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Hedge and Safe Haven Properties of Green Bonds and Clean Energy Stocks during COVID-19 and Russian-Ukraine War: A Comparison With Gold

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Abstract: Successions of crises are currently affecting the world, which have had an impact on the worldwide financial market. Indeed, the COVID-19 pandemic and the Russia-Ukraine war have caused significant disruption, slowing global economic and financial developments. As safe havens for their portfolios, foreign investors are focusing on more dependable assets. This paper examines the safe-haven and hedging characteristics of gold, green bonds, and clean energy. According to the Dynamic Conditional Correlation (DCC)-GARCH model, the hedging ratio and hedging effectiveness index show the hedging potential of gold, green bonds and clean energy in stable and volatile market phases. Our research shows that clean energy assets can effectively reduce portfolio risk during financial uncertainty by providing stronger hedging effects than gold. However, gold remains the more cost-effective option, balancing affordability with risk mitigation. During the COVID-19 pandemic and the Russia-Ukraine conflict, both gold and clean energy assets displayed weak safe-haven characteristics, which highlighted their ineffectiveness in protecting investors during extreme market turbulence. These insights underscore the need for cautious evaluation by investors and policymakers when considering these assets for crisis portfolio strategies.

Keywords: green bonds; clean energy; safe haven; hedging ratio; hedging effectiveness.

JEL classification: G01; G11.

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1. INTRODUCTION

The global economy has indeed faced considerable challenges due to recent crises, including the COVID-19 pandemic and geopolitical conflicts. Amidst these disruptions, investors and researchers have turned their attention to hedge assets, particularly green bonds and clean energy stocks. These financial instruments have gained prominence as a new asset class, especially among environmentally responsible investors (Kuang, 2021a; Rehman *et al.*, 2023). Green bonds, in particular, have seen increased demand as they align with sustainable and renewable energy initiatives. Additionally, the COVID-19 outbreak has influenced the dynamics between green bonds, clean energy, and stock prices. Research indicates that clean energy influences stock prices positively, especially during economic retrieval periods. Moreover, the rise of renewable energy have contributed to the growing interest in green bonds. Overall, these developments highlight the importance of environmentally conscious investments in today's volatile markets.

Unlike traditional assets (gold for example), which are typically used as a hedge against common hazards, green bonds are a valuable instrument for sustainable investing that may be used to protect against financial risk, climate risk, and uncommon calamities like COVID-19 (Guo and Zhou, 2021). For instance, Yousaf *et al.* (2022) found that green is a safeguard against substantial stock market changes caused by the recent COVID-19 outbreak. For the more, during this earlier epidemic, Mensi et al (2023) indicate that green bonds are haven assets for US investors. Dong *et al.* (2023) show the dominance of green bonds over conventional bonds as a safe haven in the presence of high level of economic uncertainty and climate policy risk. Karim *et al.* (2023) show that green bonds have the diversification, hedge and safe haven properties whatever the financial market situation.

Numerous studies have been prompted by the rising popularity of clean energy stocks to examine how they interact with other assets, potentially having an impact on the stocks' potential for diversification, hedging, and safe-haven status during crisis periods (Kuang, 2021a). However, they yielded mixed results. Furthermore, while some studies have explored their properties in the context of conventional stock markets, these investigations have primarily focused on the COVID-19 pandemic. Notably, absent from the literature is an examination of green bonds and clean energy assets as hedges and safe havens during the recent Russia-Ukraine conflict.

This paper seeks to fill a critical gap in the literature by offering new insights for investors and policymakers. Specifically, it examines the effectiveness of green bonds and clean energy stocks in mitigating global stock market volatility. Furthermore, it investigates their roles as safe-haven assets during periods of heightened uncertainty, particularly during the COVID-19 pandemic and the Russia-Ukraine war. The central question guiding this study is: How do green bonds and clean energy stocks compare to gold as safe-haven assets during times of crisis, such as the COVID-19 pandemic and the Russia-Ukraine conflict? By addressing this question, we aim to enhance understanding of these assets' potential to provide stability and protection in turbulent market conditions.

This article contributes to the existing literature in three keyways. First, this study examines both green bonds and clean energy stocks that have different price determinants, as hedge and safe haven instruments. The markets for corporate and government bonds are linked to the green bond market, while the markets for stock and energy commodities are not as strongly linked (Reboredo, 2018). Henriques and Sadorsky (2008) proved that technology stock and oil each individually Granger causes the clean energy stocks. Second, we will reassess the ability of green bonds and clean energy stocks to act as a hedge and safe haven amid the COVID-19 pandemic and the conflict between Russia and Ukraine. Third, we contrast the performance of green bonds and clean energy stocks with gold, which has always been seen as a safe haven and hedging asset (Baur and Lucey, 2010).

The findings herein have important policy implications for investors and policymakers. The current geopolitical crises and macroeconomic turmoil make it unlikely that financial stress around the globe will decrease in the near future. Our study offers an important guideline on the hedge and safe-haven potentials of certain novel assets during financial distress. The findings indicate that clean energy assets have a stronger hedging effect than gold for investors, making them more effective in reducing portfolio risk in certain scenarios. However, it is important to note that their effectiveness is limited in other scenarios. Therefore, investors should carefully consider their investment goals and strategies before making any decisions. Nevertheless, gold remains the more cost-effective option, balancing affordability with risk mitigation. Importantly, both gold and clean energy assets showed only weak safe-haven characteristics during the COVID-19 pandemic and the Russia-Ukraine conflict, highlighting their limited ability to protect investors in extreme market turbulence. This information can be used to construct policies aimed at promoting financial stability and resilience. This study has the potential to guide the creation of financial products by revealing opportunities to create investments that have enhanced abilities to mitigate various forms of financial instability and serve as reliable refuges during times of economic distress.

The remainder of this paper is organized as follows. Section 2 develops the literature review while Section 3 the methodology. Section 4 describes the data and discusses the empirical outcomes while Section 5 includes the robustness analysis. Section 6 concludes the paper and gives policy implications.

2. LITERATURE REVIEW

Put differently, this study investigates the relationship between green stocks and other assets, offering valuable information to investors who are concerned about their portfolios.

Díaz *et al.* (2022), for example, studied the impact of incorporating clean energy stocks into a portfolio of traditional stocks and other assets that are often considered safe havens during the COVID-19 disease. The results indicate that clean energy stocks can contribute a significant amount of diversification to the overall equity market. In addition, these stocks can be utilized to diversify and hedge investments in commodities, cryptocurrencies, and Treasury securities. Kuang (2021b) compared the performance of clean energy stock portfolios with that of the equity market benchmark and dirty energy stocks between 2010 and 2021. Clean energy stocks are typically more profitable than dirty stocks, even though they tend to underperform the overall equity market. Naeem *et al.* (2023) delved into the extreme quantile dependence between clean energy stocks and green bonds, as well as their relationship with the GCC (Gulf Cooperation Council) stock market from 2014 to 2021. Notably, their results highlighted the following: clean energy stocks exhibit significant co-movements with GCC stocks, which indicates a degree of correlation. In contrast, climate bonds demonstrate no co-movements with other assets, suggesting that green bonds may serve as a distinct diversification option. Additionally, green bonds are viewed as a suitable option for diversifying into GCC equities, which could potentially increase portfolio stability. Returning to Kuang (2021b), the study focused on the risk management aspects: both green bonds and clean energy stocks contribute to risk diversification for investors who hold dirty energy stocks. However, there is an interesting divergence: green bonds tend to reduce risk, acting as a stabilizing force, while clean energy stocks generally increased risk within international stock index portfolios. This higher risk profile may be attributed to the inherent volatility of the clean energy sector. In recent research, Mensi et al. (2024) examine the relationship between energy futures and green bonds at times of high and low volatility. This study combines the quantile connectivity approach with the Diebold and Yilmaz (2012) spillover measure. They found that green bonds offer diversification benefits, making them attractive for investors seeking to balance risk and returns. These bonds, which fund environmentally friendly projects, provide an opportunity to align investments with sustainability goals.

Additionally, Elsayed et al. (2024) investigate the links between green bonds, clean energy, socially conscious stocks, and variations in oil shocks using wavelet quantile correlation and cross-quantilogram analysis. Empirical results highlight that green bonds act as safe havens against oil shocks, both in the short and long run. When oil prices experience sudden fluctuations, green bonds remain resilient, providing stability to portfolios. Investors interested in risk management and sustainable finance can benefit from incorporating green bonds into their strategies. In the context of the COVID-19 pandemic, Hamma et al. (2024) examine the safe-haven qualities of green bonds, gold, and bitcoin for the renewable energy markets. They use a Rvine copula to account for reliance between the returns of green bonds, gold, and cryptocurrency and renewable energy commodities. The findings demonstrate that green bonds serve as a refuge for renewable energy markets. While gold and Bitcoin fail to exhibit the same safe-haven properties, green bonds shine during times of crisis. Notably, as the pandemic intensifies, the safe-haven impact of green bonds on the stock market becomes stronger. These findings provide valuable insights for portfolio managers and renewable energy investors, emphasizing the importance of considering green bonds as part of a diversified investment approach.

In previous studies, the integration of gold and environmentally focused stocks yielded varying results. Consequently, this question remains open for further empirical investigation. By employing diverse models, we can enhance our understanding of how these assets behave across different market conditions. This empirical exploration contributes valuable insights to the ongoing discussion about safe-haven assets and risk management strategies.

3. RESEARCH METHODOLOGY

The hedge and safe haven properties have been generally examined by referring to the popular framework developed by Baur and Lucey (2010), Baur and McDermott (2010). According to these authors, “A strong (weak) hedge is defined as an asset that is negatively correlated (uncorrelated) with another asset or portfolio on average” and “A strong (weak) haven is defined as an asset that is negatively correlated (uncorrelated) with another asset or portfolio in certain periods only, e.g. in times of falling stock markets”. Hence, these properties are best investigated using the DCC–GARCH model of Engle (2002).

3.1 Dynamic Conditional Correlation (DCC)-GARCH model

In the first step of our analysis, we use Engle (2002) DCC-GARCH model to measure the time-varying correlations between the return series of the international stock market and the green bonds (clean energy stocks). This model is presented in the following manner:

$$\begin{gathered} r_{t.} \mid \Omega_{t-1} \sim N(0, H_t) \\ H_t = D_t R_t D_t \\ \varepsilon_t = D_t^{-1} r_t \end{gathered} \tag{1}$$

where r_t is a 2 by 1 vector of returns of the international stock market and green bonds (clean energy stocks) at time t; H_t is the conditional covariance matrix; ε_t is a vector of standardized residuals; and D is the 2 × 2 diagonal matrix containing time-varying standard deviations. These earliers are obtained from the following univariate GARCH model with $\sqrt{h_{i,t}}$ on the ith diagonal:

$$h_t = \omega + a\varepsilon_{t-1}^2 + bh_{t-1}^2 \tag{2}$$

where h_t indicates the conditional variance, ω denotes a constant, and a and b represent ARCH and GARCH effects, respectively.

R_t=[$\rho_{ij,t}$] represents the conditional correlation matrix:

$$R_t = diag\{Q_t\}^{-1} Q_t diag\{Q_t\}^{-1} \tag{3}$$

Q_t=[$q_{ij,t}$] is a symmetric positive definite matrix that represents the time-varying unconditional correlation matrix of ε_t. The following equations can be used to calculate the estimator of the time-varying correlation:

$$Q_t = (1 - \alpha - \beta)\widetilde{Q} + \alpha\varepsilon_{t-1}\varepsilon_{t-1}^{'} + \beta Q_{t-1} \tag{4}$$

$$\rho_{ij,t} = \frac{q_{ij,t}}{\left(\sqrt{q_{ii,t}}\sqrt{q_{jj,t}}\right)} \tag{5}$$

where: $\widetilde{Q}$ represents the unconditional correlation matrix for the standardized residuals. The model complies with mean-reverting when α+β < 1.

3.2 Hedge property

To assess the hedge property of green bonds and clean energy stocks, we follow Kroner and Ng (1998), Kroner and Sultan (1993), and Balcılar *et al.* (2016), to determine the optimal portfolio weights, optimal hedge ratio, and the hedging effectiveness, respectively. This earlier task is done based on the conditional volatilities and covariance as the output of the DCC-GARCH model described previously.

First, following Kroner and Ng (1998), we determine the optimal portfolio allocation for x (MSCI world index) and y (green bond or clean energy) assets as follows:

$$w_t^{x/y} = \frac{h_t^y - h_t^{x/y}}{h_t^x - 2h_t^{x/y} + h_t^y}$$

$$w_t^{x/y} = \begin{cases} 0, if w_t^{x/y} < 0 \\ w_t^{x/y}, if\ 0 \le w_t^{x/y} \le 1 \\ 1, if\ w_t^{x/y} > 1 \end{cases} \tag{6}$$

At time t, $w_t^{x/y}$ indicates the weight of asset x (MSCI world index) in a one-dollar portfolio of both assets (x, y). The conditional covariance between the two assets is denoted by $h_t^{x/y}$. h_t^y represents the conditional variance for asset y (alternative asset) at time t.

In this portfolio, the weight of the second asset *y* (green bond or clean energy indices) corresponds to 1-$w_t^{x/y}$.

Second, we use Kroner and Sultan (1993) optimal hedge ratio to determine the rate at which is it possible to hedge a one-unit long position in the asset (x) with a similar short position in the alternative asset (y) to improve the overall risk/return profile of the portfolio. The hedge ratio is calculated as follows:

$$\beta_t^{x/y} = \frac{h_t^{x/y}}{h_t^y} \tag{7}$$

Finally, the percentage decrease in variance between the optimal and unhedged portfolios is used to assess the effectiveness of the hedging strategy. Balcılar *et al.* (2016) state that the following formula is used to calculate hedging effectiveness (HE):

$$HE = \left[\frac{variance_{unhedged} - variance_{hedged}}{variance_{unhedged}}\right] \tag{8}$$

The term '$variance_{unhedged}$'is used to represent the variance of unhedged portfolio returns as measured by the MSCI World index. In contrast, the term '$variance_{hedged}$' denotes the variance of optimal portfolio returns, which are further enhanced by a strategic position in an alternative asset. In terms of portfolio analysis, a portfolio that has higher HE (Hedging Effectiveness) value indicates that it is more effective at reducing risk.

William F. Sharpe's introduction of the Sharpe ratio in 1966 is the ultimate evaluation of the risk-adjusted performance of hedging strategies. The Sharpe ratio, which is calculated by dividing the portfolio's excess return by its standard deviation, gives valuable insight into the efficiency of the hedging approach.

3.3 Safe haven

In alignment with BenSaïda (2023), the safe haven property is evaluated by estimating the subsequent model given the dynamic conditional correlations:

$$DCCxy,_{t} = \theta_0 + \theta_1 DCC_{xy,t-1} + \theta_2 D_{COVID} + \theta_3 D_{war} + \varepsilon_{xy,t} \quad (9)$$

In the given context *DCCx y,t* symbolizes the pairwise dynamic conditional correlation between two financial assets: y is used to indicate green bonds or clean energy stocks, and *x*.

In the given context *DCCx y,t* symbolizes the is used to indicate the MSCI World index. The correlations are dynamic and change over time depending on market conditions. The dummy variables D_{covid} and *Dwar* represent the COVID-19 period and the Russia–Ukraine conflict, respectively. Each dummy variable equals one if the returns are during the crisis, and zero otherwise.

Equation (9) serves to identify an asset as a diversifier, hedge, or safe haven. The decision-making process is based on the following rules: if θ_0 is significantly positive (not equal to 1), we will consider asset y as diversifiers for the international stock market during the whole period of study. It is a weak hedging instrument if θ_0 is insignificantly different from zero, but a strong hedging instrument if θ_0 is significantly negative. If the values of θ_2 and θ_3 are zero or significantly negative, the asset j is a weak/strong safe haven during the COVID-19 and Russia–Ukraine conflict, respectively.

4. EMPIRICAL ANALYSIS

4.1 Data and descriptive statistics

This study's sample comprises daily log returns for several financial indices: the global stock market (MSCI World Index), green bonds (S&P Green Bond Index), and clean energy stocks (S&P Global Clean Energy Index). Additionally, we incorporate gold (S&P GSCI spot price index) for comparative analysis. To compute portfolio excess return, we use the 3-month US Treasury bill. The data originates from DataStream, spanning from January 3, 2019 to June 15, 2023. Notably, this comprehensive sample encompasses two pivotal crisis periods. The first was the COVID-19 pandemic, officially declared by the World Health Organization on March 11, 2020. The second crisis emerged from the Russia-Ukraine conflict, initiated by Russia's invasion of Ukrainian territory on February 24, 2022, and persisted until the trial period's conclusion on February 24, 2022. Table no. 1 presents the descriptive statistics of daily returns.

In Table no. 1, we present a brief summary of daily returns statistics. Notably, the clean energy index consistently exhibits the highest mean return over the entire study period, while green bonds yield the lowest mean return. This divergence underscores the inherent risk-reward trade-off within these asset classes. The robust mean return observed for the clean energy index is accompanied by heightened return volatility. This aligns with the research findings of Dutta *et al.* (2020) and Nguyen *et al.* (2021), who emphasize the clean energy market's propensity for significant fluctuations while maintaining its fundamental profitability. Remarkably, these results hold even during the challenging times of the COVID-19 pandemic crisis. However, during the Russia-Ukraine conflict, clean energy index returns turned negative, and the associated risks escalated. It's essential to recognize that all return series exhibit negative skewness (except for the clean energy index during the Russo-Ukrainian war) and have kurtosis values greater than 3. Moreover, the Jarque-Bera test unequivocally rejects the assumption of normal distribution for all return series. Additionally, the Ljung-BoxQ (12) statistic indicates autocorrelation in the returned series. Standard unit root tests may be biased towards non-rejection of the null hypothesis due to the presence of a structural break. In our study, the results of the ADF test with Breaks are similar to those of the standard ADF test.

Table no. 1 – Descriptive statistics of daily returns

	MSCI world	**Clean energy**	**Green bonds**	**Gold**
Panel A : Total period				
Mean	0.0004	0.0007	-0.0001	0.0004
Std. dev.	0.0122	0.0196	0.0045	0.0113
Skewness	-0.9864	-0.4235	-0.4946	1.1138
Kurtosis	14.08	8.62	9.11	18.01
Jarque-Bera	5378.58*** (0.00)	1370.62*** (0.00)	1628.60*** (0.00)	9772.74*** (0.00)
ADF	-18.13*** (0.00)	-17.32*** (0.00)	-16.27*** (0.00)	-15.87*** (0.00)
Q(12)	23.757*** (0.00)	42.659*** (0.00)	46.833*** (0.00)	29.383*** (0.00)
$Q^2(12)$	819.15*** (0.00)	659.55*** (0.00)	198.14*** (0.00)	73.798*** (0.00)
ADF with break t-stat.	-30.8195(<0.01)	-27.7439(<0.01)	-27.1531(<0.01)	-33.2583(<0.01)
Panel B : COVID-19				
Mean	0.0014	0.0039	0.0002	0.0004
Std. dev.	0.0171	0.0271	0.0045	0.0156
Skewness	-1.0556	-0.7261	-1.3645	1.3250
Kurtosis	12.76	7.09	12.23	15.39
Jarque-Bera	868.77*** (0.00)	164.43*** (0.00)	807.76*** (0.00)	1399.20*** (0.00)
ADF	-14.28*** (0.00)	-13.42*** (0.00)	-9.07*** (0.00)	-15.30*** (0.00)
Q(12)	127.70*** (0.00)	89.50*** (0.00)	58.00*** (0.00)	73.58*** (0.00)
$Q^2(12)$	115.26*** (0.00)	140.56*** (0.00)	114.38*** (0.00)	60.89*** (0.00)
ADF with break t-stat.	-29.8904(<0.01)	-28.3292(<0.01)	-23.0325(<0.01)	-29.7599(<0.01)
Panel C : Russia-Ukraine war				
Mean	0.0001	-0.0006	-0.0005	0.0001
Std. dev.	0.0109	0.0187	0.0052	0.0096
Skewness	-0.4082	0.1172	-0.2145	-0.2979
Kurtosis	6.36	5.33	6.88	4.72
Jarque-Bera	273.63*** (0.00)	126.24*** (0.00)	348.78*** (0.00)	76.51*** (0.00)
ADF	-17.30*** (0.00)	-16.07*** (0.00)	-15.42*** (0.00)	-13.59*** (0.00)
Q(12)	113.35*** (0.00)	82.51*** (0.00)	106.37*** (0.00)	141.85*** (0.00)
$Q^2(12)$	142.28*** (0.00)	182.93*** (0.00)	112.99(0.00)	169.57*** (0.00)
ADF with break t-stat.	-35.0600(<0.01)	-34.4659(<0.01)	-36.6909(<0.01)	-38.7837(<0.01)

This table reports the descriptive statistics for the daily returns for the conventional stock market (MSCI world), clean energy stocks (S&P Global Clean Energy index) green bonds (S&P Green Bond Index), and gold. The study's period is from January 03, 2019, to June 15, 2023. Panel A shows results over the entire period, while Panel B includes the results during the COVID-19 outbreak and Panel C represents the results during the Russia-Ukraine conflict. Q (12) and Q2 (12) denote the Ljung-Box statistics up to 12th order in residuals and squared residuals, respectively. P-values are in parentheses. The Breakpoint Unit Root test is designed to identify breakpoints using Dickey Fuller min-t and innovation outlier.
Note: ***indicates statistical significance at 1%.

Table no. 2 presents the unconditional correlations for the entire sample and both crisis periods. In terms of pairwise correlations, gold demonstrates the lowest associations with both MSCI World Clean Energy and green bonds. Conversely, there is a consistent negative correlation between gold and conventional stock indexes, which persists not only over total period but also throughout the COVID-19 pandemic. Gold has the potential to be a safe haven during crisis times Baur and Lucey (2010).

Table no. 2 – Unconditional correlation matrix

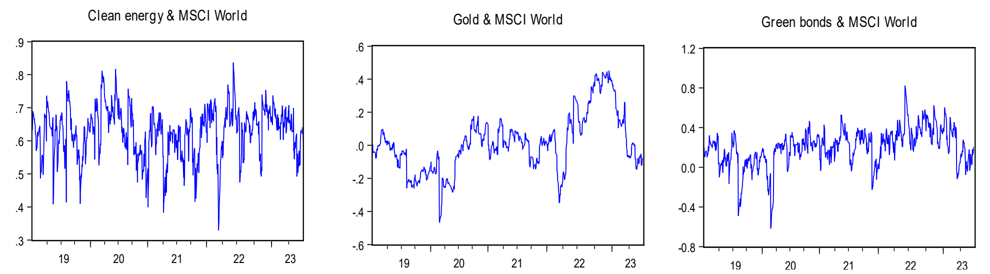
Panel A : Total period				
	MSCI world	**Clean energy**	**Green bonds**	**Gold**
MSCI world	1.00***			
Clean energy	0.69***	1.00***		
Green bonds	0.31***	0.28***	1.00***	
Gold	-0.01	0.07***	0.26***	1.00***
Panel B : COVID-19				
	MSCI world	**Clean energy**	**Green bonds**	**Gold**
MSCI world	1.00***			
Clean energy	0.77***	1.00***		
Green bonds	0.39***	0.35***	1.00***	
Gold	-0.07	0.02	0.20***	1.00***
Panel C : Russia-Ukraine war				
	MSCI world	**Clean energy**	**Green bonds**	**Gold**
MSCI world	1.00***			
Clean energy	0.61***	1.00***		
Green bonds	0.43***	0.33***	1.00***	
Gold	0.16***	0.20***	0.34***	1.00***

This table shows the unconditional correlation between the MSCI World index and clean energy, green bonds, and gold.
Note: ***indicates statistical significance at 1%.

4.2 Estimation results

4.2.1 DCC -GARCH estimations

We have employed the DCC-GARCH model to analyze time-varying correlations, as illustrated in Figure no. 1. These correlations exhibit remarkable fluctuations across various periods and markets. Notably, MSCI World, green bonds, clean energy stocks, and gold have consistently shown a downward trend in dynamic correlations until late 2019. However, since 2020 – amidst the COVID-19 pandemic and the Russia-Ukraine conflict in 2022 – these correlations have undergone a substantial increase. This shift highlights the impact of global events on market interdependencies and underscores the need for adaptive risk management strategies. The pronounced peak in conditional correlations across almost all markets during 2020 can be attributed to the pervasive uncertainty triggered by the COVID-19 pandemic. This observation aligns with findings from various studies, including those by Zhang *et al.* (2020) and Adekoya and Oliyide (2021).



Note: The figure illustrates the dynamic conditional correlations determined with the DCC-GARCH model between the MSCI World index and clean energy stocks, green bonds, and gold.

Figure no. 1 – The dynamic conditional correlations

Moreover, the financial markets, particularly in Russia and Europe, bore the brunt of the conflict between Russia and Ukraine. The resulting decline in stock prices was driven by investor caution, as they hesitated to allocate capital to these regions. Consequently, international investors are now compelled to refine their optimal asset allocation strategies. Notably, during crisis periods, the prices of gold and stocks tend to rise, making them attractive options for safeguarding wealth as highlighted by BenSaïda (2023).

4.2.2 Optimal portfolio weights

Table no. 3 provides a summary of the optimal portfolio design for conventional stocks, indexes, and other financial assets throughout the entire period, which encompasses the COVID-19 crisis and the Russia-Ukraine conflict.

Table no. 3 – Optimal portfolio weights

	Mean	S.D.	Min	Max
Panel A: Total period				
Clean energy	0.0724	0.1160	0.0000	1.0000
Green bonds	0.9084	0.0801	0.6239	1.0000
Gold	0.4847	0.1523	0.1124	1.0000
Panel B: COVID-19				
Clean energy	0.0228	0.0619	0.0000	0.3608
Green bonds	0.9335	0.0511	0.7791	1.0000
Gold	0.4394	0.1441	0.1124	0.7835
Panel C: Russia-Ukraine war				
Clean energy	0.0604	0.1048	0.0000	0.5967
Green bonds	0.8587	0.1048	0.6239	1.0000
Gold	0.5733	0.1482	0.2833	0.9414

Based on the findings, it can be concluded that in order to reduce risk while maximizing expected return, it is advisable to allocate more than 85% of the portfolio to green bonds and 40% for gold throughout the period, and sub-periods, on average. For clean energy, the optimal weights are low and do not exceed 10% for regardless of the period. The findings indicate that green bonds are the preferred option for minimizing risk in a portfolio that includes the MSCI Global Index, rather than clean energy or gold. According to the findings, the optimal weights for gold increased during the Russian-Ukrainian conflict (57,33%), compared to the optimal weights during the entire period (48,47%) and the COVID-19 pandemic (43,94%).

4.2.3 Hedge property

Employing optimal hedge weights and ratios provides a broad understanding of constructing a hedge to minimize risk. However, these measures do not offer insights into the long-term effectiveness of the hedge. Therefore, Table no. 4 displays the Hedge Effectiveness (HE) index, which addresses this aspect.

Table no. 4 – Optimal hedge ratios and hedging effectiveness

	HR	HE (%)
Panel A : Total period		
Clean energy	0.3903	0.4640
Green bonds	0.4774	0.0986
Gold	0.0273	0.0499
Panel B : COVID-19		
Clean energy	0.3229	0.4954
Green bonds	0.6050	0.0514
Gold	-0.0186	0.0331
Panel C : Russia-Ukraine war		
Clean energy	0.4128	0.4377
Green bonds	0.6154	0.1837
Gold	0.1874	0.0760

This table represents the optimal hedge ratios (HR) and hedging effectiveness (HE) indices in percent clean energy stocks , green bonds, and gold during Total period, the COVID-19 pandemic and the Russia-Ukraine war.

Based on Table no. 4, in order to mitigate risk in the asset that requires hedging, investors must adopt opposing positions in both the hedging asset and the asset that needs to be hedged. Conversely, if investors have a negative HR (hedge ratio), they should take the same position, whether long or short, in both assets. For instance, to hedge a long position of $1 in the MSCI world, one would need to short 39.03 cents in clean energy. Similarly, to hedge a long position of $1 during the COVID-19 pandemic, one would need to take a long position of 1.86 cents in gold. According to López Cabrera and Schulz (2016), if the hedge ratio is lower in absolute value, the hedge is less costly. Results show that using gold as a hedge is less expensive than using clean energy or green bonds.

Asset coverage was less expensive throughout the entire period than during the COVID-19 pandemic and the Russia-Ukraine war (Akhtaruzzaman *et al.*, 2021). This result is in line with the literature, which shows that during times of crisis, as noted by Batten *et al.* (2021), higher hedge ratios are observed because of the significant rise in uncertainty surrounding the financial and economic future. According to Table no. 4, clean energy is more effective in hedging and reducing risks than gold and green bonds. This observation pertains to the entire sample and the crisis of COVID-19 and Russia-Ukraine conflict. Gold's hedging capacity is surprisingly low, particularly during the COVID-19 pandemic, despite its cheaper hedging cost (low HR).

Our findings have significant implications. The sample period's frequent fluctuations in hedging ratios imply that the covered positions ought to be revised on a regular basis. Therefore, disregarding any notable fluctuations in markets might lead to unfavorable decisions for foreign investors who want to diversify their portfolios and protect their investment. Moreover, despite the notion that gold performs better in these situations, the current crisis has led investors and portfolio managers to reassess their faith in precious metals (Baur and McDermott, 2010).

4.2.4 Safe haven property

In this part, we focus on the extreme negative variations in the MSCI world index to analyze the hedging, diversifier, and safe haven characteristics of these assets for a passive investor. The analysis is summarized in Table no. 5. Our first point of discussion is the estimations of θ_0, which is the coefficient that enables us to distinguish between diversifier and hedge properties. With the exception of the clean energy market, all markets have a negative and insignificant coefficient of θ_0. This suggests that, over the sample period, gold and green bonds could serve as a weak hedge against changes in the conventional stocks index. Nonetheless, Clean Energy functions as a diversifier against MSCI world volatility, as suggested by the asset's positive and noteworthy θ_0 estimate. This is in fact consistent with Kuang (2021b), who shows that investors can gain from risk diversification by investing clean energy stocks.

Table no. 5 – Hedge and safe haven features

	Hedge(θ_0)	$DCC_{xy,t}$ (θ_1)	$COVID$ (θ_2)	War (θ_2)
Clean energy	0.0751***(0.00)	0.8784***(0.00)	0.0008(0.75)	0.0026(0.36)
Green bonds	-0.0102 (0.17)	0.9078***(0.00)	0.0238 ***(0.00)	0.0423 ***(0.00)
Gold	-0.0015 (0.71)	0.9839***(0.00)	0.0002(0.96)	0.0042(0.39)

This table reports the estimation results of the safe haven model. P-values are in parentheses.
Note: ***indicates statistical significance at 1%.

Upon examining the remaining model coefficients (θ2 and θ3), we find that the estimates for gold and clean energy are insignificant and/or negative in all quantiles. This observation reinforces the assets' feeble safe haven features against severe MSCI world downturns, such as those that occurred during the COVID-19 pandemic and the conflict between Russia and Ukraine.

Our results reinforce the findings of Hood and Malik (2013), Dutta *et al.* (2020), Hussain Shahzad *et al.* (2020); Shahzad *et al.* (2020)and Akhtaruzzaman *et al.* (2021), who provide evidence of gold as a weak safe haven against the downside risk of portfolios. For green bonds, the coefficients θ_2 and θ_3 are found to be significantly positive indicating green bonds don't always provide a safe refuge amid severe market downturns.

5. ROBUSTNESS TEST

We conduct a robustness analysis utilizing the Safe Haven Index (SHI) developed by Baur *et al.* (2024) Baur and Dimpfl (2021) to validate our findings and assess the safe-haven properties of green bonds, clean energy stocks, and gold. The SHI is a performance indicator that identifies the average price change for multiple safe-haven assets, as specified by:

$$SHI_t = \exp[ln(SHI_{t-1}) + R_t^b] \tag{10}$$

Let R_t^b represent the equally weighted return of n-assets, calculated as follows:

$$R_t^b = \frac{1}{n}\sum_{i=1}^{n} R_{it} \tag{11}$$

Here, R_{it} denotes the logarithmic return of the i[th] asset in the basket from time *t-1* to *t*, based on daily closing prices. Following Baur *et al.* (2024) Baur and Dimpfl (2021), the regression can be expressed as:

$$R_{i,t} = \mu_i + \theta_i \triangle SHI_t + \varepsilon_{i,t} \tag{12}$$

In this equation, $R_{i,t}$ indicates the return of asset i at time t , and $\triangle SHI_t$ represents the log-return of the safe haven index during that period. For each index, we estimate the parameters μ_i and θ_i . According to this model, an ideal safe haven index would yield μ_i= 0 and θ_i = 1. Baur *et al.* (2024) Baur and Dimpfl (2021) classify a strong safe haven index as one withμ_i = 0 and $\theta_i \geq 1$, while an index is considered a weak safe haven if \ μ_i = 0 and 0 < θ_i <1. The results are presented in Table no. 5 – we determine the first SHI by using SHI0 = 100, as suggested by Baur and Dimpfl (2020).

Table no. 6 – Robustness check test

	µ	Theta (θ)
Panel A : COVID-19		
Clean energy	0.00(0.52)	1.8249***(0.00)
Green bonds	0.00(0.73)	0.1684*** (0.00)
Gold	0.00(0.47)	0.6215*** (0.00)
Panel B : Russia-Ukraine war		
Clean energy	0.00(0.36)	0.9293*** (0.00)
Green bonds	0.00*** (0.01)	-0.1970*** (0.00)
Gold	0.00(0.69)	0.3736***(0.00)

This table reports the estimated results for link between safe haven index (SHI) with D Clean energy, Green bonds and Gold during COVID-19 period and the Russia-Ukraine war.
Note: "***" and "**" indicate significance at the 1% and 5% level respectively. P-values are shown in parentheses.

Table no. 6 above illustrates the relationship between the Safe Haven Index (SHI) and the assets of clean energy, green bonds, and gold. In our analysis, the SHI comprises these three assets.

Panel A: COVID-19 Period:

Panel (A) of Table no. 5 presents the estimated coefficients for the relationship between the SHI and the three assets during the COVID-19 pandemic. Our findings indicate that all three assets exhibit non-zero but statistically insignificant values for μ_i, alongside significant coefficients for θ_i that are less than one. This suggests that while these assets can provide some degree of safe haven, their effectiveness is weak during this health crisis.

Panel B: Russian-Ukraine War:

Panel (B) of Table no 6 details the estimated coefficients for the relationship between the SHI and the same assets during the Russian-Ukraine conflict. The results for clean energy and gold indicate that these assets can also offer a weak safe haven during the war. However, the findings reveal that green bonds have a significant and negative θ_i, indicating that they do not meet the criteria for a safe haven index during this geopolitical turmoil.

These results align with those obtained through the DCC-GARCH model, as well as the hedging ratio and hedging effectiveness index. Consequently, the robustness of our previous methodologies is reinforced by these findings.

6. CONCLUSION

Financial markets worldwide have been severely affected by the COVID-19 pandemic in 2020 and the Russian-Ukraine war in 2022. The necessity to explore alternative investment opportunities that can withstand these challenging circumstances has arisen due to the erosion of investor trust in traditional financial institutions. As a result, hedge assets that offer protections against extreme events, such as green bonds and clean energy stocks, have gained popularity among both investors and researchers. Our study directly compares the properties of clean energy, green bonds, gold hedging, and safe haven characteristics against the conventional stock index MSCI World. The sample period spans from January 3, 2019, to June 15, 2023. Utilizing the Dynamic Conditional Correlation (DCC)-GARCH model, we analyze hedge ratios and hedge effectiveness indexes. These metrics provide insights into the hedging potential of gold, green bonds, and clean energy assets across stable and volatile market condition.

Our analysis reveals that while clean energy and green bonds are more effective at hedging and reducing risks compared to gold, the latter remains a less expensive option for hedging. This finding aligns with the literature, particularly Batten *et al.* (2021), who note that higher hedge ratios emerge during crises due to increased uncertainty regarding financial and economic futures. Throughout the entire sample period, gold and green bonds were identified as weak hedges against fluctuations in the conventional stocks index. In contrast, clean energy serves as a diversifier against fluctuations in the MSCI World Index, consistent with Kuang (2021b), which indicates that investors can achieve risk diversification through clean energy stocks.

Our results suggest that both gold and clean energy exhibit weak safe-haven properties during extreme global downturns, such as the COVID-19 crisis and the Russia-Ukraine conflict. Green bonds fail to provide effective shelter during severe market downturns, reinforcing findings from Hood and Malik (2013), Dutta *et al.* (2020), Shahzad *et al.* (2020), and Akhtaruzzaman *et al.* (2021), who provide evidence of gold's limited safe-haven capabilities against portfolio downside risk.

These insights are crucial for governments, investors, and regulators seeking to mitigate losses during periods of high uncertainty. However, it is essential to approach these conclusions with caution, as the ongoing impact of the Russia-Ukraine war on global financial markets may obscure the full picture for some time. Additionally, our analysis highlights significant dynamic correlations among these assets, indicating their interdependencies and the necessity for investors to consider the broader context when making investment decisions.

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