



Green bonds and ESG stocks as safe haven or hedging asset for other financial assets

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Abstract

Climate change is posing new challenges to global sustainability, which attracts greater attention from fund managers' and investors' decisions to invest in environmental, social, and governance (ESG) aspects. Investing in financial assets, however, is subject to risks and volatility and requires sufficient knowledge to make decisions. This study investigated the potential of green bonds and ESG stocks as safe haven assets or as a hedge against other financial assets using daily data since January 2014 to November 2022 with DCC-GARCH model. The result indicated that ESG stocks and green bonds are safe havens for several other financial assets and safe havens during periods of high geopolitical risk. On the other hand, only ESG stocks were qualified as a hedge for conventional bonds. A portfolio that combines green bonds and ESG stocks with other financial assets can minimize risk, particularly the risk associated with financial assets that are not climate resilient. JEL Classification: G11, G15

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Introduction

Environment, public health and economic and finance are all affected by the climate change phenomena. Every nation is facing the same issues and with formidable difficulties in resolving (Dong et al., 2023). Both public and commercial sectors are striving to lessen greenhouse gas emissions and avoid negative consequences for ecosystems and human livelihoods by limiting the use of fossil fuels and emphasizing on using renewable clean

energy. This is a crucial strategy to lower the carbon emissions and fostering environmental sustainability. The cost of transition from traditional to clean energy is massive (Ferrer et al., 2021). In December 2015, the Paris Agreement was signed to ensure carbon reduction according to the Sustainable Development Goals (SDGs) of the United Nations (Reboredo & Ugolini, 2020). Hence, there is a demand for funding in ecologically responsible projects that seek to establish a low-carbon economy and environmental consciousness (Chopra & Mehta, 2023).

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Green bond or the climate awareness bond, founded in 2007 to establish a low-carbon economy, was significantly influenced by the concern related to climate change. Projects concerning environmental resilience economy will be invested (Reboredo, 2018). As a result, green bonds gained greater popularity and many more were subsequently adapted causing the green bond market to grow exponentially. The value between 2008 and 2019 was over USD 0.8 trillion (Ferrer et al., 2021) and the current green bond market (November 20, 2022) is USD 2.077 trillion (Climate bonds initiative, 2022).

Apart from green bonds, which sought to aid low-carbon economies, there are several businesses in the capital markets with practice on environmental, social, and governance (ESG) principles. Businesses that adhere and implement ESG principles are qualified for lower downside risk and outperform non-executing companies in the past (Chen & Mussalli, 2020). ESG stocks publish companies’ goal in promoting a low-carbon and green economy and aiming in social responsibility could draw investors’ interest (Piserà & Chiappini, 2024). Both financial assets are clear in terms of social and environmental responsibility. However, hedging function against financial market are ambiguous (Naeem et al., 2021a). The growth has encouraged risk in the financial system thus, diversification is advisable. Hence, to minimize risk, diversification is essential. Therefore, investors may consider safe haven assets (Baur & Lucey, 2010).

Adding green bonds or ESG stocks to the portfolios with other financial assets, due to a low association, is a diversification investment strategy (Piserà & Chiappini, 2024; Reboredo & Ugolini, 2020). Investing in green bonds can diversify the exposure to the capital market, crude oil, energy commodities, conventional bonds, gold, and bitcoin (Ferrer et al., 2021; Naeem & Karim, 2021; Naeem et al., 2021b; Nguyen et al., 2021; Reboredo, 2018). Investing in ESG stocks can diversify gold,

crude oil, commodity products and bitcoin (Andersson et al., 2022; Naeem & Karim, 2021). However, studies on the hedging and safe-haven functions of green bonds and ESG stocks of other financial assets is limited. Studies on green bonds (see, e.g., Arif et al., 2022; Chopra & Mehta, 2023; Naeem et al., 2023a) and ESG stocks (see, e.g., Iglesias-Casal et al., 2020; Mousa et al., 2022) illustrated that green bonds and ESG stocks are hedged and safe haven for other financial assets including gold, crude oil, and the capital markets. Naeem et al. (2021c) explained that green bonds are diversifier and ESG stocks cannot be a safe haven (Piserà & Chiappini, 2024).

Functions of both financial assets as hedging asset and safe haven remains unclear. Furthermore, the geopolitical risk associated with the Russia-Ukraine war has a negative influence on economic activities and financial markets (Umar et al., 2022), particularly energy commodities, which may force several European countries to revert to fossil fuels (Wang et al., 2022). Thus, achieving the goals of a low-carbon economy may take time, and climate change risk may increase, which is frightening investors and damaging financial markets (Naeem et al., 2021c). The integration of two financial assets has not yet been found, and the correlation between them is poor (green bonds and ESG stocks correlation is 0.237 during study, see Table 1, Panel B), which indicates uncertainty from the different angles. Hence, investors are likely to allocate proportion on various financial assets according to different threat. To address the research gap, our study analyzed the function of green bonds and ESG stocks as safe haven or hedging assets for other financial assets, as well as geopolitical risks, risk management, and hedging strategies. This study contributes to investors as well as fund managers to effectively manage their portfolios in terms of volatility and downside risks. Our findings would provide policymakers with a view to advancing environmental policy through climate-resilient funding and programs, which is essential for the global low-carbon economy.

Table 1 Summary statistics

Asset	GB	ESG	Gold	Oil	BTC	SP	Bond
Panel A: Descriptive statistics, unit root tests, and serial correlation							
Average	-0.006%	0.021%	0.017%	-0.010%	0.136%	0.036%	0.004%
S.D.	0.357%	0.934%	0.890%	3.234%	6.092%	1.150%	0.241%
Max	2.272%	8.180%	4.693%	41.202%	147.418%	8.968%	1.787%
Min	-2.410%	-9.850%	-5.898%	-64.370%	-84.883%	-12.765%	-1.687%
Skewness	-0.442	-1.134	-0.179	-2.841	4.828	0.075	-0.880
Kurtosis	4.748	17.567	3.105	92.758	175.754	16.376	5.790
J-B	2,135.319***	28,740.700***	893.859***	791,268.700***	2,838,754.00***	28,849.040***	3,071.152***
ADF	-28.907***	-14.803***	-46.735***	-35.902***	-24.354***	-15.214***	-48.046***
PP	-41.654***	-45.290***	-46.740***	-48.027***	-49.143***	-54.262***	-48.108***

Table 1 Continued

Asset	GB	ESG	Gold	Oil	BTC	SP	Bond
ARCH(10)	316.220***	747.488***	97.343***	362.676***	236.806***	774.472***	514.977***
LB-Q(10)	17.671*	143.220***	11.616	53.874***	85.747***	161.380***	17.907*
LB-Q ² (10)	777.600***	2,250.400***	154.630***	455.900***	249.350***	2,480.500***	1,434.300***
Panel B: Unconditional correlation matrix							
GB	1.000						
ESG	0.237***	1.000					
Gold	0.406***	0.058***	1.000				
Oil	0.008	0.306***	0.092***	1.000			
BTC	0.059***	0.149***	0.034	0.058***	1.000		
SP	0.097***	0.930***	0.011	0.265***	0.154***	1.000	
Bond	0.455***	-0.235***	0.362***	-0.162***	0.000	-0.263***	1.000

Note: * $p < .10$, ** $p < .05$, *** $p < .01$.

Literature Review

Green bonds were introduced in 2007 and have grown exponentially after the green bond principles were announced by International Capital Markets Association (ICMA) in January 2014. The bond markets require project disclosure and reports to make them clear (Naeem et al., 2021b). Meanwhile, there is significant investment growth in the ESG stock of capital markets because companies with better ESG performance can obtain higher risk-adjusted returns (Sherwood & Pollard, 2018). ESG stock is a prioritized criterion that stakeholders and investors are seeking for long-term profits associated with environmental, social, and commercially responsible investment (Mousa et al., 2022). Although investing in ESG stocks can help minimize risks (Umar et al., 2020), research is limited and emphasizes ESG performance and returns (see, e.g., Díaz et al., 2021; Sherwood & Pollard, 2018). Similarly, research on green bonds focus on the differences in returns on green bonds and conventional bonds (Ferrer et al., 2021; Naeem et al., 2021c). Although we might argue that green bonds and ESG stocks are investments that help to achieve a low-carbon economy and global sustainability, their financial dimensions remain uncertain. All kinds of risks associated with investments will affect investors' sentiments, both systematic risk and the Black Swan such as the 2008 financial crisis and COVID-19. Investors who desire to minimize risk may need to diversify into a variety of assets and apply effective portfolio management.

Baur and Lucey (2010) and Baur and McDermott (2010) explained the distinction between asset classes. The strong safe haven and weak safe haven are negative correlates and uncorrelated with other assets in a portfolio during high market volatility, respectively. The strong hedge and weak hedge in an average portfolio

have negative correlation and are uncorrelated with other assets, respectively. Other distinct conditions are diversifiers.

The past studies offered to our literature were about functions of green bonds and ESG stocks as safe haven and hedging for other financial assets. First, on the function of green bonds, Chopra and Mehta (2023) indicated that green bonds are a hedge and a strong safe haven for capital markets. Similarly, Naeem et al. (2023a) found that green bonds are a strong safe haven for capital markets in 10 countries, including crude oil, gold, and conventional bonds (Arif et al., 2022). Green bonds, on the other hand, according to Naeem et al. (2021c), can operate as an effective diversifier rather than a hedge for gold (Naeem et al., 2021a). Nguyen et al. (2021) presented that green bonds are a diversifier for capital markets and conventional bonds, as well as crude oil (Naeem et al., 2021b) and bitcoin (Naeem & Karim, 2021). Second, on the function of ESG stocks, Mousa et al. (2022) explained ESG stocks as a safe haven for capital market, also gold and crude oil (Cagli et al., 2023). Piserà and Chiappini (2024) concluded that ESG stocks are not a safe haven, which is consistent with the study by Rubbaniy et al. (2022) that ESG stocks can act as safe haven during the COVID-19 crisis only. Umar et al. (2020) and Andersson et al. (2022) remarked that ESG stocks operate as diversifier for capital markets, crude oil, and gold. Investing in ESG stocks can diversify risk from investing in bitcoin (Naeem & Karim, 2021).

The current geopolitical risk situation resulting from the Russia-Ukrainian war has become another major risk with a considerable impact on investors' sentiment. However, previous research has mostly neglected comparing the functions of green bonds and ESG stocks during the geopolitics but mostly considered during the COVID-19 pandemic. Dong et al. (2023) stated that green bonds are safe haven in the face of geopolitical risks,

as well as financial assets that are close to ESG stocks, such as clean energy stocks or green stocks (Sohag et al., 2022). The geopolitical risk can influence financial assets' behavior and functions differently depending on each of them (Umar et al., 2022). Therefore, we would like to investigate the functions of green bonds and ESG stocks under geopolitical risk, covering a wide range of financial assets i.e., gold, crude oil, capital markets, conventional bonds, and an intriguing digital asset with notable market growth such as bitcoin (Naeem & Karim, 2021; Piserà & Chiappini, 2024).

Baur and Lucey (2010) and Baur and McDermott (2010) used the generalized autoregressive conditional heteroskedasticity (GARCH) to analyze functions and classify financial assets. Ratner and Chiu (2013) attempted to investigate the relationship between asset pairs produced from dynamic conditional correlation GARCH (DCC-GARCH) rather than the return of each asset class. The DCC-GARCH by Engle (2002) can explain volatility and dynamic interactions that are consistent with volatile and high-frequency financial data. This approach is often used to investigate the relationship between financial assets (see, e.g., Chopra & Mehta, 2023; Naeem et al., 2023a). Consequently, before studying the functions of green bonds and ESG stocks as a hedge and safe haven to other financial assets, including geopolitical risk, risk management, and hedging strategies, we used DCC-GARCH to conditionally analyze the dynamic correlation between green bonds and ESG stocks and other financial assets.

Methodology

Data

This section discusses the function of green bonds and ESG stocks as a safe haven and hedge against other financial assets by examining the bond markets (Bond (conventional bonds, S&P U.S. treasury bond index)), capital markets (SP, S&P 500 index), commodities markets (i.e., Gold (gold price, USD per ounce); Oil (Brent crude oil spot price, USD per barrel)), and digital asset markets (BTC, bitcoin price in USD). Investors may regard gold as a store of value and a traditional safe haven; likewise, bitcoin is similar to gold as bitcoin bears a pure store of value just like gold (Dyhrberg, 2016). Crude oil is mostly linked with capital market (Umar et al., 2022) and conventional bonds with low risks. Therefore, investing in these financial assets helps to add or compensate for green bonds (GB, S&P green

bond index) and ESG stocks (ESG, MSCI all-country world ESG leaders index) in their portfolios. Data were acquired from investing.com, spglobal.com, and msci.com from January 2, 2014, to November 30, 2022, daily for 2,209 days, including the geopolitical risks since the Russian invasion of Ukraine on February 24, 2022 (Wang et al., 2022).

Data used are in the form of return and can be represented as $r_t = \ln(P_t/P_{t-1})$, where r_t is return of green bonds, ESG stocks and financial assets at time t , P_t is closing price of green bonds, ESG stocks and financial assets at time t .

For the descriptive statistics regarding the green bonds (GB), ESG stocks (ESG), and other financial assets return of all series, unit root tests display the data stationary of all series by Augmented Dickey Fuller (ADF) and Phillips-Perron (PP). Data do not follow a normal distribution since the Jarque-Bera statistic is significant. The serial correlation due to Q and Q^2 was significant, and ARCH was also significant (Table 1-Panel A). The GARCH (1,1) model is suitable to analyze the above data. The model is suitable for analyzing DCC with an adequate explanation of volatility and high-frequency data (see, e.g., Chopra & Mehta, 2023; Piserà & Chiappini, 2024), which will be further discussed.

The unconditional correlation between GB, ESG, and other financial assets revealed a significant positive correlation between green bonds and all other financial assets except crude oil (Oil); ESG also had a significant positive correlation with all other financial assets except conventional bonds (Bond), as they are negative. The fact that ESG and the capital market (SP) are highly correlated is a crucial indicator of an unconditional correlation; such assets may move in unison and cannot be initially hedged (Table 1, Panel B). Therefore, we applied DCC to indicate time-varying of co-movement.

Methodology

DCC-GARCH Model

We use the DCC-GARCH model by Engle (2002) based on the study of Ratner and Chiu (2013) as a powerhouse in explaining the time-varying volatility consistent with data on the returns of dynamic financial assets, and such is used in a multivariate fashion. The advantage of DCC-GARCH is that large covariance matrix estimation is available as the number of parameters are independent from the number of variables. The parameter estimation process consisted of 2 steps

using GARCH(1,1), which is an initial step to effectively explain volatility and equation as follows (Equation (1) and (2)).

$$\text{Mean equation: } r_t = \mu + \omega r_{t-1} + \varepsilon_t \quad (1)$$

$$\text{Variance equation: } h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} \quad (2)$$

When ε_t is residual at time t , μ is the conditional mean of r_t and ω is the coefficient, h_t is conditional variance (volatility of r_t at time t), α_0 is a parameter, α_1 reflects the ARCH effect, β_1 reflects the GARCH effect.

Step 2 estimation by DCC-GARCH(1,1) model can be presented in Equation (3), thus.

$$Q_t = (1 - \lambda_1 - \lambda_2) \bar{Q} + \lambda_1 \zeta_{t-1} \zeta_{t-1}' + \lambda_2 Q_{t-1} \quad (3)$$

When Q_t is a positive symmetric matrix conditional covariance of standardized residual (ζ_t), $\bar{Q}$ is a positive symmetric matrix unconditional covariance of standardized residual, λ_1 and λ_2 are the parameters, thus $\lambda_1 + \lambda_2 < 1$. The DCC calculation is as follow (Equation (4)):

$$\rho_{ij,t} = \frac{q_{ij,t}}{(\sqrt{q_{ii,t}} \sqrt{q_{jj,t}})} \quad (4)$$

When i and j are green bonds (or ESG stocks) and financial assets respectively. According to Equation (3) if $\lambda_1 = \lambda_2 = 0$ and $\bar{Q} = I$ it means that the conditional correlation coefficient is not time-varying or $\rho_{ij,t} = 1$ is constant. Equation (4) will, therefore, be a constant conditional correlation GARCH model (CCC-GARCH).

Safe haven and hedge asset

The classification of safe haven and hedge by Baur and Lucey (2010) and Baur and McDermott (2010) takes into account the dynamic conditional correlation, from the DCC-GARCH estimation (Ratner & Chiu, 2013), between green bonds (or ESG stocks) and other financial assets. D is dummy variable assigned under extreme fluctuation for 1st (q_1), 5th (q_5), and 10th (q_{10}) quantile of return among other financial assets is written (Chopra & Mehta, 2023) in equation (5), thus.

$$\rho_{ij,t} = m_{0,i} + m_{1,i} D(r_{j,t} q_{10}) + m_{2,i} D(r_{j,t} q_5) + m_{3,i} D(r_{j,t} q_1) + e_{j,t} \quad (5)$$

When $\rho_{ij,t}$ is dynamic conditional correlation and $r_{j,t}$ is return of financial assets, $e_{j,t}$ is the error term. Equation (5) depicted green bonds (or ESG stocks)

as strong hedge for financial asset j if $m_{0,i}$ is negative, weak hedge if zero, and diversifier if positive. Green bonds (or ESG stocks) are depicted as strong safe haven for financial assets j when $m_{1,i}$, $m_{2,i}$ and $m_{3,i}$ are negative, weak safe haven if zero, and diversifier if positive.

Functions of green bonds and ESG stocks during geopolitical risk of the Russia-Ukraine war. Referring to the regression modelling by Baur and McDermott (2010), dummy variable (D) represents period of geopolitical risk, and the equation is written, thus (Naeem et al., 2023a; Ratner & Chiu, 2013).

$$\rho_{ij,t} = \gamma_0 + \gamma_1 D(\text{Geopolitical risk}) + v_{j,t} \quad (6)$$

The commencement of geopolitical risk was on February 24, 2022, when $v_{j,t}$ is the error term. Eq. 6 depicted green bonds (or ESG stocks) as strong hedge for financial asset j when γ_0 is negative, weak hedge if zero and diversifier if positive. Similarly, green bonds (or ESG stocks) are strong safe haven for financial asset j when γ_1 is negative, weak safe haven if zero and diversifier during the period of geopolitical risk if positive.

Risk management and hedging strategies

Risk management analysis is based on optimal portfolio weights from the DCC-GARCH model by Kroner and Ng (1998) to minimize risk in green bonds (or ESG stocks) against financial assets while maintaining the expected return and the equation is as follow.

$$w_{ij,t} = \frac{h_{jj,t} - h_{ij,t}}{h_{ii,t} - 2h_{ij,t} + h_{jj,t}} \quad (7)$$

Where $w_{ij,t}$ is optimal portfolio weight for USD 1,000 in green bonds (or ESG stocks) and other financial assets at time t , $h_{ii,t}$ and $h_{jj,t}$ are conditional variance of green bonds (or ESG stocks) and other financial assets at time t respectively. When $h_{ij,t}$ is conditional covariance between green bonds (or ESG stocks) against other financial assets at time t . Therefore, optimal portfolio weight in financial assets is $1 - w_{ij,t}$, the optimal portfolio weight in green bonds and ESG stocks by Kroner and Ng (1998) is between 0 – 1.

$$w_{ij,t} = \begin{cases} 0 & \text{if } w_{ij,t} < 0 \\ w_{ij,t} & \text{if } 0 \leq w_{ij,t} \leq 1 \\ 1 & \text{if } w_{ij,t} > 1 \end{cases} \quad (8)$$

Hedge ratio will be considered for hedging strategies analysis to minimize risk between green bonds (or ESG stocks) against other financial assets. The study of hedge ratio by Kroner and Sultan (1993) can be explained thus.

$$\beta_{i,t} = \frac{h_{ij,t}}{h_{ii,t}} \quad (9)$$

Where $\beta_{i,t}$ is hedge ratio. The long position for other financial assets at USD 1,000 can hedge by offering short position of green bonds (or ESG stocks) for USD $\beta_{i,t}$.

The hedging effectiveness (HE) was calculated to evaluate hedging strategy performance based on Basher and Sadorsky (2016) thus.

$$HE = \frac{Var_{uh} - Var_h}{Var_{uh}} \quad (10)$$

Where $Var_{uh} = h_{jj,t}$ and $Var_h = h_{jj,t} + \beta_{i,t}^2 h_{ii,t} - 2\beta_{i,t} h_{ij,t}$ are used to evaluate hedge and unhedged portfolios. The analysis of optimal portfolio weights, hedge ratio, and hedging effectiveness could be demonstrated for pre and during the geopolitical risk of a Russia-Ukraine war (February 24, 2022).

Results and Discussion

Dynamic Conditional Correlation (DCC) analysis

The DCC-GARCH(1,1) model is used to investigate the dynamic correlation of volatility between green bonds (GB) and ESG stocks (ESG) with other financial assets. Since the Wald's test results are significant, this indicates model fit. The dynamic correlation of volatility can be calculated using the dynamic conditional correlation (Dong et al., 2023). The results of DCC indicated significant positive dynamic correlation between GB and other financial assets, exception crude oil (Oil) and capital market (SP). In other words, during the study, GB may not directly hedge against other financial assets (Table 2).

The ESG has a significant positive dynamic correlation with all financial assets, except gold (Gold). However, ESG has a negative significant dynamic correlation with conventional bonds (Bond). SP, for instance, has a high

dynamic correlation with ESG (Table 2). Thus, ESG may directly hedge for Bond but not for other financial assets during the study.

To consider time-varying DCC (Figure 1), it was realized that GB and ESG are positively correlated with all other financial assets during normal market condition except ESG and Bond that are negatively correlated. During a high geopolitical risk since February 24, 2022 (highlighted in Figure 1), investors may secure the information that GB and ESG could be safe haven (merely the GB vs Gold, Oil, and bitcoin (BTC); and the ESG vs Gold, Oil and Bond) as they are negatively correlated or significantly minimized. Therefore, GB and ESG are safe haven during crisis or economic downturns.

Safe Haven and Hedge Asset Analysis

The result indicated that GB are significant diversifier for all other financial assets therefore, they are not hedge (Table 3-Panel A). This is consistent with Naeem et al. (2021a, 2021b), Naeem and Karim (2021), and Nguyen et al. (2021) that GB are a diversifier for financial assets. According to Reboredo (2018) and Reboredo and Ugolini (2020), GB are also diversifier. ESG are significant diversifier for all other financial assets, except Bond where ESG would significantly be a strong hedge (Table 3-Panel B). Umar et al. (2020) also explained that ESG are diversifier for SP and Oil as well as Gold (Andersson et al., 2022). ESG may act as a strong hedge for Bond as investment on SP and Bond are good hedge (Ma et al., 2021).

Table 3-Panel A, GB as the strong safe haven for Oil during an extreme fluctuation were significantly less than the 5th quantile. Also, when SP during extreme fluctuation was significantly lower than the 1st quantile. GB are weak safe haven for all other financial assets during extreme fluctuation at significantly less than the 10th quantile, except Bond. The result is consistent with Arif et al. (2022) and Chopra and Mehta (2023) that GB are strong safe haven for SP and Oil, while being a diversifier for Bond during extreme fluctuation being significant less than the 10th quantile. Since both financial assets are bonds, investing in these financial assets merely results as diversification. Pham (2016) and Ferrer et al. (2021) concluded that GB and Bond are positively correlated.

Table 2 Dynamic conditional correlation results

Asset	λ_1	λ_2	Gold	Oil	BTC	SP	Bond	Wald test $H_0: \lambda_1 = \lambda_2 = 0$
GB	0.014***	0.972***	0.439***	0.014	0.075*	0.016	0.409***	$1.700 \times 10^{5***}$
ESG	0.016***	0.970***	0.058	0.265***	0.152***	0.920***	-0.217***	$2.100 \times 10^{5***}$

Note: This table reports the result of estimation DCC-GARCH(1,1) 2 times.

* $p < .10$, ** $p < .05$, *** $p < .01$.

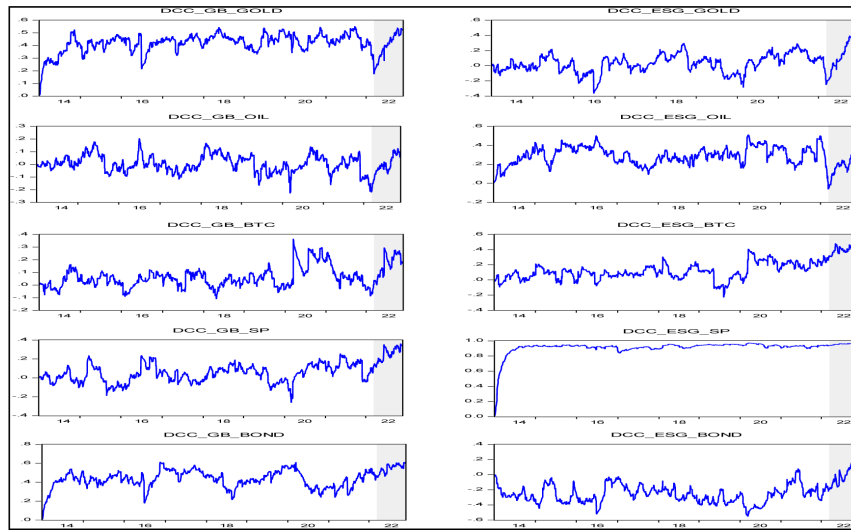


Figure 1 DCC between green bonds and ESG stock with other financial assets

Table 3-Panel B, ESG are weak safe haven for all other financial assets during extreme fluctuation at less than the 10th quantile, except Oil, SP, and Bond. ESG will merely act as diversifier for Oil and SP during extreme fluctuation being significant less than the 1st quantile, also at the 10th quantile but less than the 1st quantile for Bond. The result is consistent with the study by Pedini and Severini (2022) that ESG are weak safe haven for Gold and BTC. ESG will also be a diversifier for Bond during extreme fluctuation being significant at the 10th quantile but less than the 1st quantile. Therefore, investing in ESG can diversify risk for other financial assets. Consistent with conclusion from Andersson et al. (2022) and Piserà and Chiappini (2024) that ESG are lacking as safe haven.

Table 4 illustrates the result of safe haven and hedging assets in the geopolitical risk of a Russia-Ukraine war. GB are neither a hedge nor a safe haven for all other financial assets, except for Gold and Oil, which are both strong safe havens. Increasing geopolitical risk can cause volatility in energy commodities and Gold (Wang et al., 2022). Similarly, ESG is strong safe haven

for Oil consistent with Rubbaniy et al. (2022) that ESG can be safe haven during crisis, as well as strong hedge against Bond. According to Naem et al. (2023b), the volatility of Bond increases the effectiveness of ESG. Investing in GB and ESG provides a safe haven and diversification. GB, according to Dong et al. (2023), will act as a safe haven when geopolitical risk is high. Figure 1 confirmed the result of DCC. During the COVID-19 pandemic, Naem et al. (2023a) demonstrated that GB lacked hedging abilities.

Table 4 Green bonds and ESG stock as a safe haven or hedge against other financial assets during GPR of Russia-Ukraine war

Asset	GB		ESG	
	Hedge (γ_0)	Safe haven (γ_1)	Hedge (γ_0)	Safe haven (γ_1)
Gold	0.421***	-0.027***	0.030***	0.077***
Oil	0.005***	-0.024***	0.295***	-0.124***
BTC	0.054***	0.099***	0.108***	0.272***
SP	0.042***	0.196***	0.912***	0.043***
Bond	0.426***	0.116***	-0.264***	0.250***

Note: * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 3 Green bonds and ESG Stock as a safe haven or hedge against other financial assets

Asset	Panel A: GB				Panel B: ESG			
	Hedge (m_0)	Safe haven			Hedge (m_1)	Safe haven		
		10% (m_1)	5% (m_2)	1% (m_3)		10% (m_1)	5% (m_2)	1% (m_3)
Gold	0.419***	-0.001	-0.007	-0.000	0.036***	-0.007	-0.013	-0.035
Oil	0.004***	0.001	-0.012*	-0.075***	0.283***	0.004	0.009	0.063***
BTC	0.063***	-0.009	-0.005	-0.018	0.132***	-0.006	-0.007	-0.035
SP	0.059***	0.000	0.008	-0.042*	0.914***	0.011	0.011	0.036**
Bond	0.433***	0.027***	0.036***	0.077***	-0.247***	0.037***	0.052***	0.046

Note: * $p < .10$, ** $p < .05$, *** $p < .01$.

Thus, geopolitical risks can cause investors' sentiment about volatility of energy commodities. The sanctions imposed on Russia may force several European countries to revert to using fossil fuels (Umar et al., 2022) leading to climate change risk. The findings suggest that GB and ESG are safe haven for Oil. The investors therefore can minimize their exposure to high geopolitical risks by increasing the proportion of GB and ESG in their portfolios.

Risk Management and Hedging Strategies Analysis

The DCC-GARCH model is an extensive study that will assist investors in knowledgeable judgments during normal market condition as well as geopolitical risks of the Russia-Ukrainian war. In both periods, the optimal portfolio weight ($w_{ij,t}$) average between GB and other financial assets was 0.207 for Bond and 0.996 for BTC, implying USD 1,000 investment between USD 996 in GB and the remaining USD 4 in BTC (Table 5-Panel A). Likewise, ESG ought to have an average optimal portfolio weight between 0.135 for Bond and 0.984 for BTC (Table 5-Panel B). Bitcoin mining is energy consuming and not environmentally friendly. Consequently, investors should hold 99.6 percent of wealth in GB and 98.4 percent in ESG, in addition to other financial assets, to minimize risks. The result is consistent with Abuzayed and Al-Fayoumi (2023) that an optimal portfolio weight should include at least 80 percent GB and 60 percent ESG (Piserà & Chiappini, 2024).

Gold, Oil, and Bond were identified as increasing optimal portfolio weight from 0.009, 0.020, and 0.788 to 0.186, 0.046, and 0.857 ($1-w_{ij,t}$) for GB and increasing from 0.392, 0.032, and 0.863 to 0.614, 0.100, and 0.893 for ESG during the geopolitical risk and can be regarded

by investors as hedging assets ($\beta_{i,t}$). As a result, since the pre-geopolitical risk period, the average optimal portfolio weight of GB and ESG to these financial assets has decreased (Table 5). The optimal portfolio for ESG-SP showed ESG as alternative investment to SP during geopolitical risk and is slightly alternative during pre-geopolitical risk. ESG also bear lesser risk than SP during the study since its standard deviation (SD) is lower (Table 1-Panel A). However, following the optimal portfolio weight can minimize risk. Nevertheless, investors should decide to invest based on their risk acceptance (see, SD in Table 1-Panel A). GB and ESG, on the other hand, are good diversifiers, according to Naeem et al. (2021c), GB are effective for diversification during both normal and crisis market conditions (Ferrer et al., 2021). This is apart from Bond with the lowest average ratio (Rubbiani et al., 2022), including ESG. Cui et al. (2022) proved similar, Bond as financial assets with lowest risk during the study period (Table 1-Panel A).

If hedge ratio ($\beta_{i,t}$) is negative, hedging strategies in other financial assets can be implemented by offering short or long positions on GB and ESG in the same direction. Practically, investors should offer USD 1,000 in Oil and USD 33 in GB as well as USD 1,000 in Bond and USD 71 in ESG as a hedge. If hedge ratio is positive, investors should offer a short or long position in reverse, i.e., investors may offer long position for USD 1,000 in Gold and short position for USD 1,179 in GB, or short position for USD 42 in ESG as hedging strategies (Table 5). The hedging effectiveness (HE) analysis indicated HE for GB of other financial assets reaching between 0.47 percent for Oil and 19.89 percent for Bond (Table 5-Panel A). HE for ESG of other financial assets reaching between 1.70 percent for Gold and 84.54 percent for SP (Table 5-Panel B).

Table 5 Optimal portfolio weights, optimal hedge ratios, and hedge effectiveness

Asset	Full sample			Pre-GPR			During GPR		
	$w_{ij,t}$	$\beta_{i,t}$	HE	$w_{ij,t}$	$\beta_{i,t}$	HE	$w_{ij,t}$	$\beta_{i,t}$	HE
Panel A: GB									
Gold	0.976	1.179	18.07%	0.991	1.232	18.22%	0.814	0.611	16.54%
Oil	0.977	-0.033	0.47%	0.980	-0.010	0.44%	0.954	-0.277	0.78%
BTC	0.996	0.863	1.08%	0.996	0.836	0.88%	0.997	1.153	3.20%
SP	0.874	0.151	1.45%	0.871	0.110	1.00%	0.911	0.590	6.34%
Bond	0.207	0.302	19.89%	0.212	0.296	18.98%	0.143	0.354	29.68%
Panel B: ESG									
Gold	0.589	0.042	1.70%	0.608	0.038	1.39%	0.386	0.085	5.04%
Oil	0.962	0.967	9.04%	0.968	1.018	9.53%	0.900	0.420	3.78%
BTC	0.984	0.763	3.29%	0.983	0.690	2.23%	0.999	1.547	14.73%
SP	0.955	1.117	84.54%	0.950	1.110	83.93%	1.000	1.194	91.11%
Bond	0.135	-0.071	7.65%	0.137	-0.077	8.21%	0.108	-0.006	1.59%

Note: This table reports the optimal portfolio weights from Equation (7), optimal hedge ratios from Equation (9), and hedge effectiveness from Equation (10).

Table 5 compares portfolios with GB and portfolios with ESG as well as hedging effectiveness, demonstrating the variety in different periods and market types both pre and during geopolitical risk. An increase in investment is needed to hedge portfolios during geopolitical risk, apart from financial asset combinations such as GB and Gold, ESG and Oil, and ESG and Bond, which require less spending owing to lower hedge ratio which is a good hedging strategy. **Table 4** demonstrated strong hedge and strong safe haven that underlines the function of GB and ESG during geopolitical risk. However, investors may consider Gold, Oil, and Bond as risk minimizer. Thus, they adopted these 3 financial assets into portfolio $(1-w_{ij,t})$, therefore, the hedging cost reduced. When GB and ESG, as hedging effectiveness, were reduced during geopolitical risk, we find that a discount in investment may lead to a reduction in hedging effectiveness.

Since economy and financial markets were impacted by accumulative risks, hedging ratios for other financial asset combinations increased during geopolitical risk and consequently, investors face higher hedging expenses leading to higher hedging effectiveness. This is similar to the study from Abuzayed and Al-Fayoumi (2023) during the COVID-19 crisis. Thus, investing in GB and ESG along with other financial assets is appropriate for portfolios diversification. This is consistent with the findings of Cui et al. (2022) and Naeem et al. (2023a) that investing in GB, as well as ESG (Iglesias-Casal et al., 2020; Naeem & Karim, 2021) can hedge and diversify risks during the crisis. The study thereby, indicates that during normal market conditions, GB and ESG serve a significant hedging function as portfolio diversifier. In addition, GB and ESG can minimize risks caused by economic crises and subsequent financial markets caused by geopolitical risks of the Russia-Ukrainian war.

Robustness Test

The robustness test of safe haven and hedging assets in **Table 3** following Wang et al. (2019) is based on the approach by Baur and McDermott (2010) that considers market uncertainty with conditional variance in the return of other financial assets at different levels. We use a dummy variable to distribute the volatility of the return of other financial assets, similar to equation (5), which can be presented in the equation thus.

$$\rho_{ij,t} = \delta_{0,i} + \delta_{1,i}D(h_{jj,t-1}q_{90}) + \delta_{2,i}D(h_{jj,t-1}q_{95}) + \delta_{3,i}D(h_{jj,t-1}q_{99}) + u_{j,t} \quad (11)$$

Where $\rho_{ij,t}$ is dynamic conditional correlation between green bonds (or ESG stocks) and financial assets obtained by DCC-GARCH model (see equation (4)), $h_{jj,t-1}$ is conditional variance of financial asset j and $u_{j,t}$ is error term.

The results as indicated in **Table 6** are similar to **Table 3**. That is, green bonds (GB) cannot hedge for all other financial assets. Likewise, ESG stocks (ESG) also cannot hedge for all other financial assets except for conventional bonds (Bond) where ESG would act as a strong hedge. GB are merely a diversifier for Bond during extreme volatility, more than 90th quantile. GB will be a safe haven during extreme volatility for the following assets; crude oil (Oil) more than 90th quantile, bitcoin (BTC) more than 95th quantile, capital market (SP) more than 99th quantile, and gold (Gold) more than 90th but not up to 99th quantile.

ESG can act as a safe haven for all other financial assets during extreme volatility more than 90th quantile, except for Oil, SP and Bond. ESG would act as diversifier during extreme volatility for the following assets; Oil more than 95th quantile, SP more than 90th quantile, and Bond more than 90th but not to 99th quantile.

Table 6 Robustness test

Asset	Panel A: GB				Panel B: ESG			
	Hedge (δ_0)	Safe haven			Hedge (δ_0)	Safe haven		
		90% (δ_1)	95% (δ_2)	99% (δ_3)		90% (δ_1)	95% (δ_2)	99% (δ_3)
Gold	0.419***	-0.024***	-0.001	0.039**	0.042***	-0.074***	-0.060***	0.015
Oil	0.010***	-0.049***	-0.095***	-0.060***	0.281***	0.008	0.041***	0.132***
BTC	0.061***	0.019**	0.012	-0.018	0.133***	-0.006	-0.012	-0.103***
SP	0.054***	0.077***	0.048***	-0.087***	0.911***	0.038***	0.046***	0.058***
Bond	0.425***	0.104***	0.118***	0.111***	-0.256***	0.153***	0.192***	-0.197***

Note: * $p < .10$, ** $p < .05$, *** $p < .01$.

Conclusion and Recommendations

This study examines the function of green bonds and ESG stocks as safe haven or hedge for other financial assets as well as during geopolitical risk using the DCC-GARCH model. The result indicates time-varying between the dynamic condition correlation of green bonds and ESG stocks with other financial assets are positive except for ESG stocks and conventional bonds that are negative.

Apart from crude oil and the capital market, only ESG stocks can hedge conventional bonds and act as safe havens under extreme fluctuation of less than 1 percent and extreme volatility of more than 99 percent. Green bonds will be a safe haven when there is extreme fluctuation of less than 10 percent on other financial assets, apart from conventional bonds and during extreme volatility of more than 99 percent, except for gold and conventional bonds. During high geopolitical risk, ESG stocks act as a hedge for conventional bonds and a safe haven for crude oil, while green bonds act as a safe haven for crude oil and gold. Green bonds and ESG stocks in a portfolio will provide further diversification since both financial assets can minimize volatility during a bearish market.

Green bonds and ESG stocks can act as a diversifier than a strong safe haven for all other financial assets. A hedging strategy with effectiveness is to invest in more green bonds and ESG stocks than other financial assets in the portfolio. The above findings indicated that green bonds and ESG stocks act as diversifiers for some other financial assets, particularly during periods of high geopolitical risk. The fund managers and investors should include additional green bonds and ESG stocks in their portfolios to minimize total losses over time. In comparing diversification potential, green bonds tend to have more ability to minimize losses thus, bonds can bear lower risk than equities (see, Table 1-Panel A for GB, Bond, ESG, and SP). This study can be a reference but cannot validate the returns. Thus, an inclusive of other financial assets with green bonds and ESG stocks in the portfolio can hedge differently during the short, medium, and long term, in which fund managers and investors should invest based on their threshold.

Offering a diverse variety of financial assets, green bonds and ESG stocks have a significant function in supporting financial market growth and minimizing environmental concerns while expanding market participants, both borrowers, and lenders. Policymakers

could possibly encourage both the public and private sectors to offer green bonds and embrace ESG principles, as well as enhance environmental awareness among fund managers and investors. This is consistent with the direction of the financial market and will eventually lead to a low-carbon economy. However, the drawback of DCC-GARCH model is the conditional correlation is driven by the same underlying dynamics. Also, the applied hedging strategy cannot capture the fat tail distribution while the non-linear regression or quantile regression may limit this drawback. Additionally, function of green bonds and ESG stocks may vary according to each industry and market behavior, which could be an area of discussion in the future.

Conflict of Interest

The authors declare that there is no conflict of interest.

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