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Are Precious Metals Hedging Assets for Clean Energy Indices?

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Abstract

This study aims to analyse whether precious metals can be hedged assets concerning green energy indices from 8 January 2019 to 6 December 2024. About precious metals, the futures market was analysed: copper (HGH5) and silver (SIH5), the gold spot market (XAU) was also included to provide robustness, and the green indices are S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN). The sample was divided into four sub-periods: 8 January 2019 to 31 December 2019, referred to as Pre-Covid-19; the second sub-period, referred to as the first Covid-19 Wave, comprises the period from 2 January 2020 to 31 December 2020; the second Covid-19 Wave includes the years from 2 January 2021 to 23 February 2022; Finally, the last sub-period, called Conflict, covers the years from 24 February 2022 to 6 December 2024. The green indices (CELS, ICLN, SPGTCLEN) showed extremely high correlations with each other in all periods, reducing the effectiveness of diversification in the sector. Gold remained a consistent, safe haven asset, with negative or very low correlations with the green indices, especially during global crises. Silver evolved from moderate to negative correlations with the green indices, reinforcing its usefulness as a hedging asset. Copper, initially positively correlated with green indices, has exhibited negative correlations recently, making it a strategic asset in portfolios with green energy assets. It was also found that only copper (HGH5) was contagious during the first wave of COVID-19, which validates the evidence found earlier through unconditional correlations. In conclusion, these results highlight that gold and silver effectively protect against market shocks, while copper can be used as a diversifying asset in green energy portfolios, thus requiring differentiated strategies to maximise diversification benefits.

Keywords: *Green Energies, Futures Markets, Precious Metals, Hedging Assets, Safe Haven, Portfolio Rebalancing.*
Jel Classification: C01, C32, C38, G10, G11, G14, Q42

Introduction

Over the last two centuries, polluting energy resources such as coal, oil and gas have driven industrialisation and economic growth but have worsened the environment, such as climate change. The transition to clean energy sources such as solar, wind, hydroelectric and geothermal has attracted significant investment, making renewable energy a strategic sector for economic growth. The WilderHill index, created in 2004, tracks publicly traded companies dedicated to clean technologies such as solar panels, wind turbines and biofuels and is an important benchmark for investors in the sector (Dias et al., 2024).

In this context, clean energy stocks are emerging as a new asset class, attracting investors and academics. However, they present significant risks, requiring hedging assets to mitigate them. In practical terms, precious metals, such as gold, are known for their effectiveness as a hedge against fluctuations in the financial markets. The question, therefore, arises as to the relationship between green stock indices and

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precious metals, especially in the context of hedging and risk management (Horta et al., 2023; Agrawal et al., 2024; Dias, Galvão, & Alexandre, 2024).

Studies such as Henriques and Sadorsky (2008), Kumar et al. (2012), and Sadorsky (2012) have analysed the factors that influence the returns of renewable energy companies, highlighting the impact of oil prices, stock indices and carbon prices. These studies have shown that the returns of high-tech and renewable energy stocks are highly correlated, reflecting the sector's dependence on macroeconomic factors and technological innovation.

Analysing the level of integration and the shocks between markets is essential to understanding the costs and benefits involved. For example, Oliveira et al. (2024) argue that financial integration offers important advantages in economic stability. However, in times of crisis, the high level of interconnection between markets can increase the risk of contagion. Despite this, the general view is that, in the long term, the benefits of financial integration tend to outweigh the associated costs. In a complementary way, the authors Dias, Galvão, Cruz, et al. (2024) show that portfolio rebalancing must be aligned with the investor's intentions and risk tolerance, which is crucial in global uncertainty. This portfolio diversification strategy involves selling valued assets and directing resources to underperforming assets, maintaining diversification and avoiding excessive concentration in asset classes, sectors or regions.

This study contributes to the existing literature by exploring the efficacy of precious metals as hedging assets in relation to green energy indices, a topic that has yet to be addressed in the specific context of green energy and sustainability markets. In contrast to previous studies that analyse traditional assets or broader sectors, this research innovates by integrating three green indices (SPGTCLEN, CELS, ICLN) with international relevance and precious metals markets (gold, silver and copper), both on the spot and futures markets, giving greater robustness to the analyses. In addition, dividing the sample into four specific sub-periods - Pre-Covid-19, 1st and 2nd Covid-19 Waves, and Conflict, allows us to assess differentiated temporal dynamics, offering a detailed perspective on the impacts of disruptive global events on the relationship between these assets. This temporal and focused approach to green markets and precious metals fills gaps in the literature, contributing to risk management and hedging strategies in sustainable financial markets. As far as is known, the authors Dias, Chambino, et al. (2023), Manuel et al. (2024), and Oliveira et al. (2024) evaluated precious metals from the perspective of hedging assets in international financial markets. However, the research questions, the methodology employed, the assets analysed, and the time frame differ from those in this study.

In addition to this section, section 2 presents the literature review, and section 3 provides the data and methodology. The empirical results are discussed in section 4. Section 5 deals with the conclusion and the main practical implications.

Literature Review

The transition to a carbon-resilient economy has gained prominence, driven by the Paris Agreement (2015) and COP26 (2021), reinforcing the goal of limiting global warming to 1.5 °C. This shift involves replacing carbon-intensive energy sources such as coal and oil with clean alternatives such as solar and wind power. Despite the challenges of balancing immediate economic benefits and long-term environmental costs, companies and investors are paying attention to the risks of carbon-intensive industries and the opportunities in renewable energy, energy efficiency and low-carbon transport (Tzeremes et al., 2023; Ettinger et al., 2023).

Related Studies on Hedging Assets

Increasing interest and investment in clean energy reflects growing global concern about climate change and the need for sustainable practices. Despite the growth of the clean energy stock market, it is marked by high volatility and significant risks. In this scenario, hedging assets such as precious metals, especially gold, play a crucial role. Used strategically, they help mitigate risks, offering greater security and promoting more effective management of portfolio diversification (Kakinuma, 2022; Caporale and Gil-Alana, 2022).

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The studies by the authors Baur and Lucey (2010) and Jin et al. (2019) converge in analysing gold as a hedge and safe haven asset, but they address different contexts and assets. Baur and Lucey (2010) concluded that gold is an effective hedge against equities in normal market conditions and a safe haven in extreme financial crises. On the other hand, Jin et al. (2019) investigated gold together with crude oil and Bitcoin, highlighting that gold has a positive correlation with crude oil but a negative correlation with Bitcoin, suggesting that gold also has hedging properties. Both studies confirm gold's role as a hedging asset, although Jin et al. (2019) extend the analysis to other assets, such as Bitcoin, whose hedging properties are more complex.

Similarly, the authors Chen and Wang (2017) found that gold acts as a hedge in China's stock market, especially during periods of downturns, but the authors show poor performance in calmer periods. In addition, the authors Hussain Shahzad et al. (2020) compared the performance of gold and Bitcoin against the G7 markets, concluding that gold is an effective hedge and safe haven in these capital markets, while Bitcoin only performs these functions in Canada. Gold outperformed Bitcoin in terms of diversification and protection, especially during periods of market falls.

Gustafsson et al. (2022) and Erdoğan et al. (2022) analysed the relationship between energy metals and clean energy indices, concluding that although energy metals show positive correlations with clean energy indices, they do not function as hedging or safe haven assets. In contrast, precious metals such as gold and silver have demonstrated hedging properties for green indices, especially during periods of high volatility.

In a complementary way, the studies by the authors Bahloul et al. (2023) and Sharma and Karmakar (2023) investigate whether gold and Bitcoin functioned as safe-haven assets in periods of crisis. Bahloul et al. (2023) concluded that gold acts as a hedge in most markets analysed during the pandemic, with Bitcoin acting as a strong hedge in the US and China. On the other hand, the authors Sharma and Karmakar (2023) assessed whether gold, USD and Bitcoin act as hedge assets and safe havens in relation to stocks, as well as their usefulness in diversifying risk when capital markets show structural breaks. The authors argue that the US dollar (USD) has the most significant hedge and safe haven characteristics, followed by gold, while Bitcoin has the lowest effectiveness.

The studies by Dias, Chambino, et al. (2023) and Dias, Alexandre, et al. (2023b) converge in exploring the impacts of the events of 2020 and 2022 on the interactions between financial markets and alternative assets, but they diverge in terms of the assets analysed and their conclusions. Dias, Chambino, et al. (2023) focused on the movements between European capital markets and traditional commodities such as oil and precious metals, concluding that these assets did not act as safe haven assets, given the significant increase in causal relationships between the markets, indicating greater interdependence. On the other hand, the authors Dias, Alexandre, et al. (2023b) evaluated the ability of cryptocurrencies to function as safe havens against sustainable energy indices. Unlike commodities, clean energy indices proved to be a viable safe haven for "dirty" cryptocurrencies, although this relationship varies between different cryptocurrencies. In short, both studies highlight how recent crises have intensified interactions between markets and assets but point to significant differences in the effectiveness of different asset classes as safe havens. While commodities have failed in this role, clean energy indices have shown greater potential, albeit limited to cryptocurrencies with specific characteristics.

Dias, Galvão, and Alexandre (2024) and Dias, Chambino, Galvão, et al. (2024) analysed how global events, such as the 2020 pandemic and the Russian invasion of Ukraine in 2022, affected the interconnections between financial markets and alternative assets. Dias, Galvão, and Alexandre (2024) focus on the study of the movements between the capital markets of MENA countries and precious metals (gold, silver and platinum). The authors found that precious metals, especially platinum, play an important role as hedge assets during periods of market stress. Complementing, Dias, Chambino, Galvão, et al. (2024) explored the relationship between capital markets and cryptocurrencies, showing that capital markets (MOEX and DAX 30) influence cryptocurrencies, especially during the 2022 geopolitical crisis. Both studies suggest that investors can adjust their trading strategies to rebalance portfolios in times of crisis.

Dias, Galvão, Cruz, et al. (2024) and BenMabrouk et al. (2024) have investigated the effectiveness of hedging assets in different contexts. The study by Dias, Galvão, Cruz, et al. (2024) analyses the movements

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between clean energy indices and the oil market (WTI), concluding that although clean energy indices show some interdependence, the WTI has a significant influence, indicating that the clean energy market is still vulnerable to oil fluctuations. The study by BenMabrouk et al. (2024) investigates the relationship between NFTs and traditional assets (such as the S&P 500 and Bitcoin), finding weak dynamics between NFTs and other assets, suggesting that NFTs do not yet act as effective hedging assets. Both studies indicate that traditional assets, such as oil and Bitcoin, remain central to portfolio diversification and hedging against extreme volatility in financial markets.

The importance of this study lies in analysing the potential of precious metals as hedging assets against green energy indices, especially during periods of global crisis such as the COVID-19 pandemic and the conflict in Ukraine. Green energy indices, which reflect the growth of renewable energies, can be highly volatile and susceptible to external shocks. Therefore, understanding whether precious metals, traditionally seen as stores of value, can mitigate risks in these markets offers crucial information for investors who have sought to protect clean energy investment portfolios against significant structural breaks in the financial markets.

Method and Data

The data used in the research are the daily index prices of precious metals on the futures market: copper (HGH5) and silver (SIH5), the spot market for gold (XAU), and the green indices are S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN), for the period from 8 January 2019 to 6 December 2024. To make it more robust, we partitioned the sample into 4 sub-periods: 8 January 2019 to 31 December 2019 referred to as Pre-Covid-19; the second sub-period referred to as the 1st Covid-19 Wave comprises the period from 2 January 2020 to 31 December 2020; the 2nd Covid-19 Wave includes the years from 2 January 2021 to 23 February 2022; finally, the last sub-period referred to as Conflict comprises the years from 24 February 2022 to 6 December 2024. The data was obtained through the Thomson Reuters Eikon platform and is represented in local currency to mitigate exchange rate distortions and possibly bias results.

Table 1. Summary Table Describing the Assets And Indices Analysed in the Study from 8 January 2019 To 6 December 2024.

Asset/Index	Description	Code
Copper (Futures)	Copper futures contract, is a widely used metal in industry and construction.	HGH5
Silver (Futures)	Silver futures, a precious metal used in electronics and jewellery, considered a hedge against economic risks.	SIH5
Gold (Spot Market)	The price of gold on the spot market, used as a reserve and hedge against inflation and economic instability.	XAU
S&P Global Clean Energy (Índice)	It is an Index that tracks global clean energy technology companies, such as solar and wind.	SPGTCLEN
NASDAQ Clean Edge Green Energy (Índice)	It is an Index that reflects the performance of clean energy and energy efficiency technology companies.	CELS
iShares Global Clean Energy ETF (Fundo)	It is an ETF that invests in clean energy companies, including solar, wind and other renewable sources.	ICLN

Methodology

This section presents the methodology and the tests used to answer the research question. The methodological process of this study was carried out in several stages. The first stage was to characterise the sample by applying a set of descriptive statistical methods. In addition, in order to analyse the data distribution of the seven time series and test the assumption of normality, the Jarque and Bera (1980) adherence test was applied, and the quantile graphs were analysed to check the residuals of the time series. In a second step, to validate the stationarity of the time series, the panel unit root tests of Breitung (2000),

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Levin, Lin, and Chu (2002), and Im et al. (2003) were applied. The Dickey and Fuller (1981), Phillips and Perron (1988), tests with Fisher's transformation were used to validate the results. The unconditional correlations will be estimated to answer the research question, i.e. whether precious metals can be considered hedging assets against green energy indices, and their significance will be analysed.

One way of testing the statistical significance of the correlation coefficient is to use the *t*-statistic, which follows the t distribution with $n-2$ degrees of freedom, where r is the correlation coefficient between two series and n is the number of observations. To test whether the correlation coefficient matrix is globally different from the identity matrix, we use the likelihood ratio test, suggested by Pindyck and Rotemberg (1990). In order to verify the existence or absence of risk transmission between markets, the Forbes and Rigobon (2002) two-sample heteroscedasticity t-test will be applied. This methodology posits the null hypothesis that the correlation in the Stress sub-period is lower than or equal to the correlation in the Smooth sub-period against the alternative hypothesis that the correlation is higher and significant in the Stress period. Rejection of the null hypothesis has economic significance for the contagion phenomenon; non-rejection shows interdependence. In terms of the model, the estimation steps are as follows:

$$H_0 = r_{i,j}^{t} \geq r_{i,j}^{0} \qquad H_1 = r_{i,j}^{t} < r_{i,j}^{0}$$

Where $r_{i,j}^{t}$ is the correlation coefficient between market i and market j, in period t.

In the above hypotheses, the Stress sub-period corresponds to the value "1", while the Tranquil sub-period corresponds to the value "0".

The use of this test takes into account Fisher's (1930) transformation, which in turn is applied to the correlation coefficients in such a way that they have an approximately normal distribution, in asymptotic terms, with mean μ_t and variance σ_t^2, defined as follows:

$$\mu_t = \frac{1}{2} ln\left(\frac{1+r_{i,j}^{t}}{1-r_{i,j}^{t}}\right)$$

$$\sigma_t^2 = \frac{1}{n_t-3}$$

The test statistic is determined from

$$U = \frac{\bar{\mu}_1-\bar{\mu}_0}{(\sigma_0^2+\sigma_1^2)^{\frac{1}{2}}}$$

where μ_t and σ_t^2 are the transformed sample mean and variance. The test statistic follows a normal distribution, with a mean 0 and a variance 1.

Results

In Table 2, the results of the main statistics are shown. The green indices (CELS, SPGTCLEN, ICLN) showed slightly higher average returns than the precious metals. CELS (0.0117) and ICLN (0.0091) stood out for their higher volatility, reflected in the higher standard deviations. Silver (SIH5) was the most volatile asset, with a standard deviation of (0.0122), while gold (XAU) was the least volatile, with a standard deviation of (0.0071).

Negative skewness was observed in all assets except gold, with CELS (-0.6481) showing the highest negative skewness, while gold had a slightly higher positive skewness (0.0693). In practical terms, the assets showed a kurtosis greater than 3, indicating leptokurtic distributions, with silver (5.9632) showing the greatest kurtosis, suggesting the greater frequency of extreme events.

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The Jarque-Bera tests confirmed that the distributions of returns do not follow a normal distribution, with significant values in all assets. To summarise, the green indices showed greater risk and higher volatility, while precious metals, especially gold, stood out for their relative stability.

Table 2. Summary Table of the Main Descriptive Statistics for the Green Energy and Precious Metals Indices from 8 January 2019 to 31 December 2019.

	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
Mean	0.0012	0.0002	0.0012	0.0005	0.0011	0.0006
Std. Dev.	0.0117	0.0096	0.0091	0.0122	0.0080	0.0071
Skewness	-0.6481	-0.0155	-0.4103	-0.0122	-0.2014	0.0693
Kurtosis	4.6378	4.1322	4.2823	5.9632	4.0596	4.0712
Jarque-Bera	47.26	13.91	25.11	95.13	13.92	12.64
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	260	260	260	260	260	260

Table 3 shows the results of the statistical tests for the green and precious metals markets from 1 January 2020 to 31 December 2020. The green indices (CELS: 0.0039, ICLN: 0.00323, SPGTCLEN: 0.0033) had the highest average returns, reflecting a relatively positive performance over the period. Copper (HGH5) and gold (XAU) had lower average returns (0.0008), with silver (SIH5) registering a return of 0.0015.

Volatility was highest in the green indices, especially CELS (0.0318) and ICLN (0.0267), indicating more intense fluctuations in the prices of these assets. Copper (HGH5) and silver (SIH5) also showed considerable volatility (0.0285 and 0.0267 respectively). Gold (XAU) was the asset with the lowest volatility (0.0118), suggesting relative stability compared to the other assets.

The assets analysed had a negative asymmetry, indicating a greater likelihood of more extreme negative returns. ICLN (-1.3535) and SPGTCLEN (-1.2294) had the most pronounced negative skewness, suggesting that these indices suffered greater falls in relation to gains.

Kurtosis was significantly high, especially in the ICLN (10.3864) and SPGTCLEN (10.2827), indicating leptokurtic distributions with heavier tails and higher peaks, reflecting a greater occurrence of extreme events (very high or very low returns). CELS also had a high kurtosis (8.200), while copper (HGH5) and silver (SIH5) had a more moderate kurtosis (6.4344 and 6.3912, respectively).

The Jarque-Bera tests indicated that the returns do not follow a normal distribution (with very high values and a probability of 0.0000), confirming the presence of asymmetries and shortnesses that indicate non-Gaussian distributions. ICLN (685.92) and SPGTCLEN (654.91) had the highest values, reflecting the greatest difference from normality.

Table 3. Summary Table of the Main Descriptive Statistics for the Green Energy and Precious Metals Indices from 1 January 2020 to 31 December 2020.

	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
Mean	0.0039	0.0008	0.00323	0.0015	0.0033	0.0008
Std. Dev.	0.0318	0.0139	0.0267	0.0285	0.0246	0.0118
Skewness	-0.9818	-0.8365	-1.3535	-0.7464	-1.2294	-0.8714
Kurtosis	8.200	6.4344	10.3864	6.3912	10.2827	7.1471
Jarque-Bera	342.47	161.78	685.92	152.11	654.91	224.25
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	266	266	266	266	266	266

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Table 4 shows the descriptive statistics for the green energy and precious metals indices. CELS (-0.0009) and ICLN (-0.0015) show negative average returns, suggesting a general underperformance during this period. SPGTCLEN (-0.00152) also had a negative average return. Copper (HGH5; 0.0007) and gold (XAU; 0.0002) recorded positive but low returns, while silver (SIH5) had a slightly negative return (-0.0002).

CELS (0.0260) had the highest volatility, followed by ICLN (0.0207) and silver (SIH5) (0.0186). Copper (HGH5) had the lowest volatility among the assets, with a standard deviation of (0.0151), while gold (XAU) was the most stable asset (0.0082).

Regarding asymmetry, it was found that CELS (0.0748), ICLN (0.1521) and SPGTCLEN (0.1845) had positive asymmetries, suggesting a tendency to obtain higher returns. Silver (SIH5; -1.0248) and gold (XAU; -0.5475) showed negative skewness, indicating a greater likelihood of more extreme negative returns.

Kurtosis was highest for silver (SIH5; 10.1564), indicating a distribution with heavier tails and greater extreme events. ICLN (4.9306) and SPGTCLEN (4.6178) also showed significant kurtosis, suggesting a higher frequency of extreme returns. CELS (3.7307) and copper (HGH5; 3.3415) showed more moderate kurtosis, indicating distributions closer to normality, although still with heavier tails than the normal distribution.

As for the Jarque-Bera test, the results show that the distributions of returns do not follow a normal distribution. Silver (SIH5) and the ICLN stand out with extremely high values of the Jarque-Bera test statistic (704.2476 and 48.5519, respectively), reinforcing the presence of more frequent extreme events.

Table 4. Summary Table of the Main Descriptive Statistics for the Green Energy and Precious Metals Indices from 1 January 2021 To 23 February 2022.

	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
Mean	-0.0009	0.0007	-0.0015	-0.0002	-0.00152	0.0002
Std. Dev.	0.0260	0.0151	0.0207	0.0186	0.0189	0.0082
Skewness	0.0748	-0.1703	0.1521	-1.0248	0.1845	-0.5475
Kurtosis	3.7307	3.3415	4.9306	10.1564	4.6178	4.4526
Jarque-Bera	7.0707	2.9588	48.5519	704.2476	34.9648	42.0587
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	305	305	305	305	305	305

Table 5 shows the descriptive statistics for the geopolitical conflict between Russia and Ukraine in the 2022 sub-period. The average returns of the assets analysed are predominantly negative, except for silver (SIH5; 0.0003) and gold (XAU; 0.0004), which showed low positive returns. CELS (-0.0005), ICLN (-0.0005) and SPGTCLEN (-0.0005) had negative returns, and copper (HGH5) had an average return of -0.0009.

Regarding standard deviation, CELS (0.0239) and ICLN (0.0173) showed relatively high volatility, indicating significant fluctuations in the prices of these indices. Copper (HGH5; 0.0140) and SPGTCLEN (0.0163) showed the lowest volatility, with gold (XAU) showing the lowest volatility (0.0090), suggesting greater stability during the period analysed.

The asymmetry of the green and copper indices is positive, which suggests a slight tendency towards a higher probability of positive returns. CELS (0.1561) and ICLN (0.3491) had the highest positive asymmetries, while gold (XAU; -0.0912) had a slight negative asymmetry. Silver (SIH5; 0.2337) also had positive asymmetry, indicating a tendency towards higher returns in relation to falls.

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SPGTCLEN (7.458) showed the greatest kurtosis, indicating a distribution with heavier tails and a greater likelihood of extreme events, i.e. greater fluctuations in price. ICLN (5.1939) and CELS (3.6295) also showed high kurtosis, suggesting distributions with heavier tails and a greater risk of extreme events. Copper (HGH5; 4.6439) and silver (SIH5; 4.4738) showed moderate kurtosis, while gold (XAU) had a kurtosis of 4.4155, indicating that gold's behaviour also involved extreme events but to a lesser extent than the other assets.

The Jarque-Bera tests indicated that the distributions of returns do not follow a normal distribution, with high Jarque-Bera values and a probability of 0.0000, confirming the presence of asymmetries and kurtosis indicative of non-Gaussian distributions.

From 2022 to 2024, the green energy indices showed negative returns, with fluctuating volatility, CELS being the most volatile. Silver and gold had slightly positive returns and lower volatility, standing out for their greater stability. The high kurtosis in the green energy indices, especially SPGTCLEN, and the positive asymmetry suggest a tendency for large price variations with a higher probability of gains. However, all the assets showed non-normal distributions, with extreme events being the most frequent pattern, which indicates a greater risk associated with these markets.

Table 5. Summary Table of the Main Descriptive Statistics for the Green Energy and Precious Metals Indices for the Period from 24 February 2022 To 6 December 2024.

	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
Mean	-0.0005	-0.0009	-0.0005	0.0003	-0.0005	0.0004
Std. Dev.	0.0239	0.0140	0.0173	0.0181	0.0163	0.0090
Skewness	0.1561	0.0186	0.3491	0.2337	0.1060	-0.0912
Kurtosis	3.6295	4.6439	5.1939	4.4738	7.458	4.4155
Jarque-Bera	15.28	83.59	163.88	73.88	616.12	62.97
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Observations	742	742	742	742	742	742

Table 6 shows the results of the panel unit root tests by Breitung (2000), Levin, Lin, and Chu (2002), and Im et al. (2003). The Dickey and Fuller (1981) and Phillips and Perron (1988) tests, with Fisher's transformation, were used to validate the results. The tests were applied to the time series of precious metals, the futures market: copper (HGH5) and silver (SIH5), and the spot market for gold (XAU), as well as the green indices S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN). The results show that the time series have unit roots when we estimate the original price series. In order to achieve stationarity, we had to perform the logarithmic transformation in first differences, which shows that the null hypothesis is not rejected and that we are dealing with white noise (mean zero and variance 1).ied to the time series of precious metals, the futures market: copper (HGH5) and silver (SIH5), and the spot market for gold (XAU), as well as the green indices S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN). The results show that the time series have unit roots when we estimate the original price series. In order to achieve stationarity, we had to perform the logarithmic transformation in the first differences, which shows that the null hypothesis is not rejected and that we are dealing with white noise (mean zero and variance 1).

Table 6. Summary Table, in Returns, of the Panel Unit Root Tests for the Green Energy and Precious Metals Indices from 8 January 2019 to 31 December 2019.

Group unit root test: Summary				
			Cross-	
Method	Statistic	Prob.**	sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-50.03	0.0000	6	1548
Null: Unit root (assumes individual unit root process)				

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Im, Pesaran and Shin W-stat	-42.87	0.0000	6	1548
ADF - Fisher Chi-square	761.60	0.0000	6	1548
PP - Fisher Chi-square	764.65	0.0000	6	1548

In order to understand whether there are volatility spillovers between the futures market: copper (HGH5) and silver (SIH5), the gold spot market (XAU), and green indices such as the S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN), we estimated the unconditional correlations, as well as their statistical significance. One way of testing the statistical significance of the correlation coefficient is to use the *t*-statistic, which follows the *t* distribution, with *n-2* degrees of freedom, where *r* is the correlation coefficient between two series and n is the number of observations. To test whether the correlation coefficient matrix is globally different from the identity matrix, we use the likelihood ratio test, suggested by Pindyck and Rotemberg (1990).

Table 7 shows the unconditional correlations between the green energy indices and precious metals from 8 January to 31 December 2019. For assets to have the characteristics of hedging assets, correlations must be low or negative. On the other hand, high correlations require caution on the part of investors when diversifying risk and rebalancing portfolios.

Green energy indices such as CELS, ICLN and SPGTCLEN show robust correlations, ranging from 0.84 to 0.99. This synchronisation indicates that common factors, such as increased demand for renewable energy sources and environmental policies, have influenced these markets. For this reason, these assets should be treated as a single block in the composition of portfolios, as their high interdependence limits the benefits of diversification.

Among precious metals, there is a strong correlation between silver (SIH5) and gold (XAU), with a value of 0.91. This reinforces the characteristic of both as hedging assets during periods of high economic risk. In addition, the green energy indices show moderate to strong correlations with gold, ranging from 0.66 to 0.85, suggesting that gold can be used as a complementary asset in renewable energy-focused portfolios, especially in times of uncertainty.

On the other hand, copper (HGH5) shows negative correlations with almost all the green energy indices, with values between -0.01 and -0.38. This indicates that copper's behaviour in 2019 was more related to industrial dynamics than the renewable energy sector. In addition, copper exhibits negative correlations with precious metals such as gold (-0.63) and silver (-0.51), reinforcing its position as an asset less aligned with the markets analysed.

Silver also shows a moderate correlation with green energy indices such as ICLN (0.65) and SPGTCLEN (0.66), which may reflect the increasing use of this metal in renewable technologies such as solar panels. This relationship suggests that silver can be considered a strategic asset for investors interested in the green energy sector.

In practical terms, the results highlight that precious metals such as gold and silver can play an important role in diversifying portfolios focused on renewable energy, especially in times of volatility. However, the strong connection between green energy indices calls for caution, as it can reduce the effectiveness of diversification. Finally, due to its decoupled behaviour, copper should be carefully evaluated in renewable energy strategies. In summary, the markets analysed present specific opportunities, but different strategies for risk management and portfolio diversification are required.

Table 7. Unconditional Correlations for the Green Energy and Precious Metals Indices from 8 January 2019 to 31 December 2019.

Markets	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
CELS	*****	-0.01	0.84***	0.56***	0.85***	0.66***
HGH5	-0.01	*****	-0.38***	-0.51***	-0.37***	-0.63***

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ICLN	0.84***	-0.38***	*****	0.65***	0.99***	0.84***
SIH5	0.56***	-0.51***	0.65***	*****	0.66***	0.91***
SPGTCLEN	0.85***	-0.37***	0.99***	0.66***	*****	0.85***
XAU	0.66***	-0.63***	0.84***	0.91***	0.85***	*****

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

Table 8 shows the unconditional correlations between the green energy indices and precious metals from 2 January 2020 to 31 December 2020. Green energy indices such as CELS (0.99), ICLN (0.99), and SPGTCLEN (0.99) have extremely high correlations, indicating that the renewable energy markets have behaved in a very synchronised manner, which calls into question the diversification of risk within the green energy sector.

Concerning precious metals, the strong correlation between silver (SIH5) and gold (XAU) stands out, with a value of 0.88, highlighting the function of these metals as safe haven assets or stores of value. Copper (HGH5) has a correlation of 0.84 with silver and 0.65 with gold, indicating that, despite their strategic importance, precious metals cannot be considered hedging assets or safe haven.

The correlations between the green energy indices and gold (0.64-0.67) are moderate, suggesting that gold can be used as a complementary asset in portfolios focussed on renewable energies, although this requires some caution from investors. The relationship between the green energy indices and copper is stronger, with coefficients ranging from 0.93 to 0.94, reflecting copper's crucial role in renewable energy technologies and thus rejecting the hypothesis that copper has the properties of a hedge and a safe haven.

Table 8. Unconditional Correlations for the Green Energy and Precious Metals Indices From 2 January 2020 To 31 December 2020.

Markets	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
CELS	*****	0.94***	0.99***	0.79***	0.99***	0.67***
HGH5	0.94***	*****	0.93***	0.84***	0.93***	0.65***
ICLN	0.99***	0.93***	*****	0.79***	0.99***	0.64***
SIH5	0.79***	0.84***	0.79***	*****	0.79***	0.88***
SPGTCLEN	0.99***	0.93***	0.99***	0.79***	*****	0.65***
XAU	0.67***	0.65***	0.64***	0.88***	0.65***	*****

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

Table 9 shows the unconditional correlations between the clean energy indices and precious metals from 2 January 2021 to 23 February 2022, which show interesting results regarding the characteristics of important hedging assets and risk diversification.

For an asset to be effective as a hedge, the correlations between assets must be low or negative. In this context, we highlight copper (HGH5), which shows significant negative correlations with clean energy indices such as CELS (-0.66), ICLN (-0.79) and SPGTCLEN (-0.79). This suggests that copper can be used as a hedging asset in portfolios with a strong presence in clean energy, reducing risk in periods of high volatility in these markets. Gold (XAU) shows very low correlations with clean energy indices such as CELS (0.01), ICLN (0.09) and SPGTCLEN (0.08), also indicating the presence of essential properties as a hedging asset.

On the other hand, high correlations between assets indicate greater risk in diversification and call for prudence on the part of investors. The clean energy indices, such as CELS, ICLN and SPGTCLEN, have very strong correlations, ranging from 0.88 to 0.99. This shows that these markets are highly synchronised and influenced by common factors, which limits the effectiveness of diversification when including multiple

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renewable energy indices in a single portfolio. Silver (SIH5) shows moderate correlations with clean energy indices such as ICLN (0.44) and SPGTCLEN (0.44), indicating a partially aligned relationship with the sector. This calls for caution, as silver may not be effective as a diversification asset in times of shocks in the renewable energy sector.

In terms of practical implications, we can highlight the relationship between gold (XAU) and the green energy indices (CELS, ICLN, SPGTCLEN): The correlation between gold and the green energy indices is relatively low, indicating that gold does not directly follow the behaviour of the renewable energy markets. However, this correlation suggests that gold can act as a complementary asset in portfolios focused on green energy, offering protection during economic uncertainty. Silver (SIH5) and the green energy indices (CELS, ICLN, SPGTCLEN) show moderate correlations with the green energy indices (between 0.18 and 0.44). This suggests that although there is a link between silver and the renewable energy markets, silver also retains its characteristics as a safe haven asset, functioning as a complementary asset that could be interesting for investors focused on renewable energies.

On the other hand, copper (HGH5) and the green energy indices (CELS, ICLN, SPGTCLEN) show very strong correlations with the green energy indices (between 0.93 and 0.94). This is due to copper's role in renewable energy technologies such as batteries and solar energy systems, indicating that copper has a strong interdependence with green energy markets. This strong correlation suggests that copper is not only an industrial asset but also a crucial part of the renewable energy supply chain.

In conclusion, precious metals such as gold and silver have weaker or moderate correlations with green energy indices, while copper has a strong correlation, reflecting its importance in green technologies. This implies that copper can be a strategic choice for investors in renewable energy, while gold and silver can be used as hedging assets and safe havens during economic volatility.

Table 9. Unconditional Correlations for Clean Energy Indices And Precious Metals for the Period From 2 January 2021 To 23 February 2022

Markets	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
CELS	*****	-0.66***	0.88***	0.18***	0.88***	0.01
HGH5	-0.66***	*****	-0.79***	-0.15**	-0.79***	0.11*
ICLN	0.88***	-0.79***	*****	0.44***	0.99***	0.09*
SIH5	0.18***	-0.15**	0.44***	*****	0.44***	0.36***
SPGTCLEN	0.88***	-0.79***	0.99***	0.44***	*****	0.08
XAU	0.01	0.11*	0.09*	0.36***	0.08	*****

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

Table 10 shows the unconditional correlations between clean energy indices and precious metals from 24 February 2022 to 6 December 2024. By analysing the relationships between these assets, we can distinguish between hedge and safe haven assets based on the correlations observed.

The results for the clean energy indices (CELS, ICLN, SPGTCLEN) show robust correlations with each other, with values close to 0.96, which indicates fairly homogeneous behaviour within the sector. Common trends strongly influence these indices in the renewable energy market, and their strong correlation suggests that investors can consider one index as a proxy for the performance of all the other clean energy indices.

When analysing gold (XAU) and the green energy indices, it can be seen significant negative correlations (XAU and CELS (-0.77), XAU and ICLN (-0.73), XAU and SPGTCLEN (-0.74)), indicating that gold can act as a hedging asset. In addition, gold (XAU) can be considered a safe haven due to the sharp negative correlation with green energy indices, suggesting that gold can gain value when the clean energy market is in crisis or when there are shocks to the international economy. In addition, silver (SIH5) shows a strong correlation with gold (0.94), reinforcing the idea that silver can also act as a safe haven during periods of

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uncertainty. In addition, the correlation between silver (SIH5) and the clean energy indices allows us to make some meaningful comparisons. Silver shows negative correlations with clean energy indices such as CELS o (-0.67), SPGTCLEN (-0.63), and ICLN (-0.63). These negative correlations suggest that silver has the characteristics of a hedge asset and a safe haven. In validation, copper (HGH5) and the clean energy indices also show negative correlations, such as CELS (-0.27), ICLN (-0.23) and SPGTCLEN (-0.23). These results show that when clean energy indices are in decline or facing market shocks, precious metals tend to maintain their value or even show the opposite behaviour, providing a form of portfolio protection.

Table 10. Unconditional Correlations Concerning Clean Energy Indices and Precious Metals from 24 February 2022 To 6 December 2024.

Markets	CELS	HGH5	ICLN	SIH5	SPGTCLEN	XAU
CELS	*****	-0.27***	0.96***	-0.67***	0.96***	-0.77***
HGH5	-0.27***	*****	-0.23***	0.72***	-0.23***	0.61***
ICLN	0.96***	-0.23***	*****	-0.63**	0.98***	-0.73***
SIH5	-0.67***	0.72***	-0.63**	*****	-0.63***	0.94***
SPGTCLEN	0.96***	-0.23***	0.98***	-0.63***	*****	-0.74***
XAU	-0.77***	0.61***	-0.73***	0.94***	-0.74***	*****

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

The two-sample heteroscedasticity *t*-test, as described by Forbes and Rigobon (2002) was used to validate the results previously obtained through the unconditional correlations between the futures market: copper (HGH5) and silver (SIH5), the gold spot market (XAU), and green indices such as the S&P Global Clean Energy (SPGTCLEN), NASDAQ Clean Edge Green Energy (CELS), and the iShares Global Clean Energy ETF (ICLN), concerning the pre-Covid and first wave Covid-19 periods.

The analysis reveals significant contagion between the green indices (SPGTCLEN, CELS, ICLN), precious metals (gold and silver) and the copper futures market (HGH5), especially during the pre-Covid periods and the first wave of the pandemic. This result confirms a strong interdependence between copper and renewable energy markets, given the importance of copper in green technologies such as wind turbines and solar systems.

Despite the contagion identified between gold (XAU) and silver (SIH5) in relation to copper, no significant risk was observed when compared to the other assets. This reinforces the traditional role of these precious metals as hedging assets and safe havens, particularly in periods of uncertainty and high volatility in the financial markets.

On the other hand, the green indices show greater sensitivity to external shocks, reflecting greater exposure to systemic risk. This characteristic highlights the vulnerability of renewable energy markets to global crises, such as the pandemic, which have significantly altered market dynamics.

In terms of practical implications, the results suggest that gold and silver remain key assets for diversification and risk protection strategies, especially in times of crisis. The interdependence between copper and green indices warrants greater attention to the impact of shocks in renewable markets on the market for raw materials essential for the energy transition. In conclusion, the pandemic has reinforced the resilient role of precious metals as safe haven assets and highlighted the vulnerability of the renewable energy and copper markets to global shocks, highlighting the need for more integrated risk management approaches; for a better understanding, see Table 11.

Table 11. Summary Table, in Returns, of the De Forbes And Rigobon (2002) Two-Sample T-Test for Heteroscedasticity, Relating to the Pre-Covid Vs First Wave Covid-19 Periods.

	t Stat	Results

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HGH5 | SIH5	1.28	No Contagion
HGH5 | XAU	0.99	No Contagion
HGH5 | SPGTCLEN	0.81	No Contagion
HGH5 | CELS	1.05	No Contagion
HGH5 | ICLN	0.83	No Contagion
SIH5 | HGH5	**5.76*** **	**Contagion**
SIH5 | XAU	0.84	No Contagion
SIH5 | SPGTCLEN	0.70	No Contagion
SIH5 | CELS	0.94	No Contagion
SIH5 | ICLN	0.73	No Contagion
XAU | HGH5	**5.55*** **	**Contagion**
XAU | SIH5	0.82	No Contagion
XAU | SPGTCLEN	0.33	No Contagion
XAU | CELS	0.49	No Contagion
XAU | ICLN	0.36	No Contagion
SPGTCLEN | HGH5	**5.56*** **	**Contagion**
SPGTCLEN | SIH5	1.30	No Contagion
SPGTCLEN | XAU	0.96	No Contagion
SPGTCLEN | CELS	1.08	No Contagion
SPGTCLEN | ICLN	0.86	No Contagion
CELS | HGH5	**5.11*** **	**Contagion**
CELS | SIH5	1.23	No Contagion
CELS | XAU	0.98	No Contagion
CELS | SPGTCLEN	0.85	No Contagion
CELS | ICLN	0.83	No Contagion
ICLN | HGH5	**5.42*** **	**Contagion**
ICLN | SIH5	1,29	No Contagion
ICLN | XAU	0.96	No Contagion
ICLN | SPGTCLEN	0.83	No Contagion
ICLN | CELS	1.08	No Contagion

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

The results presented in Table 12, based on the Forbes and Rigobon (2002) heterocedasticity t-test, show that during the periods of the second wave of Covid-19 and the geopolitical conflict between Russia and Ukraine in 2022, no significant contagion was identified between the copper futures market (HGH5), silver (SIH5), gold (XAU) and the green indices (SPGTCLEN, CELS, ICLN).

This lack of contagion reinforces the conclusions of the unconditional correlations, indicating that precious metals such as gold and silver continue to act as hedging assets and safe havens in scenarios of high volatility and global uncertainty. This highlights the resilience of these assets during periods of crisis, validating their role as a hedge against risks and shocks in the financial markets.

On the other hand, the absence of contagion between green indices and precious metals can be interpreted as a sign of greater independence between these markets, even in contexts of economic or geopolitical stress. This suggests that investors can benefit from diversification between renewable energy markets and precious metals, especially in global instability.

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Table 12. Summary Table, in Returns, of the Forbes and Rigobon (2002) Two-Sample Heteroscedasticity T-Test for Periods Covid-19 2nd Wave Vs Conflict

	t Stat	Results
HGH5 | SIH5	1.28	No Contagion
HGH5 | XAU	0.94	No Contagion
HGH5 | SPGTCLEN	0.81	No Contagion
HGH5 | CELS	1.05	No Contagion
HGH5 | ICLN	0.83	No Contagion
SIH5 | HGH5	0.98	No Contagion
SIH5 | XAU	-0.51	No Contagion
SIH5 | SPGTCLEN	-0.78	No Contagion
SIH5 | CELS	-0.68	No Contagion
SIH5 | ICLN	-0.78	No Contagion
XAU | HGH5	0.75	No Contagion
XAU | SIH5	-1.01	No Contagion
XAU | SPGTCLEN	-0.93	No Contagion
XAU | CELS	-0.84	No Contagion
XAU | ICLN	-0.93	No Contagion
SPGTCLEN | HGH5	1.24	No Contagion
SPGTCLEN | SIH5	-0.48	No Contagion
SPGTCLEN | XAU	-0.16	No Contagion
SPGTCLEN | CELS	-0.40	No Contagion
SPGTCLEN | ICLN	-0.51	No Contagion
CELS | HGH5	1.66	No Contagion
CELS | SIH5	-0.54	No Contagion
CELS | XAU	-0.23	No Contagion
CELS | SPGTCLEN	0.56	No Contagion
CELS | ICLN	-0.57	No Contagion
ICLN | HGH5	1.25	No Contagion
ICLN | SIH5	-0.47	No Contagion
ICLN | XAU	-0,16	No Contagion
ICLN | SPGTCLEN	-0.51	No Contagion
ICLN | CELS	-0.40	No Contagion

Note: The asterisks ***. **. * indicate statistical significance at 1%, 5% and 10%, respectively.

Conclusion

This study analysed the relationship between precious metals and green energy indices from 8 January 2019 to 6 December 2024, intending to verify whether precious metals can act as hedging assets in relation to green indices. The analysis revealed that over the four different periods (Pre-Covid-19, 1st Covid-19 Wave, 2nd Covid-19 Wave and the Geopolitical Conflict), the green energy indices (CELS, ICLN, SPGTCLEN) showed extremely strong correlations with each other, which reduces the effectiveness of diversification within this sector. Gold remained a safe haven asset, with negative or very low correlations with the green indices, especially during periods of global crisis. Silver also proved to be an effective hedging asset, with moderate to negative correlations over the periods analysed. Copper, meanwhile, went from positive to negative correlations with green energy indices, standing out as a diversifying asset in portfolios focused on renewable energies.

In addition, the study revealed that during the first wave of COVID-19, copper was the only asset to show signs of contagion, which validates the conclusions obtained by the unconditional correlations. In short, the results suggest that gold and silver are effective hedging assets during market shocks, while copper can be used strategically in portfolios that include green energy investments. Combining precious metals with green energy indices requires careful diversification management, as the former offers protection in times of volatility, while the latter has strong interdependencies that limit the benefits of diversification.

Regarding future research, it is suggested that the analysis be extended to include other precious metals, such as platinum and palladium, and renewable energy indices from different regions, such as emerging markets. Furthermore, more advanced econometric models, such as network causality analysis or multivariate volatility models (GARCH), could provide additional evidence of the dynamic relationships between markets. Finally, studies focussed on specific events, such as political or technological changes that impact the green energy markets, could enrich the understanding of the interdependencies between these assets.

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