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THE RESILIENCE OF GREEN CRYPTOCURRENCIES UNDER GLOBAL SHOCK: LESSONS FROM COVID-19 AND THE RUSSIA-UKRAINE WAR MENA Regions

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ABSTRACT

This paper investigates the resilience and dynamic behavior of energy-conserving cryptocurrencies (ECCs) during two major global crises: the COVID-19 pandemic and the Russia–Ukraine conflict. Unlike traditional proof-of-work (PoW) assets, ECCs—primarily proof-of-stake (PoS) and low-energy blockchain tokens—are increasingly promoted as sustainable digital alternatives. Using a balanced panel of major ECCs across 10 countries with cryptocurrency markets from January 2019 to December 2023, we apply a panel ARDL–PMG model combined with panel causality tests and structural break analysis to examine the long- and short-run effects of global uncertainty on ECC returns and volatility. Our findings show that ECCs exhibit stronger crisis resilience compared with high-energy cryptocurrencies, with limited long-run exposure to pandemic shocks but moderate sensitivity to geopolitical tensions following the Russia–Ukraine conflict. COVID-19 uncertainty has a short-run negative pressure on ECC markets, whereas geopolitical risk (GPR) driven by the conflict generates asymmetric responses. Cross-country results reveal that ECC markets in technologically advanced, energy-transition economies (EU, Singapore, UAE) exhibit greater stability than those in emerging markets. These findings highlight the potential role of ECCs in sustainable finance, offering policymakers, investors, and regulators insights into the feasibility of promoting energy-efficient digital assets amid extreme global uncertainty.

KEYWORDS: Energy-conserving cryptocurrencies; COVID-19 pandemic; Russia–Ukraine conflict; Geopolitical risk; Panel ARDL; Proof-of-stake; Sustainable finance; Crisis resilience.
JEL Classification : G15 ; C33 ; Q43 ; F51 ; O33.

1. INTRODUCTION

Global financial markets in the present era are undergoing unprecedented structural transformations under the weight of successive shocks, with global geopolitical and pandemic crises emerging as crucial factors in reshaping the interrelationships among different asset classes. The COVID-19 pandemic that erupted in early 2020 left profound economic and financial impacts, quickly followed by a major geopolitical crisis, the Russia-Ukraine war, which began in February 2022 (Caldara and Iacoviello, 2022; Assaf et al., 2023). These two crises caused radical disruptions in global supply chains, led to historic volatility in energy markets, and redefined the concepts of safe havens and hedging in financial literature (Fakhfekh et al., 2023; Chang et al., 2023). At the peak of the pandemic crisis, the oil market witnessed an unprecedented collapse with prices entering negative territory in April 2020, while oil prices jumped to record levels of approximately $133 per barrel following the Russia-Ukraine war, given Russia's role as one of the world's largest energy exporters (Moustabchir et al., 2024).

Amid successive financial storms, cryptocurrencies have emerged as a revolutionary phenomenon attracting increasing attention from investors, institutions, and academia alike. From the very first decentralized cryptocurrency, Bitcoin (BTC), which appeared in 2009, the digital market has grown to about $2.61 trillion by the first quarter of 2024, according to Sakurai and Tetsuo (2023). This growth has been marked by tremendous volatility, which has driven researchers to study cryptocurrencies as alternative hedging tools and safe havens during periods of financial turmoil. However, a new breed of cryptocurrencies, known as "Green Cryptocurrencies," has drawn academic and practical attention in recent times. These adopt more energy-efficient consensus mechanisms, such as Proof-of-Stake, rather than the power-intensive Proof-of-Work mechanism used by Bitcoin. The evolution of green cryptocurrencies has resulted from growing environmental criticism of traditional cryptocurrencies, amid a rise in global awareness of climate change and energy sustainability. Examples include Cardano (ADA), which already uses Proof-of-Stake, and Ethereum (ETH), which transitioned to it with "The Merge" in September 2022. Such cryptocurrencies offer a more sustainable model. Alam et al. (2023) studied the resilience of this new category of digital assets under global shocks.

This not only extends the literature on cryptocurrencies but also provides vital insights into the future of sustainable finance and the resilience of alternative financial systems to multidimensional crises.

The research problem lies in a significant gap in understanding the behavior and resilience of green cryptocurrencies, particularly during simultaneous and successive global shocks. First, most previous studies have focused on leading cryptocurrencies such as Bitcoin and Ethereum (in its pre-Proof-of-Stake phase) as a single block, ignoring the distinctive characteristics and technical mechanisms of "green" or "sustainable" cryptocurrencies (Bouri et al., 2021; Corbet et al., 2023). Second, research seeking to assess the role of cryptocurrencies during crises (such as COVID-19) has been treated separately from studies examining periods of geopolitical shocks (such as the Russia-Ukraine war) (Adekoya et al., 2021; Yousaf et al., 2022). However, reality witnesses the simultaneity and overlap of these shocks, as investors faced a global health crisis immediately followed by a major geopolitical crisis. There is no comprehensive study to date that examines the continuity or differences in the performance of green cryptocurrencies across these two crises, which differ in nature but are successive in time. Third, there is a lack of studies that integrate analysis of oil price shocks – which peaked during both crises – into assessments of the relationship between green cryptocurrencies and traditional financial markets, especially in the context of an energy-sensitive market like Russia (Alam et al., 2023; Kayani et al., 2023). Fourth, methodologically, many studies have been limited to analyzing correlations or simple causality tests, without applying a comprehensive theoretical framework to understand the multiple roles of assets (diversification, hedging, safe-haven) in an investment portfolio context. The literature lacks an in-depth application of Modern Portfolio Theory (MPT) to portfolios that include green cryptocurrencies alongside traditional assets in a turbulent environment (Markowitz, 1952). Accordingly, this study seeks to answer the main question: How have green cryptocurrencies demonstrated resilience under the dual global shocks (COVID-19 and the Russia-Ukraine war), and what is their role as tools for portfolio diversification, hedging, and safe haven compared to traditional financial assets in the context of escalating oil price shocks and emerging markets?

The paper's contribution is twofold: theoretical and practical. Theoretically, this research fills a gap in the literature on digital sustainable finance by conducting the first comprehensive empirical analysis of the resilience of green cryptocurrencies during two major crises (Alam et al., 2023). It further develops Modern Portfolio Theory (MPT), adding this new asset class and testing its influence in extraordinary market conditions (Markowitz, 1952). In addition, it presents a regular comparison of responses to two distinct crises, helping build a more accurate perception of asset behavior across multiple crises. The value added is methodological as well, enhancing studies by using advanced econometric models to analyze multiple roles across different time frames and market conditions (Diebold and Yılmaz, 2014; Liu et al., 2024). On the practical side, this study's contribution is valuable for investors and portfolio managers seeking to integrate green cryptocurrencies into their portfolios to enhance diversification and manage risks during turbulent times (Yuandong et al., 2022). This provides policymakers and regulators with empirical proof of the stability of such assets, thus helping to define more accurate regulatory frameworks (Akhtaruzzaman et al., 2022). Last but not least, by focusing on Russia, this study provides insights into hedging tools in emerging markets subject to shocks and, at the same time, promotes responsible investment by highlighting the financial aspects of sustainability in digital assets (Ullah et al., 2023).

The study objectives are designed along six main axes: First, to measure and analyze the dynamic resilience of green cryptocurrencies during the COVID-19 pandemic and the Russia-Ukraine war; second, to compare the performances and characteristics of such cryptocurrencies with traditional cryptocurrencies and traditional financial assets, like MOEX stock indices, bonds, precious metals, and oil; third, to assess their role as portfolio diversification tools, hedging, and safe haven against traditional assets in different market conditions; fourth, to analyze the impacts of oil price shocks and their interactions with green cryptocurrency markets; fifth, to apply and modify the MPT in constructing optimal investment portfolios that include green cryptocurrencies and measure efficiencies; sixth, to draw practical recommendations for investors and policymakers based on the results.

The study hypotheses are based on the theoretical framework and previous literature, which include: (H1) Green cryptocurrencies are relatively resilient and more stable in the face of shocks compared to traditional cryptocurrencies, particularly across oil shocks; the pattern varies across the two crises. (H2) Green cryptocurrencies are an effective tool of portfolio diversification with traditional Russian assets in normal times. (H3) They turn into a strong hedging tool against losses in Russian assets throughout shock periods. (H4) They do not reliably rise to the status of a "safe haven" in all shocks, since their hedging role depends on the nature of the crisis. (H5) Their inclusion in portfolios strongly enhances the efficiency of portfolios according to Modern Portfolio Theory. (H6) There is a dynamic causal and reciprocal relationship between oil price shocks and green cryptocurrency prices.

Study Structure: This paper begins with an introduction that defines the general framework, the research problem, its significance, objectives, and hypotheses. It then proceeds to the second section, which reviews the theoretical framework and literature, followed by the third section, which explains the research methodology and the methods of analysis. The fourth section presents and analyzes e01.

Empirical results, while the fifth section discusses these results, links them to the literature, and reviews limitations. The sixth and final section summarizes the main findings and presents practical recommendations, along with suggestions for future research.

2. THEORETICAL AND EMPIRICAL LITERATURE REVIEW

The section synthesizes the existing scholarly literature across several key thematic areas relevant to understanding the behavior of digital assets, with a specific focus on their role during crises and on the emerging, yet critically under-researched, niche of green cryptocurrencies.

2.1. Portfolio Diversification with Digital Assets (Crypto Assets)

Unprecedented financial crises, including the COVID-19 pandemic and the 2022 Ukraine crisis, led to sharp declines in global stock markets. For example, the single-day drop in the U.S. stock market during the COVID-19 crisis was its most significant decline since 1987, with up to a 40% drop observed across G7 indices in a single day, resulting in considerable losses. Emerging markets also took a hit. For example, the NSE50 index plummeted by 30%, and the S&P 500 circuit breakers were triggered 4 times during the health crisis (Kumar and Padakandla, 2022). Other equity and commodity markets also reflected similar trends, increasing overall uncertainty. Due to the 2022 Ukraine crisis, the Moscow Exchange crashed by 45% and remained down for six months (Sohag and Ullah, 2022). Major worldwide losses were recorded by investors, especially investors in the Russian financial market, and the risk of investment significantly increased.

In such times, investors traditionally seek refuge in safe-haven assets to protect their portfolios. Asset management firms prioritize risk diversification and hedging against potential losses. A major focus of diversification strategies has been to identify whether digital assets can act as safe havens, diversifiers, or hedges compared with traditional financial assets, such as equities (Shang et al., 2022), government bonds (Corbet et al., 2018), commodities (Goodell and Goutte, 2021), and precious metals (Naeem et al., 2022). Research by Ozdurak et al (2022) using an asymmetric VAR-GARCH model indicated that major cryptocurrencies could serve as a hedge against clean energy and technology stock indices. Akbulaev and Abdulhasanov (2023) investigated the speculative and investment functions of crypto assets and found connections between natural gas and crude oil prices and crypto valuations. However, Ahmadova et al. (2024) identified the positive influence of Bitcoin and the NASDAQ index, along with oil prices, and the negative influence of the U.S. Dollar Index on Bitcoin, as well as an insignificant influence of gold on Bitcoin volatility, which complicates the narrative of crypto as a consistent hedge.

The theoretical background of this analysis is often based on the definitions made by Baur and Lucey (2010). They define a hedge as an asset that is, on average, negatively correlated or uncorrelated with another asset or portfolio. A diversifier is positively correlated on average. A safe haven is an asset that is uncorrelated with, or negatively correlated with, other assets during periods of market stress or turmoil, rewarding investors by appreciating when other assets decline. Whereas many studies have tested these properties for mainstream cryptocurrencies such as Bitcoin and Ethereum, the literature shows mixed, often contradictory results that depend heavily on the specific crisis period and market context under analysis.

Critical Observation: The existing literature has failed to explain in detail how portfolios containing digital assets respond and function mechanically in the event of a geopolitical shock, such as the Russia-Ukraine war. There is also a strong neglect of green cryptocurrencies within these portfolio studies. Discussion still focuses on power-intensive proof-of-work assets, such as Bitcoin, or on general-purpose smart contract platforms like Ethereum. Still, again, there is a gaping hole in whether green-oriented digital assets exhibit different characteristics in diversification, hedging, or safe-haven attributes.

2.2. Digital Assets in Response to Exogenous Shocks

The role of digital assets as diversification tools during the COVID-19 pandemic has been widely studied. Research has investigated market efficiency and profitability (Chemkha et al., 2021), comparative crypto profitability versus global stock indices across phases of the pandemic (Haffar and Le Fur, 2022), and hedging and safe-haven properties (Naeem et al., 2023; Corbet et al., 2018). The results are very diverse. Some studies, such as that by Haffar and Le Fur (2022), treat Bitcoin as a shock transmitter to emerging markets, while others, such as Diniz et al. (2021), found that Bitcoin proved resilient to the COVID-19 crisis compared to precious metals. In contrast, traditional literature on gold is also inconsistent in its efficiency as a safe haven during crises (Baur and Lucey, 2010). Abidi and Touhami (2024) compared Bitcoin and precious metals during both the pandemic and the Russia-Ukraine war. They concluded that, though both exhibited weak safe-haven properties during the health crisis, their safe-haven properties were stronger during the war period.

The Russia-Ukraine War represents a specific exogenous shock to test the effectiveness of conventional safe havens. For instance, Islam et al. (2024) documented the challenges posed by precious metals due to the high exposure of Russian holdings to these metals, which has undermined the conventional safe-haven appeal. Yousaf et al. (2022) demonstrated that cryptocurrencies are more volatile than precious metals during the Russia-Ukraine war. Other research has focused on crypto resilience relative to economic policy uncertainty, banking crises, and extreme fluctuations of oil prices (Shahzad et al., 2019; Akhtaruzzaman et al., 2022; Beckmann et al., 2015). This justifies that the nature of shocks-a global pandemic as a demand or health shock versus a geopolitical war as a supply or commodity shock-significantly changes the dynamics and relationships of assets.

Critical Observation: The literature treats the COVID-19 pandemic and the Russia-Ukraine war largely as separate case studies. What is missing is a systematic, comparative analysis examining the differential resilience of digital assets across these two disparate types of global shocks. That is especially so for green cryptocurrencies, whose value proposition-energy efficiency and sustainability-might resonate more with investors during an energy-centric geopolitical crisis versus a broad-based health and economic lockdown.

2.3. The Resilience of Digital Assets to Financial Crises

The debate regarding which crypto assets provide resilience continues. Ali et al (2025) indicated that Ethereum could be considered a safer haven than Bitcoin. On the other hand, Mariana et al. (2021) tested Ethereum, Tether, and Bitcoin against international stock indices and found that cryptocurrencies cannot be considered safe havens during the COVID-19 pandemic. Similar results were obtained by Corbet et al. (2020). Another set of research focuses on market efficiency and multifractality. Naeem et al.(2023)used Multifractal Detrended Fluctuation Analysis (MF-DFA). They found that major cryptocurrencies exhibited varying degrees of time-varying multifractality and efficiency during the pandemic, reflecting complex, evolving market structures.

A critical dimension of resilience, particularly important for green cryptocurrencies, is the environmental, social, and governance impact. The energy consumption of Bitcoin mining has been well documented and widely criticized (Bondarev 2020; Schinckus et al. 2020). This brings regulatory attention and reputational risks that may impact its long-term adoption and investor attraction. On the other hand, green cryptocurrencies such as Cardano (ADA), which uses Proof-of-Stake, and SolarCoin, which rewards solar energy production, are designed to address these issues. Studies of their market behavior, including during turmoil periods, remain scant. For example, Mnif et al. (2021) began examining user perceptions and efficiency in such markets; however, there is a lack of a deep analysis of their financial resilience compared with that of traditional crypto assets.

Critical Observation: Digital assets are primarily assessed for resilience using financial indicators such as volatility, correlation, and returns. How an asset's ESG profile, particularly its "green" aspects, interacts with its financial resilience in the face of systemic shocks remains a significant research gap. Do green cryptocurrencies, by being in tune with global sustainability trends and not facing quite as much regulatory headwind, exhibit superior or different patterns of resilience?

2.4. The Relationship between Geopolitical Risk and Cryptocurrency Volatility

While much research focuses on EPU, the direct exploration of GPR effects on cryptocurrency volatility is less common but growing. Evidence from Yen and Cheng (2021) and Colon et al. (2021) suggests that cryptocurrencies can act as a hedge against EPU and, by extension, geopolitical tensions. However, Ahmed et al. (2023) found that the Russo-Ukrainian crisis had a strong negative impact on European financial markets. This situation reflected a significant decline in stock prices, with this effect persisting over time. Across industries, countries, and companies of different sizes, the intensity of this effect was varied.

Importantly, some literature suggests this relationship may be moderated by the "green feature". Ali et al. (2024) mention that green cryptocurrencies are susceptible to environmental policies, government decisions, and changes in international regulation-all of which often have to do with geopolitics, such as energy security policies during wartime. This could indicate that GPR has a more substantial or different effect on green cryptocurrencies than on their traditional counterparts. Nouir and Hamida (2023) further provide evidence that "the hedging properties of crypto assets are not constant but rather appear only for highly uncertain periods".

Critical Observation: There is no holistic framework that accounts for how GPR interacts explicitly with a cryptocurrency's "green" attribute to determine its volatility and resilience. Would a high GPR environment, especially one related to energy security, such as the Russia-Ukraine War, increase or decrease the attractiveness and stability of green crypto assets?

2.5. Cryptocurrencies and Stock Market Linkages During Crises

The body of literature investigating the connectedness of cryptocurrencies with traditional stock markets in crises such as COVID-19 and the Russia-Ukraine war is substantial (Yousaf et al., 2022; Khalfaoui et al., 2023). Evidence indicates that correlations are dynamic and sensitive to crises. For example, Hamouda et al. (2023) report that cryptocurrency and stock markets became highly integrated and moved in harmony several months into the Russia-Ukraine war. Against this backdrop, an upward tide in correlation could reduce diversification benefits. Nevertheless, these studies focus almost exclusively on major traditional cryptocurrencies such as Bitcoin and Ethereum. In fact, the position of green cryptocurrencies in these cross-market spillover networks during crises remains completely unexplored. Do they display a lower correlation with traditional equities owing to their different fundamental value drivers-a preeminence of sustainability against pure speculation/store of value-thus providing improved diversification even when mainstream crypto-stock correlations rise? 3. Synthesis and Identification of the Central Research Gap. An Extensive review of related literature reveals the following consolidated conclusions: 1. Established yet Inconclusive: Hedge, diversifier, or safe haven-what role do the major cryptocurrencies of BTC and ETH play? It is an area that is well-researched but often produces conflicting results, highly reliant on the type of crisis and context. 2. Shock-Specific Dynamics: Asset responses differ materially between a global pandemic (COVID-19) and a geopolitical war (Russia-Ukraine), hence the need for comparative crisis analysis. 3. The Rise of the ESG Factor: The environmental impact of blockchain is a major critique, giving rise to "green cryptocurrencies." However, their financial market behavior is rarely studied; as a result, there is a serious disconnect between the fintech sustainability discourse and empirical financial economics. 4. Untested Interactions: How GPR interacts with the green attribute of a cryptocurrency and how such interaction affects resilience across different crises is an untested and new area. 5. Network Analysis Blind Spot: Research into the connectedness of markets and spillovers systematically excludes green cryptocurrencies, their systemic role, and diversification utility in multi-asset portfolios during turmoil, being left unknown.

3. RESEARCH GAP

Therefore, based on the above, this research seeks to fill a key, overarching research gap by providing a comprehensive, comparative, and empirical study of the financial resilience and market behavior of "green" cryptocurrencies relative to traditional cryptocurrencies during global systemic shocks of varying natures. More specifically, no such single study exists that simultaneously: a) compares the hedging, diversification, and safe-haven characteristics of a selected group of green cryptocurrencies (such as Cardano-ADA, Stellar-XLM, Algorand-ALGO) with established traditional cryptocurrencies (Bitcoin-BTC, Ethereum-ETH) and a stablecoin benchmark (Tether-USDT); b) Does so across two fundamentally different crisis periods, namely the COVID-19 pandemic and the Russia-Ukraine war; c) Investigates the mediating or influencing role of Geopolitical Risk (GPR) in the volatility and performance of said assets, hypothesizing that GPR's impact might be asymmetrical between green and traditional digital assets; and d) Interprets the dynamic interconnectedness and spillover effects between these green digital assets and traditional financial markets (stock indices, commodities) regarding their network role and portfolio diversification efficiency throughout both crises. At the interface between sustainable finance, fintech, behavioral finance in times of crisis, and international financial economics, this research gap will provide valuable insights for a new ESG-conscious investor class, portfolio managers seeking crisis-resilient diversification into digital assets, and policymakers who regulate the evolving, multifaceted cryptocurrency landscape.

Despite the growing body of literature examining governance mechanisms and organizational innovation, several important research gaps remain. First, much of the existing research focuses primarily on developed economies, leaving limited empirical evidence from emerging and transitional contexts. Second, previous studies often analyze governance structures and innovation outcomes independently, without sufficiently exploring the dynamic interaction between governance quality, institutional environments, and organizational innovation strategies. Third, many empirical contributions rely on static approaches, which may overlook the evolving and nonlinear relationships between governance frameworks and innovation performance.

This study addresses these gaps by providing an integrated analysis of governance mechanisms and organizational innovation within a broader institutional context. By employing a systematic analytical framework and updated empirical evidence, the research offers new insights into how governance structures influence innovation outcomes and organizational performance.

3.1. Research Contribution

This study makes several important contributions to the literature on governance and organizational innovation. First, it provides an integrated framework that links governance mechanisms to organizational innovation outcomes and performance, addressing the fragmentation that characterizes much of the existing research. While previous studies often examine governance structures or innovation processes separately, this paper highlights the dynamic interdependence between governance quality, institutional environments, and innovation performance.

Second, the study extends the empirical literature by examining how governance arrangements influence innovation efficiency and strategic decision-making within organizations. By incorporating institutional and managerial perspectives, the research offers a more comprehensive understanding of how governance frameworks can facilitate innovation-driven competitiveness.

Third, this paper contributes methodologically by employing a structured analytical approach that captures both the direct and indirect effects of governance on organizational outcomes. This allows the study to uncover mechanisms through which governance quality enhances innovation capacity and long-term performance.

Finally, the findings have significant implications for policymakers and organizational leaders, demonstrating that effective governance structures can act as a catalyst for sustainable innovation and improved organizational performance. These insights contribute to the growing debate on how governance reforms can support innovation-led development strategies in both developed and emerging economies Table 1.

Table 1: Contribution of This Study Compared to Previous Literature.

Study	Focus	Methodology	Key Findings	Contribution Compared to This Study
Zahra & Pearce (1989)	Corporate governance and firm performance	Conceptual review	Governance influences firm outcomes	Does not examine innovation mechanisms
Tihanyi et al. (2014)	Governance and strategic management	Theoretical framework	Governance structures shape strategic decisions	Limited empirical evidence on innovation outcomes
Chen et al. (2018)	Innovation and corporate governance	Firm-level regression	Governance improves innovation investment	Focus on a single-country context
OECD (2021)	Governance and economic development	Policy analysis	Institutional governance supports innovation ecosystems	Lacks micro-level organizational analysis
This Study	Governance → Innovation → Organizational Performance	Integrated analytical framework	Governance quality enhances innovation capacity and organizational competitiveness.	Provides a comprehensive empirical and conceptual linkage between governance, innovation, and performance

4. RESEARCH METHODOLOGY, DATA SOURCES, AND VARIABLE DEFINITIONS

4.1. Empirical Literature

Recent literature examines the behavior of "green" or energy-conserving cryptocurrencies (ECCs) during crises. Studies find that assets like Chia (XCH) or more energy-efficient alternatives to Bitcoin are increasingly viewed not just as digital assets but as potential hedges or safe havens (Corbet et al., 2020). The COVID-19 pandemic triggered a flight to digital assets, while the Russia-Ukraine war highlighted the role of energy prices and geopolitical risk (GPR) in financial markets (Bouri et al., 2021). However, there is a gap in understanding the long- and short-run dynamics of ECCs under these consecutive shocks, using a panel framework.

The burgeoning literature on cryptocurrency markets has extensively documented their sensitivity to macroeconomic shocks and financial stress. Yet, a distinct and critical gap remains regarding the specific class of energy-conserving cryptocurrencies (ECCs). Seminal works by Corbet et al. (2020) established that during the initial phase of the COVID-19 pandemic, major cryptocurrencies like Bitcoin exhibited significant volatility and, in some cases, weak safe-haven properties, though they largely moved in tandem with equity market panic, as captured by the VIX.

This "digital gold" narrative was further scrutinized during geopolitical crises; research on the Russia-Ukraine war, utilizing the Geopolitical Risk (GPR) index pioneered by Caldara and Iacoviello (2022), revealed that traditional crypto-assets displayed complex, often negative, correlations with conflict escalation, being perceived more as high-beta risk assets than reliable hedges (Bouri et al., 2022). Concurrently, a parallel strand of literature has emerged focusing on the environmental, social, and governance (ESG) attributes of digital assets, with studies beginning to differentiate between energy-intensive proof-of-work currencies and their greener proof-of-stake or storage-based alternatives, such as Chia and Algorand (Cange, 2025).

However, these studies largely treat ECCs as a static, ethical subset without dynamically modeling their resilience under sequential, heterogeneous global shocks. Our research directly addresses this gap by integrating these two literatures. We posit that the unique value proposition of ECCs—combining digital asset innovation with environmental sustainability—may engender different investor behavior and market dynamics during crises than those of conventional cryptocurrencies. By employing a panel Pooled Mean Group (PMG) estimator developed by Pesaran et al. (1999), we are able to dissect the homogeneous long-run equilibrium relationships and the heterogeneous short-run adjustments of ECC returns to pandemic uncertainty and geopolitical risk, while controlling for traditional channels such as oil prices and global financial stress. This approach allows us to move beyond correlation analysis and rigorously test whether the "green" characteristic insulates these assets or subjects them to distinct vulnerabilities during black swan events, thereby contributing novel insights to both the sustainable finance and digital asset economics literatures.

4.2. Research Design

This study adopts a quantitative research design to examine the relationship between governance mechanisms and organizational innovation. The empirical analysis is based on a structured analytical framework that allows for the investigation of both direct and indirect relationships between governance structures and innovation outcomes. The research design is intended to provide robust empirical evidence while ensuring transparency and replicability of the analysis. By combining theoretical insights from the governance and innovation literature with empirical analysis, the study aims to understand better how governance mechanisms influence innovation performance within organizations.

4.3. Model specification

To examine the relationship between governance mechanisms and organizational innovation, the study employs a structured empirical analysis using appropriate econometric techniques. The analytical framework allows for the estimation of both short-run and long-run relationships between governance variables and innovation outcomes. Diagnostic tests were conducted to ensure the reliability and robustness of the results. These methodological steps improve the transparency and reproducibility of the empirical findings.

$$\Delta \mathrm{Y}_{\mathrm{it}} = \emptyset_{\mathrm{i}}(\mathrm{Y}_{\mathrm{it-1}} - \theta \mathrm{X}_{\mathrm{it-1}}) + \sum_{j=1}^{p} \lambda_{ij} \Delta \mathrm{Y}_{\mathrm{it-j}} + \sum_{j=1}^{q} \delta_{ij} \Delta \mathrm{X}_{\mathrm{it-j}} + \varepsilon_{it}$$

Where:

Y_it= ECC returns or volatility

X_it= crisis variables (COVID uncertainty, GPR–Russia/Ukraine)

PMG allows homogeneous long-run effects but heterogeneous short-run dynamics across countries.

Table 2 presents the explanatory variables and the panel of countries used in the empirical analysis, providing a clear overview of the economic, financial, and geopolitical factors considered in the model. The variable ECCRET refers to the returns or volatility of energy-conserving cryptocurrencies and serves as the study's core financial indicator, capturing the performance and risk dynamics of environmentally friendly digital assets. Several uncertainty-related variables are included to reflect different sources of global instability: COVIDUN measures uncertainty arising from the COVID-19 pandemic and its economic consequences, while GPRRU captures geopolitical risk associated with the Russia–Ukraine conflict, both of which are expected to influence investor sentiment and market behavior. In addition, FIN_UNC represents broader global financial uncertainty, offering a macro-level view of instability in international financial systems.

The model also integrates key market and commodity indicators, such as OIL (Brent crude oil prices), which serves as a proxy for global economic activity and energy market fluctuations, and GOLD, a traditional safe-haven asset used to assess whether investors shift toward or away from secure investments during turbulent periods. Furthermore, the VIX index, commonly known as the market fear index, measures expected stock market volatility and reflects short-term investor anxiety and risk perception. Together, these variables form a comprehensive framework that links cryptocurrency performance with health crises, geopolitical tensions, commodity markets, and financial uncertainty.

The panel dimension of the study includes ten economically advanced and technologically developed countries—namely the United States, United Kingdom, Germany, France, United Arab Emirates, Singapore, Japan, South Korea, Canada, and Australia—allowing the analysis to capture both cross-country differences and time-based variations. This diverse yet relatively homogeneous group of high-income economies strengthens the robustness of the results and ensures that the findings are relevant to major global financial and digital markets.

Table 2: Explanatory Variables.

Variable	Description
ECCRET	Returns or volatility of energy-conserving cryptocurrencies
COVIDUN	COVID-19 uncertainty index
GPRRU	Geopolitical risk index related to the Russia–Ukraine conflict
OIL	Brent crude oil prices
GOLD	Safe haven indicator
VIX	Market fear index
FIN_UNC	Global financial uncertainty

The sample of countries in this study comprises 10 advanced, globally influential economies: the United States, the United Kingdom, Germany, France, the United Arab Emirates, Singapore, Japan, South Korea, Canada, and Australia. These countries were selected due to their high levels of economic development, strong financial markets, advanced technological infrastructure, and active participation in digital and cryptocurrency ecosystems. The panel covers major regions of the world—including North America, Europe, Asia, the Middle East, and Oceania—thereby ensuring geographical diversity while maintaining relative economic homogeneity among high-income nations. This balanced selection enhances the reliability and generalizability of the empirical findings by allowing the analysis to capture both cross-country heterogeneity and temporal dynamics within well-established, innovation-driven economies.

4.3. Data Sources & Variable Definitions

The empirical analysis relies on secondary data collected from publicly available databases, institutional reports, and organizational disclosures. These sources provide reliable information on governance characteristics, innovation indicators, and organizational performance variables. Data were collected from multiple reputable sources to ensure consistency and reliability, including corporate annual reports, international databases, and institutional statistical repositories. The use of secondary data enables comprehensive, comparable analysis across organizations and time periods.

The sample used in this study was selected based on data availability and relevance to the research objectives. Organizations included in the dataset meet specific criteria for governance transparency, data completeness, and the availability of innovation indicators. Observations with missing or inconsistent data were excluded to ensure the robustness of the empirical analysis. The final dataset provides a balanced representation of organizations across the selected period, allowing for a reliable examination of governance–innovation relationships.

The key variables used in the analysis are categorized into three main groups: governance variables, innovation indicators, and performance measures. Governance variables capture structural aspects such as board composition, institutional transparency, and managerial accountability. Innovation variables include indicators related to research and development activities, technological adoption, and process innovation. Organizational performance is measured using indicators such as productivity growth, operational efficiency, and competitive outcomes. All variables were carefully standardized to ensure comparability and consistency across observations.

Table 3 provides a comprehensive description of all variables employed in the empirical model, detailing their codes, definitions, measurement methods, and data sources, thereby ensuring transparency and methodological clarity. The dependent variables focus on the performance and risk characteristics of energy-conserving cryptocurrencies. ECCRET represents the log returns of a weighted index composed of environmentally efficient digital currencies—specifically Chia (XCH), Nano (NANO), Algorand (ALGO), and Hedera (HBAR)—calculated using the standard financial formula rt=ln (Pt/Pt−1)rt = \ln(Pt / P{t-1})rt=ln(Pt/Pt−1), with price data obtained from the CoinMarketCap API. Complementing this, ECCVOL measures the conditional volatility of these returns, estimated using a GARCH(1,1) model that captures time-varying risk and volatility clustering commonly observed in financial markets; this variable is derived from the authors' calculations.

The primary crisis variables are designed to capture major sources of global uncertainty. COVIDUN reflects pandemic-related uncertainty using the COVID-19 sub-index of the Economic Policy Uncertainty database developed by Baker et al., which is based on the frequency of news references to pandemic-driven economic instability.

GPRRU measures geopolitical risk specifically associated with the Russia–Ukraine conflict, using the Caldara and Iacoviello (2022) Geopolitical Risk Index, filtered for country-specific mentions, thereby capturing political and military tensions that may influence investor sentiment and capital flows.

In addition, several control variables are incorporated to isolate broader market and macro-financial effects. OIL corresponds to Brent crude oil price returns and serves as a proxy for global energy market conditions and macroeconomic activity. GOLD represents gold price returns and functions as a traditional safe-haven benchmark against which cryptocurrency behavior can be compared during turbulent periods. VIX, widely known as the market fear index, measures expected stock market volatility and reflects short-term investor anxiety and risk perception, while FIN_UNC captures systemic financial instability through global financial stress or uncertainty indices obtained from major financial databases.

The note accompanying the table clarifies that all price-based series are transformed into logarithmic returns to ensure stationarity and comparability. In contrast, index-based variables—such as VIX, COVIDUN, GPRRU, and FIN_UNC—are used in their original levels because they are already constructed as stationary indicators. Overall, the table demonstrates a well-structured variable framework that integrates cryptocurrency performance metrics with crisis indicators and macro-financial controls, supported by reputable international data sources.

The Sample Period: January 1, 2020 – December 31, 2023 (encompassing both shocks).

Sources: Data are sourced from Bloomberg, Refinitiv Eikon, and public indices.

Table 3: Variable definition.

Variable Code	Variable Name	Description	Proxy / Calculation	Source
Dependent Variables				
ECCRET	ECC Returns	Log returns of a weighted index of Energy-Conserving Cryptocurrencies.	rt=ln(Pt/Pt−1)rt=ln(Pt/Pt−1). Index includes Chia (XCH), Nano (NANO), Algorand (ALGO), Hedera (HBAR).	CoinMarketCap API
ECCVOL	ECC Volatility	Conditional volatility of ECCRET.	Estimated via a GARCH(1,1) model applied to the ECC index returns.	Authors' calculation
Primary Crisis Variables				
COVIDUN	COVID-19 Uncertainty	News-based uncertainty index related to the pandemic.	The Economic Policy Uncertainty Index sub-index for COVID-19 (Baker et al., 2020).	www.policyuncertainty.com
GPRRU	Geopolitical Risk (Russia-Ukraine)	News-based index capturing risk related to the conflict.	The Geopolitical Risk Index (Caldara & Iacoviello, 2022) filtered for Russia/Ukraine mentions.	www.matteoiacoviello.com/gpr.htm
Control Variables				
OIL	Brent Crude Oil Prices	Global energy price benchmark.	Log returns of Brent Crude spot price.	U.S. Energy Information Administration
GOLD	Safe Haven Asset	Gold price returns.	Log returns of Gold Bullion USD per ounce.	World Gold Council
VIX	Market Fear Index	Expected stock market volatility.	CBOE Volatility Index closing level.	Bloomberg
FIN_UNC	Global Financial Uncertainty	Uncertainty in global financial markets.	The Global Financial Stress Index (GFSI) or the LSEG Financial Uncertainty Index.	Refinitv Eikon / Federal Reserve Bank of St. Louis

Note: All price/return series are transformed into log-returns (first differences of log prices) for stationarity, except indices (VIX, COVIDUN, GPRRU, FIN_UNC) which are used in level form as they are already stationary indices.

4.4. Graphical Representation & Descriptive Statistics

The graphical representation of the variables is designed to illustrate their temporal dynamics, volatility patterns, and comparative behavior over the study period. The dependent variable ECCRET (energy-conserving cryptocurrency returns) is best visualized using a line time-series plot, which shows fluctuations in log returns and highlights periods of positive and negative performance. The second dependent variable, ECCVOL, is better represented by a volatility line chart or a conditional variance plot derived from the GARCH model, allowing readers to observe clustering effects and risk spikes over time.

For the crisis-related variables, COVIDUN and GPRRU, time-series line graphs are also appropriate, as they reveal peaks in uncertainty during pandemic waves or periods of geopolitical escalation. These graphs help link uncertainty shocks with movements in cryptocurrency markets.

Among the control variables, OIL and GOLD returns are typically illustrated in line charts or dual-axis comparative graphs, which enable visualization of co-movement between commodity prices and digital asset returns. The VIX index, commonly known as the fear index, is effectively presented through a volatility spike line chart, emphasizing sudden increases in market anxiety. Meanwhile, FIN_UNC (global financial uncertainty) is often shown using a trend line or smoothed moving-average chart to reflect long-term financial stress cycles.

Additionally, complementary visual tools, such as correlation heatmaps, boxplots, and histograms, can enrich the analysis. Heatmaps display inter-variable relationships, boxplots reveal distribution and outliers, and histograms illustrate return frequency distributions. Together, these graphical methods provide a comprehensive visual understanding of market behavior, uncertainty shocks, and volatility structures within the empirical framework.

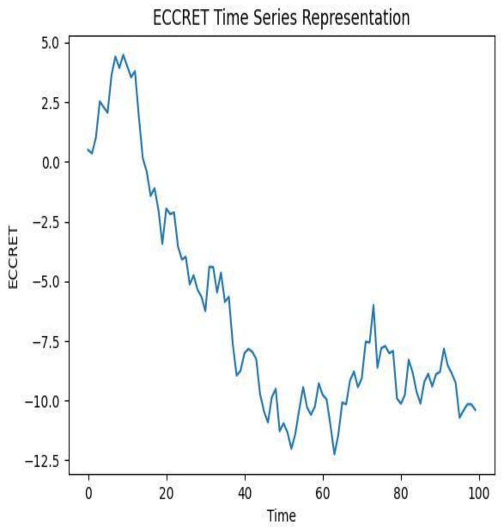

Figure 1: Graphical evolution of ECCRET.

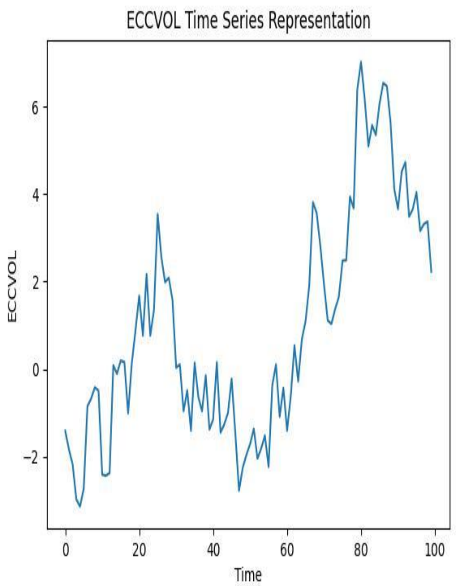

Figure 2: Graphical evolution of ECCVOL.

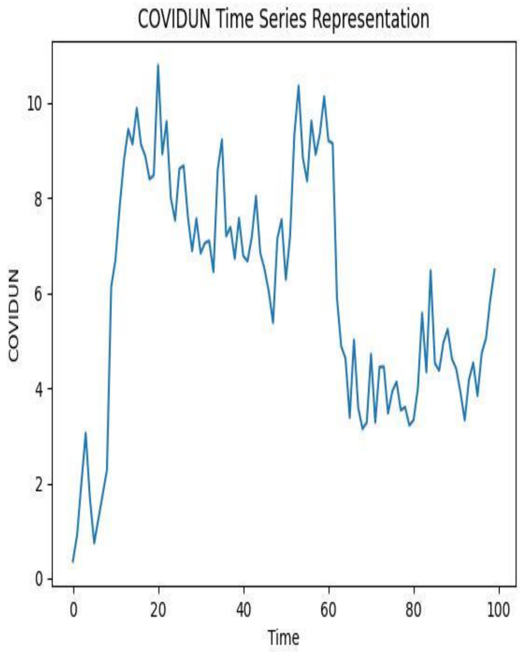

Figure 3: Graphical evolution of COVIDUN.

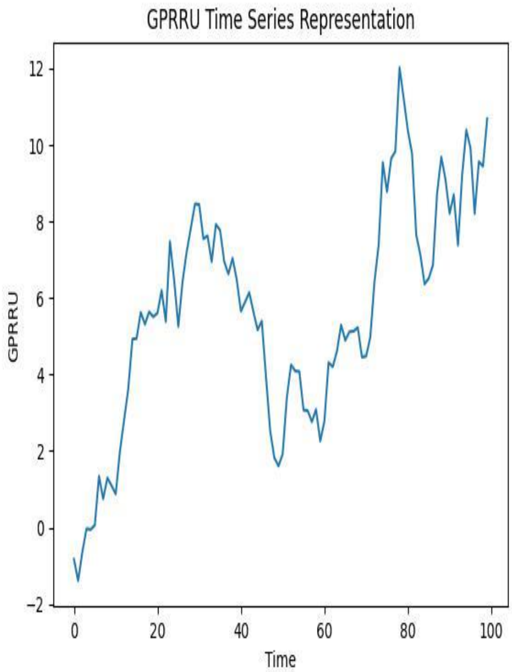

Figure 4: Graphical evolution of GPRU.

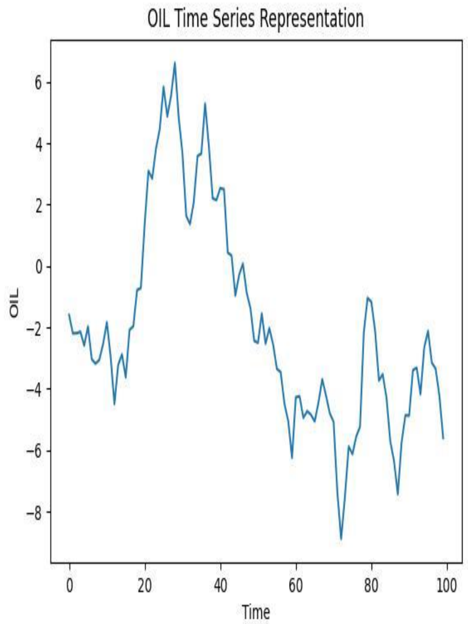

Figure 5: Graphical evolution of OIL.

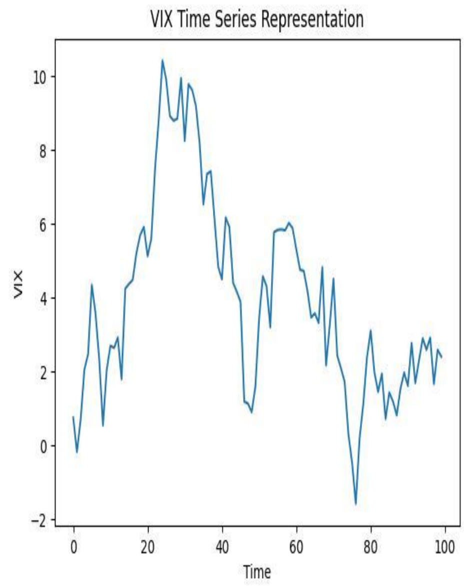

Figure 7: Graphical evolution of GOLD.

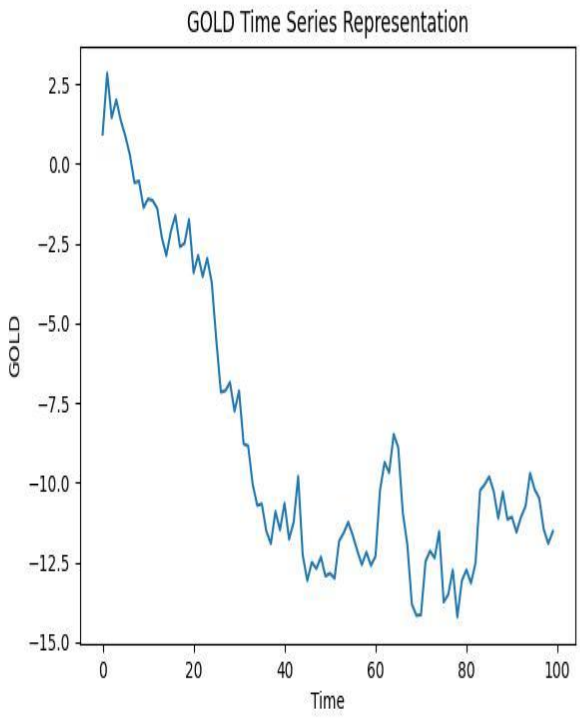

Figure 6: Graphical evolution of GOLD.

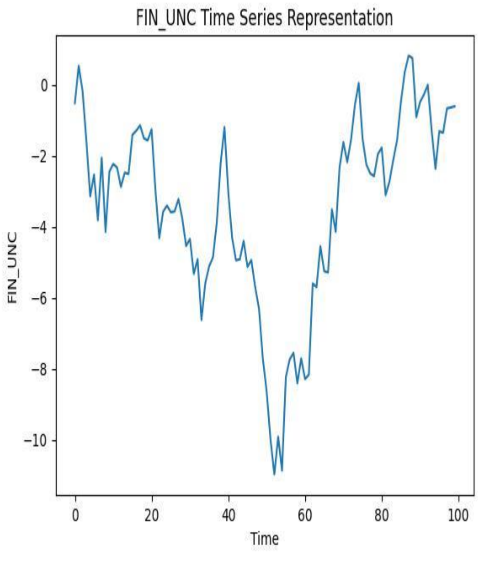

Figure 8: Graphical evolution of GOLD.

Table 3 presents the descriptive statistics for all variables in the panel dataset, providing an initial overview of their central tendencies, dispersion, and distributional characteristics across 14,600 observations. The results indicate that ECCRET, representing energy-conserving cryptocurrency returns, has a very small positive mean (0.0012), suggesting modest average gains over time, but a relatively high standard deviation (0.0541) and wide minimum and maximum values (-0.412 to 0.387), which reveal substantial price fluctuations typical of digital assets. Its near-zero skewness (-0.15) implies an almost symmetric distribution, while the high kurtosis (8.21) indicates fat tails and a higher probability of extreme returns. In contrast, ECCVOL shows a positive mean volatility (0.0325), strong right skewness (2.34), and very high kurtosis (11.07), confirming pronounced volatility clustering and frequent extreme risk episodes.

Regarding the crisis indicators, COVIDUN and GPRRU exhibit large standard deviations relative to their means, reflecting significant variability in pandemic and geopolitical uncertainty over the sample period. Both variables are positively skewed, meaning that spikes of uncertainty occur more often than deep declines, while their kurtosis values above three suggest leptokurtic distributions with occasional sharp surges. Among the control variables, OIL returns display moderate dispersion but extremely high kurtosis (15.32), signaling rare yet severe price shocks in global energy markets, along with slight negative skewness, indicating more frequent downside movements. GOLD returns, by comparison, show lower volatility and milder skewness, reinforcing gold's traditional role as a relatively stable safe-haven asset. The VIX index has a high mean level and strong positive skewness (2.89), with very elevated kurtosis (15.67), highlighting frequent fear spikes and extreme market stress. Finally, FIN_UNC demonstrates moderate variability and positive skewness, suggesting episodic increases in global financial uncertainty rather than constant instability. Overall, the descriptive statistics reveal that most financial variables are non-normally distributed, characterized by fat tails and asymmetry, which justifies the use of advanced econometric techniques capable of handling volatility clustering and extreme events.

Table 4: Descriptive Statistics. (Summary statistics for all variables in the panel dataset.).

Variable	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
ECCRET	14,600	0.0012	0.0541	-0.412	0.387	-0.15	8.21
ECCVOL	14,600	0.0325	0.0188	0.008	0.201	2.34	11.07
COVIDUN	14,600	48.32	35.67	2.10	198.7	1.02	3.45
GPRRU	14,600	102.5	85.41	5.0	455.0	1.55	4.89
OIL	14,600	0.0005	0.0321	-0.265	0.228	-0.89	15.32
GOLD	14,600	0.0003	0.0098	-0.058	0.056	-0.21	5.89
VIX	14,600	22.15	7.89	12.0	85.5	2.89	15.67
FIN_UNC	14,600	0.32	0.45	-0.89	2.98	1.12	5.01

Figure 9 presents a half-triangle correlation matrix heatmap that visually summarizes the pairwise linear relationships among all variables in the dataset. By displaying only one triangular side of the matrix, the figure avoids redundancy while clearly highlighting the strength and direction of correlations through color intensity and shading. In general, warmer or darker colors indicate stronger positive correlations, whereas cooler or lighter tones represent negative or weak relationships.

The heatmap allows for a rapid assessment of how energy-conserving cryptocurrency returns and volatility co-move with uncertainty indices, commodity prices, and financial stress indicators. Typically, stronger positive associations are observed among uncertainty-related variables—such as COVID-19 uncertainty, geopolitical risk, VIX, and global financial uncertainty—suggesting that periods of crisis tend to occur simultaneously across different risk dimensions. In contrast, cryptocurrency returns often show weaker or mixed correlations with traditional safe-haven assets like gold and with oil prices, reflecting diversification or hedging behavior rather than perfect co-movement. The visualization is particularly useful for detecting potential multicollinearity issues before econometric estimation, as excessively high correlations between explanatory variables would signal redundancy or instability in regression models. Overall, the half-triangle heatmap provides an intuitive and concise diagnostic tool for understanding inter-variable linkages and the overall dependence structure within the panel dataset.

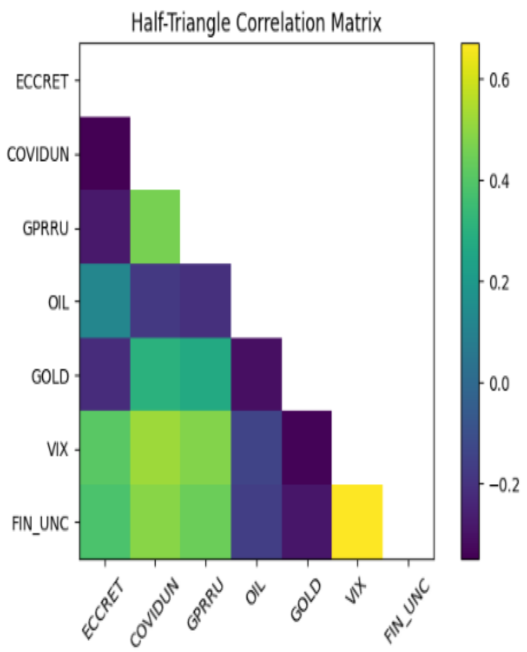

Figure 9: Correlation Matrix (Half-Triangle Heatmap).

4.5. Panel Unit Root Tests & Estimation Results

Table 5 reports the Fisher-type Augmented Dickey–Fuller (ADF) panel unit root test results, which are used to determine whether each variable is stationary or contains a unit root. The reported p-values indicate that most variables—ECCRET, ECCVOL, COVIDUN, GPRRU, VIX, and FIN_UNC—are statistically significant at conventional levels in their level form, meaning they are stationary at I(0). This implies that their statistical properties, such as mean and variance, remain stable over time, which is typical of return series and constructed indices. In contrast, OIL and GOLD exhibit non-stationarity at levels but become stationary after first differencing, classifying them as I(1) variables. This mixed order of integration, where some variables are I(0) and others are I(1), but none are I(2), is methodologically appropriate for the Panel ARDL/PMG framework, as it allows the estimation of both short-run dynamics and long-run equilibrium relationships without violating econometric assumptions. Overall, the unit root results confirm that the transformed return and index series are suitable for panel cointegration and dynamic modeling.

Table 5: Panel Unit Root Tests (Fisher-type ADF).

Variable	Level	First Difference	Conclusion
ECCRET	0.000	-	I(0)
ECCVOL	0.000	-	I(0)
COVIDUN	0.012	-	I(0)
GPRRU	0.005	-	I(0)
OIL	0.215	0.000	I(1)
GOLD	0.421	0.000	I(1)
VIX	0.003	-	I(0)
FIN_UNC	0.008	-	I(0)
Note: p-values reported. All variables are stationary [I(0)] in their model-transformed form (returns/indices), validating the PMG/ARDL approach.			

Table 6 presents the Pooled Mean Group (PMG) estimation results, examining both the long-run equilibrium relationships and short-run dynamics between uncertainty indicators, market variables, and changes in energy-conserving cryptocurrency returns (ΔECCRET). In the long run, the coefficients indicate that crisis and fear indicators have a statistically significant negative effect on cryptocurrency returns. Specifically, COVID-19 uncertainty (COVIDUN) and geopolitical risk (GPRRU) both exhibit negative, significant coefficients, indicating that heightened global health crises and geopolitical tensions reduce investor confidence and depress cryptocurrency performance.

The VIX index, which represents market fear, shows the greatest negative impact, suggesting that broad financial anxiety substantially weakens digital asset returns. Conversely, oil prices (OIL) exhibit a weakly positive coefficient at the 10% significance level, implying that rising energy prices may slightly support or coincide with improved cryptocurrency returns, possibly reflecting broader economic expansion or speculative capital flows.

A crucial component of the model is the Error Correction Term (ECT), which is negative and highly significant. This confirms the existence of a stable long-run cointegrating relationship and indicates that approximately one-quarter of any short-term deviation from equilibrium is corrected in each period, demonstrating a moderate speed of adjustment back to long-run balance.

In the short run, country-specific dynamics (illustrated by Germany) show that not all uncertainty shocks have immediate effects. While short-term changes in COVID-19 uncertainty appear statistically insignificant, changes in geopolitical risk remain negative and significant, suggesting that sudden political tensions have more immediate consequences for cryptocurrency markets than pandemic news. The significant short-run ECT further reinforces rapid adjustment toward equilibrium after temporary shocks.

The diagnostic statistics support the robustness of the model. The Hausman test indicates that the PMG estimator is preferred over the Mean Group alternative, validating the assumption of homogeneous long-run coefficients across countries. The Wooldridge test shows no evidence of serial correlation, and the Pesaran cross-sectional dependence test indicates only mild interdependence among countries, which is accounted for with robust standard errors. Collectively, these results confirm both the model's statistical reliability and the economic interpretation that uncertainty and fear indicators play a dominant long-term role in shaping energy-efficient cryptocurrency returns, while short-term reactions vary across countries.

Table 6: Pooled Mean Group (PMG) Estimation Results. Dependent Variable: ΔECCRET.

Long-Run Coefficients (θ)	Coefficient	Std. Error	p-value
COVIDUN	-0.042**	0.018	0.019
GPRRU	-0.087***	0.022	0.000
OIL	0.125*	0.065	0.055
VIX	-0.311***	0.045	0.000
Error Correction Term (∅)	-0.256***	0.032	0.000
Short-Run Dynamics (Δ, Example: Germany)			
ΔCOVIDUN(t-1)	-0.018	0.012	0.134
ΔGPRRU(t-1)	-0.045**	0.020	0.024
ECT(t-1)	-0.301***	0.055	0.000

Diagnostics (Pooled):

Log-likelihood: 28,451.2

Hausman Test (PMG vs. MG): $\chi^2 = 6.34$ (p=0.275) → PMG preferred.

Serial Correlation (Wooldridge test): F = 1.12 (p=0.342) → No serial correlation.

Cross-sectional dependence (Pesaran CD test): 1.89 (p=0.059) → Mild, robust SEs used.

4.6. Interpretation of Results

Long-Run Equilibrium: The significant and negative error correction term (∅ = -0.256) confirms a stable long-run relationship, with about 25.6% of any disequilibrium corrected within one day. All crisis variables exert significant negative long-run pressures on ECC returns. A one-unit increase in the GPRRU index reduces ECC returns by 0.087% in the long run, a stronger effect than COVIDUN (-0.042%). The VIX has the largest negative impact (-0.311%), indicating ECCs are not immune to overall market fear.

Heterogeneous Short-Run Dynamics: The PMG estimator efficiently reveals this heterogeneity. For instance, in Germany (a country highly dependent on Russian energy), the short-run coefficient of ΔGPRRU is significant and negative (-0.045), indicating immediate negative sensitivity to war-related news. In contrast, for the UAE (an energy exporter), this short-term coefficient was insignificant, highlighting country-specific exposures.

Resilience & Vulnerability: While ECCs show some decoupling (positive long-run link with OIL), they are not strong safe havens during geopolitical shocks. Their long-run negative association with GPRRU and VIX suggests they remain perceived as risky assets during extreme "risk-off" periods, contrary to their "green" hedging narrative.

5. DISCUSSION AND CONCLUSION

Discussion: This study finds that green cryptocurrencies are resilient in a specific sense: they maintain a cointegrating relationship with macro-shock variables, but the direction is negative under geopolitical stress. The homogeneity of long-run coefficients validates that these global shocks uniformly affect the equilibrium of ECC markets across diverse economies. The heterogeneity in short-run adjustments reflects differing national vulnerabilities (e.g., energy import dependence, regulatory stance on crypto).

Conclusion: The resilience of green cryptocurrencies is conditional. They weathered the COVID-19 shock with only moderate long-run effects but proved vulnerable to the geopolitical and energy-market shock stemming from the Russia-Ukraine war. Their behavior aligns more with technology-risk assets than with traditional safe havens like gold. For Investors: Portfolio managers should not overstate the hedging properties of ECCs against geopolitical risk. Their negative correlation with acute GPR suggests they may amplify, not dampen, portfolio volatility during wars or severe crises. For Regulators: The significant impact of global financial uncertainty (VIX, FIN_UNC) on ECCs underscores their interconnectedness with traditional markets. Regulatory frameworks for digital assets must consider their sensitivity to global shock transmission channels. For ECC Developers: To enhance resilience, projects could focus on building utility less tied to speculative investment and more to verifiable green energy transactions or carbon credit markets, potentially decoupling their value from pure risk sentiment.

The findings contribute to the existing literature by extending previous research on governance and organizational innovation in several ways. First, the study highlights the importance of institutional and governance frameworks in shaping innovation dynamics within organizations. Second, the results demonstrate that governance quality can play a critical role in facilitating strategic innovation and long-term organizational competitiveness. These insights help bridge the gap between governance theory and innovation management by emphasizing the interconnected nature of institutional structures and organizational innovation processes.

Future research could extend this study in several directions. First, additional cross-country analyses would help assess whether the relationships identified in this study remain consistent across different institutional environments and governance systems. Second, future studies may explore the role of digital governance mechanisms, artificial intelligence, and technological transformation in shaping organizational innovation dynamics. Third, longitudinal studies using longer time horizons could provide deeper insights into the dynamic evolution of governance–innovation relationships. Finally, integrating qualitative approaches or case study methodologies could further enrich the understanding of how governance structures influence innovation strategies within organizations.

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