

Alternative Asset Diversification for ESG Investments: Evidence from G7 Countries Under Economic and Geopolitical Crises

Alternatywna dywersyfikacja aktywów dla inwestycji ESG: dowody
z krajów G7 w obliczu kryzysów gospodarczych i geopolitycznych

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Abstract

In recent years, environmental, social, and governance (ESG)-oriented investments have emerged as a key pillar of sustainable finance. This study analyses the resilience of the ESG Leaders indices of G7 countries to global economic and geopolitical shocks, as well as their dynamic relationships with alternative assets such as Bitcoin, gold, the Japanese yen, and the Swiss franc. Covering the period from January 2019 to May 2025, the analysis incorporates major global developments, including the COVID-19 pandemic, the Russia–Ukraine war, the collapse of the Silicon Valley Bank, the Israel–Palestine conflict, and U.S. tariff policies targeting China. The empirical findings reveal that ESG indices are significantly affected by such shocks and emphasize the necessity for investors to adapt their portfolio diversification strategies to evolving market conditions. The results show that the Japanese yen (excluding Japan) consistently exhibits the lowest correlation with the G7 ESG indices and provides considerable cost efficiency. While gold and the Swiss franc also serve as effective diversifiers under high uncertainty, Bitcoin generally offers a cost-effective diversification option.

Key words: ESG investments, alternative assets, portfolio diversification, hedging effectiveness, GO-GJRGARCH, geopolitical risks, economic shocks

Streszczenie

W ostatnich latach inwestycje zorientowane na środowisko, społeczeństwo i ład korporacyjny (ESG) stały się kluczowym filarem zrównoważonych finansów. Niniejszy artykuł analizuje odporność indeksów ESG Leaders krajów G7 na globalne wstrząsy gospodarcze i geopolityczne, a także ich dynamiczne relacje z alternatywnymi aktywami, takimi jak Bitcoin, złoto, jen japoński i frank szwajcarski. Analiza obejmująca okres od stycznia 2019 r. do maja 2025 r. uwzględnia główne wydarzenia globalne, w tym pandemię COVID-19, wojnę rosyjsko-ukraińską, upadek Banku Doliny Krzemowej, konflikt izraelsko-palestyński oraz politykę celną USA wobec Chin. Wy-

niki badań empirycznych pokazują, że indeksy ESG są znacząco podatne na takie wstrząsy i podkreślają konieczność dostosowania przez inwestorów strategii dywersyfikacji portfela do zmieniających się warunków rynkowych. Wyniki pokazują, że jen japoński (z wyłączeniem Japonii) konsekwentnie wykazuje najniższą korelację z indeksami ESG krajów G7 i zapewnia znaczną efektywność kosztową. Chociaż złoto i frank szwajcarski również stanowią skuteczne dywersyfikatory w warunkach dużej niepewności, Bitcoin ogólnie rzecz biorąc oferuje opłacalną opcję dywersyfikacji.

Słowa kluczowe: inwestycje ESG, aktywa alternatywne, dywersyfikacja portfela, efektywność zabezpieczeń, GO-GJRGARCH, ryzyka geopolityczne, wstrząsy gospodarcze

1. Introduction

Recently, growing environmental challenges have drawn the attention of investors and stakeholders toward socially responsible investment. These challenges and the evolving investment landscape have brought environmental, social, and governance (ESG) investing from the fringe to the centre of the world's financial markets. This trend is reflected in the increasing integration of ESG metrics into investment strategies across global financial systems. Existing literature indicates that investor activism toward environmental sustainability has compelled stakeholders in financial markets to incorporate ESG dimensions into their decision-making processes (Alharbi et al., 2025). The integration of ESG factors into investment strategies has experienced notable expansion, particularly in the post-pandemic period. Moreover, the recognition of sustainability within the framework of the United Nations' Sustainable Development Goals (SDGs) has significantly contributed to the growing prominence of ESG investments.

ESG investment is intrinsically aligned with several United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Moreover, the governance dimension of ESG supports SDG 16 (Peace, Justice and Strong Institutions), while sustainable capital allocation contributes to SDG 8 (Decent Work and Economic Growth). Given that the G7 economies play a central role in global climate financing and institutional stability, understanding the resilience of ESG investments during crises is critical for sustaining financial flows necessary to achieve these interconnected SDGs. The rapid growth of ESG investments is reflected in the expansion of the global sustainable investment market. The ESG investing market was valued at approximately USD 27,480 billion in 2023 and is projected to reach USD 130,880 billion by 2032, exhibiting a compound annual growth rate of 17.31 percent during the period 2024–2032. The recent expansion in ESG investing can also be linked to the increasing proliferation of ESG-focused indices across both developed and emerging economies. Existing literature suggests that investment strategies incorporating ESG considerations are often associated with higher returns, reduced downside risk during periods of market volatility, enhanced corporate reputation, and improved environmental and social outcomes.

Despite the rapid growth in sustainable investment flows and the increasing prominence of ESG indices, these investments remain susceptible to financial shocks, geopolitical tensions, and economic uncertainties, similar to conventional financial assets. Recent geopolitical and policy developments have further intensified these uncertainties. For instance, policies enacted during the Trump administration including the withdrawal of the United States from the Paris Climate Agreement, the rollback of environmental regulations, and shifting priorities in climate-related policies have created a more uncertain environment for ESG investments. Such developments have compelled investors to reassess their portfolio strategies in response to evolving political and regulatory landscapes. The increasing popularity of ESG investments, coupled with their vulnerability to global shocks, geopolitical tensions, and political developments, raises an important question regarding the hedging and diversification of ESG portfolios. Existing literature indicates that studies on ESG investments have grown substantially in recent years (see Wang et al., 2024; de Boyrie et al., 2024; Piserà et al., 2024). However, research examining the diversification and hedging properties of ESG investments in the context of portfolio performance remains relatively limited. Against this backdrop, the present study attempts to explore the hedging and safe-haven potential of ESG portfolios, particularly during periods of market turbulence and policy uncertainty associated with the political developments linked to the Trump administration, which we refer to as the *Trump effect*. To achieve these objectives, the study investigates the hedging and diversification potential of several alternative assets – namely Bitcoin, gold, the Japanese yen, and the Swiss franc – against the ESG Leaders indices of the G7 economies.

This study contributes to the existing literature in several ways. First, while numerous studies have examined the hedging properties of gold and fiat currencies against traditional financial markets, limited attention has been given to their interaction with sustainable ESG investments. Much of the existing literature on ESG investments has focused on the hedging potential of ESG assets relative to traditional equity and bond markets (see Rubbiani et al., 2022; Jin et al., 2023; Wang et al., 2024). Therefore, examining the relationship between ESG indices and alternative assets contributes to a deeper understanding of how sustainable assets interact with non-traditional hedging instruments under diverse economic and geopolitical conditions. Second, the inclusion of Bitcoin – one

of the most widely discussed digital assets in the empirical analysis adds a novel dimension to the literature on portfolio risk management within ESG investment strategies. While several studies consider Bitcoin a weak safe-haven asset during periods of financial turmoil, others highlight concerns related to its high volatility, lack of intrinsic value, and evolving regulatory framework. By examining Bitcoin alongside more traditional hedging instruments such as gold and safe-haven currencies, this study provides comparative insights into the diversification potential of different asset classes within ESG-oriented portfolios. Third, the study introduces an important geographical dimension by focusing on the ESG Leaders indices of the G7 economies. The G7 countries collectively account for more than 40 percent of global GDP and contribute approximately 25 percent of global greenhouse gas emissions. Their substantial economic influence highlights their pivotal role in shaping global ESG standards and climate-related investment frameworks. Furthermore, existing evidence suggests that G7 nations are among the leading investors in renewable energy and sustainable infrastructure. Countries such as the United States, France, Germany, the United Kingdom, and Japan rank among the largest contributors to global renewable energy investment. Their commitment to sustainable development not only advances their own carbon-neutrality objectives but also provides a model for other nations to follow. Additionally, the ESG market structure, investor sentiment, and macroeconomic conditions differ across G7 economies. Consequently, examining the hedging dynamics within this context allows the study to capture heterogeneity and asymmetries in diversification effectiveness across major global economies. Fourth, the study incorporates a dynamic timeline that encompasses several major global events, including the COVID-19 pandemic (beginning March 2020), the Russia–Ukraine conflict (beginning February 2022), the Silicon Valley Bank collapse (March 2023), the Israel–Palestine conflict (beginning October 2023), the U.S. presidential election cycle (2024), and the introduction of tariffs and trade-related tensions by the United States in April 2025, particularly targeting China. These events contributed to heightened global uncertainty, supply-chain disruptions, and policy ambiguity, which collectively influence investor sentiment and market volatility. In such contexts, capital flows may temporarily shift away from long-term sustainability priorities toward short-term risk management strategies. Examining ESG investments during such turbulent periods is therefore crucial for understanding their resilience and for guiding policy decisions aimed at sustaining long-term sustainable investment flows. Finally, the study employs advanced multivariate dynamic GARCH models to examine the safe-haven and diversification roles of alternative assets for the G7 ESG Leaders indices. This methodological framework allows the analysis to capture time-varying volatility dynamics and interdependencies between assets while accounting for both global and regional shocks. The use of dynamic volatility modelling enhances the methodological robustness of the study and provides deeper insights into the evolving hedging effectiveness of alternative assets within ESG-oriented investment portfolios.

The remainder of the paper is structured as follows. Section 2 provides a comprehensive review of the relevant literature and theoretical foundations. Section 3 describes the methodology and data used in the analysis. Section 4 presents the empirical results and discussion. Finally, Section 5 concludes the study and outlines key policy implications.

2. Literature review and theoretical foundation

In view of the recent inclination of investors towards ESG investments, several scholars have attempted to explore the intricacies of ESG investments within the framework of global financial markets and conventional financial instruments. The present section provides a comprehensive review of existing literature delving into the interaction of ESG investments with equities, commodities, digital assets, and other conventional financial instruments. Nofsinger and Varma (2014) conducted one of the pioneering studies, exploring the returns of ESG mutual funds and conventional mutual funds with the objective of analysing how ESG and non-ESG funds perform during crisis periods. The authors confirmed that there is a common belief that investors restrict their investments by choosing ESG funds. However, in the long run these ESG funds outperform non-ESG funds, especially during crisis periods. Sadorsky (2014) extended the above study by modelling the correlation and hedging between the Dow Jones Sustainability Index, the S&P 500, and gold and oil prices and concluded that the sustainability index shares similar results in terms of dynamic conditional correlation, optimum portfolio weight, and hedge ratios as obtained while investing in oil, gold, and the S&P 500.

In line with the above studies, recently several other scholars also attempted to explore the safe haven and hedging characteristics of ESG indexes against traditional financial assets (Jawadi et al., 2019; Lean and Pizzutilo, 2020; Rehman et al., 2021; Sharma et al., 2022; Almansour et al., 2023). Jawadi et al. (2019) investigated the comparability between ESG indices, Islamic indices, and conventional U.S. stock indices and concluded that, although all three indices have different criteria for investments, they exhibit similar levels of uncertainty (or risk). However, the level of risk varies with the changes in economic situations. Lean and Pizzutilo (2020) corroborated the above findings while exploring the performance and risk of socially responsible indices against conventional indices during crisis periods. Moreover, the author suggested ESG indices have a high idiosyncratic volatility, indicating that the price fluctuations of these indices are largely influenced by factors unique to the investment rather than by broader market movements. Rehman et al. (2021) investigated the integration of MSCI ESG indices and MSCI

conventional indices of BRICS economies and concluded that all ESG equity indices are highly integrated with conventional indices in all BRICS countries. Therefore, any volatility in conventional indices creates a ripple effect on the return of ESG indices. Sharma et al. (2022) also explored a similar relationship by including NASDAQ clean energy as a measure of ESG investments and concluded that NASDAQ clean energy indices perform similarly to the NASDAQ Composite Index and NASDAQ Global Select Market Composite Index. However, the author suggested high integration among the selected indices post-Covid pandemic. In a similar vein, Almansour et al. (2023) investigated the interconnectedness and risk transmission between the sustainability indices of the S&P and Dow Jones (DJ) and their traditional counterparts. Their findings indicated a significant level of connectedness and risk transmission among the indices both during and after the Covid-19 pandemic.

In addition to the aforementioned studies that are exclusively focused on the integration of ESG investments with conventional equities, researchers have also investigated the potential integration and hedging of ESG with digital assets and commodities. In this context, Pedini and Severini (2022) examined the quantile correlation between traditional investments, including gold, commodities, cryptocurrencies, equity indices, and ESG assets. Their findings indicate that none of the ESG assets can be considered safe havens for traditional investment options. However, we can view ESG assets as an excellent means of diversifying risk. Recently, Piserà and Chiappini (2024) explored the safe haven and hedging effectiveness of ESG leader indexes against bitcoin, oil, gold and West Texas Intermediate (WTI). The authors found strong evidence indicating that ESG indexes possess risk-hedging characteristics in comparison to cryptocurrency. Nevertheless, they did not observe safe-haven attributes for ESG, Bitcoin, gold, and WTI throughout the pandemic period. Likewise, de Boyrie and Pavlova (2024) explored the connectedness of ESG leader indices of Asia, Europe and Latin America with equity and commodities within the context of the portfolio management practices and concluded that there is no significant difference that can be observed while investing in either the ESG leaders or conventional emerging market indexes when combined in portfolios with commodities. In a recent empirical investigation, Pedini and Severini (2025) explored the hedging, diversifying, and safe haven properties of different ESG assets, like green bonds and ESG equity indices, against commodities, gold, and conventional equity indices. The empirical results conclude that ESG investments demonstrate mainly diversifying options with minimal hedging or safe haven traits under diverse economic conditions.

Beyond the financial and econometric dimensions discussed above, the growing literature on ESG investments is inherently connected to the broader framework of the United Nations Sustainable Development Goals (SDGs). ESG-oriented capital allocation directly supports United Nations SDG 7 (Affordable and Clean Energy) through investments in renewable infrastructure, SDG 9 (Industry, Innovation and Infrastructure) via sustainable industrial transformation, and SDG 13 (Climate Action) by channeling resources toward low-carbon transitions. Moreover, the governance component of ESG aligns closely with SDG 16 (Peace, Justice and Strong Institutions), emphasizing transparency, accountability, and institutional resilience, while sustained capital flows to sustainable firms contribute to SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). Given the global interconnectedness of financial markets, diversification strategies that stabilize ESG portfolios during crises also reinforce SDG 17 (Partnerships for the Goals) by preserving cross-border capital cooperation and long-term climate financing commitments. However, despite this intrinsic alignment, existing empirical studies largely evaluate ESG performance from a portfolio efficiency perspective rather than examining how financial resilience mechanisms contribute to sustaining SDG-aligned investment flows during systemic shocks. This conceptual gap underscores the importance of investigating whether alternative assets can safeguard ESG capital allocation under heightened economic and geopolitical uncertainty, thereby supporting the continuity of sustainable development financing.

In a nutshell, based on the aforementioned literature review, we can say that following the pandemic, numerous scholars have investigated the safe haven and hedging potential of ESG investments. However, most of the available literature has explored the safe haven and hedging characteristics of ESG investment against conventional equity indices. As per the author's knowledge, there are a limited number of studies available that have examined the potential of bitcoins, gold, and particularly currency pairs as a safe haven or hedge against ESG investments. In addition, with the exception of a limited number of studies, the majority of the previously mentioned research has relied on either a singular stock to represent ESG investments or has utilised individual sustainability indices for the assessment of ESG investments. There is no available literature that has examined the above relationship within the framework of G7 ESG leader indices, thus creating a significant opportunity for further exploration. Furthermore, the literature review highlights that most of the studies mentioned have explored the risk-diversifying and hedging potential of ESG investments and alternative assets during both the pre- and post-Covid-19 pandemic. However, with the exception of a recent study by Alhamis (2025), which examined the implications of ESG investments amid the shifting political landscape during the Trump administration, there remains a notable gap in the literature regarding the assessment of time-varying correlations and volatility spillovers of this asset class under varying economic conditions. This gap is particularly evident in relation to the pandemic, trade conflicts, war, and the effects of Trump's policies on climate change.

In light of these existing gaps in the literature and drawing insights from contemporary portfolio and hedging theories, particularly focussing on the hypothesis concerning hedging effectiveness, safe havens, and diversification, the present study attempts to evaluate the time-varying correlations and volatility spillovers between G7 ESG leader indices and the four alternative assets employing the GO-GJRGARCH (Generalized Orthogonal-GJRGARCH) model. The study aims to explore the hedging capability of each asset across diverse market conditions, assess the extent to which these assets exhibit safe-haven characteristics during major financial disruptions such as the COVID-19 pandemic, wars and geopolitical events, and finally compare the performance of conventional versus non-conventional hedging instruments (including gold, Bitcoin, and currency pairs) across different G7 ESG leader indices.

3. Methodology

This study examines the dynamic diversification characteristics of Bitcoin, gold, Japanese yen, and Swiss franc (hereafter referred to as diversification options) for the G7 countries' ESG Leaders indices. To achieve this, we first transform the daily price series into a daily return series. Then, for each dataset consisting of individual G7 ESG Leaders indices and diversification options, we estimate the most suitable multivariate GARCH model. Subsequently, we apply the GO-GJRGARCH model, identified as the optimal common model across all datasets (see Table 3), to each ESG-diversification pair. Following this analysis, we obtain the dynamic correlations and covariances between each G7 ESG Leaders index and its respective diversification options, as well as the variances of each individual asset. In the final step, using these dynamic covariances and variances, we calculate hedge ratios for portfolios comprising a long position in the G7 ESG Leaders index and a short position in the diversification asset, along with the corresponding portfolio weights of the ESG index. In this section of the study, we introduce the GO-GJRGARCH model and present the methodologies for calculating the dynamic hedge ratios and portfolio weights.

3.1. GO-GJRGARCH

The GO-GJRGARCH is an extension of the GO-GARCH model originally developed by Van der Weide (2002). The GO-GJRGARCH model assumes that the observed multivariate return vector i_t is linearly related to a vector of independent but unobserved components i_t .

$$i_t = Cj_t \quad (1)$$

Where, C is a constant and invertible transformation matrix, and the components follow the distribution " $j_t \sim N(0, D_t)$ " where D_t , is a diagonal matrix representing the conditional covariance matrix of the components.

$$D_t = \text{diag}(d_{1,t}, d_{2,t}, \dots, d_{m,t}) \quad (2)$$

The conditional variance for each component $j_{x,t}$ is modeled by the GJR-GARCH(1,1) process:

$$d_{x,t} = \omega_x + \alpha_x j_{x,t-1}^2 + \gamma_x j_{x,t-1}^2 I_{\{j_{x,t-1} < 0\}} + \beta_x d_{x,t-1} \quad (3)$$

In this specification, $I_{\{j_{x,t-1} < 0\}}$ is an indicator function activated only by negative shocks, capturing the leverage effect in volatility. The conditional covariance matrix of the observed returns derived from the model is illustrated by Equation (4).

$$K_t = CD_t C^T \quad (4)$$

Through this model, the variances of each variable and the pairwise covariances between the G7 ESG Leaders indices and diversification options can be dynamically obtained. The estimation of the transformation matrix C is carried out in a two-stage process. In the first stage, the orthogonal components are derived from the unconditional covariance matrix. In the second stage, the structure of C and the parameters of the GJR-GARCH model are estimated through the maximization of the likelihood function. The GO-GJRGARCH model overcomes the restrictive assumptions of classical models by employing linear independent component analysis, thus providing a more realistic representation of the dynamic impacts of market shocks and the evolving correlation structures between assets.

3.2. Dynamic correlation, hedge ratio and portfolio weight

Following the GO-GJRGARCH analysis conducted on the multivariate datasets comprising the G7 ESG Leaders indices and diversification options, we calculated the dynamic hedge ratios and portfolio weights by utilizing the dynamically obtained variances of each variable and the dynamic correlations between the G7 ESG Leaders indices and diversification asset

$$HR_{xy,t} = \frac{\text{cov}_{xy,t}}{\text{var}_{yy,t}} \quad (5)$$

Equation (5) defines $HR_{xy,t}$, the hedge ratio for the G7 ESG Leaders index in a one-unit portfolio composed of a long position in the G7 ESG Leaders index and a short position in a diversification option at time t , along with the hedging cost (Kroner and Sultan, 1993). Where, x represents the G7 ESG Leaders indices, while y represents the diversification options. The term $\text{var}_{yy,t}$ refers to the variance of the diversification asset at time t , while $\text{cov}_{xy,t}$ denotes the covariance between the G7 ESG Leaders index and the diversification asset at the same time.

$$PW_{xy,t} = \frac{\text{var}_{yy,t} - \text{cov}_{xy,t}}{\text{var}_{xx,t} - 2\text{cov}_{xy,t} + \text{var}_{yy,t}} \quad (6)$$

Equation (6) calculates the portfolio weight $PW_{xy,t}$, of the G7 ESG Leaders index within a one-unit portfolio that includes a long position in the G7 ESG Leaders index and a short position in the diversification asset at time t (Kroner and Ng, 1998). The term $\text{var}_{xx,t}$, represents the variance of the G7 ESG Leaders index at time t .

4. Data and empirical results

In the study examining the hedging of sustainable investments in developed countries, we utilize daily price data for the ESG Leaders indices of G7 countries, Bitcoin, gold, the Japanese yen, and the Swiss franc. The study's sample period covers the period from January 4, 2019, to April 30, 2025. Data for the G7 ESG Leaders indices are obtained from msci.com, while data for diversification options are sourced from investing.com. Table 1 presents the definitions and uses of the series employed in the analysis.

Table 1. Series definitions

Series	Definitions	Usage of the Series
USA	MSCI United States of America ESG Leaders Index	$100 \times \ln(\text{USA}_t/\text{USA}_{t-1})$
CAN	MSCI Canada ESG Leaders Index	$100 \times \ln(\text{CAN}_t/\text{CAN}_{t-1})$
UK	MSCI United Kingdom ESG Leaders Index	$100 \times \ln(\text{UK}_t/\text{UK}_{t-1})$
FRA	MSCI France ESG Leaders Index	$100 \times \ln(\text{FRA}_t/\text{FRA}_{t-1})$
GER	MSCI Germany ESG Leaders Index	$100 \times \ln(\text{GER}_t/\text{GER}_{t-1})$
ITA	MSCI Italia ESG Leaders Index	$100 \times \ln(\text{ITA}_t/\text{ITA}_{t-1})$
JAP	MSCI Japan ESG Leaders Index	$100 \times \ln(\text{JAP}_t/\text{JAP}_{t-1})$
BTC	BTC/USD	$100 \times \ln(\text{BTC}_t/\text{BTC}_{t-1})$
GOLD	Gold per ounce/USD	$100 \times \ln(\text{GOLD}_t/\text{GOLD}_{t-1})$
JPY	Japanese Yen/USD	$100 \times \ln(\text{JPY}_t/\text{JPY}_{t-1})$
CHF	Swiss Franc/USD	$100 \times \ln(\text{CHF}_t/\text{CHF}_{t-1})$

To further clarify the relationship between the variables used in this study and their relevance to sustainable development, Annexure 1 provides a mapping of the analysed variables with the corresponding United Nations Sustainable Development Goals (SDGs). This mapping highlights how ESG Leaders indices and diversification assets contribute to broader sustainability objectives such as climate action, responsible production, and global financial stability.

For the G7 ESG Leaders indices, we calculate the dynamic correlations, hedge ratios, and portfolio weights of binary portfolios with Bitcoin (BTC), gold (GOLD), the Japanese yen (JPY), and the Swiss franc (CHF) using the GO-GJRGARCH model. Daily price series are converted into daily return series before the analysis. Table 2 presents the daily return series's descriptive statistics and unit root tests.

Table 2. Descriptive statistics

	USA	CAN	UK	FRA	GER	ITA	JAP	BTC	GOLD	JPY	CHF
Mean	0.0478	0.0262	0.0175	0.0218	0.0307	0.0363	0.0228	0.1948	0.0567	-0.0167	0.0108
Median	0.0341	0.0632	0.0616	0.0718	0.0767	0.1033	0.0261	0.0756	0.0783	-0.0319	-0.0177
Maximum	9.4595	11.5640	8.9125	8.5999	9.6900	7.9970	8.5756	20.0785	4.2968	3.8673	4.1196
Minimum	-12.9249	-13.9444	-13.2484	-14.9516	-14.2130	-20.1451	-10.0330	-49.7278	-5.8975	-3.1617	-2.0596
Std. Dev.	1.3008	1.2721	1.2124	1.3509	1.3678	1.4749	1.2441	4.1042	0.9330	0.5690	0.4771
Skewness	-0.6139	-1.3649	-0.9682	-0.9322	-0.6382	-1.9524	-0.2309	-1.1490	-0.3446	0.4415	0.724
Kurtosis	17.675	27.973	17.441	16.087	14.890	27.562	11.823	19.274	5.899	8.418	8.421
JB	14892.16**	43335.25**	14577.02**	11998.63**	9820.009**	42473.49**	5359.733**	18549.42**	609.5012**	2068.882**	2162.149**
ADF	-12.1524**	-13.9227**	-26.331**	-26.7037**	-26.1995**	-26.6908**	-44.263**	-42.6039**	-39.6793**	-41.4573**	-39.0943**
LBQ ² (5)	1482.98**	1039.36**	177.606	167.967**	131.748**	94.5782**	293.138**	23.1033**	42.8409**	143.4**	54.872**
LBQ ² (10)	2110.52**	1535.11**	549.407**	336.546**	345.074**	127.675**	372.231**	24.408**	124.016**	219.78**	71.882**
LBQ ² (20)	2433.6**	1594.67**	618.282**	392.042**	408.515**	146.73**	380.981**	25.7926	152.818**	314.98**	86.02**
LBQ ² (50)	2466.07**	1613.24**	653.7**	426.182**	452.978**	152.24**	407.74**	42.1599	187.992**	415.11**	133.58**

Note: "**" indicates significance at 1% level.

Descriptive statistics indicate that the return means of all series, except for JPY, are positive, with BTC having the highest return mean (0.201). BTC also exhibits the highest standard deviation (4.36), followed by the ESG Leaders indices (1.254–1.529), GOLD (0.956), JPY (0.576), and CHF (0.468). Gold and foreign exchange rates display lower standard deviations than other series, which may be attributed to the smaller range between their maximum and minimum values following shocks. The kurtosis values suggest that none of the series follows a normal distribution, a conclusion further supported by the Jarque-Bera (JB) statistics. ADF test results, used to determine whether the series contain unit roots, reveal that all series are stationary at level (I_0). However, Ljung-Box (LB)

test results indicate the presence of autocorrelation across various lag lengths, suggesting multicollinearity issues in the series. Consequently, all series exhibit time-varying volatility, or ARCH effects, making GARCH-inclusive models suitable for addressing these effects. The observation period includes globally significant events such as the COVID-19 pandemic (beginning March 2020), the Ukraine-Russia conflict (beginning February 2022), the Silicon Valley Bank collapse (March 2023), the Israel-Palestine conflict (beginning September 2023), and the April 2025 introduction of tariffs and associated rhetoric by the U.S., primarily targeting China, which significantly affected global markets. These events underscore the importance of examining the effectiveness of diversification options and their sensitivity to global shocks for the G7 ESG Leaders indices through a dynamic model. Figure 1 illustrates the time-varying trends of the return series.

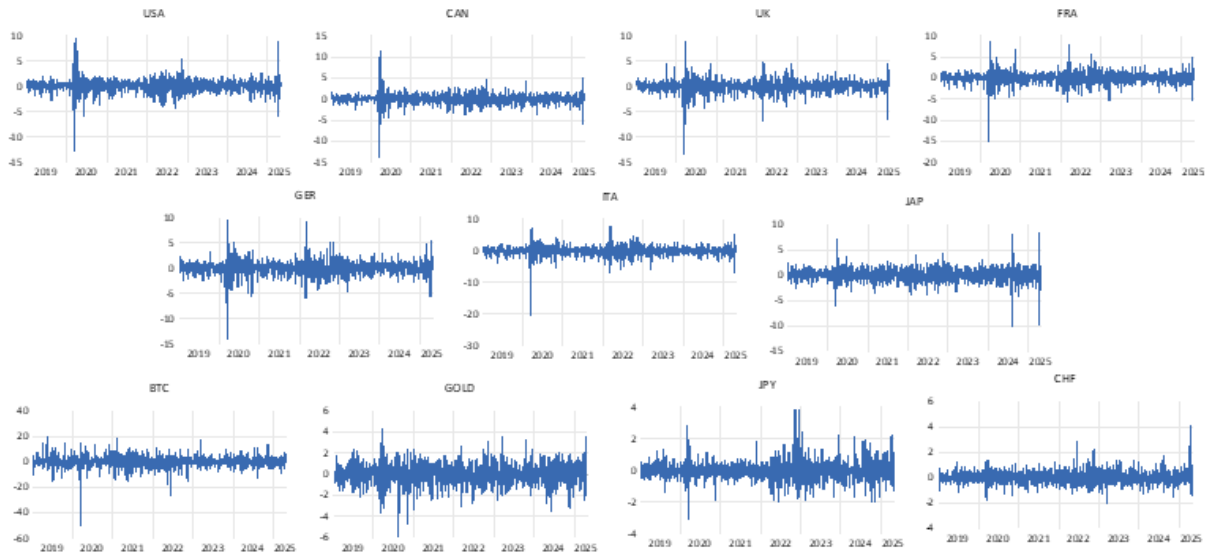


Figure 1. Time series graphs of return series

The findings reveal that all series exhibit volatility and are influenced by global economic events. In particular, the initial phase of the COVID-19 pandemic and the tariffs along with the associated rhetoric introduced by Trump (USA) in April 2025 had substantial impacts across all series. Additionally, the effects of the Russia–Ukraine conflict, the collapse of the Silicon Valley Bank, and the Israel–Palestine conflict are also observable in the data. The influence of global events varies depending on the event and the series it affects. Furthermore, the earthquake in Japan in August 2024 significantly impacted Japan's ESG Leaders index, as confirmed by the outlier observed during that period. Using a dynamic model to analyze the safe-haven roles of diversification options for the G7 ESG Leaders indices enables consideration of both global and regional shocks and the examination of time-varying effects. For this reason, we employ multivariate dynamic GARCH models to analyze the safe-haven roles of BTC, GOLD, JPY, and CHF for the G7 ESG Leaders indices.

The analysis begins with estimating the most appropriate multivariate GARCH model for the dataset, which includes the G7 ESG Leaders indices and the diversification options. Subsequently, the selected model is applied to the dataset to calculate each series's dynamic correlations, covariances, and variances. In the final step, we compute the dynamic hedge ratios and portfolio weights for binary portfolios consisting of a G7 ESG Leaders index and a diversification option.

Table 3 presents the most suitable multivariate GARCH models for the datasets comprising the G7 ESG Leaders indices and diversification options.

The results indicate that the GO-GJRGARCH model is the most suitable approach for the datasets comprising all G7 ESG Leaders indices and diversification options. Using the GO-GJRGARCH model, we analyze the relationship between the G7 ESG Leaders indices and diversification options. Table 4 displays the residuals obtained from applying the GO-GJRGARCH model to these datasets.

The findings demonstrate that the squared residuals of all GO-GJRGARCH models established with G7 ESG Leaders indices exhibit no evidence of autocorrelation, indicating the absence of multicollinearity issues. Furthermore, the problem of time-varying variance, or ARCH effects, has been resolved for each series. These results confirm that the GO-GJRGARCH model is appropriate and applicable for all datasets. By applying the GO-GJRGARCH model to the G7 ESG Leaders indices and diversification options, we dynamically derive each series's pairwise correlations, covariances, and variances. Subsequently, we calculate the dynamic hedge ratios and portfolio weights by utilizing the covariance between the two series and the variance of each series. The hedge ratio reflects the proportion and cost of hedging a one-unit portfolio where the G7 ESG Leaders index is held in a long position and the diversification option in a short position. Conversely, the portfolio weight indicates the pro-

Table 3. Best-fit multivariate GARCH type model estimation for G7 ESG leaders and diversification options

	USA - Div. Opt.		CAN - Div. Opt.		UK - Div. Opt.		FRA - Div. Opt.		GER - Div. Opt.		ITA - Div. Opt.		JAP - Div. Opt.	
	SBC	AIC	SBC	AIC	SBC	AIC	SBC	AIC	SBC	AIC	SBC	AIC	SBC	AIC
DCC-GARCH	13.26	13.253	13.231	13.226	13.428	13.424	13.595	13.586	13.591	13.586	13.751	13.746	13.51	13.505
DCC-EGARCH	13.298	13.293	13.225	13.217	13.447	13.443	13.592	13.588	13.585	13.602	13.779	13.774	13.542	13.537
DCC-GJGARCH	13.256	13.252	13.198	13.193	13.397	13.392	13.554	13.549	13.546	13.546	13.727	13.722	13.493	13.489
DCC-IGARCH	13.284	13.279	13.276	13.248	13.445	13.442	13.619	13.614	13.611	13.606	13.773	13.768	13.532	13.524
DCC-FIGARCH	13.206	13.201	13.198	13.177	13.382	13.377	13.546	13.541	13.539	13.542	13.688	13.683	13.452	13.444
DCC-HYGARCH	13.13	13.126	13.123	13.096	13.298	13.294	13.461	13.456	13.454	13.455	13.604	13.6	13.597	13.358
eDCC-GARCH	13.263	13.259	13.256	13.237	13.434	13.429	13.602	13.597	13.594	13.596	13.759	13.752	13.512	13.507
eDCC-EGARCH	13.311	13.306	13.304	13.285	13.46	13.455	13.605	13.6	13.597	13.618	13.79	13.785	13.549	13.541
eDCC-GJGARCH	13.257	13.252	13.249	13.2	13.4	13.395	13.556	13.552	13.549	13.555	13.724	13.721	13.494	13.487
eDCC-IGARCH	13.332	13.327	13.324	13.311	13.487	13.484	13.671	13.666	13.663	13.659	13.823	13.818	13.561	13.554
eDCC-FIGARCH	13.317	13.312	13.31	13.294	13.487	13.482	13.669	13.664	13.662	13.657	13.803	13.798	13.539	13.532
eDCC-HYGARCH	13.134	13.129	13.127	13.106	13.302	13.298	13.465	13.461	13.458	13.464	13.608	13.603	13.358	13.353
ADCC-GARCH	13.265	13.258	13.254	13.236	13.434	13.426	13.6	13.593	13.589	13.585	13.782	13.774	13.515	13.507
ADCC-EGARCH	13.303	13.296	13.291	13.273	13.452	13.445	13.597	13.59	13.586	13.611	13.784	13.777	13.546	13.539
ADCC-GJGARCH	13.261	13.254	13.25	13.202	13.402	13.395	13.559	13.552	13.548	13.559	13.732	13.725	13.498	13.487
ADCC-IGARCH	13.289	13.282	13.278	13.257	13.455	13.448	13.624	13.617	13.613	13.616	13.778	13.771	13.534	13.523
ADCC-FIGARCH	13.209	13.202	13.197	13.18	13.386	13.379	13.55	13.543	13.538	13.546	13.691	13.684	13.453	13.441
ADCC-HYGARCH	13.135	13.128	13.124	13.106	13.304	13.297	13.466	13.459	13.455	13.465	13.609	13.602	13.362	13.351
eADCC-GARCH	13.268	13.261	13.257	13.242	13.438	13.431	13.607	13.6	13.596	13.601	13.761	13.754	13.513	13.506
eADCC-EGARCH	13.316	13.309	13.305	13.243	13.464	13.457	13.608	13.601	13.597	13.621	13.795	13.788	13.55	13.543
eADCC-GJGARCH	13.261	13.254	13.25	13.203	13.405	13.398	13.561	13.554	13.55	13.56	13.733	13.726	13.497	13.486
eADCC-IGARCH	13.338	13.331	13.326	13.317	13.496	13.489	13.676	13.669	13.665	13.664	13.828	13.821	13.562	13.555
eADCC-FIGARCH	13.321	13.314	13.31	13.303	13.492	13.485	13.674	13.667	13.663	13.662	13.807	13.8	13.542	13.531
eADCC-HYGARCH	13.139	13.132	13.128	13.111	13.308	13.301	13.471	13.463	13.459	13.469	13.613	13.606	13.361	13.354
GOGARCH	13.204	13.157	13.129	13.181	13.34	13.293	13.509	13.463	13.435	13.543	13.66	13.613	13.409	13.362
GO-GJGARCH	13.179	13.121	13.086	13.146	13.087	13.052	13.486	13.427	13.392	13.454	13.642	13.584	13.387	13.329

Note: The optimal Multivariate GARCH model for binary variables is chosen according to the Schwarz (SBC), Hannan-Quinn (HQ), and Akaike (AIC) information criteria. When these criteria suggest different models, preference is given to the AIC. The bolded values highlight the models deemed most appropriate by the information criteria.

portion of the G7 ESG Leaders index in a one-unit portfolio with a long position in the index and a short position in the diversification option.

Table 4. Residual diagnostics

Series	USA - Div. Opt.					CAN - Div. Opt.				
	USA	BTC	GOLD	JPY	CHF	CAN	BTC	GOLD	JPY	CHF
LB Q ² (5)	4.53207	0.379852	2.55312	1.58616	2.23022	0.751812	0.441607	2.6118	3.80948	2.24747
LB Q ² (10)	6.43455	4.22552	13.9052	6.61918	3.98443	18.9638	4.15658	16.0672	6.26299	3.96959
LB Q ² (20)	20.0919	8.54769	21.2617	21.3302	10.2084	29.3553	7.35437	24.6299	26.7892	9.00552
LB Q ² (50)	43.9466	36.2967	61.3291	53.3817	33.8741	59.0138	34.5685	63.5057	57.8098	31.4478
Series	UK - Div. Opt.					FRA - Div. Opt.				
	UK	BTC	GOLD	JPY	CHF	FRA	BTC	GOLD	JPY	CHF
LB Q ² (5)	0.186827	1.36329	2.81042	2.36966	1.31748	4.41982	0.950363	2.65966	4.43939	1.68852
LB Q ² (10)	4.75691	4.05568	13.2358	3.79763	3.81524	12.1353	3.7787	13.6673	5.77857	4.97679
LB Q ² (20)	18.8114	6.52386	20.7393	17.0655	9.69659	27.3149	6.09535	21.8684	27.2214	10.156
LB Q ² (50)	48.9773	29.0458	61.4736	53.7066	30.8606	64.7663	27.3644	60.4834	56.8319	34.8807
Series	GER - Div. Opt.					ITA - Div. Opt.				
	GER	BTC	GOLD	JPY	CHF	ITA	BTC	GOLD	JPY	CHF
LB Q ² (5)	6.75556	1.48693	2.64302	3.69828	2.69854	1.6884	1.89295	2.55926	2.89769	1.36536
LB Q ² (10)	15.1218	4.07722	15.0804	4.51874	5.31033	19.1881	5.37417	14.365	4.19068	4.37114
LB Q ² (20)	24.3709	6.22429	22.7092	20.5175	10.4851	27.5765	8.48282	21.8253	20.1356	9.41194
LB Q ² (50)	54.7268	26.8335	62.3459	51.251	31.4207	59.4925	39.0718	63.1551	51.026	34.1721
Series	JAP - Div. Opt.									
	JAP	BTC	GOLD	JPY	CHF					
LB Q ² (5)	5.72035	4.16992	3.19549	3.15007	1.01911					
LB Q ² (10)	8.60758	6.79073	12.5127	5.47356	2.96763					
LB Q ² (20)	19.6824	9.35239	20.9417	19.2817	8.46064					
LB Q ² (50)	66.7236	33.2337	66.6905	56.9139	35.7958					

Table 5 presents the averages of correlations, hedge ratios, and portfolio weights for the pairwise combinations of G7 ESG Leaders indices and diversification options.

Table 5. Correlation, hedge ratio, and average portfolio weights between G7 ESG leaders and diversification options

	Correlation				Hedge Ratio				Portfolio Weight			
	BTC	GOLD	JPY	CHF	BTC	GOLD	JPY	CHF	BTC	GOLD	JPY	CHF
USA	0.2813	0.1423	-0.1190	0.0942	0.0934	0.1714	-0.3869	0.1169	0.9947	0.3941	0.2236	0.1334
CAN	0.3036	0.2450	-0.0267	0.1867	0.0963	0.3164	-0.1584	0.3940	0.9950	0.3579	0.1929	0.0938
UK	0.1885	0.1672	0.0712	0.2473	0.0592	0.2257	0.0901	0.5842	0.9686	0.3517	0.1641	0.0690
FRA	0.2340	0.1577	0.0237	0.2728	0.0826	0.2293	-0.0808	0.6672	0.9696	0.3084	0.1456	0.0354
GER	0.2235	0.1901	0.0591	0.2858	0.0801	0.2781	0.0027	0.7099	0.9646	0.2968	0.1322	0.0299
ITA	0.2600	0.1652	0.0407	0.2635	0.0998	0.2645	-0.0387	0.7009	0.9665	0.2692	0.1230	0.0277
JAP	0.0307	0.1863	0.2985	0.2351	0.0152	0.2649	0.6019	0.5727	0.9249	0.3481	0.0846	0.0750

The findings show that among the diversification options, JPY exhibits the lowest correlation with the G7 ESG Leaders indices (excluding JAP). For G7 ESG Leaders indices, JPY is followed by CHF for USA and CAN, GOLD for UK, FRA, GER, and ITA, and BTC for JAP in terms of low correlation. BTC generally has the highest correlation with G7 ESG Leaders indices, except for JAP. A weak correlation between two assets indicates strong diversification potential, while a negative and strong correlation suggests that the assets may act as safe havens for one another (Baur & Lucey, 2010; Kandemir & Gökgöz, 2022; Gökgöz et al., 2024a). From this perspective, JPY emerges as the most effective diversifier for G7 ESG Leaders indices, except JAP, and even acts as a safe haven in some cases. JPY is not the most effective diversifier for JAP, as it is already the domestic currency of Japan, thus not expected to provide diversification. This distinction highlights JAP's divergence from the other G7 ESG Leaders indices. After JPY, GOLD and CHF stand out as the next most effective diversifiers.

Hedge ratio averages reveal that portfolios, including JPY, have the lowest hedge ratios compared to portfolios with other diversification options. Moreover, many portfolios combining JPY with G7 ESG Leaders indices exhibit negative hedge ratios, suggesting that JPY should be added to the portfolio in the same direction (long-long or short-short) as the G7 ESG Leaders index (excluding UK and JAP). These hedge ratio findings support the correlation results and underscore JPY's cost-effectiveness. Unlike the correlation findings, however, BTC follows JPY regarding cost efficiency. This indicates that investors should consider risk reduction and cost when selecting diversification options for their portfolios.

Portfolio weights show that in binary portfolios consisting of G7 ESG Leaders indices and diversification options, JPY and CHF generally have the highest weights among the diversification options. In contrast, BTC consistently has the lowest weight across all G7 ESG Leaders indices. The amount of BTC required to diversify a one-unit

portfolio is lower than that of other options. In this regard, BTC demonstrates stability in diversifying G7 ESG Leaders indices at a low cost but needs to be more effective regarding hedge ratios than other diversification options. Thus, when evaluated based on risk and cost factors, the diversification options analyzed exhibit different characteristics in terms of diversification potential for G7 ESG Leaders indices. We dynamically examine the hedging capabilities of diversification options for G7 ESG Leaders indices through correlations, hedge ratios, and portfolio weights. This dynamic analysis allows us to identify the impact of global events during the observation period and to capture the changing effects over time. Figure 2 illustrates the time-varying correlations between G7 ESG Leaders indices and the diversification options.

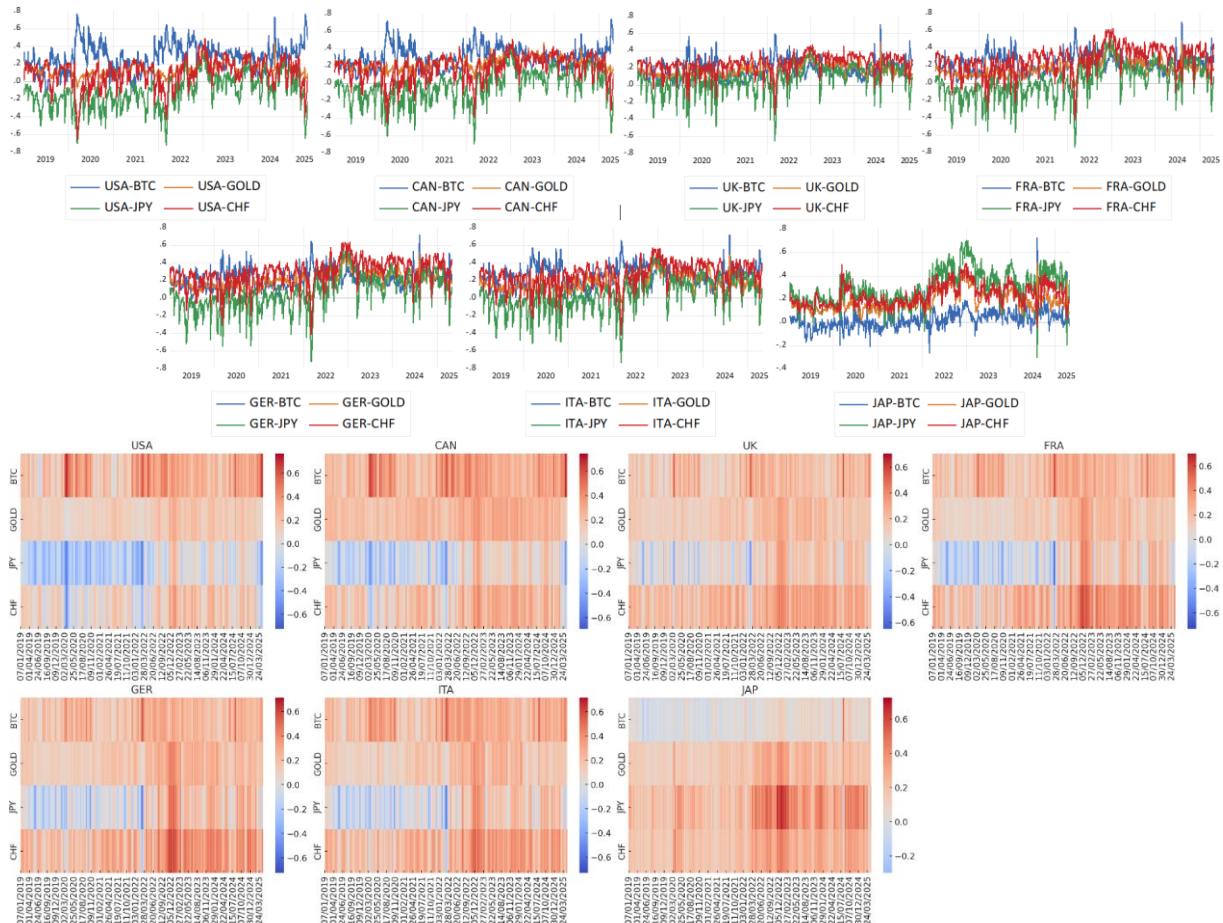


Figure 2. Dynamic correlations

The dynamic correlations demonstrate that the correlations between G7 ESG Leaders indices and diversification options fluctuate over time, with significant increases and decreases observed during specific periods. Among the diversification options, JPY consistently exhibits the lowest correlation with the G7 ESG Leaders indices (excluding JAP) throughout the observation period, followed generally by GOLD and CHF. Periods of extreme correlation fluctuations align with global economic events and regional incidents.

The impact of COVID-19 is particularly evident across all correlations. On March 11, 2020, COVID-19 was declared a pandemic, followed by a series of measures, including lockdowns, which initially impacted financial markets and assets. At the onset of COVID-19, correlations between G7 ESG Leaders indices (excluding JAP) and diversification options other than BTC experienced significant declines, while correlations with BTC surged dramatically. A similar pattern is evident during the tariff implementations and rhetoric by Trump in April 2025. Additionally, events with regional origins but global impacts, such as the Ukraine-Russia conflict, the SVB collapse, and the Israel-Palestine conflict. The effect of global events varies depending on the specific event and the correlation groups affected. Additionally, the 7.1 magnitude earthquake in Japan in August 2024 and its subsequent risks significantly impacted the Japanese market, creating a shock evident in the correlation findings.

According to the correlation findings, JPY emerges as a more prominent diversification option over the long-term investment horizon than other options. However, the time-varying correlations and responses during periods of global events highlight the necessity of adopting a dynamic portfolio investment strategy. Such a strategy should account for global risks and adapt to the differing responses of G7 ESG Leaders indices to these events.

We analyse hedge ratios and portfolio weights dynamically to investigate further the diversification characteristics of BTC, GOLD, JPY, and CHF for G7 ESG Leaders indices. Figure 3 illustrates the hedge ratios and portfolio costs for binary portfolios, where G7 ESG Leaders indices are held in long positions, and diversification options are held in short positions.

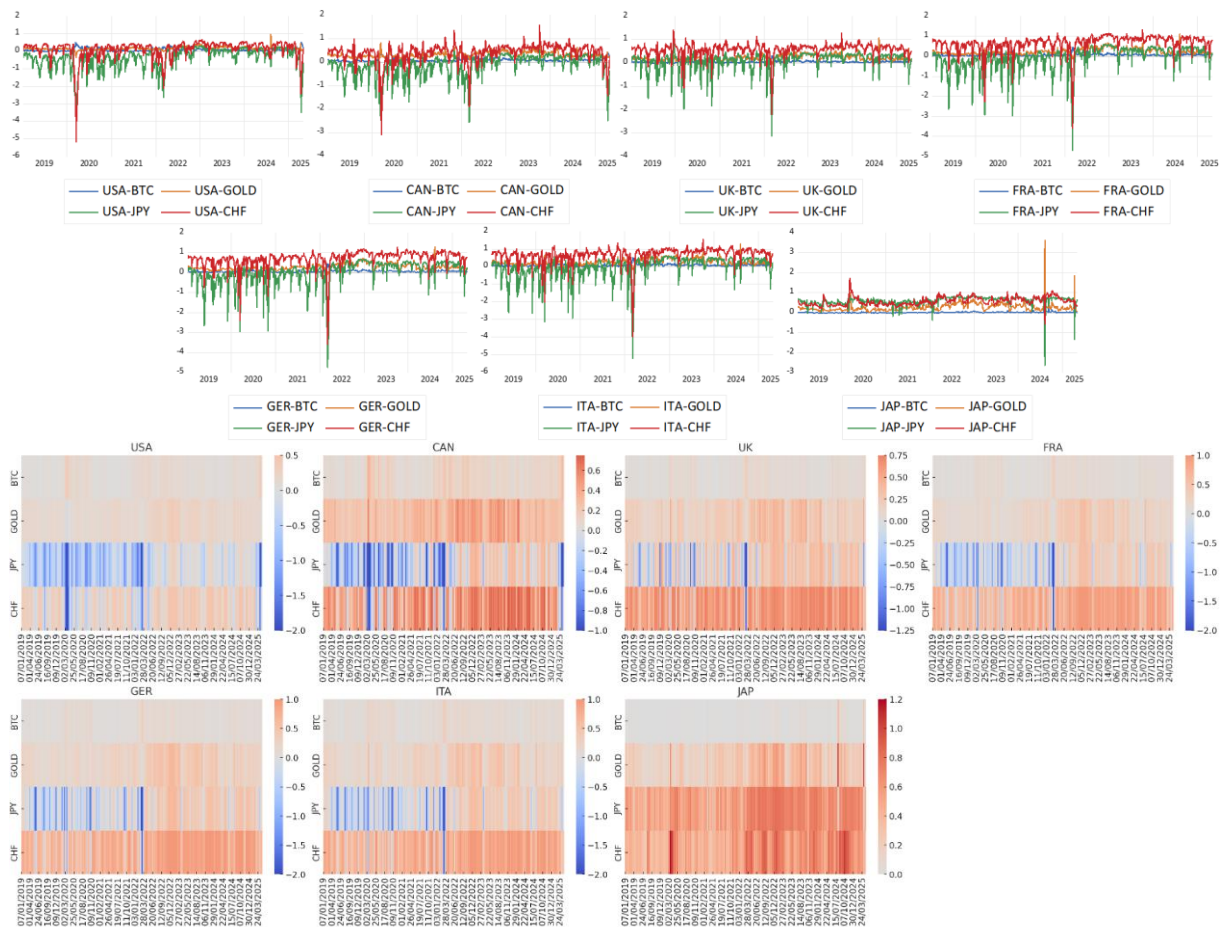


Figure 3. Dynamic hedge ratios

In binary portfolios consisting of G7 ESG Leaders indices and diversification options, the hedge ratio and portfolio cost of G7 ESG Leaders indices vary over time. Notably, hedge ratios generally exhibit significant declines during global economic events. For portfolios including JPY (excluding JAP), hedge ratios are predominantly negative. Similarly, during global economic events, portfolios constructed with diversification options such as CHF and GOLD also tend to exhibit negative hedge ratios. Therefore, JPY should be added to a portfolio containing a G7 ESG Leaders index (excluding JAP) in the same direction (long-long or short-short) over both short- and long-term investment horizons. Conversely, other diversification options generally need to be added in the opposite direction (long-short or short-long). However, during global economic events, diversification options such as GOLD and CHF should also be added in the same direction as the G7 ESG Leaders index.

For JAP, BTC typically offers a lower-cost hedging option. However, during the August 2024 earthquake, CHF emerged as a much more effective option. During that period, adding CHF to a portfolio containing JAP in the same direction proved to be a more effective strategy. These findings align with the correlation results and indicate that investors may need to adapt their risk strategies, investment preferences, and policies based on risk, cost, and varying investment horizons.

Figure 4 illustrates the portfolio weight of G7 ESG Leaders indices in a one-unit portfolio where the indices are in a long position and diversification options are in a short position.

In binary portfolios consisting of G7 ESG Leaders indices and diversification options, the weights of G7 ESG Leaders indices are more stable and exhibit lower volatility in portfolios constructed with BTC. This stability positions BTC as a more prominent option for long-term investment horizons. However, throughout the entire period, BTC consistently has the lowest portfolio weight among the diversification options. On the other hand, CHF generally holds the highest portfolio weight across the period compared to other diversification options. While JPY exhibits greater variability in portfolio weights compared to CHF, it stands out as the second-highest weighted diversification option after CHF, followed by GOLD. Although GOLD achieves a certain average port-

folio weight, it displays greater variability than other options. Periods of global economic events introduce significant volatility in portfolio weights. During such periods, an optimal portfolio strategy for G7 ESG Leaders indices (excluding JAP) involves increasing the weights of BTC and GOLD while reducing the weights of JPY and CHF, which emerges as a more effective diversification approach. For JAP, increasing the weights of BTC, GOLD, and CHF proves to be a more effective portfolio strategy.

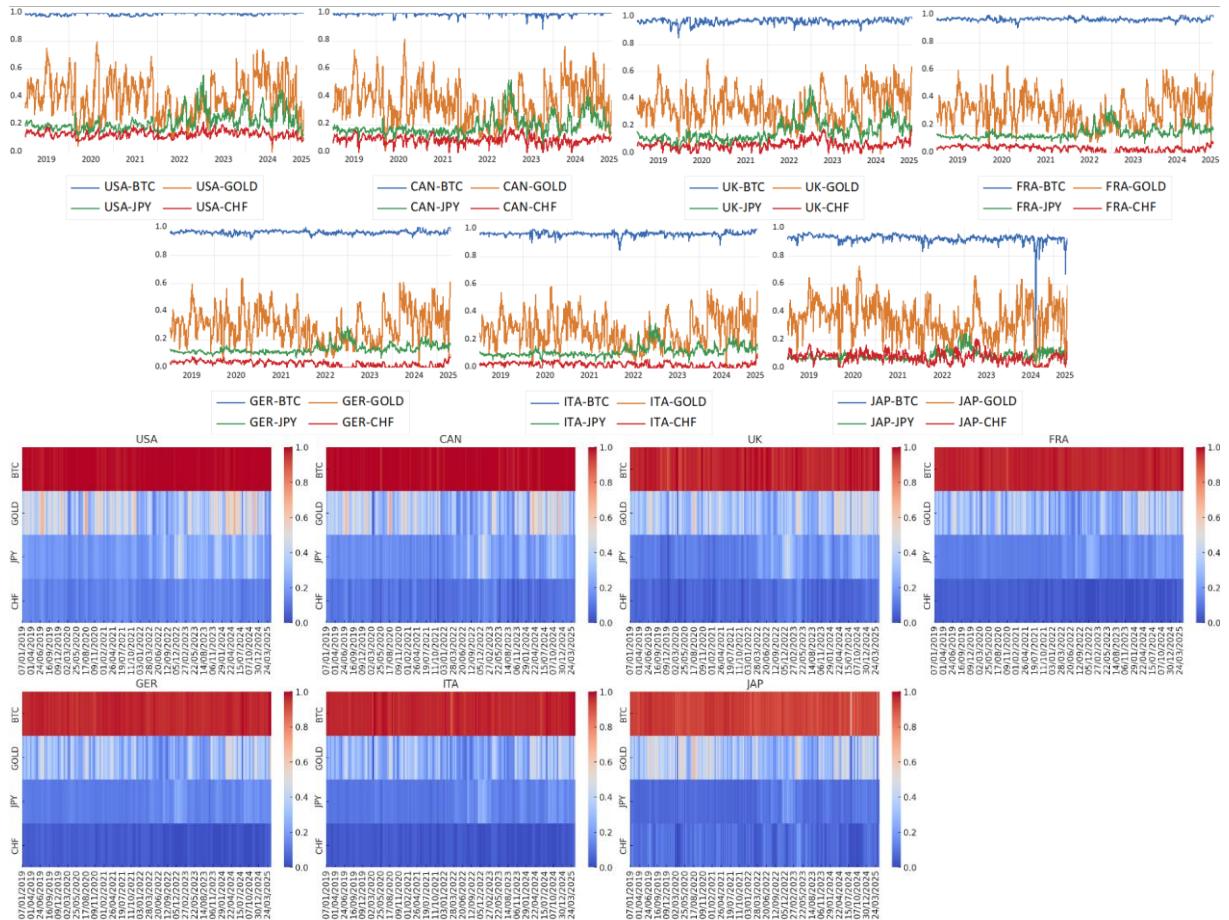


Figure 4. Dynamic portfolio weights

All the diversification options analyzed for the G7 ESG Leaders indices are generally effective, with JPY standing out in correlation and cost efficiency. CHF and GOLD follow JPY. However, over the long-term investment horizon, BTC emerges as a more effective diversifier. Moreover, diversification findings vary over time, showing significant shifts during periods of global economic events. This highlights the importance of accounting for global events and adopting a dynamic strategy.

The findings align with those of prior studies, including Bouri et al. (2017), Baur et al. (2018), Wang et al. (2019), Long et al. (2021), Choi and Shin (2022), and Ustaoglu (2023), which demonstrate that Bitcoin is not a better diversifier compared to gold or other diversification options. They also support Kumamoto et al. (2021), who identify gold, JPY, and CHF as effective diversifiers for U.S. equity markets. Additionally, the results are consistent with Elsayed et al. (2022), who show that global economic events influence the correlation between BTC, gold, and the S&P 500, and Gökgoz et al. (2024b), who emphasize the need for dynamic portfolio diversification strategies that consider global events.

The findings underscore the importance of correlation, hedge ratios, costs, and the required quantity of diversification options in developing investment and risk-monitoring strategies for the G7 ESG Leaders indices. Alongside the correlations between assets in the portfolio, the cost of diversification also plays a critical role in risk management strategies. Furthermore, the results demonstrate that the strategy to be followed varies depending on the investment horizon, the necessity of considering global economic events in strategy formulation, and the significance of adopting a dynamic approach to implement an effective portfolio diversification strategy. From a sustainable development perspective, these dynamic diversification results carry broader implications beyond portfolio optimization. The resilience of G7 ESG Leaders indices during systemic shocks directly affects the stability of capital flows toward sectors aligned with the Sustainable Development Goals (SDGs). In particular, maintaining stable ESG investment performance during crises supports continued financing for renewable energy expansion and low-carbon transitions consistent with SDG 7 and SDG 13. Similarly, sustained capital allocation toward ESG-

oriented firms contributes to long-term innovation and sustainable industrial transformation under SDG 9, while reinforcing responsible production frameworks aligned with SDG 12. The governance dimension embedded in ESG indices further strengthens transparency and institutional resilience, contributing to SDG 16, particularly during periods of geopolitical instability. Moreover, the effectiveness of global safe-haven assets such as the Japanese yen and Swiss franc in stabilizing ESG portfolios underscores the importance of international financial interconnectedness, indirectly supporting SDG 17 through sustained cross-border capital cooperation during crises. Therefore, our findings suggest that dynamic diversification strategies are not merely financial risk-management tools but mechanisms that help safeguard the continuity of SDG-aligned investment flows under heightened economic and geopolitical uncertainty.

5. Conclusion

This study investigates the dynamic relationships of ESG Leaders indices from G7 countries with alternative investment assets, namely BTC, gold, the JPY, and the CHF, and evaluates their sensitivity to global economic and geopolitical shocks. The analysis, covering the period from January 2019 to May 2025, demonstrates that ESG indices are significantly affected by global shocks, highlighting the necessity for investors to continuously adapt their portfolio strategies to changing market conditions.

Empirical results reveal that the Japanese yen consistently exhibits the lowest correlations with the examined ESG indices (excluding Japan), thus offering substantial diversification potential. In terms of hedge ratio analysis, the JPY displays notable cost efficiency compared to other assets, often resulting in negative hedge ratios. Gold and CHF also serve as effective diversifiers under specific conditions, albeit generally less consistently than JPY. BTC, characterized by consistently lower portfolio weights, emerges as a cost-effective diversification option during particular market conditions. Nevertheless, the analysis underscores that diversification effectiveness is not static, varying significantly over time and depending on the nature of the shocks. Global events such as the COVID-19 pandemic and U.S. trade policies targeting China have led to considerable fluctuations in the relationships between ESG indices and diversification assets. Additionally, regional incidents, including the 2024 earthquake in Japan, have substantially influenced national ESG indices.

This research contributes to the sustainable finance literature by emphasizing that ESG investments should be reinforced through resilient and cost-efficient strategies. The findings suggest that ESG-focused investors and portfolio managers must adopt dynamic rather than static portfolio management strategies to enhance resilience against global and regional shocks. Such dynamic strategies should incorporate not only correlation structures but also hedge costs and investment horizons. Due to the variability in the effectiveness of diversification options across different periods and shock types, policymakers should facilitate more flexible and responsive investment platforms to sustain ESG investments. In this context, market regulators may introduce protective mechanisms aimed at reducing volatility in ESG investments during crises. Furthermore, to enhance the effectiveness of ESG investments, investors and portfolio managers should be supported with educational programs and practical guidelines that promote the adoption of sustainable investment strategies. Consequently, ESG investments can achieve greater resilience and sustainability during periods of economic and geopolitical uncertainty. Effective diversification strategies are not merely financial tools; they are mechanisms that stabilize capital flows toward SDG-oriented investments during periods of crisis. Ensuring ESG portfolio resilience supports the continuity of climate financing, renewable energy expansion, and sustainable industrial development.

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Appendix

In this section, we replicate the analysis conducted for the G7 ESG Leaders indices on the G7 stock market indices. The findings are generally consistent with those of the G7 ESG Leaders indices. The results confirm that JPY is the most effective diversifier, which is in line with the patterns observed in ESG indices. Unlike the findings for ESG indices, CHF emerges as the second most effective diversifier after JPY for all stock market indices. The similarity in findings can be attributed to the growing importance of ESG in developed markets and its increasing correlation with primary indices.

Table A1. Descriptive statistics of G7 stock market indices

	USA	CAN	UK	FRA	GER	ITA	JAP
Mean	0.044235	0.031814	0.011988	0.026493	0.041706	0.039841	0.030998
Median	0.074553	0.086583	0.065552	0.095955	0.084836	0.117299	0.064471
Maximum	9.08949	11.29446	8.666807	8.056079	10.41429	8.549457	9.736556
Minimum	-12.7652	-13.1761	-11.5124	-13.0984	-13.0549	-18.5411	-13.2341
Std. Dev.	1.273536	1.079444	1.039387	1.231862	1.251729	1.364586	1.297239
Skewness	-0.68197	-1.71051	-1.23601	-1.03476	-0.75118	-2.22749	-0.44905
Kurtosis	18.94491	41.68706	19.81432	16.68275	16.87805	30.44316	15.84487
JB	17340.13**	102130.7**	19556.34**	12966.19**	13193.47**	52336.77**	11225.86**
ADF	-12.1178**	-13.5874**	-40.8113**	-40.7245**	-26.7885**	-26.7051**	-26.3253**
LBQ ² (5)	1474.300**	1375.710**	352.206**	337.948**	231.796**	215.111**	388.238**
LBQ ² (10)	2090.660**	1962.090**	782.516**	564.988**	529.923**	281.744**	437.637**
LBQ ² (20)	2411.160**	2027.320**	918.084**	655.928**	638.530**	307.573**	449.211**
LBQ ² (50)	2442.650**	2033.750**	986.803**	693.967**	694.584**	317.076**	469.181**

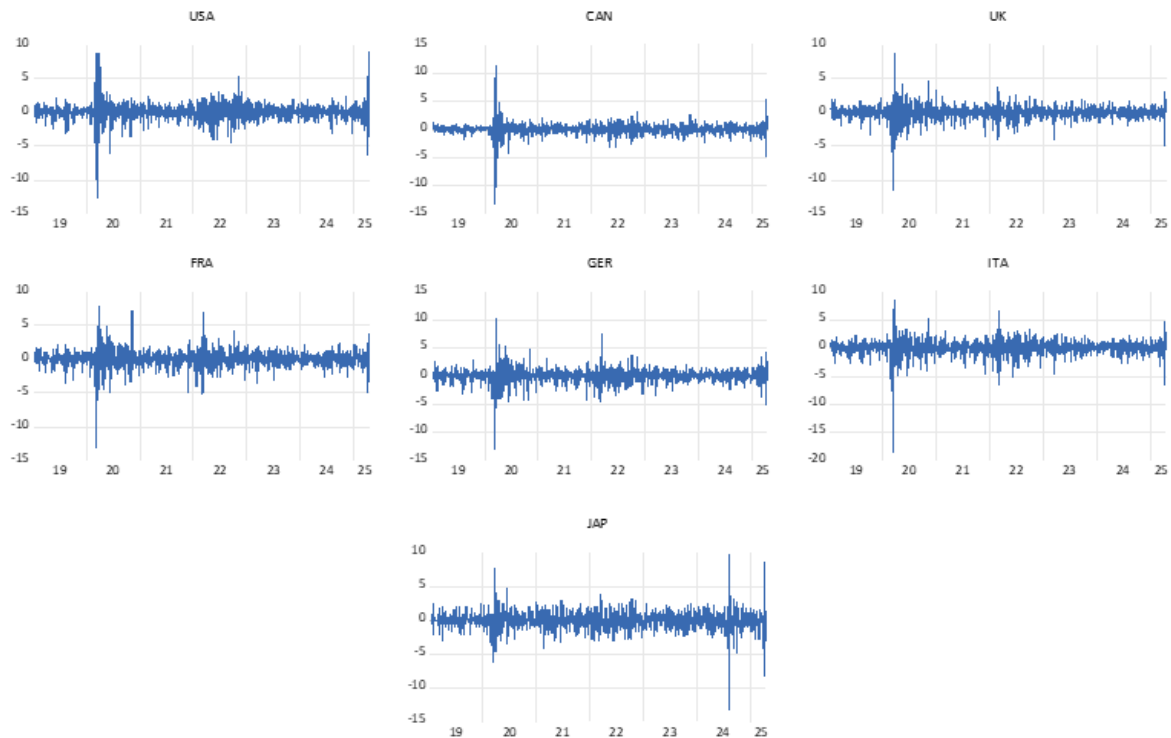


Figure A1. Time series graphs of G7 countries' Stock Market Index return series

Table 3. Best-fit multivariate GARCH type model estimation for G7 Stock Market Indices and diversification options

	USA - Div. Opt.			CAN - Div. Opt.			UK - Div. Opt.			FRA - Div. Opt.			GER - Div. Opt.			ITA - Div. Opt.			JAP - Div. Opt.		
	SBC	HQ	AIC	SBC	HQ	AIC	SBC	HQ	AIC	SBC	HQ	AIC	SBC	HQ	AIC	SBC	HQ	AIC	SBC	HQ	AIC
DCC-GARCH	13.196	13.191	13.188	12.651	12.647	12.644	13.069	13.064	13.061	13.428	13.423	13.42	13.411	13.406	13.403	13.59	13.585	13.582	13.663	13.659	13.656
DCC-EGARCH	13.227	13.222	13.219	12.652	12.648	12.645	13.07	13.066	13.063	13.41	13.406	13.403	13.423	13.419	13.416	13.582	13.578	13.575	13.702	13.697	13.695
DCC-GJRARCH	13.191	13.186	13.183	12.629	12.624	12.621	13.056	13.052	13.049	13.387	13.382	13.38	13.386	13.382	13.379	13.571	13.566	13.563	13.65	13.645	13.642
DCC-IGARCH	13.22	13.215	13.212	12.677	12.672	12.67	13.086	13.082	13.079	13.449	13.444	13.441	13.429	13.424	13.421	13.61	13.605	13.603	13.685	13.681	13.678
DCC-FIGARCH	13.138	13.133	13.13	12.6	12.595	12.593	13.001	12.997	12.994	13.359	13.354	13.352	13.351	13.346	13.343	13.527	13.522	13.52	13.608	13.603	13.601
DCC-HYGARCH	13.063	13.058	13.055	12.526	12.522	12.519	12.926	12.921	12.918	13.277	13.272	13.27	13.272	13.268	13.265	13.449	13.444	13.441	13.523	13.518	13.516
dDCC-GARCH	13.199	13.194	13.191	12.658	12.653	12.651	13.074	13.069	13.066	13.433	13.428	13.425	13.416	13.411	13.408	13.594	13.59	13.587	13.666	13.661	13.659
dDCC-EGARCH	13.24	13.235	13.232	12.666	12.661	12.658	13.082	13.077	13.075	13.421	13.416	13.413	13.433	13.428	13.425	13.592	13.588	13.585	13.711	13.706	13.703
dDCC-GJRARCH	13.191	13.186	13.183	12.631	12.627	12.624	13.059	13.054	13.052	13.389	13.384	13.382	13.388	13.383	13.381	13.572	13.568	13.565	13.651	13.646	13.644
dDCC-IGARCH	13.269	13.264	13.262	12.739	12.735	12.732	13.133	13.128	13.125	13.497	13.492	13.489	13.475	13.471	13.468	13.657	13.652	13.649	13.72	13.716	13.713
dDCC-FIGARCH	13.249	13.245	13.242	12.716	12.711	12.709	13.106	13.101	13.099	13.467	13.462	13.459	13.456	13.452	13.449	13.632	13.628	13.625	13.702	13.698	13.695
dDCC-HYGARCH	13.066	13.061	13.058	12.531	12.527	12.524	12.93	12.925	12.922	13.28	13.275	13.273	13.275	13.271	13.268	13.451	13.447	13.444	13.525	13.52	13.517
ADCC-GARCH	13.201	13.194	13.19	12.656	12.649	12.644				13.432	13.425	13.421	13.416	13.409	13.405	13.595	13.588	13.583	13.668	13.661	13.657
ADCC-EGARCH	13.232	13.225	13.221	12.657	12.65	12.645	13.075	13.068	13.064	13.415	13.408	13.404	13.428	13.421	13.417	13.588	13.581	13.576	13.707	13.7	13.696
ADCC-GJRARCH	13.196	13.189	13.184	12.632	12.625	12.621	13.061	13.054	13.05	13.393	13.386	13.381				13.576	13.569	13.565	13.655	13.648	13.644
ADCC-IGARCH	13.225	13.218	13.214	12.681	12.674	12.67	13.091	13.084	13.08	13.453	13.446	13.442	13.434	13.427	13.423	13.615	13.608	13.604	13.691	13.684	13.679
ADCC-FIGARCH	13.141	13.134	13.129	12.601	12.594	12.59	13.006	12.999	12.995				13.355	13.348	13.344	13.532	13.525	13.52	13.613	13.606	13.602
ADCC-HYGARCH	13.068	13.061	13.056	12.531	12.524	12.52	12.931	12.924	12.919				13.278	13.271	13.266	13.454	13.447	13.443	13.528	13.521	13.517
eADCC-GARCH	13.203	13.196	13.192	12.661	12.654	12.65				13.437	13.43	13.426	13.421	13.414	13.41	13.599	13.592	13.588	13.671	13.663	13.659
eADCC-EGARCH	13.244	13.237	13.233	12.667	12.66	12.655				13.425	13.418	13.414	13.437	13.43	13.426	13.597	13.59	13.586	13.714	13.707	13.703
eADCC-GJRARCH	13.195	13.188	13.184	12.631	12.624	12.62							13.393	13.386	13.382	13.577	13.57	13.566	13.656	13.649	13.645
eADCC-IGARCH	13.275	13.268	13.264	12.744	12.737	12.733	13.137	13.13	13.126	13.389	13.384	13.382	13.48	13.473	13.469	13.661	13.654	13.65	13.76	13.753	13.749
eADCC-FIGARCH	13.253	13.246	13.242	12.718	12.711	12.707	13.111	13.104	13.1	13.5	13.493	13.489	13.461	13.454	13.45	13.638	13.631	13.626	13.707	13.7	13.696
eADCC-HYGARCH	13.071	13.064	13.06	12.536	12.529	12.525	12.935	12.928	12.923	13.281	13.274	13.269	13.281	13.274	13.269	13.456	13.449	13.445	13.53	13.523	13.519
GO-GARCH	13.132	13.085	13.057	12.592	12.545	12.517	12.969	12.922	12.894	13.341	13.294	13.266	13.32	13.292	13.292	13.508	13.461	13.433	13.585	13.538	13.51
GO-GJRARCH	13.11	13.051	13.016	12.56	12.501	12.466	12.957	12.898	12.863	13.298	13.24	13.205	13.324	13.265	13.23	13.455	13.396	13.361	13.567	13.509	13.474

Table A4. Residual diagnostic

Series	USA - Div. Opt.					CAN - Div. Opt.					
	USA	BTC	GOLD	JPY	CHF	CAN	BTC	GOLD	JPY	CHF	
LB Q ² (5)	6.06159	0.392867	2.52425	1.57883	2.44297	5.08988	0.288285	2.44675	2.76941	2.23104	
LB Q ² (10)	7.7484	4.414	13.5759	6.71176	4.13537	21.3424	4.41518	15.7652	4.42619	3.61264	
LB Q ² (20)	20.4158	8.79941	20.8518	21.3489	10.1469	28.3567	8.7484	25.2559	21.0672	8.68184	
LB Q ² (50)	47.5286	36.4421	60.7077	52.639	33.8768	51.7936	42.7769	61.4501	54.1444	34.2563	
Series	UK - Div. Opt.					FRA - Div. Opt.					
	UK	BTC	GOLD	JPY	CHF	FRA	BTC	GOLD	JPY	CHF	
LB Q ² (5)	2.88421	0.530645	2.57698	1.8839	2.44297	3.20023	0.475379	2.61538	2.31253	1.74292	
LB Q ² (10)	3.96033	3.85284	11.3388	4.2847	4.13537	5.09356	3.68305	10.7966	3.82572	4.65313	
LB Q ² (20)	8.74431	7.20572	19.2106	21.9067	10.1469	18.5648	6.48567	19.2709	23.167	12.4161	
LB Q ² (50)	43.8726	33.2258	60.5686	55.0912	33.8768	40.5359	30.6756	57.7237	55.3168	38.6125	
Series	GER - Div. Opt.					ITA - Div. Opt.					
	GER	BTC	GOLD	JPY	CHF	ITA	BTC	GOLD	JPY	CHF	
LB Q ² (5)	4.02604	0.657785	2.60759	2.50322	1.77776	2.06625	0.977408	2.66648	2.63474	1.55606	
LB Q ² (10)	8.43141	3.58726	12.8699	3.66501	4.31678	8.57666	4.77361	13.2487	4.7111	3.7136	
LB Q ² (20)	28.6102	6.19945	21.1831	22.6034	11.0904	19.4452	8.60716	21.3551	25.7682	10.6691	
LB Q ² (50)	55.8491	29.4473	61.0356	54.5081	35.9677	50.7438	40.5613	60.8707	57.3821	34.1649	
Series	JAP - Div. Opt.										
	JAP	BTC	GOLD	JPY	CHF						
LB Q ² (5)	9.51467	3.79046	3.93175	1.09883	1.46789						
LB Q ² (10)	17.4324	6.46689	13.5437	2.30897	3.46529						
LB Q ² (20)	25.472	9.01317	20.435	15.3972	8.91253						
LB Q ² (50)	49.563	33.359	68.47	52.3275	35.2761						

Table A5. Correlation, Hedge Ratio, and Average Portfolio Weights Between G7 Stock Market Indices and Diversification Options

	Correlation				Hedge Ratio				Portfolio Weight			
	BTC	GOLD	JPY	CHF	BTC	GOLD	JPY	CHF	BTC	GOLD	JPY	CHF
USA	0.2570	0.1263	-0.1023	0.0861	0.0773	0.1486	-0.347	0.0834	0.9945	0.4340	0.2434	0.1581
CAN	0.2538	0.2481	-0.0361	0.1054	0.0619	0.2261	-0.161	0.0871	0.9997	0.6045	0.3508	0.2789
UK	0.1549	0.0399	-0.1091	0.0343	0.0402	0.0419	-0.269	0.0205	0.9801	0.4907	0.2810	0.2096
FRA	0.1846	0.0250	-0.1074	0.0601	0.0564	0.0282	-0.35	0.0786	0.9706	0.3957	0.2180	0.1407
GER	0.1840	0.0572	-0.0764	0.0602	0.0570	0.0716	-0.282	0.0847	0.9688	0.3834	0.2060	0.1356
ITA	0.1992	0.0457	-0.0885	0.0521	0.0683	0.0599	-0.331	0.0687	0.9647	0.3519	0.1893	0.1216
JAP	0.0271	0.0413	-0.0695	0.0523	0.0139	0.0833	-0.133	0.1722	0.9202	0.3582	0.1892	0.1300

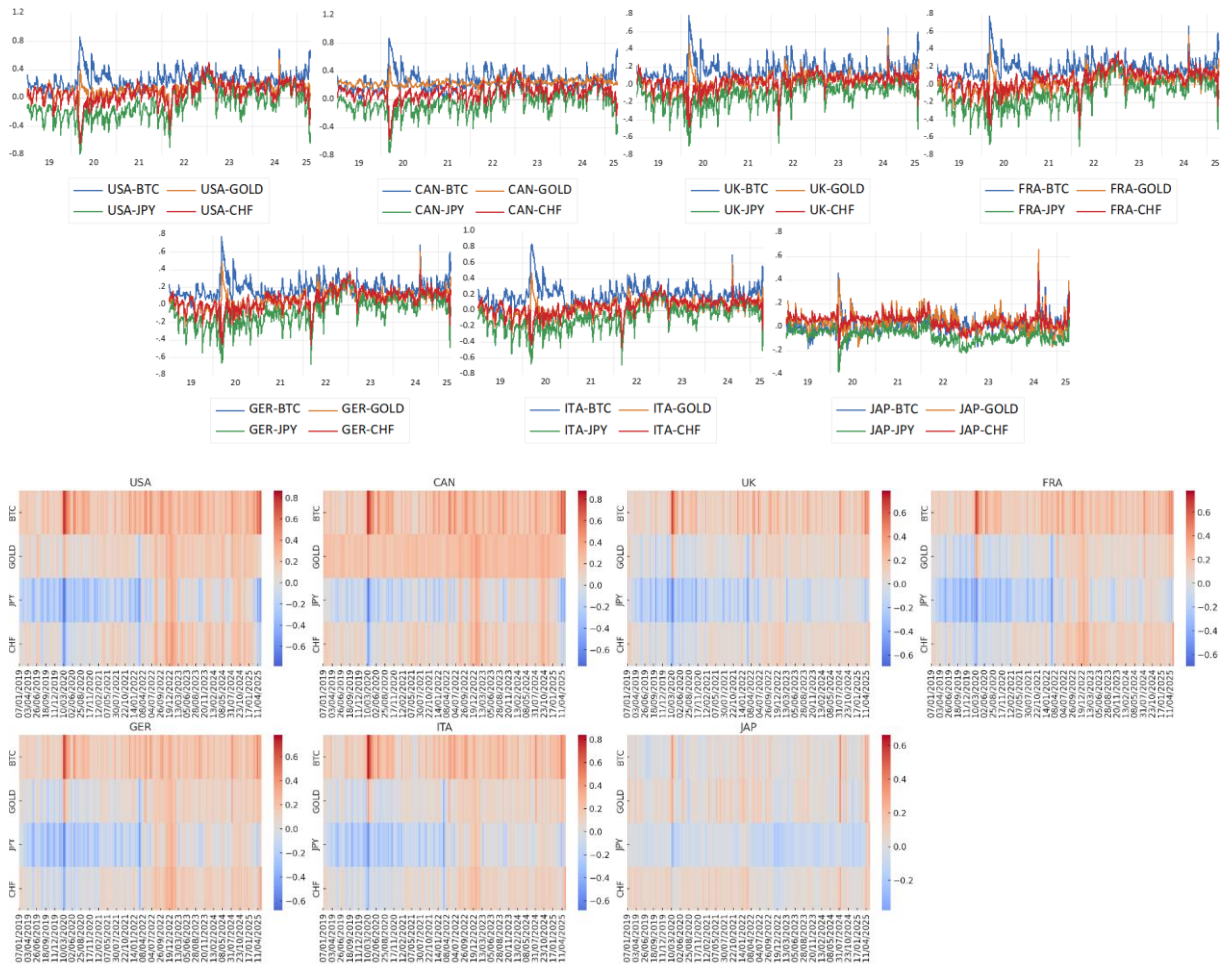


Figure A2. Dynamic correlations

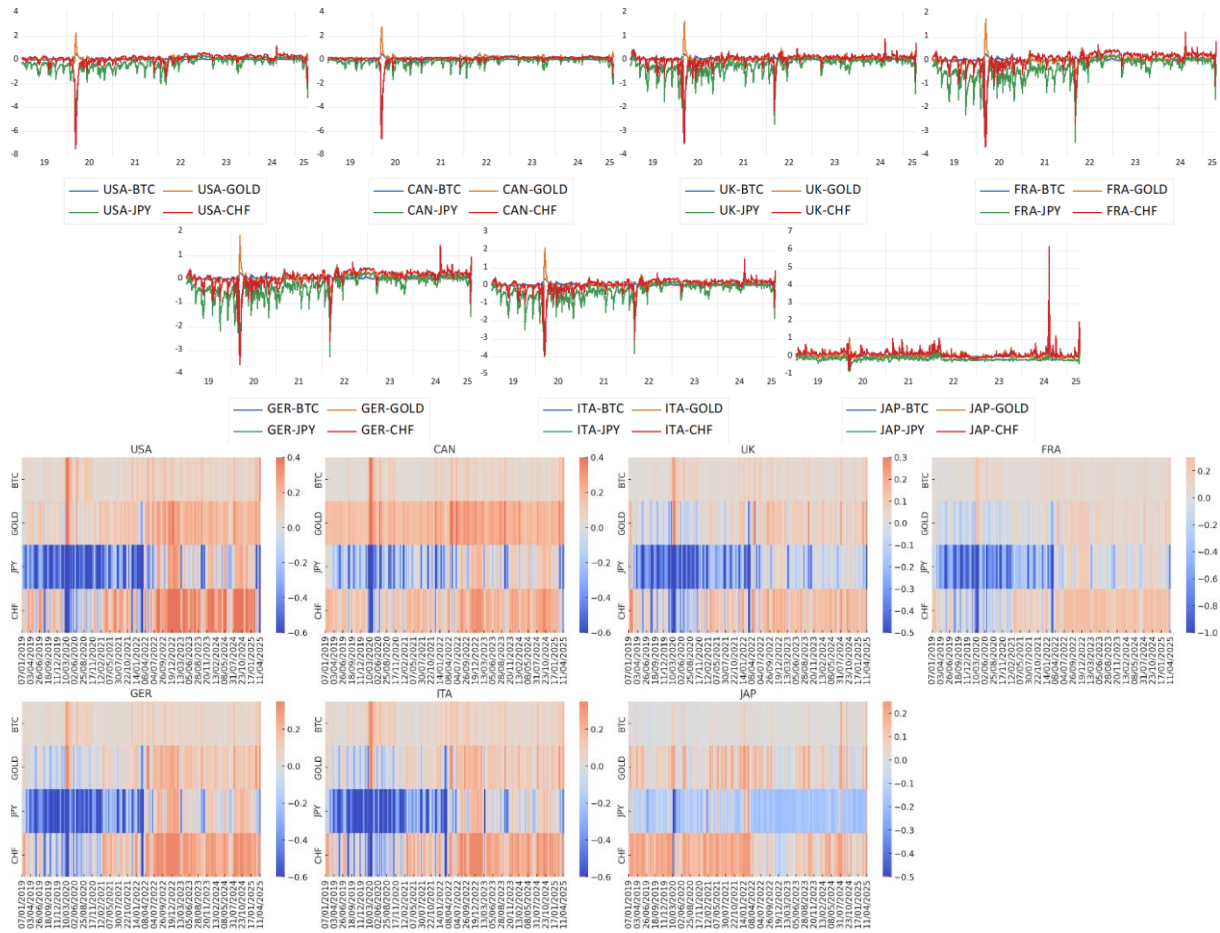


Figure A3. Dynamic hedge ratios

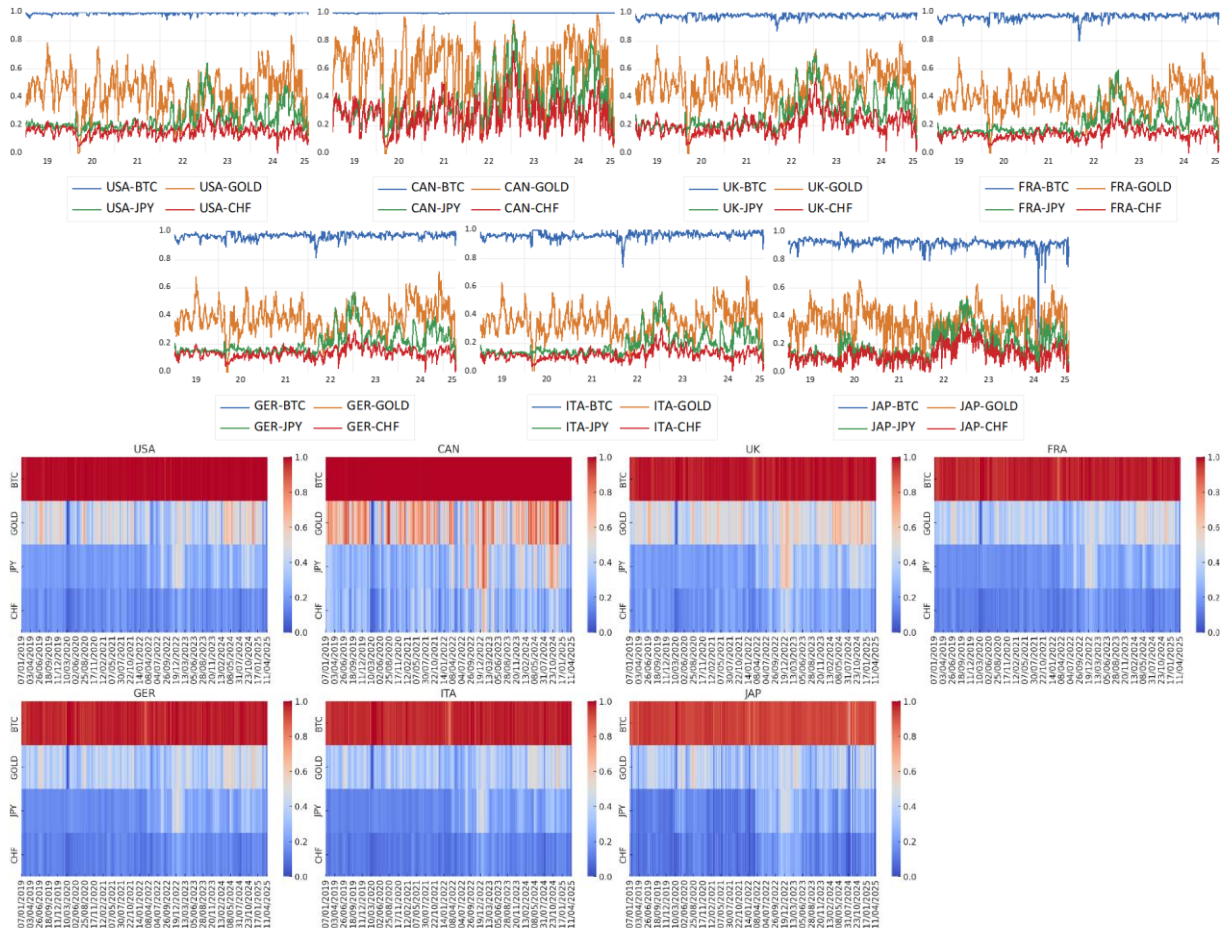


Figure A4. Dynamic portfolio weights

Annexure 1

Variable	Description	Role in Study	Related SDGs	Explanation
ESG Leaders Indices (USA, CAN, UK, FRA, GER, ITA, JAP)	MSCI ESG Leaders indices representing sustainable companies	Main dependent investment assets	SDG 7, SDG 9, SDG 12, SDG 13	ESG indices represent firms committed to sustainable practices, renewable energy adoption, and responsible production.
Bitcoin (BTC)	Cryptocurrency asset	Alternative diversification asset	SDG 9	Represents technological innovation in financial markets and digital infrastructure.
Gold	Precious metal asset	Safe-haven diversification asset	SDG 12	Represents stable resource-based asset often used during financial uncertainty.
Japanese Yen (JPY)	Major global currency	Safe-haven currency asset	SDG 17	Supports international financial stability and global capital cooperation.
Swiss Franc (CHF)	Major safe-haven currency	Diversification and hedging asset	SDG 16, SDG 17	Reflects strong institutional stability and international financial cooperation.