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# Global Spillovers Between Sustainable And Traditional ETFs: Crisis Dynamics And Policy Implications

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**Received:** 16 January 2025 | **Revised:** 20 June 2025 | **Accepted:** 21 July 2025

**Keywords:** exchange-traded funds | pandemic crisis | spillovers | sustainable developments goals | Ukrainian war

## ABSTRACT

This paper examines the interconnections between segments of exchange-traded funds (ETFs), bridging the traditional financial perspective with the sustainability-driven approach based on the Sustainable Development Goals (SDGs) outlined in Agenda 2030. The analysis is endogenous, focusing on the shocks that emerge within the system composed of these segments. Utilizing daily data from six sustainable segments, each corresponding to different SDGs, alongside one traditional segment, spanning a sample period of approximately 14 years, the study reveals notable spillover effects. Specifically, the periods associated with the pandemic and the war in Ukraine were marked by a significant surge in information transmission across the segments. Furthermore, the findings indicate that sustainable segments exhibit a strong interdependence with their traditional counterparts, a dynamic that facilitates contagion risk and limits the effectiveness of portfolio diversification strategies.

## 1 | Understanding the Shift: ESG Investing and Market Dynamics

The introduction of the 17 Sustainable Development Goals (SDGs) under the UN Agenda 2030 marks a transformative milestone in the global effort to address pressing challenges. This framework promotes a unified approach, urging collaboration across public and private sectors to achieve goals centered around people, the planet, and prosperity, while fostering peace, justice, and inclusive societies. Certain SDGs specifically highlight the role of business in advancing sustainability, underscoring the relevance of these goals in modern investment strategies.

Over recent decades, escalating concerns related to issues such as water scarcity, human rights, poverty, environmental degradation, global warming, and financial crises have driven the integration of sustainability into investment decision-making

(KPMG 2011). This shift has given rise to socially responsible investment (SRI) and sustainable investment strategies, which merge financial returns with environmental, social, and governance (ESG) criteria (Renneboog et al. 2008).

The financial sector has increasingly embraced its pivotal role in supporting the transition to a more sustainable, carbon-neutral economy. Evidence suggests that investors are progressively incorporating ESG considerations into their investment decisions (Lombardo and D'Orio 2012; Ng and Zheng 2018). The surge in sustainable investment—from USD 13.3 trillion in 2012 to USD 30.7 trillion in 2018 (GSIA 2019)—illustrates this growing trend and its impact on global capital markets (Cortez et al. 2009).

Exchange-Traded Funds (ETFs) have emerged as a prominent investment vehicle, favored for their liquidity, diversification potential, and cost-efficiency (Krause et al. 2014). Researchers

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## Policy implications

- The interconnectedness of sustainable and traditional investments highlights the need for enhanced regulatory frameworks. These frameworks should closely monitor both markets and prevent financial contagion. Policymakers must ensure that regulations are flexible enough to address spillover effects, which could lead to systemic financial instability during times of crisis.
- Both traditional and sustainable markets are subject to the same macroeconomic and geopolitical risks. Therefore, policymakers should implement policies that address systemic risk across various financial sectors. These policies should focus on mitigating market contagion risks and ensuring financial market resilience, especially during periods of economic stress.
- There is a potential overestimation of the diversification benefits of sustainable ETFs in stable markets. Policymakers may need to take action to ensure investors are accurately informed about the potential risks, particularly in volatile conditions. This could involve strengthening consumer protection laws and enhancing transparency in financial markets to maintain public trust and mitigate the risk of financial losses.
- Policymakers and regulators should proactively develop crisis management strategies, such as the use of hedging instruments and the creation of more resilient market structures to reduce systemic risks during market disruptions.
- Policymakers should reassess the support and promotion of sustainable investments, taking into account their vulnerability to market stress. While there is a political trend favoring sustainable finance, it is essential to balance sustainability goals with realistic risk assessments to ensure that sustainability-driven policies do not unintentionally increase market vulnerability during crises.

have highlighted ETFs as one of the most successful financial innovations in recent years (Antoniewicz and Heinrichs 2014; Amenc et al. 2017). The expansion of ETF offerings necessitates an in-depth understanding of the relationships between traditional ETFs—driven primarily by financial logic—and sustainable ETFs, which integrate ESG considerations and SDG alignment.

This study investigates the connection between traditional ETFs, which follow conventional financial principles, and sustainable ETFs that emphasize ESG factors. The analysis, spanning from June 2008 to October 2023, includes data from traditional ETFs and those linked to six SDGs: Quality Health (Goal 3), Clean Water and Sanitation (Goal 6), Renewable Energy (Goal 7), Decent Work and Economic Growth (Goal 8), Industry and Infrastructure (Goal 9), and Sustainable Consumption and Production (Goal 12). This provides a robust framework to examine spillover effects and their implications for portfolio diversification.

Employing the methodology of Diebold and Yilmaz (2012), the study assesses connectivity and spillover dynamics between the two types of ETFs. The literature on sustainable assets has expanded significantly (Miralles-Quirós et al. 2019; Kuang 2021; Gabriel et al. 2022; Chen et al. 2022), with recent studies emphasizing the importance of understanding the interactions between conventional and sustainable investments (Arif et al. 2021; Naeem et al. 2021). Dumitrescu et al. (2023) argue that green financial instruments hold considerable potential for advancing sustainability, while Broadstock et al. (2021) demonstrate the resilience of eco-friendly assets during both market volatility and stability.

Given the growing importance of sustainability, especially considering global crises like the pandemic and the war in Ukraine, this study aims to explore several key aspects. First, it investigates whether different ETF segments behave similarly. It also seeks to understand whether sustainable segments influence traditional ETFs and whether the spillover effects between these segments are static or dynamic. Additionally, the study examines which segments act as net transmitters or net receivers of spillover effects. Lastly, it considers how the dynamics of these relationships have been impacted by the pandemic and the war in Ukraine.

While previous research has explored information transmission within ETFs (e.g., Krause et al. 2014; Ben-David et al. 2018; Chen et al. 2022), this study contributes in three key ways. To the best of our knowledge, this study is the first to analyze sustainable and traditional ETFs within a unified empirical framework. By constructing a dual-segment system, we investigate both the magnitude and direction of spillover effects, uncovering dominance structures and revealing the underlying channels of information transmission between ESG-aligned and conventional ETFs. Second, leveraging a broad dataset that spans multiple market regimes—including the COVID-19 pandemic and the onset of the war in Ukraine—we examine the evolution of interlinkages under conditions of acute financial stress. These episodes, marked by economic contraction, inflationary shocks, and energy market disruptions, offer a unique environment for analyzing systemic connectedness and the resilience of sustainable assets relative to their traditional peers. Third, we adopt the dynamic connectedness framework of Diebold and Yilmaz (2012), which enables a time-varying assessment of directional spillovers across asset classes. To achieve optimal diversification, investors must carefully assess the magnitude and trajectory of spillover effects across various assets within their portfolios (Khalfaoui et al. 2022; Gabriel et al. 2022). This methodological choice allows for a nuanced understanding of the flow of market information and volatility across the sustainable–traditional asset divide, contributing novel insights to both sustainable finance and systemic risk literatures.

Crucially, by emphasizing the dimension of resilience, our study advances the ongoing debate on the role of ESG investments—not only as tools for portfolio diversification but also as potential stabilizers during episodes of elevated market uncertainty. In doing so, we position resilience as a core and distinguishing feature of our contribution to the sustainable finance literature.

The results indicate significant connectivity between the ETF segments, with spillover effects varying across different periods, particularly during the Covid-19 pandemic and the war in Ukraine. The traditional segment and the SDG 8 segment (Decent Work and Economic Growth) act as net transmitters of spillover effects, while the SDG 7 segment (Renewable Energy) functions as a net receiver. These findings highlight the importance of integrating sustainable investment strategies into broader portfolio management practices.

This study contributes to the ongoing discourse in sustainable finance by providing valuable insights into how sustainable investments—aligned with the SDGs—can inform and interact with traditional investment strategies, ultimately fostering a more resilient and sustainable financial system.

The study is structured as follows: Section 2 reviews the theoretical background, Section 3 presents the data and methodology, Section 4 discusses the results, and Section 5 concludes.

## 2 | Theoretical Background

The initial research on the connectivity between financial assets focused on stock markets, finding that market behavior was primarily influenced by market-specific factors, leading to significant opportunities for international diversification (Grubel 1968; Ripley 1973; Bertoneche 1979). However, as economic and financial integration deepened, markets became more interconnected, reducing these diversification opportunities. Crisis events, such as the 2008 global financial crisis (Mandigma 2014; Elsayed and Yarovaya 2019; Zhang and Broadstock 2018) and the COVID-19 pandemic, have exacerbated this trend, impacting asset classes including sustainable assets (Singh et al. 2021; Salisu and Shaik 2022; Umar et al. 2021).

The US stock market, accounting for about 43% of global listed company capitalization (World Bank 2020), plays a significant role in explaining the performance of other markets. Gabriel and Pazos (2018) used a DCC-GARCH model to show that the US market helps predict movements in other markets. Tsai (2014), Akhtaruzzaman et al. (2019), and Kang and Lee (2019) also found that the US market has positive spillover effects on others. Much research has explored contagion and volatility spillover in conventional assets, including stocks, commodities, and currencies (Akhtaruzzaman and Shamsuddin 2016; Liew et al. 2022; Malik and Umar 2019; Singh et al. 2021; Tiwari et al. 2018; Umar et al. 2019; Yang et al. 2021), though studies on sustainable assets are limited.

Exchange-traded funds (ETFs) are an appealing indirect investment in international equity, differing from traditional funds by being traded like shares, with prices fluctuating throughout the day. ETFs offer lower fees, higher liquidity, and greater diversification (Krause et al. 2014). They have grown rapidly, with over 6400 ETFs globally, covering various sectors and countries, totaling assets over \$3.7 trillion (Investment Company Institute 2019). In the US, seven ETFs are among the top ten most traded securities. Sustainable development ETFs reconcile financial and sustainability goals.

Though ETFs are relatively new, they have been extensively studied, particularly regarding liquidity, price efficiency, and comovement. Research suggests that ETFs improve portfolio liquidity, although this is impacted by extreme market conditions (Bae et al. 2012; Marshall et al. 2015; Agarwal et al. 2018), and illiquidity can occur during crises (Borkovec et al. 2010; Dannhauser 2017; Ben-David et al. 2018). Studies on ETFs and market efficiency yield mixed results, with some indicating that ETF liquidity enhances price efficiency (Glosten et al. 2020; Madhavan and Sobczyk 2016; Ben-David et al. 2018), while others suggest that noise transmission may reduce efficiency (Deville et al. 2014; Israeli et al. 2017).

Da and Shive (2013) identified arbitrage opportunities between ETFs and underlying securities. Staer and Sottile (2018) found that higher ETF turnover increases stock returns. Lau et al. (2017) concluded that information from prior weeks contributes to spillover effects between gold and oil markets, with variations over time. Chen et al. (2022) found that traditional financial ETFs are primary contributors to spillovers, while Fintech ETFs receive them.

The limited research on ETF connectedness has primarily focused on traditional sectors, yielding results similar to those involving stock market indices (Zhang and Broadstock 2018; Elsayed and Yarovaya 2019; Gabriel et al. 2022). Few studies address ETFs in energy sectors, such as Saeed et al. (2021), Bouri (2023), and Banerjee (2024), who use dynamic methods to analyze clean energy stocks, green bonds, crude oil, and energy ETFs. Their results show asymmetric return connectedness that fluctuates during crisis periods, particularly COVID-19. Saeed et al. (2021) found differences between negative and positive return periods, while Bouri (2023) and Banerjee (2024) highlighted increased spillovers during crises, especially in sustainable energy ETFs.

Studies of the relationship between sustainable and traditional indices include Gabriel and Pazos (2018) and Zhang and Umair (2023). Gabriel and Pazos (2018) used cointegration tests and multivariate models, finding that environmental indices diverged from traditional ones in the long term, while short-term behavior was similar. Zhang and Umair (2023) explored contagion effects between green bonds, renewable energy stocks, and carbon markets, showing significant dynamic contagion effects.

The literature lacks consensus on the robustness and resilience of sustainable assets during crises and turbulent periods. On one hand, several studies have examined ESG stocks as potential hedging or safe-haven assets amid systemic shocks like financial crises, pandemics, and geopolitical events (Lins et al. 2017; Singh 2020; Omura et al. 2021). Findings suggest ESG assets may offer defensive qualities during downturns (Bouslah et al. 2018; Naeem and Karim 2021; Naeem et al. 2022), while also enhancing diversification and lowering portfolio risk (Ameur et al. 2020; Reboredo et al. 2020; Nguyen et al. 2020; Naeem et al. 2021). However, Andersson et al. (2022) question their effectiveness, showing that ESG assets provide limited systemic risk reduction when combined with traditional instruments like currencies, equities, or commodities. Similarly, Lei et al. (2023), using the cross-quantilogram method, found that during the pandemic, palladium served as a more effective short-term safe

haven than gold, though both metals acted as net risk receivers under extreme market stress.

### 3 | Data and Methodology

#### 3.1 | Data

To achieve the goals outlined in this research, we utilized daily frequency data, as recommended by Narayan and Sharma (2015), Narayan et al. (2015), and Umar et al. (2020), since such data provide richer insights into asset behavior compared to lower-frequency data (such as weekly, monthly, or quarterly). The data was sourced from Thomson Reuters Datastream, spanning approximately 14 years, from June 2008 to October 2023. This dataset includes six exchange-traded funds (ETFs) that focus on companies aligned with sustainable development goals, each representing a distinct objective. For each goal, we selected the ETF with the highest market value in assets under management, as well as the traditional ETF with the largest capitalization, which serves as a proxy for investments driven by financial criteria. The selected ETFs are as follows:

- Health Care Select Sector SPDR Fund (XLV), linked to health and well-being (Goal 3);
- PowerShares Water Resources Portfolio (PHO), focused on clean water and sanitation (Goal 6);
- iShares Global Clean Energy ETF (ICLN), aimed at affordable and clean energy (Goal 7);
- iShares Russell 1000 Growth ETF (IWF), associated with decent work and economic growth (Goal 8);
- Technology Select Sector SPDR Fund (XLK), connected to industry, innovation, and infrastructure (Goal 9);
- iShares MSCI KLD 400 Social ETF (DSI), representing responsible consumption and production (Goal 12);
- SPDR S&P 500 ETF Trust (SPY), the largest ETF by assets under management, which follows a purely financial logic and tracks the S&P 500, comprising the top 500 U.S. companies, with a focus on sectors like information technology, healthcare, consumer goods, and finance.

Using ETFs presents several significant advantages. First, ETFs mitigate the challenges associated with non-synchronous trading, which are common when dealing with individual stocks and may lead to misleading results (Lo and MacKinlay 1990). Second, ETFs, while being funds, function similarly to stocks, providing investors with substantial liquidity and diversification opportunities. They offer international diversification by exposing investors to various regions, countries, and global markets. Beyond geographical diversification, these funds allow for investment across a broad spectrum of asset classes, each with unique strategies, objectives, and themes. This makes ETFs one of the most notable financial innovations in recent years (Antoniewicz and Heinrichs 2014; Amenc et al. 2017). Third, ETFs help track general market sentiments and assess the performance of different asset classes (Banerjee et al. 2023). In this study, daily data was analyzed for the period between June 26, 2008, and October 11, 2023. The daily values of the

diverse variables studied were transformed into variation series,  $r_t$ , by applying the expression  $\ln(P_t/P_{t-1})$ , in which  $P_t$  and  $P_{t-1}$  represent the daily values of a given series, on days  $t$  and  $t-1$ , respectively.

#### 3.2 | Methodology

To analyze the study of the links generated between the variables, we turn to the methodological proposal of Diebold and Yilmaz (2012), which sets out from the decomposition of variance associated with a generalized auto-regressive vector, which produces variance decompositions that will not be affected by the ordering of the variables included therein.

The decompositions of variance of the error in forecasting  $H$  steps forward are given by:

$\theta_{ij}^g(H)$ , for  $H = 1, 2, \dots$ , we have

$$\theta_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \quad (1)$$

where  $\sum$  is the matrix of variance for the vector of error  $\epsilon$ ,  $\sigma_{jj}$  is the standard deviation of the error term for the equation  $j$ -th, and  $e_i$  is the selection vector, with one as the  $i$ -th element and zeros otherwise. To use the information available in the variance of the decomposition matrix in calculating the spillover index, each entry of the variance decomposition matrix is normalized by the sum of the line as:

$$\vartheta_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (2)$$

by construction,

$$\sum_{j=1}^N \vartheta_{ij}^g(H) = 1 \text{ and } \sum_{i,j=1}^N \vartheta_{ij}^g(H) = N \quad (3)$$

For total spillovers, the contributions of volatility of the decomposition of the variable are used, allowing construction of the index of reversion of total volatility:

$$S^g(H) = \frac{\sum_{i,j=1, i \neq j}^N \vartheta_{ij}^g(H)}{\sum_{i,j=1}^N \vartheta_{ij}^g(H)} \times 100 = \frac{\sum_{i,j=0, i \neq j}^N \vartheta_{ij}^g(H)}{N} \times 100 \quad (4)$$

Estimating the spillovers of directional volatility, received by market  $i$  from all other markets  $j$ , gives:

$$S_i^g(H) = \frac{\sum_{j=1, j \neq i}^N \vartheta_{ij}^g(H)}{\sum_{i,j=1}^N \vartheta_{ij}^g(H)} \times 100 = \frac{\sum_{j=1, j \neq i}^N \vartheta_{ij}^g(H)}{N} \times 100 \quad (5)$$

Similarly, estimating the spillovers of directional volatility transmitted by market  $i$  to all other markets  $j$ , gives:

$$S_{.i}^g(H) = \frac{\sum_{j=1, j \neq i}^N \vartheta_{ji}^g(H)}{\sum_{i,j=1}^N \vartheta_{ji}^g(H)} \times 100 = \frac{\sum_{j=1, j \neq i}^N \vartheta_{ji}^g(H)}{N} \times 100 \quad (6)$$

## 4 | Empirical Results

### 4.1 | Descriptive Analysis and Stationarity

Table 1 provides key descriptive statistics for the daily returns of ETFs. Most ETFs show positive average returns, with the exception of ICLN. XLK leads with the highest average return at 0.00052, followed by IWF (0.00042) and XLV (0.00038). On the other hand, ICLN displays the greatest standard deviation, while XLV exhibits the lowest variability. All return series deviate from the normality assumption, as indicated by their skewness and kurtosis values. Specifically, the skewness values are negative, suggesting that these ETFs tend to experience larger losses during periods of high volatility. Additionally, the high kurtosis values point to fat tails in the distribution. These deviations from normality are further supported by the JB test, which rejects the null hypothesis of normality at the 1% significance level for all return series.

The traditional augmented Dickey-Fuller (ADF) tests were applied to check the stationarity of the yield series. The null hypothesis ( $H_0$ ) of this test stipulates that the series has unit root, that is, that the series is integrated of order 1,  $I(1)$ , against the alternative hypothesis ( $H_a$ ) that the series has no unit root or is  $I(0)$ . The results of the stationarity tests are presented in Table 1. In all cases, the returns series exhibited stationarity,  $I(0)$ , at a significance level of 1%.

The Ljung-Box test, conducted up to 20 lags, identifies significant linear and non-linear dependencies in the returns of all series. Additionally, the ARCH test detects the presence of heteroscedasticity across all series. These findings highlight the need for models that can account for time-varying volatility, which is why the models selected for this study are appropriate.

By using the chosen multivariate framework, the analysis can effectively incorporate the effects of fluctuating return volatility, helping to address potential biases in correlation estimates and spillover effects.

## 4.2 | Empirical Results

### 4.2.1 | Analysis of Static Connectivity

To analyze the static connectivity between the various ETF segments, we applied the methodological proposal of Diebold and Yilmaz (2012), presented in Section 3, according to which an autoregressive vector with seven variables was estimated, including the six sustainable ETFs and the traditional ETF, for the sample period considered. The optimal lag was selected based on the usual Akaike and Schwarz information criteria, to deepen the study of information flows and transmission mechanisms established between the variables studied. To this end, we resorted to two differentiated analyses, one involving the construction of a spillover table, of a static nature, and the other involving a rolling window analysis, of a dynamic nature, which will be presented in the next topic.

Starting from the autoregressive vector, we proceeded to the generalized variance decomposition, as mentioned in Section 3, to estimate the spillovers generated for the returns of the seven variables. The summary of the results is presented in Table 2, where the  $i$ -th entry corresponds to the estimated contribution to the variance of the forecast error of variable  $i$  from innovations of variable  $j$ . Thus, the diagonal elements of the table measure the spillovers of the returns of each market, while the off-diagonal elements measure the cross-spread between the returns of the different markets considered. In addition, the row

**TABLE 1** | Descriptive statistics of profitability.

	DSI	ICLN	IWF	PHO	XLK	XLV	SPY
Mean	0.00034	-0.00033	0.00042	0.00025	0.00052	0.00038	0.00032
Maximum	0.09753	0.16000	0.11609	0.12318	0.13014	0.11382	0.13558
Minimum	-0.12843	-0.16723	-0.12543	-0.12954	-0.14866	-0.10382	-0.11589
Std. Dev.	0.01284	0.02125	0.01330	0.01551	0.01473	0.01129	0.01293
Skewness	-0.52156	-0.56888	-0.42275	-0.39572	-0.23433	-0.33763	-0.37102
Kurtosis	14.83184	13.37768	12.46138	12.35376	12.77132	13.88961	16.62211
JB	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*
ADF	(0.00010)*	(0.00000)*	(0.00010)*	(0.00000)*	(0.00010)*	(0.00010)*	(0.00010)*
LB (20)	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*	(0.00000)*
LB <sup>2</sup> (20)	(0.00005)*	(0.00002)*	(0.00537)*	(0.00024)*	(0.00041)*	(0.00006)*	(0.00084)*
ARCH (20)	(0.00038)*	(0.00052)*	(0.00005)*	(0.00025)*	(0.00009)*	(0.03240)**	(0.00048)*

Note: This table presents descriptive statistics for the returns of various exchange-traded funds (ETFs): DSI (iShares MSCI KLD 400 Social ETF), ICLN (iShares Global Clean Energy ETF), IWF (iShares Russell 1000 Growth ETF), PHO (PowerShares Water Resources Portfolio), XLK (Technology Select Sector SPDR Fund), XLV (Health Care Select Sector SPDR Fund), and SPY (SPDR S&P 500 ETF Trust). The Augmented Dickey-Fuller (ADF) test is applied to assess the stationarity of the return series. LB(k) and LB<sup>2</sup>(k) (with  $k = 20$ ) represent the Ljung-Box Q statistics for the  $k$ th order autocorrelation of residuals and their squared residuals, respectively. The ARCH (20) test, based on Engle (1982), is used to detect the presence of autoregressive conditional heteroscedasticity (ARCH) effects up to 20 lags.

\*Statistical significance at 1% levels.

\*\*Statistical significance at 5% levels.

**TABLE 2** | Matrix of profitability connectivity.

	DSI	ICLN	IWF	PHO	XLK	XLV	SPY	Receivers
DSI	18,30	9,32	16,08	13,75	14,71	11,49	16,34	81,70
ICLN	13,17	25,70	13,44	13,89	11,45	8,35	14,00	74,30
IWF	15,65	9,24	17,73	13,09	16,32	11,50	16,47	82,27
PHO	14,99	10,69	14,64	19,79	12,79	10,97	16,13	80,21
XLK	15,44	8,48	17,60	12,36	19,13	10,56	16,43	80,87
XLV	14,34	7,37	14,68	12,49	12,38	22,87	15,87	77,13
SPY	15,63	9,47	16,16	14,15	14,89	12,24	17,47	82,53
Givers	89,21	54,57	92,60	79,74	82,54	65,12	95,24	559,01
Incl. own	107,51	80,26	110,33	99,53	101,67	87,99	112,71	<b>SI = 79,86</b>
NET	7,51	-19,74	10,33	-0,47	1,67	-12,01	12,71	

Note: Table 2 reports the pairwise directional connectedness for returns across various exchange-traded funds (ETFs), including DSI (iShares MSCI KLD 400 Social ETF), ICLN (iShares Global Clean Energy ETF), IWF (iShares Russell 1000 Growth ETF), PHO (PowerShares Water Resources Portfolio), XLK (Technology Select Sector SPDR Fund), XLV (Health Care Select Sector SPDR Fund), and SPY (SPDR S&P 500 ETF Trust). The table presents the percentage of forecast error variance in market  $i$  attributable to shocks originating from market  $j$ . The column labeled “receivers” shows the total directional connectedness from all other markets to market  $i$ , while the row labeled “givers” displays the total directional connectedness from market  $j$  to all other markets. The diagonal elements represent the contributions of each market’s own returns to their forecast error variance. Additionally, the row labeled “net” indicates the total net pairwise directional connectedness, which is the difference between transmitters and receivers. The bottom-right cell, highlighted in bold, represents the overall connectedness, which is the average of the “receivers” or equivalently, the average of the “givers” connectedness across all markets.

sums, without including the main diagonal elements, show the spillovers received by each variable from the remaining variables. In turn, the column sums, excluding diagonal values, represent the contribution of each variable to the other variables.

Overall, 20.14% of the variation in the variables studied is due to idiosyncratic factors, while the remaining 79.86% is explained by the system formed by these variables, that is, it is the result of market interactions, and the spillover effect generated within the system. This high percentage certainly finds an explanation in the close connection between the segments considered in the analysis. The high value of the global connectivity suggests great proximity between the sustainable segments and the traditional segment, which can be justified by the fact that the segments studied have a common basis, so they can be affected by systematic risk phenomena. Thus, shocks occurring in one of these segments generate significant impacts on the others, resulting in a high degree of connectivity. It is possible to conclude that the segments studied are not independent from each other, with the average influence of each segment exceeding 80%. This high value allows us to conclude that the transmission of spillover in the global context is an important factor in the dynamics of the segments studied.

In general, the segments studied do not present a high self-explanatory power and do not show very significant differences among them. The ICLN shows the greatest self-explanatory power, with approximately 26% of its own variations, followed by XLV (22.87%). In turn, the traditional ETF reports the most modest self-explanatory power, at 17.47%.

SPY and IWF returns are the largest net contributors to the system, reporting the highest net spillovers of 12.71% and 10.33%, respectively, in line with the results obtained for the conditional correlations estimated in the previous topic. On the other hand,

the ICLN, XLV, and PHO showed negative net spillovers and are therefore net receivers of the system.

#### 4.2.2 | Analysis of Dynamic Connectivity

The static model discussed earlier assumes that the relationships between variables remain constant throughout the period of analysis. This static spillover index overlooks the potential for sudden shifts in returns, which are often triggered by significant economic or financial events. These abrupt fluctuations, which may have occurred during the sample period, can substantially affect both the intensity and direction of the dependencies between the sectors. Therefore, we extend our analysis to explore the presence of time-varying linkages among the seven sectors under consideration.

To capture the dynamic nature of connectivity over time, we employed a rolling window approach with a 250-day interval. This window size was selected to ensure an adequate number of observations for reliable model estimation, while also providing a sufficient timeframe for analyzing the evolving connectivity dynamics. To validate the robustness of our findings, several sensitivity checks were conducted. First, we examined various lag lengths in the VAR model; however, the spillover results remained stable across these different specifications. Second, we assessed the impact of alternative forecast horizons, and the dynamic and total spillovers showed minimal variation, which reinforces the robustness of our conclusions. Third, in order to assess the robustness of the empirical results, an alternative set of ETFs aligned with the SDGs examined in this study was selected, replacing those with the highest market value in assets under management. These alternative ETFs also exhibited substantial market capitalization and a sufficient historical data record to meet the pre-established sample period. The selected

funds include: IYH—iShares U.S. Healthcare ETF (SDG 3), FIW—First Trust Water ETF (SDG 6), TAN—Invesco Solar ETF (SDG 7), VUG—Vanguard Growth ETF (SDG 8), VGT—Vanguard Information Technology ETF (SDG 9), SUSA—iShares MSCI USA ESG Select ETF (SDG 12), and IVV—iShares Core S&P 500 ETF (traditional benchmark ETF). The estimates derived from this alternative selection of funds were highly consistent with the initial results, thereby reinforcing the robustness of the findings and supporting the validity of the conclusions drawn.

Figure 1 illustrates the temporal evolution of both the total spillover index (on the left) and the net spillover indices (on the right) across the sample period. Both indices exhibit clear time-varying patterns, consistent with the findings of Lau et al. (2017) and Chen et al. (2022). Regarding the total spillover index, we observe that overall connectivity remained high, indicating strong interdependence between the variables throughout the period. Notably, the evolution of this index reveals two distinct cycles: one during the global financial and sovereign debt crisis (2009–2012), where total connectivity peaked at approximately 0.84, and another during the onset of the COVID-19 pandemic crisis (2020), when connectivity surged beyond this threshold. These findings support the view that, as highlighted in previous studies (e.g., Elsayed and Yarovaya 2019; Zhang and Broadstock 2018; Singh et al. 2021; Salisu and Shaik 2022; Umar et al. 2021), periods of financial market turbulence tend to amplify the transmission of information across sectors, without any noticeable distinction between sustainable and traditional sectors.

To gain a deeper understanding of the directional relationships between the variables, we also estimated the net spillover indices, presented on the right side of Figure 1. These indices provide further insights into the dynamic interdependencies between the returns of the studied variables over time.

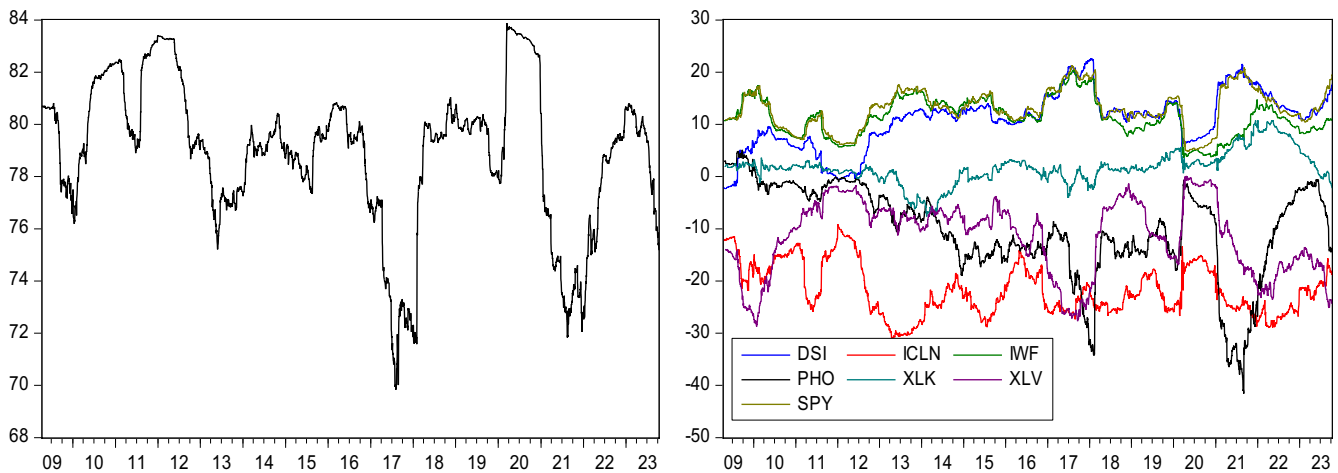
In terms of net transmission to the system, both IWF and SPY emerge as consistent net transmitters throughout the entire analysis period. Conversely, ICLN acts as a net receiver of shocks originating from the other sectors across the sample.

The distinction between ETFs that function as net transmitters versus net receivers of spillover effects is critical for understanding contagion mechanisms and the effectiveness of diversification within portfolios composed of both sustainable and traditional assets. This study reveals that certain ETFs, such as SPY (a traditional ETF) and IWF (linked to SDG 8—Decent Work and Economic Growth), predominantly act as net spillover transmitters. In contrast, others—such as ICLN (aligned with SDG 7—Affordable and Clean Energy)—consistently function as net receivers throughout the analysis period.

This dynamic can be attributed to both structural and systemic factors. ETFs with higher market capitalization and broader representation in financial markets, such as SPY, exert greater systemic influence due to their heightened sensitivity to macroeconomic shocks and their role as market benchmarks. These assets tend to initiate the transmission of shocks, particularly during periods of financial distress, thereby affecting other segments—such as specialized sustainable ETFs—that exhibit relatively lower liquidity or responsiveness.

The findings of this study align with the broader literature, which widely recognizes the interconnection and proximity between financial assets, particularly in times of crisis or market turbulence. During the pandemic and the Ukraine war, the heightened connectivity between the sectors under study, as evidenced in our results and consistent with Bouri (2023) and Banerjee (2024), can be attributed to the global nature of these events, which quickly impacted economies and financial asset prices worldwide. These unexpected global shocks led to negative investor sentiment regarding asset profitability, triggering more defensive investment strategies, including asset liquidations.

Such crisis episodes likely led to a shift in investor risk perception. The anticipation of high-impact negative shocks created significant pressure on the markets, which amplified risk transmission. During periods of heightened uncertainty, the interrelationship between assets or markets becomes more pronounced than in stable times, as investors lose confidence in their forecasts, and adverse news results in heightened spillovers.



**FIGURE 1** | Dynamic connectivity.

Our empirical results carry important implications for exchange-traded fund (ETF) investors, highlighting that spillover effects between sectors are time-varying. Both sustainable and traditional sectors serve as channels for both transmitting and receiving contagion, underscoring the need to consider these dynamic interdependencies.

This study contributes to the understanding of information transmission between sustainable and traditional assets, a subject that has received limited attention in the literature. Our findings show that while each sector exhibits distinct idiosyncratic behaviors, there is clear evidence of information flow between them. The traditional sector appears to exert a more substantial influence on its sustainable counterpart, as if leading the latter, though reverse transmission is also observed, albeit to a lesser extent. These results are consistent with a large body of research documenting the growing convergence of markets and assets across segments, particularly in the context of financial globalization (Mandigma 2014; Elsayed and Yarovaya 2019; Zhang and Broadstock 2018; Gabriel and Pazos 2018; Sharma et al. 2022; Gabriel et al. 2022), with more pronounced effects during periods of market turbulence (Salisu and Shaik 2022; Gabriel et al. 2022; Hasan et al. 2023).

The findings regarding the interdependence between sustainable and traditional ETFs indicate a significant degree of interconnectedness, which intensifies during periods of heightened uncertainty, such as the COVID-19 pandemic and the war in Ukraine. This evidence challenges the notion that ESG investments can serve as robust hedging instruments during times of crisis. Although some studies have documented the defensive properties of ESG assets (Lins et al. 2017; Naeem et al. 2022), the empirical results presented here suggest that, under systemic shocks, the correlation between ESG and traditional assets increases substantially, thereby diminishing the expected diversification benefits (Andersson et al. 2022; Lei et al. 2023).

Consequently, the conclusion that sustainable ETFs are not independent from their traditional counterparts is supported by the data and indicates that, while ESG investments play a crucial role in the construction of sustainable portfolios, they do not, on their own, offer meaningful protection during financial crises. These findings underscore the need for more dynamic risk management approaches that account for the interconnectedness between market segments and the non-static nature of asset correlations, particularly under conditions of systemic financial stress.

The implications of these results are significant for various market participants, especially in the context of formulating trading strategies, pricing options, and optimizing portfolio allocations. A failure to account for potential contagion between sustainable and traditional assets could undermine hedging strategies and threaten financial stability, particularly during crisis events that introduce systemic risk. Such shocks affect a broad range of assets and diminish the ability to diversify portfolios effectively. Consequently, both investors and policymakers can benefit from incorporating a more nuanced understanding of contagion dynamics into asset pricing models, portfolio risk management strategies, and broader market stability measures—particularly during times of systemic stress, such as the COVID-19 pandemic or the war in Ukraine.

## 5 | Conclusions, Implications, and Future Research

This study examines the dynamic connectivity between six sustainable exchange-traded funds (ETFs) and one traditional ETF, aiming to identify potential risk transmission channels. To achieve the research objectives, a sample period of 14 years with daily frequency was selected. Methodologically, we adopted the framework proposed by Diebold and Yilmaz (2012).

Addressing a gap identified in the literature review regarding sustainable ETFs, the selection of this topic was intended to fulfill two primary goals. First, it aims to conduct an in-depth analysis of the performance and behavior of seven distinct investment segments, six of which follow sustainable investment principles aligned with sustainable development goals. Second, it seeks to integrate both sustainable and traditional ETFs into a unified multivariate framework to explore potential contagion channels and the diversification opportunities that arise from these investment segments.

Applying the Diebold and Yilmaz (2012) methodology to the system comprising these seven segments enabled a detailed examination of the information transmission process, utilizing both static and dynamic approaches. From a static perspective, the analysis revealed that spillover effects between the studied segments are largely driven by shocks originating from other pairs, rather than specific factors, indicating that systemic forces play a dominant role in shaping segment behavior. From a dynamic perspective, this approach highlighted the impact of two significant market events—the COVID-19 pandemic and the Russian invasion of Ukraine—both of which caused a marked intensification of spillover effects across segments.

The results offer valuable insights into the magnitude of interconnectedness between sustainable and traditional ETFs during both stable and turbulent periods. The findings suggest a strong link between the two ETF categories, with their connectivity significantly increasing during periods of market turmoil. In times of high volatility, such as the pandemic or the Ukraine crisis, these assets exhibit synchronized responses, leading to a sharp increase in correlation intensity and reducing the potential for diversification.

This research contributes to the fields of theoretical and applied finance by advancing the understanding of the interconnectedness between sustainable and traditional ETFs. It underscores the limitations of diversification during periods of market stress and highlights potential avenues for future research in portfolio management, risk optimization, and global financial stability.

### 5.1 | Theoretical Implications

The research extends the theoretical understanding of risk transmission and contagion within financial markets, particularly in the context of sustainable versus traditional ETFs.

The study supports the theoretical framework proposed by Diebold and Yilmaz (2012) concerning information spillovers, showing that sustainability-driven ETFs exhibit both static and dynamic spillover effects. The finding suggests that financial markets, regardless of asset class, exhibit interconnectedness,

especially during periods of financial turmoil, which challenges prior theories that may have suggested these sustainable investments would behave independently of traditional markets. This aligns with modern financial theory that incorporates behavioral finance, market efficiency, and systemic risk, suggesting that sustainable investments are subject to the same macroeconomic and geopolitical risks as traditional assets, thereby influencing their diversification potential.

The findings imply that diversification benefits from sustainable ETFs might be overestimated in tranquil market conditions but are reduced during turbulent phases, as the spillover effects increase significantly during crises. This contributes to the theoretical debate surrounding the diminishing returns of diversification during market stress, which has important implications for portfolio theory.

## 5.2 | Practical Implications

For investors and portfolio managers, empirical research suggests that integrating sustainable ETFs into a portfolio may not deliver the anticipated diversification benefits, particularly during periods of heightened market volatility. Consequently, portfolio managers should consider a more nuanced approach by combining sustainable ETFs with alternative asset classes, such as commodities or fixed income securities, to optimize risk-adjusted returns. Furthermore, portfolio construction strategies should incorporate hedging mechanisms to mitigate systemic risks, particularly in times of elevated market uncertainty.

The findings emphasize the importance of dynamic risk management approaches that are responsive to periods of significant systemic risk, such as geopolitical crises or global pandemics. Investors must remain cognizant of the increased correlation across different ETF categories during turbulent market conditions and adjust their strategies accordingly to reduce exposure to systemic risks.

From a regulatory perspective, the study highlights the need for enhanced monitoring of the interconnections within investment segments, particularly during crises. A more robust regulatory framework is essential to mitigate contagion risks and safeguard against potential financial instability arising from the integration of traditional and sustainable investment products.

Ultimately, the research underscores the critical importance of understanding the interdependencies between sustainable and conventional asset classes, especially in times of crisis. Both investors and policymakers must recognize the potential for contagion effects that could undermine diversification strategies, destabilize markets, and threaten financial stability. Integrating a more comprehensive analysis of these dynamics is vital for informed decision-making, protecting portfolio integrity, and enhancing market resilience.

The evidence highlights the need for enhanced regulatory frameworks aimed at mitigating contagion risk and improving market resilience. Regulatory bodies should implement concrete measures, such as: mandatory disclosure of ETFs' underlying exposure to systemic risk factors, including concentration

in highly interconnected sectors, harmonization of ESG classification and labeling standards at the international level to reduce greenwashing and enhance transparency across markets, and standardized stress testing protocols for ESG-labeled funds to evaluate their behavior under adverse macro-financial scenarios.

By strengthening the regulatory architecture and promoting better-informed investment practices, these measures can reduce the amplification of systemic shocks through ETF channels and support the credibility and resilience of sustainable finance. Furthermore, this reinforces the importance of adopting a systemic risk lens in sustainable portfolio construction—one that integrates both environmental and financial stability objectives.

## 5.3 | Limitations

The study focuses on a relatively limited sample of six sustainable ETFs and one traditional ETF. While this provides useful insights, the results may not be generalizable to all sustainable investment vehicles or across different market conditions. Future research could benefit from a broader dataset that includes a wider range of sustainable assets and additional market periods to validate the findings. The research highlights the effects of specific geopolitical events like the pandemic and the Ukraine war, but it may not fully account for other macroeconomic factors such as monetary policy changes, interest rate fluctuations, or trade wars, which could further influence the connectivity between these ETFs.

## 5.4 | Future Research Areas

Future studies could explore more advanced optimization techniques, such as mean–variance optimization or alternative risk models (e.g., Conditional Value-at-Risk), to evaluate the risk–return profile of sustainable ETFs in diversified portfolios. This could offer deeper insights into how sustainable investments can be integrated with traditional assets for more robust portfolio construction.

Given the growing interest in sustainable investing, further research could investigate the behavioral factors influencing investment decisions in these ETFs. This could include analyzing investor sentiment, ESG (Environmental, Social, and Governance) scoring methodologies, and how these factors affect the financial performance of sustainable assets.

Investigating how different types of sustainable ETFs respond to a broader range of macroeconomic shocks (beyond geopolitical events) could be beneficial. This would help identify whether certain segments are more resilient to specific risks and provide more granular insights into their diversification potential.

Future research could expand the geographical scope of the study to include emerging markets, where the adoption of sustainable investment strategies may differ. This would allow for a more comprehensive understanding of how sustainable ETFs behave in diverse regulatory and economic environments, offering valuable insights for global investors.

## Acknowledgements

The first author recognizes and is grateful for the financial support received from FCT—*Fundação para a Ciência e Tecnologia* (grant UIDB/04043:CICF and UIDP/04043:CICF). The second author is grateful to the IME, the Department of Education of the Junta de Castilla y León, FEDER Funds (Reference: CLU-2025-2-03), and the European Regional Development Fund (Grant CLU-2019-03) for the financial support given to the Unidad de Excelencia Gestión Económica para la Sostenibilidad (GECOS), Universidad de Salamanca, the Spanish Ministry of Science and Innovation under the Grant Agreement PID2020-113498RA-C22 (IRENE) and the Spanish Ministry of Science and Innovation under the Grant Agreement PID2020-114797GB-I00 (SODEFGOC). We are also grateful to the FCT—Portuguese Foundation for Science and Technology under the project UIDB/04011/2020.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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