 2023; Wang *et al.*, 2022;

Wendl *et al.*, 2023). Concerns about high energy consumption have sparked debates about sustainability initiatives and their effectiveness (Mora *et al.*, 2018; Shin and Rice, 2022; Erdogan *et al.*, 2022; Haq *et al.*, 2023). For instance, Xia *et al.* (2023) used GARCH-MIDAS models with the Cryptocurrency Environmental Attention Index (CVI) to capture climate risk, finding that heightened environmental concerns exacerbate cryptocurrency volatility. These studies collectively highlight the emerging intersection between climate-related risks and digital asset markets.

The debate over the environmental footprint of proof-of-work cryptocurrencies, such as Bitcoin, has intensified. Wang *et al.* (2022) introduced the Index of Cryptocurrency Environmental Attention (ICEA) to quantify public discourse on cryptocurrency energy use and sustainability. They found positive correlations between ICEA, Bitcoin prices and cryptocurrency uncertainty indices, and negative correlations with global economic and temperature uncertainty. This evidence underscores the growing importance of regulatory oversight and sustainability-focused strategies for resource-dependent economies (Rafei *et al.*, 2022). The resource curse hypothesis further emphasizes that weak institutional frameworks exacerbate environmental degradation (Auty, 1994; Sachs and Warner, 1995, 2001; Zuo *et al.*, 2021; Adebayo *et al.*, 2022), underscoring the relevance of governance in harmonizing financial growth with environmental stewardship.

However, a critical gap remains at the intersection of three rapidly evolving domains:

(1) cryptocurrency innovation;

(2) Islamic finance principles; and

(3) sustainable investing.

From an Islamic finance perspective, cryptocurrencies are increasingly regarded as an emerging asset class, yet their compatibility with Shari'ah principles and their interaction with Islamic capital markets are underexplored (Abdeldayem *et al.*, 2021; Chaho and Aswad, 2021). Understanding how shocks spill over from crypto assets to Shari'ah-compliant ESG indices can reveal new structural linkages, indicating whether these ethical indices are insulated, vulnerable or correlated with crypto stress. This inquiry forces a deeper engagement with the foundational principles of Islamic finance, which extends beyond mere prohibition-based screening to a broader ethical-economic vision rooted in *maqāṣid al-Sharīʿah* (the purposes of Islamic law), emphasizing justice (*ʿadl*), public interest (*maslahah*) and mutual responsibility (*taẓāmun*). While studies like Harahap *et al.* (2023) connect Islamic law and finance to the UN SDGs via *maqāṣid* theory, sustainability in Islamic finance is often treated as an overlay on conventional ESG frameworks, rather than a rethinking of sustainability from a distinct Islamic logic (Orsagh *et al.*, 2019; Qoyum *et al.*, 2022).

Simultaneously, the literature on the linkage between cryptocurrency and sustainability is emerging. The intersection is multifaceted, encompassing energy consumption (Lee *et al.*, 2024), the tokenization of green assets (Patel *et al.*, 2024; Alharbi *et al.*, 2025) and blockchain-based verification for climate projects (Campbell-Verduyn, 2024; Jha, 2025). Despite this, crypto's environmental reputation remains largely negative. Embedding crypto within a Shari'ah-ESG framework forces the critical question:

Q. Which crypto activities align with sustainability and ethical finance, and how do they dynamically interact with Islamic ESG indices?

Our connectedness analysis provides empirical insight into this question, integrating crypto into the green finance debate through an Islamic lens and exploring its potential role in Islamic green finance.

This leads directly to implications for risk management and portfolio diversification. A robust financial economics literature underscores the importance of understanding cross-asset connectedness for portfolio construction, hedging and safe-haven strategies (Almeida and Gonçalves, 2022; Lamine *et al.*, 2024). The highly volatile nature of cryptocurrencies makes their role in diversification particularly salient (Gadi and Sicilia, 2022). While evidence suggests cryptocurrencies can act as hedges under certain conditions, their effectiveness is regime-dependent (Conlon *et al.*, 2020), and even stablecoins face constraints (Kołodziejczyk, 2023; Wang *et al.*, 2020). In this context, the comparison between Islamic and conventional cryptocurrencies becomes critically significant. They represent two distinct paradigms: one operating within a framework of ethical constraints and sustainability commitments and the other representing a more value-agnostic model of innovation. Examining their connectedness with Shari'ah-based sustainability indices is not merely academic; it reveals whether Islamic cryptocurrencies offer a more aligned and stable investment vehicle for ethically minded portfolios, thereby providing clearer guidance for asset allocation under uncertainty. This comparison is essential for shaping a future financial system that is not only efficient but also equitable and sustainable, a goal that resonates with the fusion of behavioral finance and Fintech for strategic decision-making (Abdeldayem and Aldulaimi, 2025) and the development of innovative Islamic financial mechanisms (Abdeldayem and Aldulaimi, 2025; Ahmed, 2023; Bataineh *et al.*, 2024; Abdeldayem, 2010; Abdeldayem and Aldulaimi, 2024).

Understanding the interplay between governance, sustainability and ethical considerations is critical for guiding Shari'ah-based investments. Shari'ah-compliant indices integrate Islamic law with ESG factors, providing ethical benchmarks for investors (Halawi, 2023). By excluding prohibited industries, these indices support responsible growth and transparency (Ahmed *et al.*, 2015). The literature highlights the alignment of Islamic finance with the United Nations' Sustainable Development Goals (SDGs), where instruments such as sukuk, zakat and microfinance facilitate philanthropy, employment and sustainable development (Shahid *et al.*, 2023; Dirie *et al.*, 2024; Gundogdu, 2018). However, the integration of cryptocurrencies into Shari'ah-compliant portfolios remains underexplored, particularly regarding volatility management, environmental impact and compliance with principles such as Gharar (excessive uncertainty) (Izadin *et al.*, 2025; Razak *et al.*, 2024; Bakar and Foziah, 2024; Ahmed, 2021).

Recent studies increasingly use quantile-based connectedness approaches (QVAR) to examine the propagation of shocks among cryptocurrencies, traditional assets and green or ESG-related instruments. These methods capture the tail behavior of financial shocks and extreme market conditions more effectively than mean-based approaches (Kyriazis *et al.*, 2024; Bouri *et al.*, 2021; Joo and Park, 2023; Shao *et al.*, 2025; Marco *et al.*, 2023). Time-frequency and quantile methods further reveal heterogeneity in connectedness across horizons, highlighting the importance of short-term versus long-term spillovers (Le, 2023; Bhattacherjee *et al.*, 2025; Kyriazis and Corbet, 2024; Bouzguenda and Jarboui, 2025). Complementary techniques such as TVP-VAR have also been applied in financial econometrics to account for dynamic spillovers and mitigate the influence of heavy tails, offering a robust alternative to traditional VAR models. Discussing these approaches strengthens the rationale for using quantile connectedness, as it allows for nuanced insights into extreme events, asymmetric shocks and tail dependencies that are particularly relevant for Islamic cryptocurrencies and Shari'ah-based sustainability indices.

Despite the growing literature on connectedness, a notable gap remains in assessing the tail-dependent interactions between Islamic cryptocurrencies and Shari'ah-based sustainability indices. While prior research has investigated the volatility transmission of cryptocurrencies or

Shari'ah-compliant equities individually, few studies explicitly examine their joint connectedness under extreme market conditions. This study advances the literature by applying a quantile connectedness framework to capture the asymmetric transmission of shocks across Islamic digital assets and sustainable investments, offering both theoretical and practical insights for portfolio management. Methodologically, our approach extends previous work by integrating a tail-dependent perspective that complements existing TVP-VAR and mean-based analyses, thereby providing a more comprehensive understanding of dynamic interactions in Shari'ah-compliant financial markets.

This study makes a significant contribution to the literature by providing the first comprehensive analysis of quantile connectedness between Islamic cryptocurrencies and Shari'ah-based sustainability indices. Unlike prior research that primarily examines mean-based relationships or conventional volatility spillovers, our approach explicitly captures tail-dependent interactions and asymmetric shock propagation across extreme market conditions. This is particularly relevant in the context of Islamic finance, where adherence to Shari'ah principles emphasizes risk-sharing and ethical investment, making the understanding of extreme downside and upside market behavior critical for portfolio design and risk management. Methodologically, our study advances the emerging literature on Islamic cryptocurrencies by using a quantile connectedness framework, which allows us to disentangle the dynamic interdependencies across different points of the return distribution. This approach captures nuances that traditional VAR or TVP-VAR methods may overlook, including differential shock transmission during bullish, bearish or crisis periods. By focusing on extreme quantiles, we provide deeper insights into how Islamic cryptocurrencies may act as shock transmitters or receivers in relation to sustainability indices, highlighting their role in portfolio diversification, hedging strategies and systemic risk mitigation within ethical investment contexts.

Our findings offer empirical evidence that can guide Islamic investors, fund managers and policymakers in designing Shari'ah-compliant investment strategies that are resilient to extreme market fluctuations. In doing so, the study bridges a critical gap between the growing literature on cryptocurrency volatility, sustainable finance and Shari'ah-compliant investments, providing actionable insights for both academic research and practical financial decision-making.

3. Data and empirical strategy

3.1 Sample description

For our benchmark analysis, we obtained daily data for two Islamic cryptocurrencies (MRHB and X8X) and two conventional cryptocurrencies (Bitcoin and Ethereum) from the CoinMarketCap website. Data on the Shari'ah-based sustainability indices were gathered from the LSEG Refinitiv database. Our sample period spans January 3, 2022, to September 30, 2024. Table 1 provides a description of the variables.

The selection of Islamic cryptocurrencies was based on explicit Shari'ah-compliance claims, underlying asset-backing and public endorsements. MRHB DeFi positions itself as a Shari'ah-compliant decentralized finance ecosystem, with its tokenomics and operational model reviewed and endorsed by recognized Islamic finance scholars and bodies. X8X Token is a gold and fiat currency-backed cryptocurrency that has undergone a Shari'ah compliance screening, explicitly marketing itself as a stable and ethical digital asset aligned with Islamic financial principles. These assets were chosen over other purported "Islamic" cryptocurrencies due to their more transparent compliance claims, established market presence and the availability of sufficiently long time-series data, which is essential for rigorous empirical analysis and facilitates comparison with conventional cryptocurrencies.

Table 1. Variables description and data sources

	Symbols	Type	Source
Shari'ah-based sustainability indices			
S&P/Hawkamah ESG UAE Index	SPHMUEUP	Index	LSEG Refinitiv
FTSE Bursa Malaysia Top 100 ESG Low Carbon Select Shariah Index	FTFBM100LS	Index	LSEG Refinitiv
Cryptocurrencies			
Islamic DeFi asset (MRHB DeFi)	MRHB	Islamic Crypto	coinmarketcap.com
X8X Token	X8X	Islamic Crypto	coinmarketcap.com
Bitcoin (BTC-USD)	BTC	Conventional Crypto	coinmarketcap.com
Ethereum (ETH-USD)	ETH	Conventional Crypto	coinmarketcap.com

Other Islamic cryptocurrencies, such as Zamzam Token, ISLM and ISLAMICOIN, have a relatively limited market presence and shorter histories.

We focus on MRHB and X8X as the primary Islamic cryptocurrencies in this study due to the availability of sufficiently long time-series data, which is essential for rigorous empirical analysis and facilitates comparison with conventional cryptocurrencies. MRHB and X8X are also among the more established Islamic cryptocurrencies in terms of market presence and adoption. To further ensure the robustness of our results, we additionally examine alternative Islamic cryptocurrencies (such as Zamzam Token, ISLM and ISLAMICOIN) in the robustness analysis, confirming that the main findings are consistent across multiple Shari'ah-compliant digital assets.

Regarding the Shari'ah-based sustainability indices, our selection was guided by their representation of key Islamic financial markets and their explicit integration of ESG criteria. The S&P/Hawkamah ESG UAE Index (SPHMUEUP) represents a major Gulf Cooperation Council (GCC) economy and combines Shari'ah screening with ESG metrics from S&P and the Hawkamah Institute for Corporate Governance. The FTSE Bursa Malaysia Top 100 ESG Low Carbon Select Shariah Index (FTFBM100LS) represents Malaysia, a global leader in Islamic finance, and integrates Shari'ah screening with a specific focus on low carbon emissions and broader ESG factors from FTSE. These two indices were selected as they are among the most prominent and accessible benchmarks that directly embody the intersection of Shari'ah compliance and sustainability, providing a robust proxy for this niche asset class. In our robustness analysis section, we also use the FTSE4Good Bursa Malaysia Index (FTF4GBM), the FTSE ADX ESG Screened Index (FTFADXSI) alternative sustainability-based indices.

3.2 Empirical strategy

3.2.1 Diagnostic tests. We start our empirical strategy with the pre-test diagnostics, and the test result is reported in Table 2 and Figures 1–3. Our results presented in Table 2 show that out of the six variables, MRHB, X8X, FTFBM100LS and SPHMUEUP are indicating positive skewness, i.e. these variables show longer tail on the right side of the distribution. Contrary, BTC and ETH are indicating negative skewness, i.e. these two variables show a longer tail on the left side of the distribution. Thus, these variables indicate the asymmetric distribution pattern. In addition, the significant tests results of the Jarque–Bera and ARCH-LM suggest the rejection of normality and homoskedasticity in all six variables. Therefore, these variables are log-transformed to avoid the level of heteroskedasticity.

Table 2. Diagnostic tests

Variable	Obs	Mean	SD	Skewness	Kurtosis	Jarque–Bera	ARCH-LM (1)
MRHB	144	0.011	0.021	3.188	13.674	927.4***	133.682***
X8X	144	0.005	0.003	1.200	3.767	38.12***	109.159***
BTC	144	4.53	0.189	−0.183	1.875	8.392**	125.288***
ETH	144	3.317	0.146	−0.089	1.997	6.227*	100.995***
FTFBM100LS	144	2.291	0.031	0.650	3.132	10.25***	120.488***
SPHMUEUP	144	3.158	0.015	0.482	3.482	6.961**	67.183***

Note(s): The distribution of the variables is described using skewness and kurtosis statistics. Normality is assessed through the Jarque–Bera test, while heteroskedasticity is evaluated using the ARCH-LM (1) test. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Finally, all variables are described in Table 1

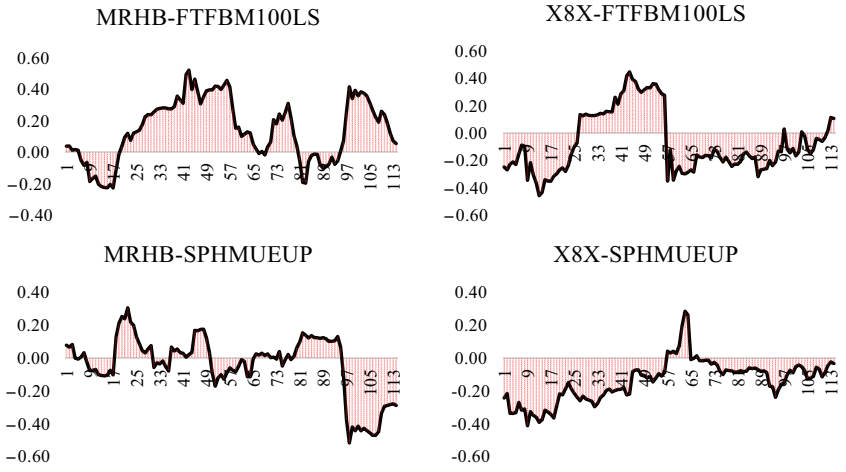

Figure 1. Moving-window correlation estimates between the Islamic cryptocurrency market and Shari'ah-based sustainability indices (with a 30-week rolling period)
Source: Authors' own work

Before applying the quantile-based estimations, it is important to check whether the series have any possible time-varying correlation (Sinha *et al.*, 2023). Therefore, moving window correlation and dynamic conditional correlation between the Shariah-based sustainability indices and cryptocurrencies are estimated, and the results are shown in Figures 1–3.

The 30-week rolling-window correlation estimates show that the correlation among variables is changing both in direction and magnitude. To address the issue of heteroskedasticity, the dynamic conditional correlation is computed. The findings reveal that the correlation fluctuates periodically in both direction and magnitude, aligning with the estimates obtained from the moving-window correlation method. This pattern in the correlation structure suggests the possibility of quantile dependence between these series.

3.2.2 Method of moments quantile regression. To capture the tail behavior under different market conditions (bearish and bullish), we follow existing literature (Shan *et al.*, 2024; Dias *et al.*, 2022; Khan *et al.*, 2024; Bouri *et al.*, 2021) and use the method of moments

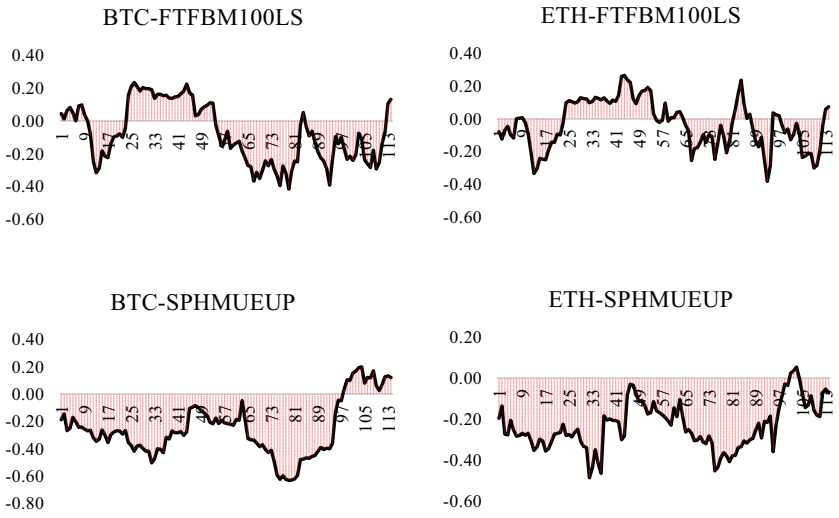

Figure 2. Moving-window correlation estimates between the conventional cryptocurrency market and Shari'ah-based sustainability indices (with a 30-week rolling period)
Source: Authors' own work

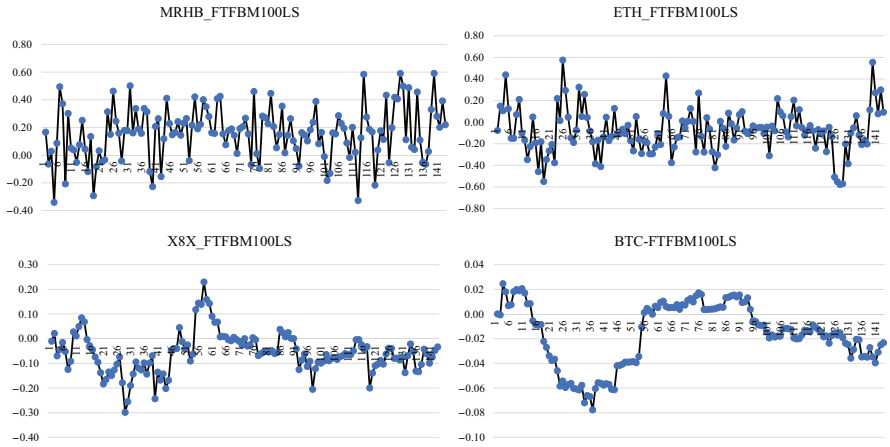

Figure 3. Dynamic conditional correlation estimates between the cryptocurrency market and Shari'ah-based sustainability indices
Note(s): The dynamic conditional correlation estimates between the SPHMUEUP index and the cryptocurrency market are qualitatively similar to those of the FTFBM100LS. For the sake of brevity, these results are not reported
Source: Authors' own work

quantile regression (MMQR) approach. The general quantile conditional function for quantile τ is given as:

$$Q_{SS\_Index,t}(\tau IX_t) = \beta_{1,\tau} MRHB_t + \beta_{2,\tau} X8X_t + \beta_{3,\tau} BTC_t + \beta_{4,\tau} ETH_t + \varepsilon_{\tau,t} \quad (1)$$

where τ represents quantiles such as 5th, 10th, 15th (bearish market), and 85th, 90th and 95th (bullish market), t is the time-period starting from t = 1,……144, *SS_Index*, t represents the Shariah-based sustainability indices, namely, FTFBM100LS (FTSE Bursa Malaysia Top 100 ESG Low Carbon Select Shariah Index) and SPHMUEUP (S&P/Hawkamah ESG UAE Index) and is our dependent variable.

Equations for each quantile under bearish market are given as:

$$Q_{0.05}(SS\_index_t) = \lambda_{0.05} + \gamma_{1,0.05} MRHB_t + \gamma_{2,0.05} X8X_t + \gamma_{3,0.05} BTC_t + \gamma_{4,0.05} ETH_t + \varepsilon_{0.05,t} \quad (2)$$

$$Q_{0.10}(SS\_index_t) = \lambda_{0.10} + \gamma_{1,0.10} MRHB_t + \gamma_{2,0.10} X8X_t + \gamma_{3,0.10} BTC_t + \gamma_{4,0.10} ETH_t + \varepsilon_{0.10,t} \quad (3)$$

$$Q_{0.15}(SS\_index_t) = \lambda_{0.15} + \gamma_{1,0.15} MRHB_t + \gamma_{2,0.15} X8X_t + \gamma_{3,0.15} BTC_t + \gamma_{4,0.15} ETH_t + \varepsilon_{0.15,t} \quad (4)$$

Equations for each quantile under bullish market are given as:

$$Q_{0.85}(SS\_index_t) = \lambda_{0.85} + \gamma_{1,0.85} MRHB_t + \gamma_{2,0.85} X8X_t + \gamma_{3,0.85} BTC_t + \gamma_{4,0.85} ETH_t + \varepsilon_{0.85,t} \quad (5)$$

$$Q_{0.90}(SS\_index_t) = \lambda_{0.90} + \gamma_{1,0.90} MRHB_t + \gamma_{2,0.90} X8X_t + \gamma_{3,0.90} BTC_t + \gamma_{4,0.90} ETH_t + \varepsilon_{0.90,t} \quad (6)$$

$$Q_{0.95}(SS\_index_t) = \lambda_{0.95} + \gamma_{1,0.95} MRHB_t + \gamma_{2,0.95} X8X_t + \gamma_{3,0.95} BTC_t + \gamma_{4,0.95} ETH_t + \varepsilon_{0.95,t} \quad (7)$$

4. Empirical results

4.1 Baseline analysis

The outcomes of the test results based on MMQR analysis are reported in Tables 3 and 4. Table 3 presents the quantile connectedness of both Islamic (MRHB and X8X) and conventional (BTC and ETH) cryptocurrencies with the FTSE Bursa Malaysia Top 100 ESG Low Carbon Select Shariah Index (FTFBM100LS).

We estimate the connectedness among MRHB, X8X, BTC, ETH and FTFBM100LS at heterogenous quantiles under bearish and bullish market conditions. It is important to consider both bearish and bullish market trends because of the following reasons. First, positive connectedness can signal integration between the cryptocurrency market and Shariah-based sustainability index. Our results show that, in the bullish market, Islamic cryptocurrencies are significantly and positively connected with FTFBM100LS, indicating

Table 3. Method of moments quantile regression (MMQR) outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Bearish market condition					Bullish market condition	
FTFBM100LS	Location	Scale	$Q_{0.05}$	$Q_{0.10}$	$Q_{0.15}$	Location	Scale	$Q_{0.85}$	$Q_{0.90}$	$Q_{0.95}$
MRHB	0.452*** (0.123)	0.0393 (0.0661)	−0.389*** (0.135)	−0.399*** (0.128)	−0.403*** (0.125)	0.452*** (0.123)	0.0393 (0.0661)	0.504*** (0.172)	0.519*** (0.191)	0.532** (0.209)
X8X	0.211*** (0.0526)	0.0697** (0.0282)	−0.0990* (0.0583)	−0.117** (0.0550)	−0.124** (0.0532)	0.211*** (0.0526)	0.0697** (0.0282)	0.304*** (0.0733)	0.330*** (0.0816)	0.353*** (0.0894)
BTC	1.858 (1.167)	0.223 (0.626)	1.501 (1.283)	1.557 (1.211)	1.580 (1.186)	1.858 (1.167)	0.223 (0.626)	2.154 (1.629)	2.237 (1.808)	2.312 (1.978)
ETH	−0.149** (0.0663)	−0.0895** (0.0356)	−0.00489 (0.0736)	−0.0278 (0.0693)	−0.0370 (0.0670)	−0.149** (0.0663)	−0.0895** (0.0356)	−0.268*** (0.0925)	−0.301*** (0.103)	−0.331*** (0.113)
Constant	1.815*** (0.0533)	−0.00137 (0.0286)	1.817*** (0.0586)	1.816*** (0.0553)	1.816*** (0.0542)	1.815*** (0.0533)	−0.00137 (0.0286)	1.813*** (0.0745)	1.812*** (0.0826)	1.812*** (0.0904)
Observations	144	144	144	144	144	144	144	144	144	144

Note(s): Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Moreover, all variables are described in Table 1

Table 4. Method of moments quantile regression (MMQR) outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Bearish market condition					Bullish market condition	
SPHMUEUP	Location	Scale	$Q_{0.05}$	$Q_{0.10}$	$Q_{0.15}$	Location	Scale	$Q_{0.85}$	$Q_{0.90}$	$Q_{0.95}$
MRHB	0.0991*** (0.0258)	0.0152 (0.0157)	−0.0676* (0.0371)	−0.0767** (0.0310)	−0.0794*** (0.0294)	0.0991*** (0.0258)	0.0152 (0.0157)	0.120*** (0.0370)	0.125*** (0.0409)	0.130*** (0.0453)
X8X	4.599*** (0.846)	0.989* (0.516)	−2.555** (1.236)	−3.142*** (1.038)	−3.319*** (0.978)	4.599*** (0.846)	0.989* (0.516)	5.949*** (1.216)	6.277*** (1.338)	6.603*** (1.502)
BTC	−0.305*** (0.0797)	−0.0650 (0.0486)	−0.171 (0.115)	−0.209 (0.1964)	−0.221 (0.1913)	−0.305*** (0.0797)	−0.0650 (0.0486)	−0.394*** (0.114)	−0.416*** (0.126)	−0.437*** (0.141)
ETH	−0.0943*** (0.0325)	−0.0218 (0.0198)	−0.0493 (0.0468)	−0.0622 (0.0391)	−0.0661 (0.0470)	−0.0943*** (0.0325)	−0.0218 (0.0198)	−0.124*** (0.0465)	−0.131** (0.0514)	−0.138** (0.0571)
Constant	3.003*** (0.0311)	0.00981 (0.0190)	2.983*** (0.0446)	2.989*** (0.0372)	2.990*** (0.0353)	3.003*** (0.0311)	0.00981 (0.0190)	3.017*** (0.0446)	3.020*** (0.0494)	3.023*** (0.0545)
Observations	144	144	144	144	144	144	144	144	144	144

Note(s): Standard errors in parentheses. $***p < 0.01$, $**p < 0.05$, $*p < 0.1$. Moreover, all variables are described in Table 1

that positive connectedness can improve hedging strategies since the movement is predictable and consistent. Moreover, synergy between crypto and stock markets can lead to mutual growth opportunities. In the case of the bearish market, Islamic cryptocurrencies are significantly and negatively connected with FTFBM100LS providing a good signal for diversification opportunities for investors as the markets move inversely, indicating that losses in one market could be offset by gains in the other. This negative connectedness in the bearish market is valuable during times of financial distress, as it helps in hedging risks and achieving portfolio diversification.

However, conventional cryptocurrencies are less connected with sustainability index. Only ETH has significant but negative connectedness in the bullish market situation. Significant and negative connectedness in the bullish market trend can lead to risk of decoupling, reducing their co-movement. While good for risk management, it could limit broader market predictability.

These findings can be contextualized within the existing literature. The stronger connectedness of Islamic cryptocurrencies with Shari'ah-based sustainability indices aligns with the theoretical expectation that assets sharing similar ethical foundations and investor bases will exhibit co-movement (Ahmed, 2021; Razak *et al.*, 2024). This confirms the premise of niche market integration within Islamic finance. Conversely, the weak and often insignificant connectedness of conventional cryptocurrencies like Bitcoin reinforces the findings of studies that highlight their decoupling from traditional ethical and sustainable investment streams, often due to environmental, governance and regulatory concerns (Wang *et al.*, 2022; Hendrickson and Luther, 2017). Our results thus challenge the notion that all digital assets behave homogeneously, instead highlighting a clear divergence based on their underlying ethical design and compliance.

Furthermore, the regime-dependent behavior, positive connectedness in bull markets and negative in bear markets, offers a nuanced perspective that extends prior research. While studies like Bouri *et al.* (2021) have established quantile connectedness within the crypto market, and Bossman *et al.* (2024) have examined faith-based stocks, few have documented this dual role in the context of Islamic digital assets. The positive connectedness in bullish periods supports growth-oriented strategies, confirming that market integration can drive mutual gains during upswings. The shift to negative connectedness during bearish periods provides empirical evidence for the hedging potential theorized by scholars (e.g. Lahmiri and Bekiros, 2019; Ali *et al.*, 2022), suggesting that Islamic cryptocurrencies can act as a diversifying asset class within an ethical portfolio during downturns, a finding that had previously been more speculative.

In summary, our findings are valuable for two key types of investors: investors aiming for diversification, who may favor negative connectedness, and growth-focused investors, who might see greater advantages in the positive connectedness associated with market integration.

Table 4 presents the quantile connectedness of both Islamic and conventional cryptocurrencies with the S&P/Hawkamah ESG UAE Index (SPHMUEUP). Overall, these findings qualitatively confirm the results reported in Table 3.

The results indicate that Islamic cryptocurrencies (MRHB and X8X) exhibit a distinct pattern of connectedness with Shari'ah-based sustainability indices, which aligns with existing literature on ethical investment integration. Specifically, the significant positive connectedness in bullish markets with both the FTFBM100LS and SPHMUEUP indices suggests that Islamic cryptocurrencies tend to move in tandem with sustainable Shari'ah indices during favorable market conditions. This finding supports prior studies highlighting the potential synergy between Shari'ah-compliant assets and emerging digital financial

instruments when markets are expanding (Izadin *et al.*, 2025; Razak *et al.*, 2024). Such positive connectedness can enhance growth-oriented investment strategies, as it reflects market integration and predictable co-movement that could benefit portfolio performance in bullish market trends.

Conversely, the results also reveal that during bearish market conditions, Islamic cryptocurrencies tend to exhibit significant negative connectedness with the same sustainability indices. This aligns with the literature on portfolio diversification benefits derived from assets with inverse market movements during downturns (Ahmed, 2021; Bakar and Foziah, 2024). The inverse relationship implies that Islamic cryptocurrencies may serve as effective hedging instruments for sustainability-focused Islamic portfolios, thereby mitigating downside risks. This is consistent with the Maqasid al-Shariah emphasis on risk management and protection of wealth, where diversification is encouraged to safeguard against excessive loss (Shahid *et al.*, 2023). The dual behavior, positive integration in bullish periods and negative connectedness in bearish markets, highlights the adaptive role that Islamic cryptocurrencies could play in ethical and sustainable investment strategies.

In contrast, conventional cryptocurrencies, Bitcoin (BTC) and Ethereum (ETH), demonstrate weaker or inconsistent connectedness with Shari'ah-based sustainability indices. While ETH shows significant negative connectedness in bullish markets, BTC's relationship remains largely insignificant across both market conditions. This limited linkage suggests that conventional cryptocurrencies may be less aligned with the dynamics of sustainability-oriented Islamic indices, which could stem from their environmental footprint and perceived incompatibility with ethical investment criteria (Hendrickson and Luther, 2017; Wang *et al.*, 2022). Given the strong emphasis on environmental stewardship and responsible resource use in Islamic finance (Halawi, 2023; He, 2024), the muted connectedness of conventional cryptocurrencies underscores the ongoing tension between high-carbon blockchain systems and sustainability objectives.

Overall, these findings contribute to the emerging discourse on the integration of digital assets into Shari'ah-compliant sustainable finance. They not only confirm prior evidence of distinct market behavior between Islamic and conventional cryptocurrencies but also highlight the potential for Islamic digital assets to complement sustainability indices in both growth and defensive investment contexts. This dual role, facilitating integration in bullish markets and providing diversification in bearish periods, could make Islamic cryptocurrencies a strategic addition to portfolios seeking to balance financial returns with ethical and environmental considerations. This perspective echoes calls in the literature for innovative financial tools that align with the UN SDGs (Dirie *et al.*, 2024; Gundogdu, 2018).

4.2 Robustness analysis

In this section, we conduct a sensitivity analysis to test the robustness of our baseline findings. Following recent literature on dynamic time-varying connectedness (Das *et al.*, 2025; Shao *et al.*, 2025; Kyriazis *et al.*, 2024; Kyriazis and Corbet, 2024; Dai *et al.*, 2023; Jena *et al.*, 2022; Billah *et al.*, 2022), we first apply an alternative estimation method, the quantile VAR (QVAR) connectedness model, to our original sample.

Second, we alter the sample size and period. Due to the limited availability of data for the Islamic cryptocurrencies ISLAMICOIN and ISLM, we restrict our sample period to June 14, 2024, through August 6, 2025. Accordingly, we include five Islamic cryptocurrencies, the top five conventional and green cryptocurrencies, based on market capitalization, to ensure a balanced number of crypto-assets in each category. Finally, we include four Shari'ah-based sustainability indices, based on data availability. Specifically, the Shari'ah-based sustainability indices are the FTSE4Good Bursa Malaysia Index (FTF4GBM), the FTSE Bursa Malaysia

Top 100 ESG Low Carbon Select Shariah Index (FTFBM100LS), the S&P/Hawkamah ESG UAE Index (SPHMUEUP) and the FTSE ADX ESG Screened Index (FTFADXSI).

4.2.1 Results of quantile VAR connectedness using the original sample. This section presents the robustness of our main findings using the QVAR connectedness model. Figures 4–7 provides the results. Figure 4 exhibits the time-varying dynamic total connectedness of Islamic, conventional and green cryptocurrencies, alongside Shari'ah-based sustainability indices. Colder (warmer) hues indicate lower (higher) connectedness levels. The consistently high levels of connectedness across quantiles, 5th, 10th and 15th (bearish market) and 85th, 90th and 95th (bullish market), suggest that these variables are strongly integrated, with volatility in one asset rapidly spilling over to others. This interconnectedness implies limited safe haven properties during systemic shocks, as contagion effects are widespread. However, the presence of sustainability indices introduces a stabilizing layer, particularly during climate-related or ESG-driven market events. Their lower volatility and ethical orientation may offer partial insulation, enhancing the diversification potential of portfolios that combine crypto assets with climate indices.

Figure 5 shows the net total directional connectedness (NTDC), illustrating the asymmetric roles of cryptocurrencies as shock transmitters and receivers within the cryptocurrencies-sustainability network. Specifically, the red shade indicates positive connectedness (increasing spillover effects), the blue shade indicates negative connectedness (decreasing spillover effects) and the white or neutral shade indicates little to no spillover.

Considering conventional cryptocurrencies, Bitcoin (BTC), it is noted that heatmap is mostly positive (red shades), and its magnitude fluctuates across the quantiles of change and over time. It exhibits irregular periods of high positive spillover (dark red) around early 2023 and mid-2024. Negative spillovers (blue) appear occasionally, indicating BTC is sometimes influenced inversely by other variables. Overall, BTC shows a mix of positive and negative connections but tends to have stronger positive spikes, suggesting it often drives connectedness. Ethereum (ETH) exhibits similar patterns to BTC but with slightly stronger positive spikes in mid-2024. Negative spillovers are more pronounced in early 2023. It suggests ETH is also a key transmitter in the network, sometimes mirroring BTC behavior.

In the case of Islamic cryptocurrencies, X8X shows strong positive connectedness in early 2023 and early 2024. Negative spillovers are also present but more scattered, indicating that X8X is responsive to shocks in the system, but also occasionally drives spillovers. MRHB exhibits less extreme spillovers compared to the other three crypto-assets. Peaks in positive connectedness appear in early 2024, with intermittent negative spillovers, suggesting MRHB is somewhat more isolated but still participates in the connectedness network. Conventional cryptocurrencies show stronger and more frequent connectedness spikes than Islamic ones and indicating a system-wide shock affecting both conventional and Islamic markets. Finally, the negative NTDC of Shari'ah-based sustainability indices maintain their role as net receivers and absorb shocks, reinforcing their potential as buffers in ethically aligned portfolios. The NTDC patterns suggest that while crypto assets are not traditional safe havens, strategic inclusion of sustainability indices and Islamic cryptos can enhance portfolio resilience and diversification, especially under climate-related stress scenarios.

Figure 6 provides the net directional connectedness (NDC) of each asset. Conventional cryptocurrencies such as Bitcoin and Ethereum act as dominant transmitters of shocks, reinforcing their systemic importance but undermining their safe haven status.

Islamic cryptocurrencies, particularly the MRHB, due to their emerging nature and ethical positioning, predominantly absorb shocks, suggesting potential as diversifiers in

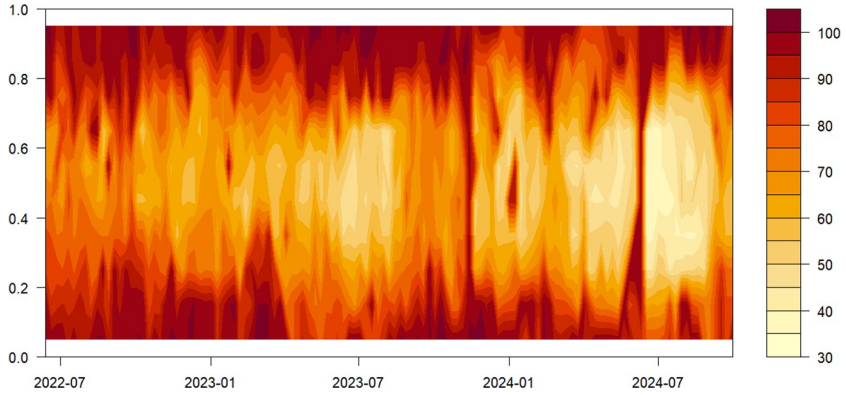

Figure 4. Dynamic total connectedness (DTC) of crypto-assets and Shari'ah-based sustainability indices

Source: Author's own work

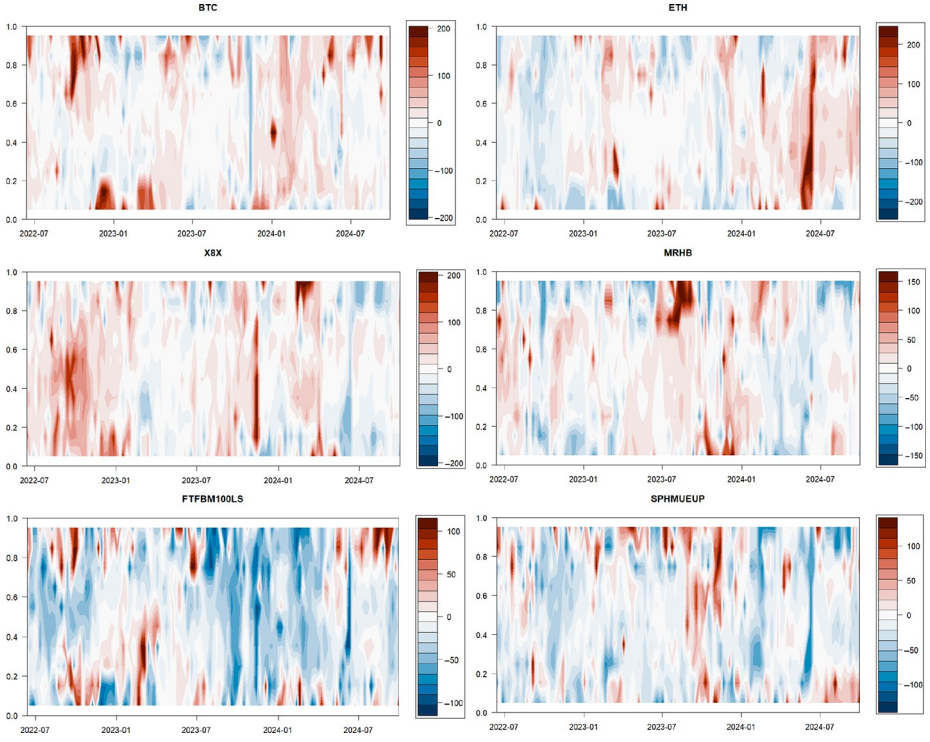

Figure 5. Net total directional connectedness (NTDC) of crypto-assets and Shari'ah-based sustainability indices

Source: Authors' own work

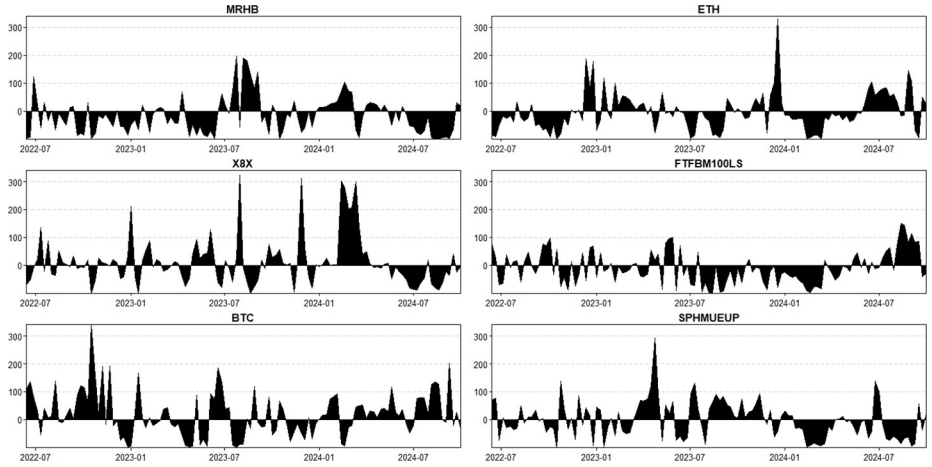

Figure 6. Net directional connectedness (NDC) of crypto-assets and Shari'ah-based sustainability indices

Source: Authors' own work

ESG-sensitive portfolios. Sustainability indices generally act as net receivers, especially during market stress, supporting their role as stabilizers and safe havens in diversified portfolios.

Figure 7 visualizes the quantile connectedness under contrasting regimes through network plots across quantiles, with yellow (blue) representing net receivers (transmitters) of shocks to the system.

In bearish market conditions, conventional cryptos, particularly BTC, dominate the transmission of shocks, while sustainability indices and Islamic cryptos, especially MRHB, remain peripheral, absorbing volatility. This positioning supports their safe-haven potential during downturns. In bullish markets, at the 90th quantile, Islamic crypto (X8X) acts as dominant transmitter, while MRHB and the sustainability indices become more central in absorbing shocks, reflecting increased investor interest in ESG themes. The overall network connectedness illustrates how climate-aligned assets can shift from passive to active roles depending on market sentiment, offering both diversification and thematic exposure.

4.2.2 Results of quantile VAR connectedness using the extended sample. This section tests the robustness of our main findings by altering the sample size and period. We apply the QVAR connectedness model to five Islamic cryptocurrencies, five conventional cryptocurrencies, five green cryptocurrencies and four Shari'ah-based sustainability indices, covering the period from June 14, 2024, to August 6, 2025. The results for dynamic total connectedness, NDC and NTDC (Figures A1-A3 in Appendix) display patterns largely consistent with those observed for the original sample in Section 4.2.1. For brevity, these results are not discussed further.

The network plots across quantiles in Figure 8 illustrate the quantile connectedness of all variables under bearish (lower quantiles) and bullish (upper quantiles) market conditions. In both bearish and bullish market trends, major conventional cryptocurrencies mostly act as transmitters of shocks. In the case of Islamic crypto-assets, the major assets X8X and MRHB are receivers of shocks in both market conditions. Interestingly, in bullish market trends, all Islamic crypto-assets with Shari'ah-based sustainability indices absorb shocks, offering

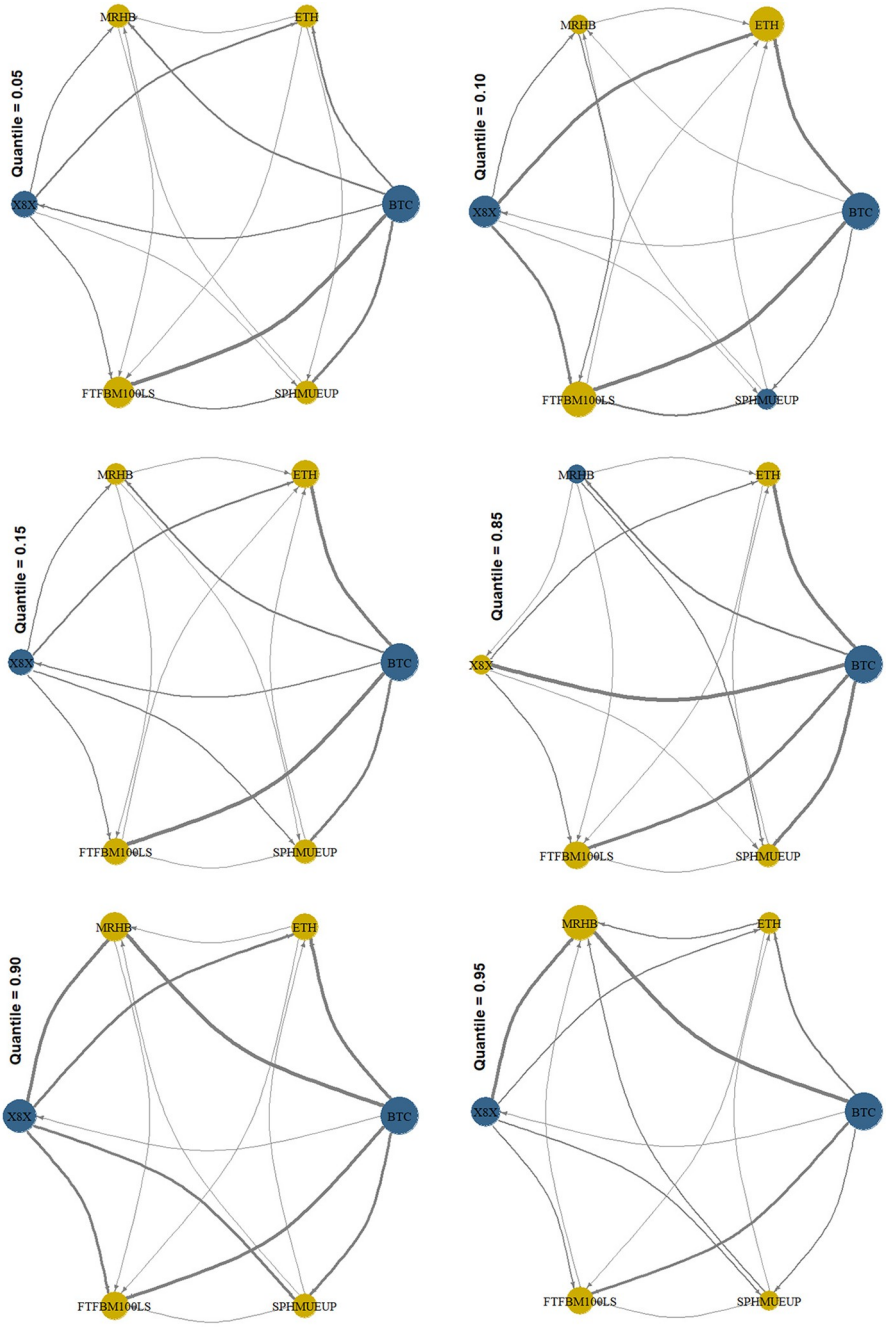

Figure 7. Network plots on bearish and bullish market conditions
Source: Authors' own work

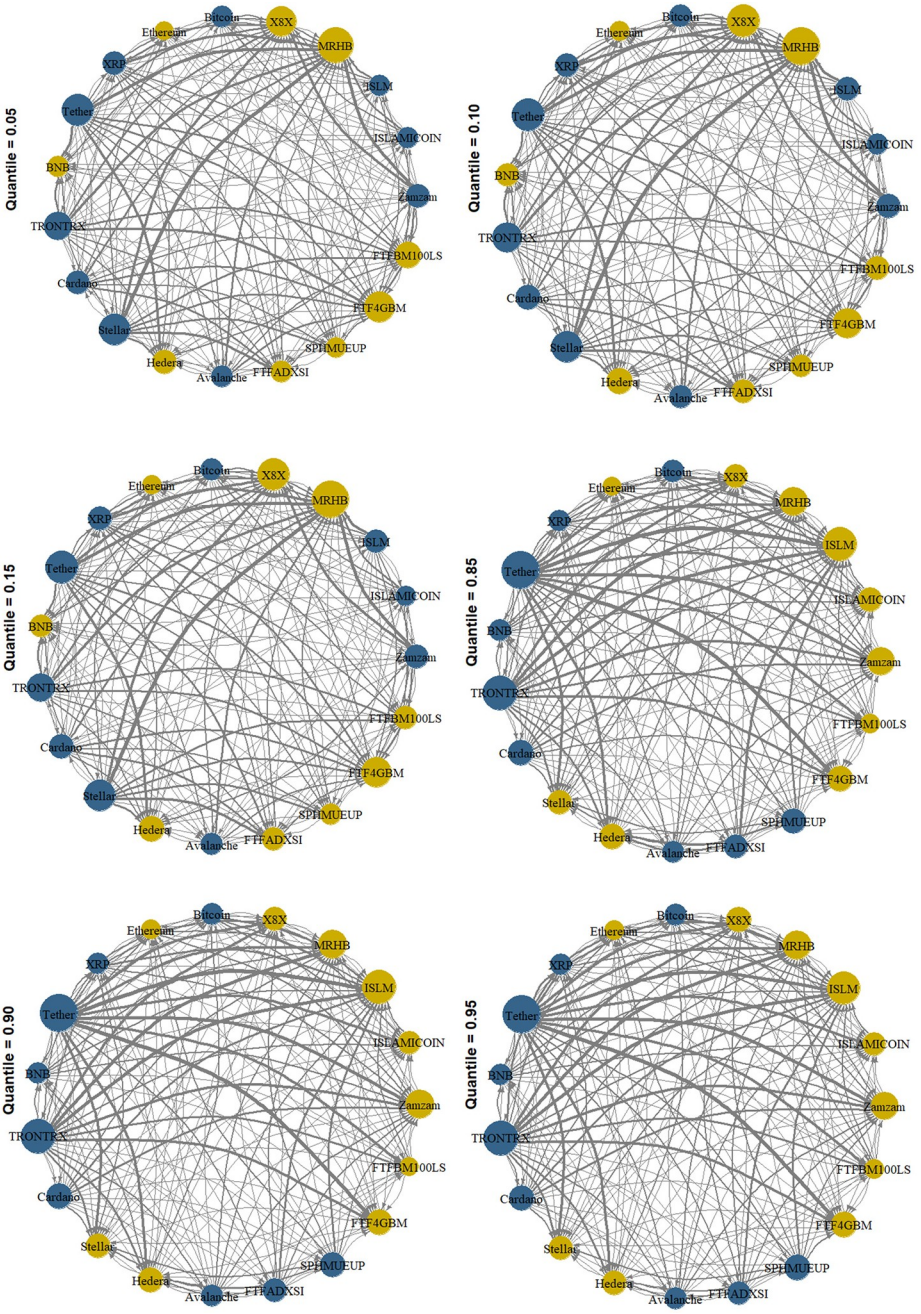

Figure 8. Network plots on bearish and bullish market conditions
Source: Authors' own work

safe-haven characteristics. Green crypto-assets provide mixed results for both lower and upper quantiles. These regime-dependent roles of conventional, Islamic and green cryptocurrencies in the cryptocurrency-sustainability network highlight the importance of dynamic allocation strategies that leverage the diversification and safe-haven properties of climate-aligned and ethical assets.

4.2.3 Comparison of method of moments quantile regression and quantile VAR findings. The MMQR results in Tables 3 and 4 show that Islamic cryptocurrencies (MRHB and X8X) exhibit significant negative connectedness with the Shari'ah-based sustainability index FTFBM100LS under bearish market conditions, and significant positive connectedness under bullish conditions. This dual behavior aligns with the QVAR findings in Figures 5 and 6, where MRHB and X8X are identified as net receivers during downturns and net transmitters during upswings. Specifically, in the QVAR NTDC plots, MRHB and X8X display increased transmission during bullish phases, reinforcing their role in market integration and growth opportunities. The MMQR results (Table 3) further validate this by quantifying the strength of these relationships across quantiles, showing that MRHB's positive coefficients increased from 0.504 to 0.532 in bullish quantiles, while X8X's rose from 0.304 to 0.353. These findings support the interpretation that Islamic cryptocurrencies offer diversification benefits during downturns and hedging potential during upswings, consistent with their dynamic roles in the QVAR network. This dynamic, acting as a diversifier in downturns and a growth asset in upswings, provides a more granular understanding than mean-based analyses, which might average out these opposing effects. It confirms and quantifies the adaptive role of Islamic digital assets, a nuance that was less visible in earlier, non-quantile studies.

For conventional cryptocurrencies (BTC and ETH), the MMQR results reveal a more nuanced picture. BTC shows positive but statistically insignificant connectedness with FTFBM100LS across both bearish and bullish quantiles, while ETH demonstrates significant negative connectedness, particularly in bullish conditions. This is consistent with the QVAR findings in Figures 5 and 6, where ETH is identified as a net transmitter but with negative NTDC values, suggesting it transmits volatility without contributing to systemic integration. BTC's role in QVAR is more balanced, with modest NTDC values, and the MMQR results confirm its limited predictive power in relation to sustainability indices. These patterns suggest that, while conventional cryptocurrencies are influential in the broader crypto ecosystem, their integration with sustainability indices is weaker, and they may not provide the same diversification or hedging benefits as Islamic cryptocurrencies. This reinforces the view that the high energy consumption and perceived speculative nature of major conventional cryptocurrencies (Zhang *et al.*, 2023; Howson and De Vries, 2022) create a fundamental disconnect with the principles underpinning Shari'ah-based sustainability indices.

The MMQR results also reinforce the safe-haven and diversification potential of Shari'ah-based sustainability indices. In both Tables 3 and 4, indices such as FTFBM100LS and SPHMUEUP show inverse relationships with Islamic cryptocurrencies during bearish conditions, and positive relationships during bullish phases. This mirrors the QVAR findings in Figures 7 and 8, where these indices are consistently net receivers of shocks, absorbing volatility from crypto markets. Their NTDC values are low or negative, confirming their role as stabilizers in diversified portfolios. The MMQR coefficients further quantify this behavior, showing statistically significant negative values in bearish quantiles and positive values in bullish ones, especially for MRHB and X8X. These results validate the earlier interpretation that sustainability indices can mitigate risk exposure and enhance portfolio resilience, particularly when paired with Islamic crypto assets.

Taken together, the MMQR and QVAR results have important implications for investors. Growth-oriented investors may benefit from the positive connectedness observed in bullish markets, particularly between Islamic cryptocurrencies and sustainability indices, which signals predictable co-movement and synergy. Conversely, risk-averse or diversification-seeking investors may find value in the negative connectedness during bearish phases, where inverse relationships help offset losses and stabilize portfolios. The consistency between MMQR and QVAR findings strengthens the reliability of these insights and supports the strategic use of Islamic and green crypto assets in climate-conscious investment frameworks.

5. Conclusion and implications

This study offered valuable insights into the quantile connectedness between Islamic cryptocurrencies and Shari'ah-based sustainability indices, in comparison to conventional cryptocurrencies. Our findings challenge the homogeneous treatment of digital assets and instead reveal a clear segmentation based on ethical and Shari'ah-compliant characteristics. By using the MMQR and QVAR connectedness approach, the study robustly demonstrates that Islamic cryptocurrencies show a stronger and more dynamic connectedness with Shari'ah-based sustainability indices than conventional cryptocurrencies. This suggests that Islamic cryptocurrencies, which adhere to Shari'ah principles, are more intrinsically aligned with the ethical and sustainability metrics that define these indices. Overall, although Islamic cryptocurrencies remain a niche market, they offer valuable opportunities for diversification and thematic ESG exposure, particularly when combined with Shari'ah-based sustainability indices.

5.1 Theoretical implications

Our findings carry significant theoretical implications for the fields of Islamic finance and sustainable digital assets. The stronger quantile connectedness between Islamic cryptocurrencies and Shari'ah-based sustainability indices provides robust empirical evidence that the principles of Shari'ah compliance and sustainability create a tangible, measurable financial synergy. This extends Islamic finance theory beyond static screening mechanisms (halal/haram) into the dynamic realm of risk and return connectedness. It suggests that the ethical foundation of an asset, as defined by Maqasid al-Shari'ah (objectives of Islamic law), which emphasizes the preservation of wealth (mal) and environmental stewardship, can manifest in its price dynamics, fostering integration with other ethically aligned investments. Conversely, the weaker connectedness of conventional cryptocurrencies underscores a theoretical dissonance; despite being a technological innovation, their perceived non-compliance with ethical and environmental norms limits their integration into the core framework of Islamic sustainable finance. This study, therefore, provides a quantile-based framework for evaluating the theoretical alignment of emerging digital assets with established Islamic financial principles.

5.2 Practical implications

For investors and portfolio managers, particularly those operating in Islamic markets or with ESG mandates, our results offer clear, actionable strategies rooted in the regime-dependent behavior of Islamic cryptocurrencies. During bullish market phases, the significant positive connectedness indicates a synergistic co-movement with sustainability indices, allowing growth-oriented investors to build concentrated thematic positions to capitalize on upward trends in ethical finance. Conversely, and perhaps more critically, the significant negative connectedness observed during bearish markets provides a powerful tool for risk management. This inverse relationship allows portfolio managers to strategically allocate a small portion of their portfolio to Islamic cryptocurrencies as a potential hedge, helping to

offset losses and reduce overall volatility during downturns in conventional markets or even within the sustainability indices themselves. Consequently, the most effective approach is a dynamic asset allocation strategy: increasing exposure to Islamic cryptocurrencies during periods of positive ESG momentum and stable growth, while leaning more heavily on the shock-absorbing qualities of sustainability indices during financial distress, rebalancing as market regimes shift.

5.3 Policy implications

Our study provides a compelling evidence base for regulators, standard-setting bodies and Shari'ah boards to proactively shape the future of Islamic digital finance. For regulators, such as the Islamic Financial Services Board (IFSB) and central banks in key markets, the findings highlight the need for clear, differentiated frameworks that distinguish Shari'ah-compliant digital assets from their conventional counterparts. Policies could be developed to actively encourage this niche by providing tax incentives or favorable regulatory treatment for projects that verifiably meet green and Shari'ah-compliant criteria, thereby channeling investment toward sustainable fintech innovation. For Shari'ah advisory boards and standard-setters like AAOIFI, the demonstrated alignment between these assets and sustainability indices calls for the urgent development of explicit, universal standards and certification processes for "Islamic Cryptocurrencies." This would move beyond individual, fragmented fatwas to create a unified global framework, assessing everything from underlying value and mining energy sources to governance, thereby enhancing market confidence and stability. Finally, policymakers have a pivotal opportunity to foster collaboration between fintech companies, traditional Islamic financial institutions and Shari'ah scholars, encouraging the development of groundbreaking products such as green sukuk tokenization or blockchain-based zakat platforms, ensuring that financial innovation is both impactful and firmly aligned with ethical and religious standards.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Compliance with ethical standards

Research involving human participants and/or animals: This paper does not contain any studies with the involvement of human participants and animals.

Informed consent: The authors are responsible for correctness of the statements provided in the manuscript. All authors contributed equally. All authors read and approved the final manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work, the authors used ChatGPT to improve the language of the article. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix

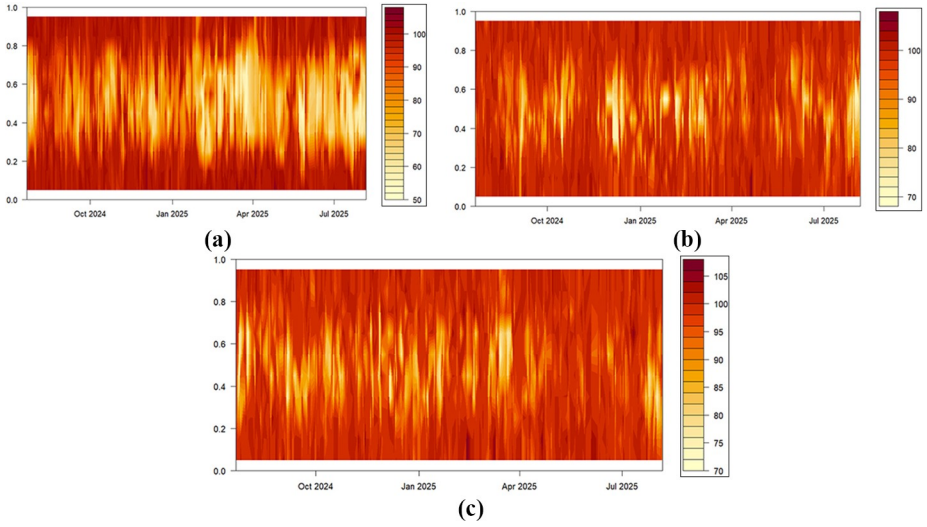

Figure A1. Dynamic total connectedness (DTC) of conventional, Islamic and green crypto-assets and Shari'ah-based sustainability indices

Note(s): (a) DTC of Islamic cryptos and Shari'ah-based sustainability indices, (b) DTC of conventional cryptos and Shari'ah-based sustainability indices, (c) DTC of green cryptos and Shari'ah-based sustainability indices

Source: Authors' own work

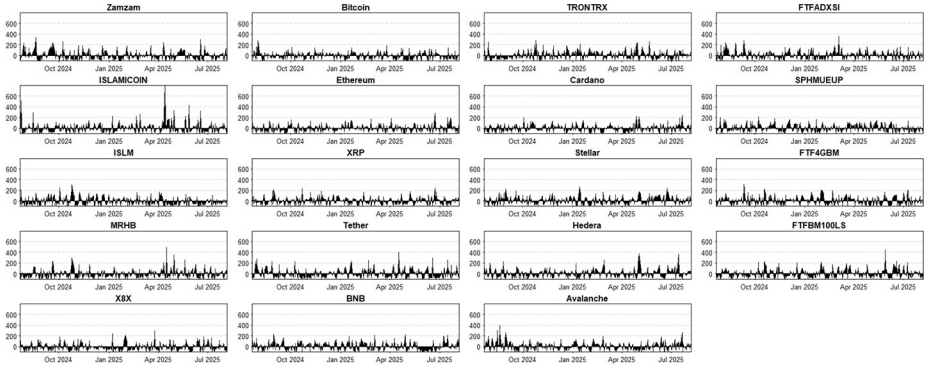

Figure A2. Net directional connectedness (NDC) of conventional, Islamic and green crypto-assets and Shari'ah-based sustainability indices

Source: Authors' own work

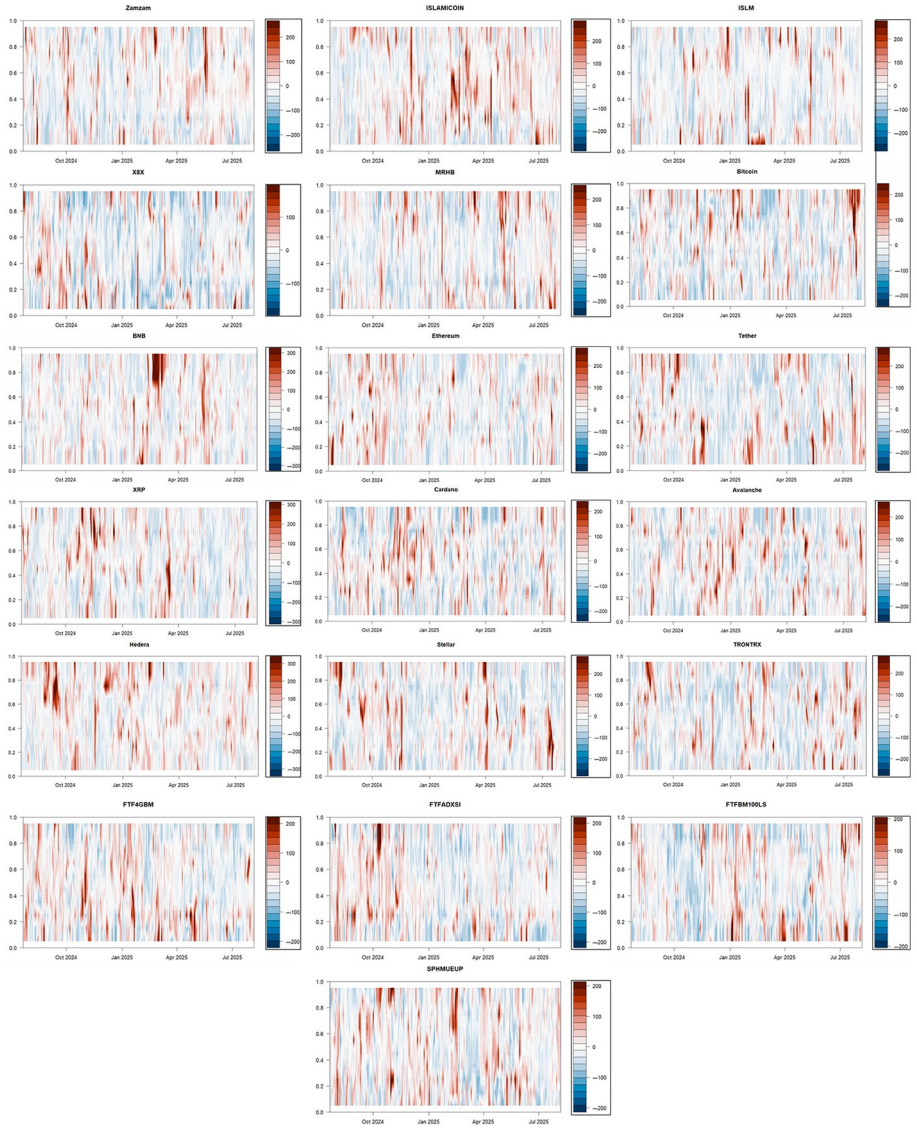

Figure A3. Net total directional connectedness (NTDC) of conventional, Islamic and green crypto-assets and Shari'ah-based sustainability indices

Source: Authors' own work

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