



Research article

Measuring the dynamics of ESG-related uncertainty in financial markets: Evidence from the sustainability uncertainty index¹

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Abstract: The aim of this study was to identify the systemic connectedness between ESG-based sustainability uncertainty (ESGUI) and stock markets and to reveal how these relationships changed under different volatility regimes and time horizons for the period 2002–2024. The analysis process integrated the time domain connectedness index of Diebold and Yılmaz (2012), the frequency-domain connectedness method of Baruník and Křehlík (2018), the quantile-based connectedness analysis of Ando et al. (2018), and the combined quantile–frequency connectedness approach of Chatziantoniou et al. (2022). The findings were evaluated separately for the entire period and for the subperiods of the Paris Agreement (2015–2016), COVID-19 (2020–2021), Russia–Ukraine war (2022–present), energy crisis (2021–2022), EU Green Deal (2019–2020), and carbon pricing process (2021–2023).

Keywords: ESG uncertainty; financial connectedness; stock markets; quantile connectedness; frequency-domain analysis

Jel Codes: C59, G15, Q01

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1. Introduction

Faced with increased competition, companies are striving to meet the expectations of various segments of society, including suppliers, consumers, employees, investors, and government agencies. These relationships require companies to assess the social and environmental impacts of their operations (Liu and Song, 2025). In this context, the concepts of environment (E), social (S), and governance (G) (ESG) are essential indicators reflecting companies' ability to combat climate change and their potential for sustainable development (Zumenté and Bistrova, 2021; Chen et al., 2023).

Environmental, social, and governance (ESG) standards have long been a symbol of corporate social responsibility and have become a benchmark for long-term competitiveness and value creation in financial markets. In recent years, interest in ESG performance has increased significantly in international financial markets (Ge and Zhang, 2025). At the same time, climate change and related risks pose a major threat to the financial stability of countries. Therefore, climate change is defined as a systemic risk that disrupts markets, causes economic stress, and triggers macroeconomic shocks (Yu et al., 2022; Nakhli et al., 2024; Gaies, 2025; Ge and Zhang, 2025). As a result, countries around the world have implemented various climate policies aimed at facilitating the transition to a low-carbon economy and strengthening climate protection.

In line with the United Nations Sustainable Development Goals, companies are looking for ways to reduce harmful emissions, such as greenhouse gases. To achieve these goals, they need to change their traditional business models and adapt their products and operations accordingly. However, it is important to remember that environmental innovation is a long-term process (Kyaw, 2022). Sustainable development guidelines aim to achieve this goal by preventing and mitigating climate risks while taking responsibility for their impacts (McDonald, 2011).

Environmental regulations hinder firms' competitiveness (Dechezleprêtre and Sato, 2017). The implementation of sustainable development policies is often characterized by uncertainty. This is due to the complexity of implementation processes, the dynamic evolution of policy objectives, and the difficulty of regional coordination of policy measures. Uncertainties strengthen firms' beliefs, complicate resource allocation and investment behavior, and affect their strategic plans (Kyaw, 2022; Ge and Zhang, 2025).

In recent years, uncertainties and increasing geopolitical risks, along with sustainability (ESG) issues such as climate change and social inequality, have made countries' financial markets a more profound risk factor (Alnafrah, 2024). On the other hand, while firms' transitions to a circular economy in terms of sustainability and the rapid development of artificial intelligence create new business opportunities, they can also trigger systemic risks through different channels (Alnafrah et al., 2025; Zhou and Alnafrah, 2025). Uncertainties related to climate and social policies expose firms to short-term externalities and increase pressure to adapt to policy changes. This can increase companies' costs and make them more cautious about environmental and social responsibility (Hu et al., 2023). This effect is particularly pronounced in capital-intensive or high-emitting sectors. Conflicting sustainability policies increase the associated uncertainty and consequently complicate firms' strategic decisions and resource allocation (Ge and Zhang, 2025). These regulations change frequently, especially in developing countries, adding to uncertainty. Frequent changes in policy direction and inconsistent policy formulation in these countries put businesses under pressure (Hu et al., 2023). Therefore, it is argued that the impact of political uncertainty on economic activity may increase due to the prolongation of the economic growth process and the waste of resources and time (Yung and

Root, 2019; Ongan et al., 2025). Furthermore, incorporating environmental (E), social (S), and governance (G) factors into the concept of uncertainty provides a new approach to the concept of sustainability. This approach also highlights the need to develop a new sustainability uncertainty index (Ongan et al., 2025). Sustainability uncertainty based on ESG criteria refers to unexpected changes and challenges in these criteria affecting global markets. This uncertainty can lead to significant fluctuations in market behavior (Ongan et al., 2025). Particularly in recent years, various geopolitical risks have emerged, closely intertwined with other environmental, social, and economic risks. These geopolitical risks affect almost all firms, whether directly related to ESG or not, to varying degrees. Firms are particularly affected by these uncertainties in terms of investment decisions, investor behavior, and resource allocation mechanisms (Alnafrah, 2024).

Growing societal concerns about corporate social responsibility and climate change are forcing companies to align their business practices with sustainable development goals. However, uncertainty about regulatory changes related to climate policies and compliance with ESG standards could lead to market instability (Gaies, 2025). This affects not only businesses but also the overall financial stability. Research shows that changes in ESG-related policies, such as tightening environmental regulations or improving governance mechanisms, can influence energy prices and market expectations (Olanrewaju et al., 2025). When investors and companies face uncertainty regarding ESG regulations (e.g., emissions, sustainability reporting, and risk assessment), they often delay or change their investment policies (Šević et al., 2024; Zhao et al., 2025). Several studies have examined the impact of political uncertainty on corporate performance or stock indices, which is the main motivation for this study. However, almost all of these studies have focused on uncertainty in countries' economic policies (Li et al., 2020; Kushwaah and Symss, 2025). Although various instruments (such as cryptocurrencies) have emerged in financial markets, there are gaps in the literature regarding the relationship between sustainable (ESG) investments and these markets. Therefore, this topic deserves to be examined within a broader framework (Qing and Alnafrah, 2025).

There are numerous studies in the literature examining the relationship between ESG performance and stock market results. In addition, there are also numerous studies on the impact of ESG activities and investments on corporate risk and performance (Sassen et al., 2016; Chairani and Siregar, 2021; Huang, 2021; Frambo and Kok, 2022; Aldieri et al., 2023; Neo et al., 2025). These studies focused on the impact of ESG performance on stock returns and company valuation, showing that higher ESG scores are generally associated with better financial performance. Some studies, particularly during periods of economic stress, examined the role of ESG in shaping market risk and volatility (Potì et al., 2024; Xu et al., 2025; Agustin et al., 2025). These studies suggest that ESG factors can mitigate negative risks or stabilize markets. In addition, various studies have investigated the effects of ESG on market quality indicators such as liquidity and efficiency (He et al., 2023). Based on their findings, it is argued that ESG is effective in reducing information asymmetry and improving market functioning. However, the effects of sustainability (ESG) uncertainty at the firm level have not been sufficiently addressed in the literature. The increasing intensity of global geopolitical risks within the study period and the lack of conclusive evidence regarding the impact of these risks on the performance of ESG-related firms (Alnafrah, 2024) are another motivation for this study. However, these studies primarily focus on ESG scores, ratings, or performance indicators, treating ESG as a static property. They largely ignore the role of uncertainty related to ESG, which refers to the unpredictability of ESG policies, regulations, and expectations. Unlike previous studies, this article focuses on ESG uncertainty and examines its impact on stock market dynamics.

Moreover, the study offers a different perspective by presenting the phenomenon of general sustainability in terms of sample (22 national MSCI indices) and period (2002–2024). Moreover, the variable used for ESG uncertainty in this study (ESGUI) is from Ongan et al. (2025), who reformulated the concept and brought innovation to the literature by adding the dimension of uncertainty to the concept. This study contributes to the literature by demonstrating that financial interconnectivity is shock-type dependent and can vary depending on the dominant transmission channel, rather than treating global shocks as directly comparable shocks. Building on this contribution, the study examines whether ESG-related uncertainty affects financial markets in a time-dependent, frequency-dependent, and regime-dependent manner. In this framework, ESG uncertainty is considered as a transmission channel that affects financial markets by altering expectations, risk perception, and investment behavior. Specifically, it investigates whether ESG–market connectedness changes over time, differs across short, medium, and long-term horizons, strengthens during periods of market stress, and weakens in more recent periods. The findings suggest that the ESG–market link changes over time and under different market conditions. Therefore, understanding the impact of changes in sustainability policies on equity indices can serve as a basis for policymakers to design future regulatory frameworks. This introduction is followed by a practical application.

2. Data and empirical methodology

The ESG Uncertainty Index (ESGUI) used in this study is obtained from the policy uncertainty database from January 2002 to December 2024 and is based on the methodology developed by Ongan et al. (2025). The index is constructed using text-mining techniques applied to monthly country reports from the Economist Intelligence Unit (EIU). Specifically, it measures the frequency of ESG-related keywords combined with uncertainty-related terms to capture sustainability-related uncertainty at the country level. The ESGUI extends traditional uncertainty measures by incorporating environmental, social, and governance dimensions into the uncertainty framework, thereby providing a more comprehensive measure of sustainability-related risks. The database covers 22 countries. To account for geographic and economic differences, countries were divided into five regions: North America (Canada, USA), Latin America (Brazil, Chile, Colombia, Mexico), Europe (Belgium, Germany, Spain, France, the UK, Greece, Ireland, Italy, the Netherlands, Sweden), Asia (China, India, Japan, Pakistan, Singapore), and the Pacific region (Australia). MSCI country data consists of monthly index values expressed in US dollars, and all series have been converted to logarithmic returns to ensure stationarity. The analysis is conducted separately for each country. Therefore, the results capture ESG–market connectedness at the country level rather than a fully integrated global spillover structure.

Stability tests were performed using the Augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests, which confirmed the stability of the regression models. While the ADF test yielded statistically significant results at the 1% level, the KPSS test failed to reject the stationary hypothesis in most countries. This confirms that the stationary hypothesis is satisfied based on the unit root test results.

The analysis was based on a combination of methods from previous studies. First, the Connectedness Index developed by Diebold and Yilmaz (2012) was used. Second, the frequency-domain connectedness approach of Baruník and Křehlík (2018) was used. This approach is based on the spectral analysis of the VAR model and allows the partitioning of shocks into short-term (1–6 months) and long-term (6–60 months) periods. Third, Ando et al. (2018) conducted a quantile-based

connectedness analysis. Finally, Chatziantoniou et al. (2022) used a combined quantile-frequency connectedness approach. This method estimates the degree of connectedness by considering both quantile and frequency measures within the same index. The forecast horizon ($H = 100$) and rolling-window size (60 months) are selected in line with the standard connectedness literature to ensure comparability and to capture medium-term dynamics. The robustness of the results was also verified using alternative rolling-window lengths and forecast horizons, and the main findings remain qualitatively unchanged.

The analysis was conducted not only over the entire sample period but also over periods of specific policy and market shocks. In this context, the Paris Climate Agreement (2015–2016), the EU Green Deal (2019–2020), the COVID-19 pandemic (2020–2021), the energy crisis (2021–2022), and the War between Russia and Ukraine (2022–present) were considered. We thus comprehensively assess how global ESG uncertainty changes short- and long-term market attitudes during different shock periods.

3. Results

This section presents the findings of a multidimensional analysis between ESG uncertainty indices (ESGUI) and MSCI country equity indices. The findings are analyzed for both the entire period and subperiods, comparing short- and long-term outcomes across different volatility regimes. Results reflect country-level connectedness rather than a fully integrated global system. Although the magnitude of reported measures appears small in percentage terms, these values are consistent with the connectedness literature. Moreover, results reflect persistent and economically meaningful transmission mechanisms across markets.

3.1. Stationarity tests

Before starting the empirical analyses, the stationarity of the series used was tested using the Augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests. Detailed test results are reported in Appendix 1. The ADF test strongly rejects the unit root hypothesis for both the MSCI and ESGUI series across all countries. The KPSS test, on the other hand, fails to reject the null hypothesis of stationarity in most cases, supporting the stationarity of the series. Both the ADF and KPSS tests indicate that the series are largely stationary. The results reveal that MSCI series are stationary by construction, as they are expressed in logarithmic returns. For the ESG Uncertainty Index (ESGUI), unit root tests confirm that the series are stationary at levels for the majority of countries. In cases where minor deviations are observed, the series remains within acceptable bounds for VAR estimation. Therefore, all variables satisfy the stationarity requirement of the VAR framework, ensuring the validity of the empirical results.

3.2. Diebold and Yilmaz (2012) connectedness index

3.2.1. Static connectedness analysis

This study primarily uses the Diebold and Yilmaz (2012) approach to measure the fundamental interconnectedness between ESG uncertainty shocks and stock markets. This method reveals the

transmission of ESG uncertainty shocks to stock markets and their reverse effects using total, directional, and net interconnectedness measures. Analyses were conducted for the period 2002–2024.

Table 1. Static Diebold–Yilmaz (2012) connectedness results between ESG uncertainty and MSCI Returns.

Country	Obs	p	H	ESG→MSCI(%)	MSCI→ESG(%)	NET_MSCI(%)	TCI(%)	Status
AUS	271	3	100	0.63231171	0.991135616	-0.358823907	0.811723663	ok
BEL	271	4	100	1.218960994	0.129000646	1.089960348	0.67398082	ok
BRA	271	3	100	0.434908417	0.328914808	0.105993608	0.381911612	ok
CAN	271	2	100	0.408974439	1.131089891	-0.722115452	0.770032165	ok
CHL	271	2	100	0.629951418	1.025479382	-0.395527964	0.8277154	ok
CHN	271	2	100	0.128796777	0.204372982	-0.075576204	0.16658488	ok
COL	271	2	100	0.606529686	0.134849115	0.471680571	0.370689401	ok
DEU	271	2	100	0.389772674	0.55498442	-0.165211746	0.472378547	ok
ESP	271	2	100	0.246372581	0.857120927	-0.610748346	0.551746754	ok
FRA	271	2	100	0.513291942	1.299145218	-0.785853276	0.90621858	ok
GBR	271	3	100	1.307076374	1.155963653	0.15111272	1.231520013	ok
GRC	271	6	100	3.061535751	2.892587779	0.168947973	2.977061765	ok
IND	271	5	100	5.950182137	0.989146343	4.961035794	3.46966424	ok
IRL	271	3	100	0.964718747	0.777093036	0.187625711	0.870905892	ok
ITA	271	4	100	1.926160271	2.219044971	-0.292884699	2.072602621	ok
JPN	271	2	100	0.891127386	0.574194744	0.316932643	0.732661065	ok
MEX	271	3	100	0.377649582	0.053041085	0.324608497	0.215345333	ok
NLD	271	5	100	1.125521145	3.512260495	-2.38673935	2.31889082	ok
PAK	271	6	100	2.158133258	1.381109755	0.777023503	1.769621507	ok
SGP	271	2	100	0.995408659	0.172956472	0.822452186	0.584182565	ok
SWE	271	4	100	1.346910194	3.409265338	-2.062355144	2.378087766	ok
USA	271	1	100	0.668301575	0.147266027	0.521035548	0.407783801	ok

Note: ESG→MSCI represents the contribution of ESG shocks to MSCI returns; MSCI→ESG represents the contribution of MSCI shocks to ESG uncertainty; NET_MSCI represents MSCI's net shock emitter/receiver role; and TCI represents the total connectedness across the system.

The results in the table show that the directional effects between ESG uncertainties and equity markets are generally low but significant. While the ESG→MSCI and MSCI→ESG effects are in the range of 0.1%–1% in most countries, this rate reaches 2%–6% in some developing countries. This finding indicates that ESG shocks have a limited but systemic effect on financial markets, and this effect differs among country groups. According to the TCI results, which represent the overall level of system connectedness, the highest values were found for India (3.47%), Greece (2.98%), the Netherlands (2.32%), and Sweden (2.38%). The ESG–MSCI interaction is more intense in these countries. In contrast, China (0.16%), Mexico (0.22%), and the USA (0.41%) have the lowest TCI values, and the interaction between ESG and financial returns remains weak in these markets.

In conclusion, the table reveals that the relationships between ESG and financial markets are not homogeneous. In some countries, ESG shocks drive financial markets, while in others, financial shocks dominate ESG uncertainty; in some major economies, this relationship remains quite weak.

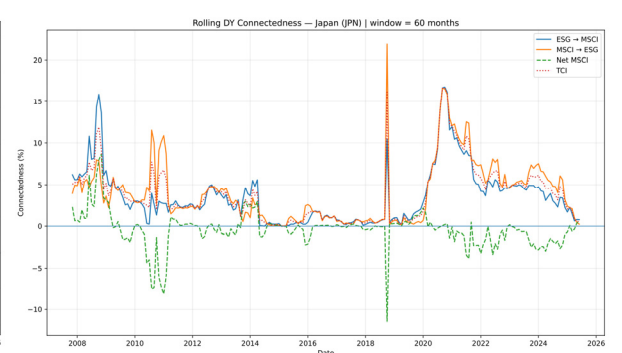
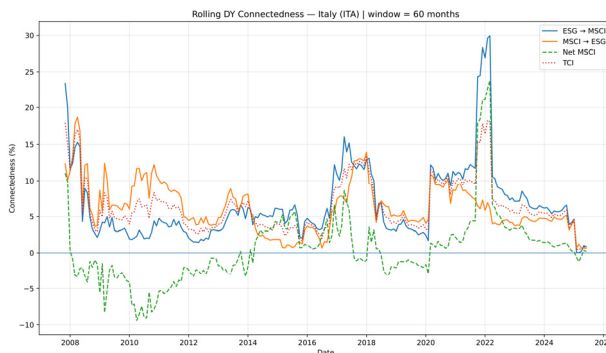
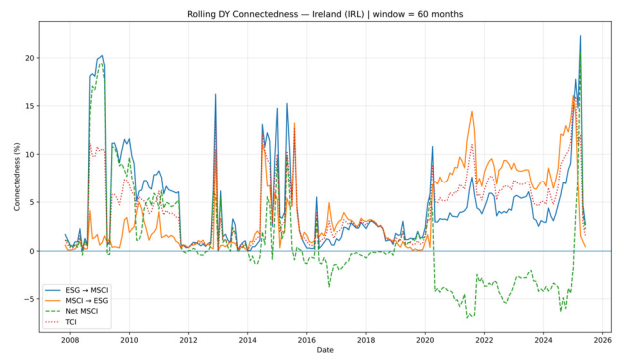
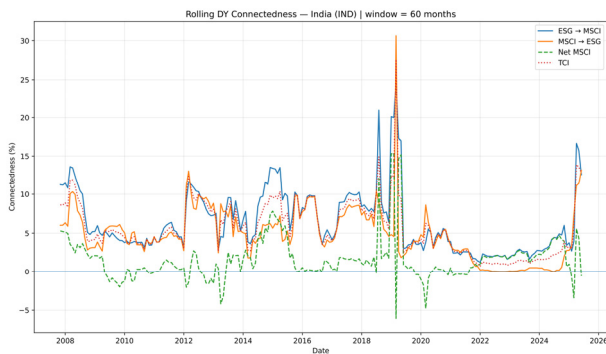
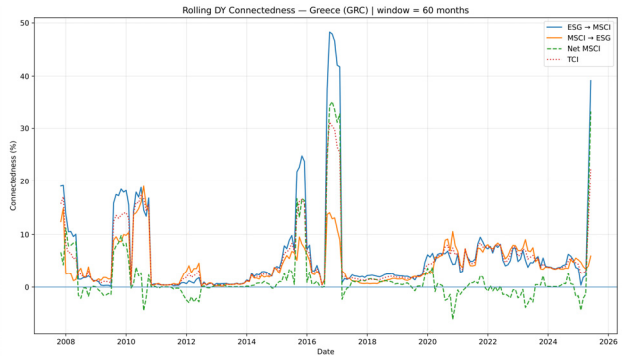
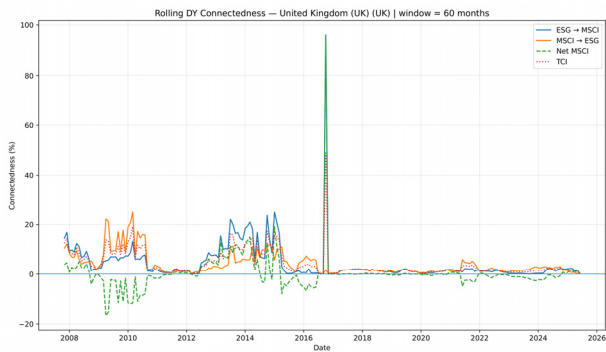
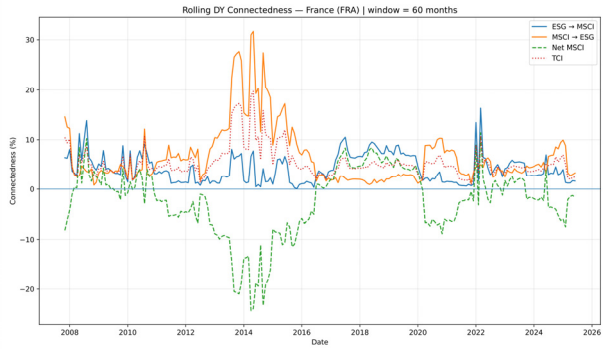
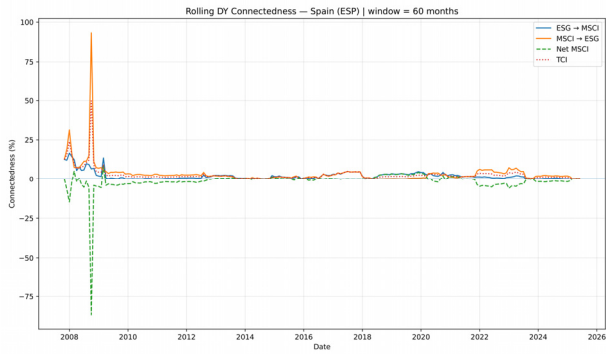
3.2.2. Time-varying connectedness dynamics

The figure 1 below report the two-way interactions as percentages of shock transmission from ESG uncertainty to MSCI returns and from MSCI returns to ESG uncertainty. The net MSCI series indicates whether the relevant market is predominantly a shock emitter (positive values) or a shock

receiver (negative values). Finally, the Total Connectedness Index (TCI) summarizes the overall level of connectedness between ESG and MSCI and reveals how this connectedness has changed over time using a 60-month rolling window.



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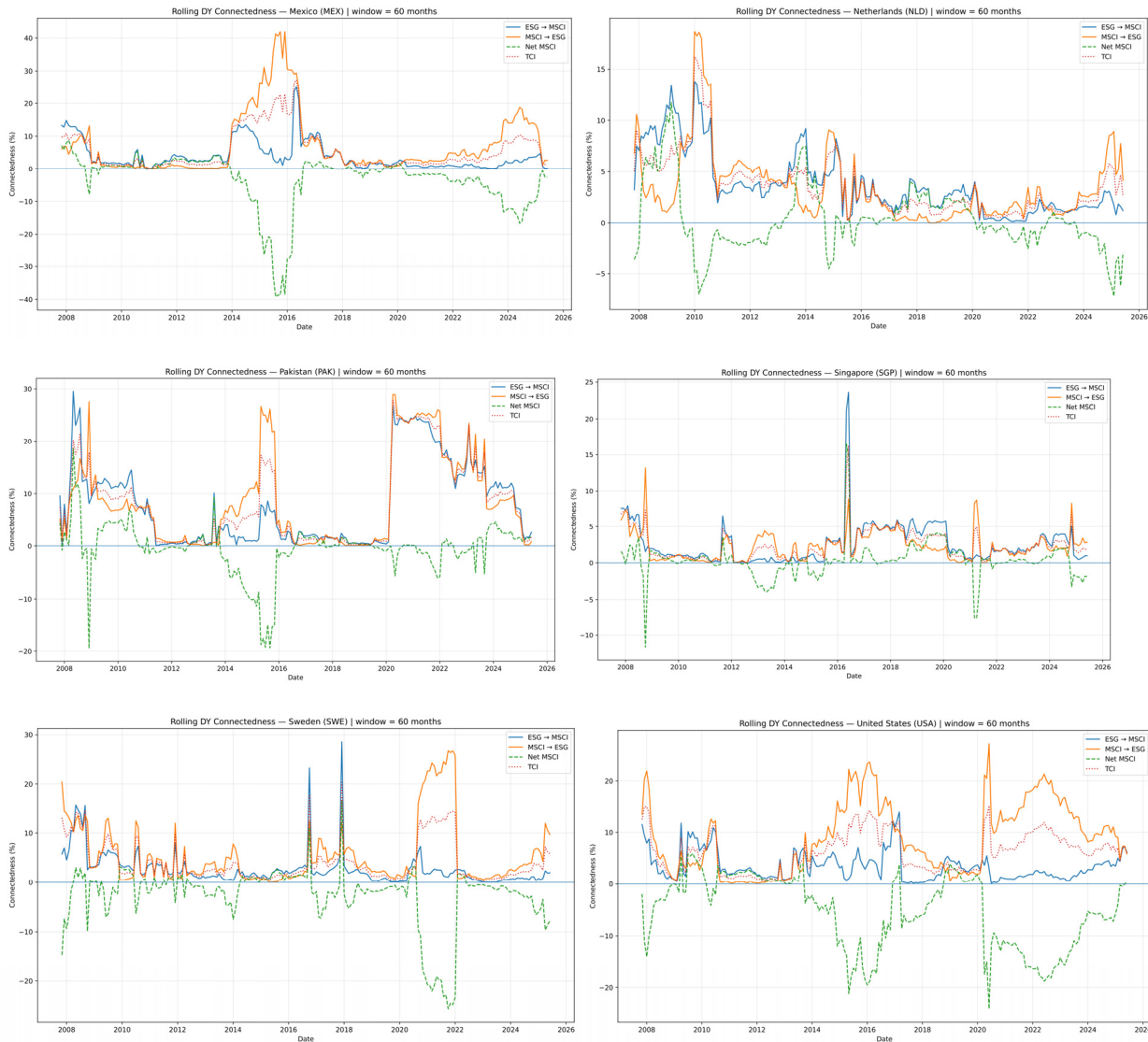


Figure 1. Rolling Diebold–Yılmaz (2012) connectedness dynamics (60-month window).
Source: Authors' calculations based on the Diebold and Yılmaz (2012) methodology.

The results obtained from the tables and graphs reveal that the relationships between ESG uncertainties and stock markets have changed over time. The Total Connectedness Index (TCI) has increased significantly, especially during periods of crisis and shock (2008 global crisis, Paris Agreement, COVID-19, energy crisis, and the Russia–Ukraine war). At the country level, stronger interactions are observed in several emerging markets and European economies, while the degree of connectedness varies across major economies such as the United States and China, rather than remaining uniformly low. This indicates that the impact of environmental, social, and governance (ESG) uncertainty on financial stability varies across countries and regions and is sensitive to global shocks.

3.2.3. Subperiod connectedness analysis

To determine how the responses vary for different crises and policy regimes, a time series analysis was conducted. Each period (global financial crisis, Paris climate agreement, COVID-19 pandemic,

energy crisis, European Green Deal, and Russia–Ukraine war) was studied separately. The Total Connectedness Index (TCI), calculated for each period, allows for a comparative assessment of the strength of the interaction between ESG uncertainty and MSCI index returns. This allows us to identify periods when shocks were more severe, and market correlation increased. The statistics are based on data from 22 countries.

Table 2. Subperiod summary statistics.

Period	Paris	GreenDeal	COVID	EnergyCrisis	UkraineWar
ESG→MSCI(%)_mean	20.4615	23.6252	26.0967	29.6829	20.0988
ESG→MSCI(%)_median	6.6300	19.5377	21.9921	36.8445	4.8193
ESG→MSCI(%)_std	27.3018	20.6375	25.9335	25.6699	32.5234
MSCI→ESG(%)_mean	23.7660	37.0880	30.3273	37.9941	4.6240
MSCI→ESG(%)_median	8.0823	31.1672	24.7637	41.7904	3.6540
MSCI→ESG(%)_std	27.2471	28.3654	29.5862	30.3134	4.2807
NET_MSCI_mean	-3.3045	-13.4628	-4.2306	-8.3112	15.4748
NET_MSCI_median	-0.6363	-9.7549	0.2684	-4.7765	1.3502
NET_MSCI_std	36.2184	36.9769	39.7278	36.5763	32.7297
TCI(%)_mean	22.1137	30.3566	28.2120	33.8385	12.3614
TCI(%)_median	11.6435	25.6748	29.3624	48.4929	5.9225
TCI(%)_std	20.3949	16.5357	19.4775	21.3182	16.4390
N	22	22	22	22	22

Although formal statistical tests have not been conducted, the consistent patterns across countries and periods suggest that the differences are not random but reflect the impact of major global shocks. Therefore, the interpretation is based on economically meaningful variation rather than purely statistical significance. These patterns are also consistent across alternative model specifications, further supporting the robustness of the results.

During the Paris Agreement period, the Total Connectedness Index (TCI) was relatively low, averaging 22.1%. Shock transmission from ESG uncertainties to MSCI returns (20.5%) and from MSCI returns to ESG uncertainties (23.8%) remained limited. This result suggests that the relationship between market and sustainability uncertainties was weaker during the Paris Agreement period. During the Green Deal period, connectedness levels increased, reaching an average TCI of 30.4%. During this period, the directional effect from MSCI to ESG (37.1%) was particularly stronger than the effect from ESG to MSCI (23.6%). Therefore, a period in which market movements are more likely to drive ESG uncertainties, i.e., market-based shocks are decisive, stands out. During the COVID-19 period, the TCI was high at 28.2%. The interactions from ESG to MSCI (26.1%) and from MSCI to ESG (30.3%) were quite close, resulting in a relatively balanced bidirectional relationship. This finding suggests that both sustainability uncertainties and market developments simultaneously affected stock markets and ESG uncertainties during the pandemic. The Energy Crisis period represents the highest level of interconnectedness. The average TCI was 33.8%, the highest among all periods. Shock transmission from ESG to MSCI (29.7%) and from MSCI to ESG (38.0%) was strong. This result suggests that the interconnectedness between market and ESG uncertainties intensified during the energy crisis. During the Ukrainian War, connectedness weakened, with the TCI reaching its lowest level at an average of 12.4%. Although an impact of ESG uncertainties on MSCI (20.1%) was observed, the direct interaction from MSCI to ESG was quite low (4.6%). This suggests that shock transmission during the war was unilateral; ESG uncertainties affected stock markets, but market returns had a very limited impact on ESG uncertainties.

Subperiod analyses reveal that connectedness levels increased during crisis and shock periods, while remaining relatively low during more stable periods. The Energy Crisis and the COVID-19 pandemic periods witnessed the strongest bidirectional connectedness between ESG uncertainties and MSCI returns. High connectedness was also observed during the Green Deal period, but during this period, the interaction shifted more from markets to ESG uncertainties. The Paris Agreement period indicated relatively limited connectedness, while the Ukraine War period was notable for its lowest connectedness levels. These results suggest that market–ESG interactions intensify under crisis conditions, but geopolitical shocks such as wars weaken systemic connectivity and make it unidirectional.

3.2.4. Cross-country connectedness patterns

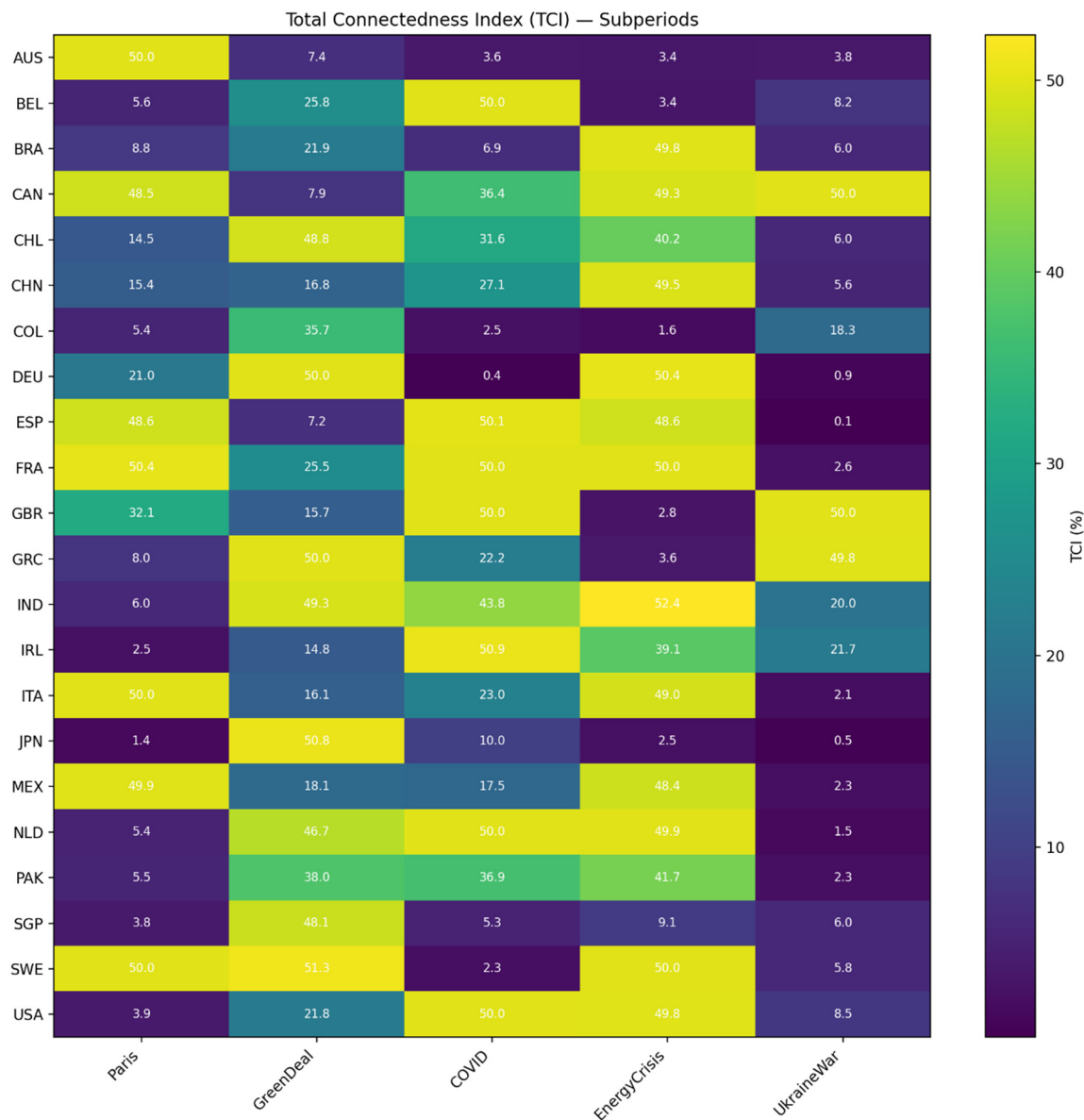


Figure 2. Heatmap of subperiod connectedness. Source: Authors' calculations based on the Diebold and Yılmaz (2012) methodology.

In subperiod analysis, simply viewing aggregate engagement levels is not enough. Comparisons across countries are also important. Therefore, the Total Engagement Index (TCI) values calculated by country for each subperiod (Paris Agreement, European Green Deal, COVID-19 pandemic, Energy Crisis, and Russia–Ukraine War) are presented as a heatmap. This visualization easily distinguishes which countries exhibited higher engagement in certain periods and which countries exhibited relatively weaker interactions. Furthermore, color intensities allow for visual comparison of differences between subperiods, clearly revealing how engagement patterns shifted in response to crises, policy, and geopolitical shocks.

According to figure 2, during the Paris Agreement, some countries (such as France, Italy, Spain, Australia, Sweden, and Mexico) achieved high TCI scores and connectedness level rates of around 50%. In contrast, countries like Ireland, Japan, Pakistan, and Belgium showed a much lower connectedness level. This suggests that the Paris Agreement strengthened the link between markets and ESG in some countries but did not have a significant impact globally.

During the Green Deal period, connectedness increased in several countries, particularly in Europe and parts of Asia. Countries such as Sweden (51.3%), Japan (50.8%), Singapore (48.1%), and India (49.3%) exhibited high levels, while some economies, including Canada and Australia, remained at lower levels. During the COVID-19 period, connectedness generally increased across many countries. However, while the magnitude of this increase varied, it indicates a widespread but heterogeneous response. The energy crisis period exhibited the highest levels of connectedness, particularly in major economies such as India (52.4%), China (49.5%), the United States (49.8%), Canada (49.3%), and Mexico (48.4%). This suggests that global shocks related to energy markets intensified ESG–market interactions. In contrast, during the Ukraine War period, connectedness declined substantially in most countries, although a few economies (such as the United Kingdom, Canada, and Greece) maintained relatively high levels. Overall, the results suggest that ESG–market connectedness is highly time-varying and country-specific, with stronger interactions during global crises and more heterogeneous patterns during policy-driven periods.

3.3. *Frequency-domain connectedness (Barunik and Křehlik (2018))*

3.3.1. Country-level results

Mixed-frequency connectedness analysis extends the approach of Diebold and Yilmaz (2012) to understand how a shock propagates not only globally but also across different time periods. This method allows for the analysis of the temporal structure of dependencies by combining short-term, medium-term, and long-term frequency components. For example, it can be determined whether shocks are more effective in the short-term or long-term during crisis periods. This pattern reflects not only the strength of market interactions with ESG but also the time periods over which they intensify.

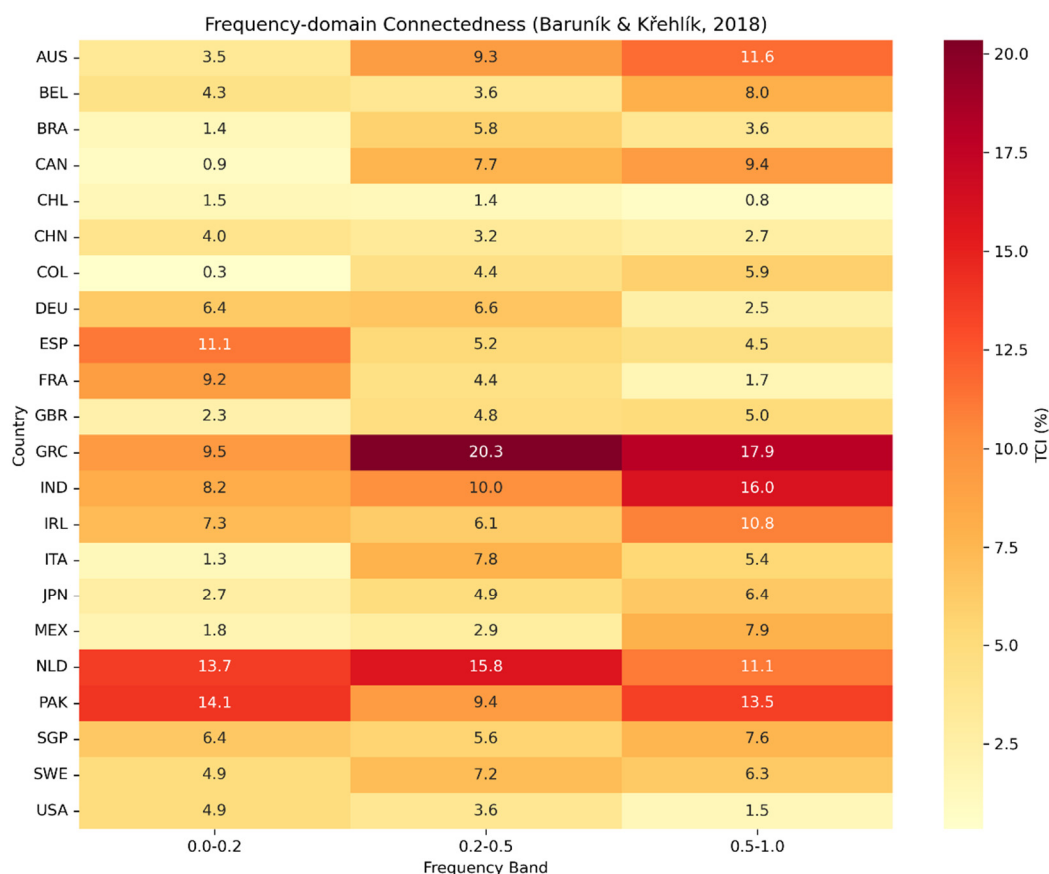


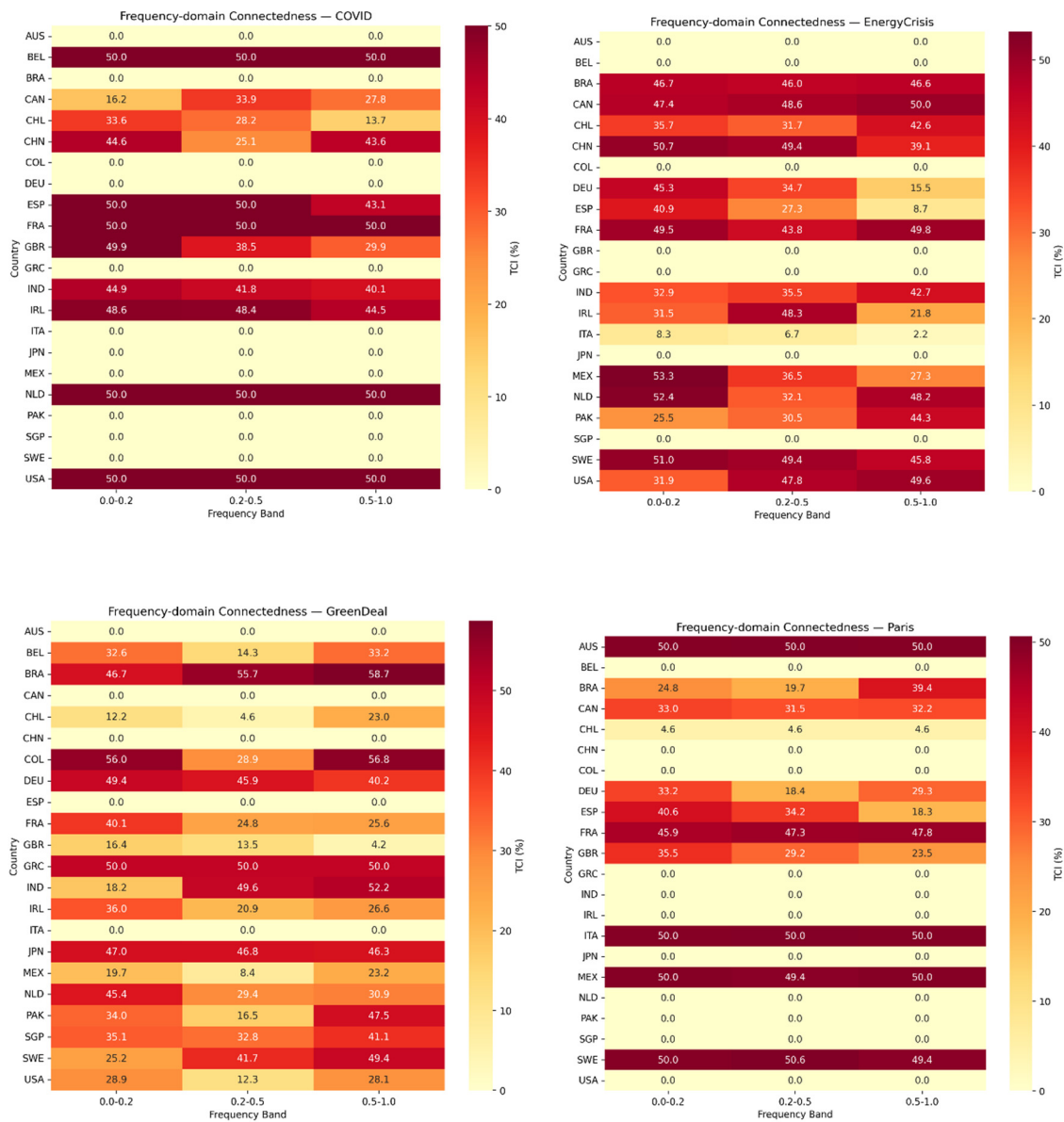
Figure 3. Frequency-domain connectedness heatmap (Baruník & Křehlík, 2018) Source: Authors' calculations based on the Baruník & Křehlík (2018) methodology.

Figure 3 shows the results of the frequency-domain analysis by country. The horizontal axis represents the short-term (0.0–0.2), medium-term (0.2–0.5), and long-term (0.5–1.0) frequency bands, while the vertical axis represents the countries. Color intensity and values reflect the Total Connectedness Index (TCI, %) levels calculated in each frequency band. This shows which countries exhibit stronger connectedness in the short, medium, and long term.

According to the findings, Greece (GRC), India (IND), the Netherlands (NLD), and Pakistan (PAK) stand out with high TCI values, especially in the medium and long-term frequencies. This indicates that connectedness is more pronounced in medium and long-term frequencies in these countries. Spain (ESP) and France (FRA), exhibiting high connectedness values (0.0–0.2) in the short-term range, are among the countries where shocks are concentrated in the short term. Some countries, such as Australia (AUS), Mexico (MEX), and the United States (USA), exhibit relatively low TCI values across all frequency bands. This indicates that shocks have a more limited impact in these countries. The results reveal that connectedness changes not only between periods of crisis but also across time horizons. In particular, short-term shocks are dominant in some countries, while medium and long-term effects are more pronounced in others.

3.3.2. Subperiod analysis

In this section, frequency-decomposed connectedness results are presented separately for each subperiod. The graphs show the distribution of shocks across countries in the short-term (0.0–0.2), medium-term (0.2–0.5), and long-term (0.5–1.0) frequency bands. Due to the relatively low overall level of connectivity and the nature of the frequency domain, some frequency components may yield values close to zero. It should be noted that this reflects limited diffusion density over specific time intervals. Figure 4 illustrates how the impact of ESG uncertainty on financial markets varies across different subperiods in short, medium, and long-term horizons.



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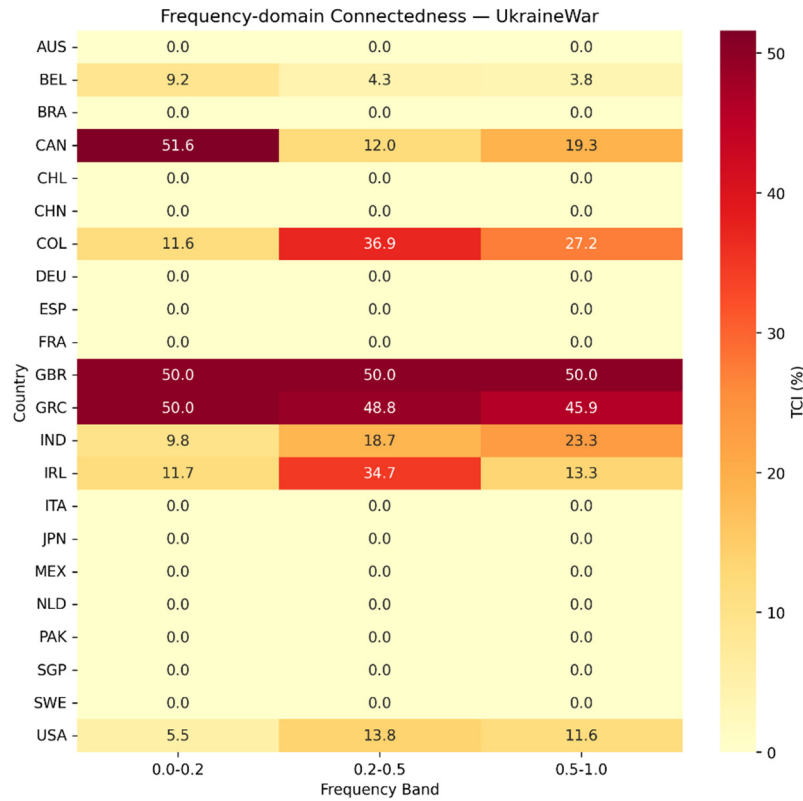


Figure 4. Frequency-domain connectedness across subperiods (Baruník & Křehlík, 2018).
Source: Authors' calculations based on the Baruník & Křehlík (2018) methodology.

A detailed frequency-dependent analysis reveals that the impact of shocks on markets varies significantly over time. Figure 4 shows that, while varying across countries during the Paris Agreement, the emergence of medium- and long-term benefits during the European Green Deal suggests that green transition measures generated sustained market effects. The COVID-19 pandemic exhibits a global and simultaneous shock trajectory, with strong variations in the short and long term. The inclusion of long-term observations during the energy crisis reveals that energy price shocks had a structural impact on markets. On the other hand, the conflict between Ukraine and Russia is characterized by a more limited and fragmented nature, reflecting the regional concentration of its impacts. Overall, these results suggest that shock effects can be observed across different time horizons, ranging from short-term market reactions to long-term persistence.

3.4. Quantile connectedness (Ando et al., 2018)

The quantile adjustment method, developed by Ando et al. (2018), expands the scope of traditional supply chain analysis by considering different market conditions. Unlike traditional average-based methods, this approach estimates shock transmission separately during low quantiles (q10: crisis or recession phases), medium quantiles (q50: normal conditions), high quantiles (q90), or quiet growth phases. This helps us determine whether the market impact of ESG-related shocks is stronger during crisis or stability phases. This method takes into account system-related dynamics not captured by the standard timeframe or frequency-domain connectedness approach and more clearly

reflects the symmetric nature of market and ESG interactions. Figure 5 illustrates the symmetric and systematic nature of ESG shocks, showing the average beta coefficients at three different percentage points for each continent.

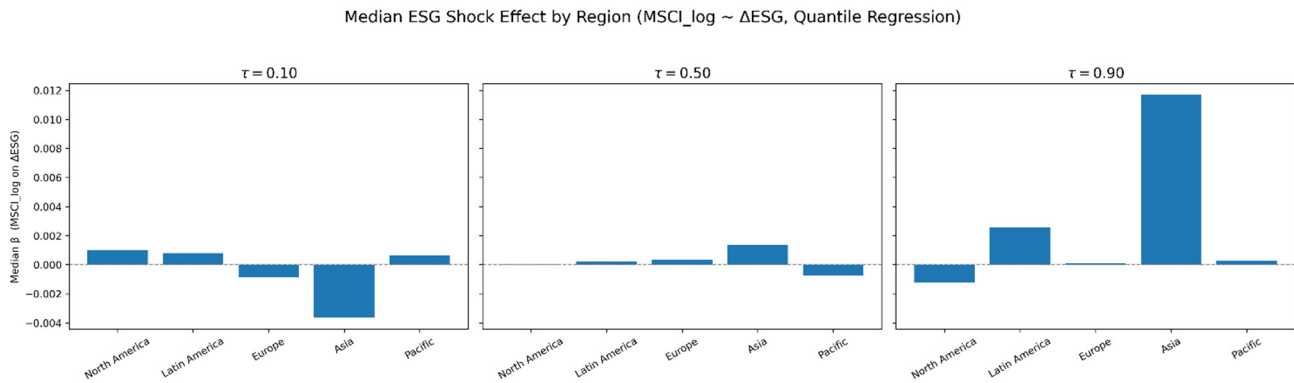


Figure 5. Regional median effects of ESG shocks across quantiles. Source: Authors' calculations based on the Ando et al. (2018) methodology.

The regional summaries of the quantile regression results show that the impact of ESG uncertainty shocks on equity markets varies according to quantile levels and regional differences. In other words, the findings indicate that the impact of ESG uncertainty on financial markets is not constant but dependent on market conditions. At the lower quantile ($\tau = 0.10$), the effects are limited and positive in most regions. At the middle quantile ($\tau = 0.50$), more stable but weaker positive effects are observed. Conversely, at the upper quantile ($\tau = 0.90$), the impact of ESG uncertainty becomes more pronounced, particularly in Asia. This suggests that ESG-related shocks exert stronger pressure on financial markets during periods of high volatility or stress. Overall, the results show that ESG–market interactions are situation-dependent, with stronger effects observed under adverse market conditions.

3.5. Combined quantile–frequency (CQF) connectedness results (Chatziantoniou et al. (2022))

In the final step, the method of Chatziantoniou et al. (2022) was used. The graphs below show the average TCI values for three subperiods (2002–2008, 2009–2015, 2016–2023) under regimes (low, median, high) and time dimensions (short-term impact: 1–6 months; long-term impact: 6–60 months). The height of the bars represents the average Total Connectedness Index for countries in the relevant subperiod. Therefore, the higher the bar, the stronger the ESG–market interaction in that regime and time dimension. Thus, both inter-period (e.g., pre-crisis vs. post-crisis), inter-regime (low–median–high), and short-term and long-term effects can be compared.

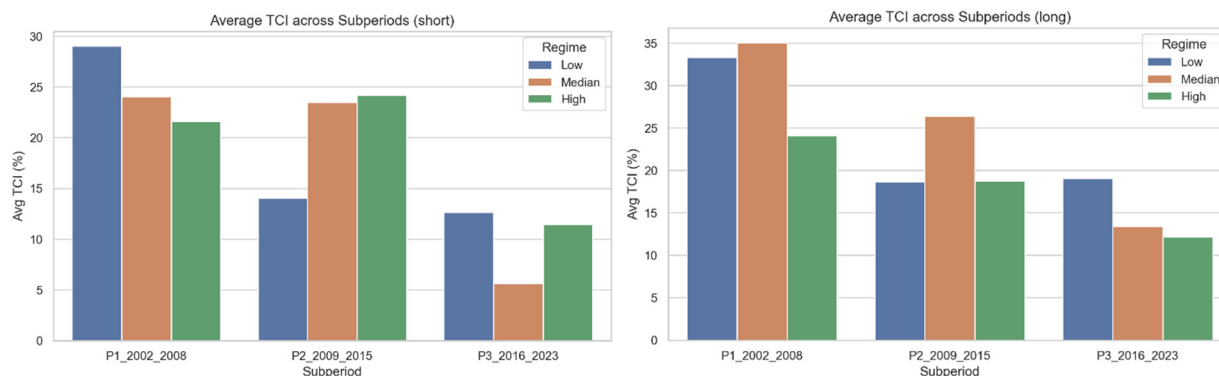


Figure 6. Average TCI across subperiods under different quantile regimes (short- and long-term effects). Source: Authors' calculations based on the Chatziantoniou et al. (2022) methodology.

Figure 6, the analysis findings indicate that the link between ESG and the market was relatively high in the pre-global financial crisis period (2002–2008) and decreased during the post-crisis recovery period (2009–2015). Furthermore, it appears that these levels reached their lowest points in the more recent period (2016–2023), which witnessed numerous global shocks such as the Paris Agreement, the EU Green Deal, the COVID-19 pandemic, the energy crisis, and the Russia–Ukraine war. This finding indicates that ESG–market interactions were stronger and more widespread before the crisis, and more limited in the recent period.

When evaluated in terms of time horizons, it is seen that both short-term and long-term effects were strong in the pre-crisis period, but the dominance of these effects varied depending on the regime. However, in the following periods, these effects weakened, and short-term and long-term effects gradually converged. In the recent period, ESG effects are observed to be quite limited in both time periods. This finding suggests that information related to ESG is reflected in markets more quickly and effectively over time, and that lasting spillover effects are decreasing. The results also show that ESG effects are generally stronger in high volatility regimes and relatively limited in stable market conditions. Overall, the findings confirm that ESG–market interactions are both regime- and time horizon-dependent, and show a general tendency to weaken over time.

4. Conclusions

This study examines the interaction between ESG uncertainty indices (ESGUI) and country-specific MSCI country indices using a comprehensive and multidimensional approach for the period 2002–2024. Four methodologies were applied: the traditional Connectedness Index developed by Diebold & Yılmaz (2012), followed by the frequency domain connectedness analysis proposed by Baruník & Křehlík (2018), the quantile-VAR approach developed by Ando et al. (2018), and the combined quantile-frequency connectedness method developed by Chatziantoniou et al. (2022). The combined evaluation of these methodological approaches reveals that the impact of the ESG Uncertainty Index on financial markets is not unidimensional but rather exhibits a structure that varies depending on time, frequency, and volatility regimes. The results of all these methodologies are consistent.

The findings demonstrate how ESG–market interactions change across time, frequency, and different volatility regimes. Significant increases in the Total Connectedness Index have been observed, particularly during shocks such as the global financial crisis, the COVID-19 pandemic, and the Russia–Ukraine war. This indicates that ESG-related shocks are felt more intensely in markets during crisis periods, increasing the spread of financial risk. On the other hand, the long-term effects of ESG shocks have weakened relatively in the post–Paris Agreement period, with market movements being shaped more by macroeconomic and geopolitical factors. These findings are consistent with previous research showing that interconnectedness changes over time and depends on the type, persistence, and transmission channel of the shock (Diebold and Yilmaz, 2012; Baruník and Křehlík, 2018).

Subperiod analysis further strengthens this interpretation by revealing that ESG–market interactions have weakened over time. While both short-term and long-term interconnectedness were strong during the 2002–2008 period, these interactions decreased during the 2009–2015 period and reached their lowest levels during the 2016–2023 period. Furthermore, while long-term effects were dominant before the crisis, recently, short-term and long-term effects have converged and remained at low levels. This indicates that information related to ESG is reflected in prices more quickly and effectively over time. Consequently, the capacity for persistent spillover effects in markets has decreased. These results show that the impact of ESG shocks on markets is sensitive to cyclical conditions. In the literature, these differences in how markets price ESG uncertainty can be interpreted through institutional theory and the geographical or sectoral positions of countries, where stronger regulatory environments increase the importance and pricing of ESG-related risks (Sun and Zhao, 2024; Zhang and Zhang, 2026). In this context, the findings reveal that the impact of ESG uncertainty on market pricing is not fixed, but a conditional process that varies depending on market regimes and institutional structures.

From a policy perspective, the findings emphasize that the responses of financial markets to ESG uncertainties are not uniform but manifest themselves with different magnitudes in different periods. Given that ESG shocks have a more pronounced impact on markets, especially under crisis conditions, it is crucial for policymakers to consider global uncertainties when designing ESG regulations. This indicates that ESG policies should be designed not as static but flexible structures sensitive to changing market conditions. For investors, the implications show that the integration of ESG factors into portfolio diversification and risk management strategies should take cyclical conditions into account.

In conclusion, this study demonstrates that the relationship between ESG uncertainty and financial markets is dynamic, regime-dependent, and sensitive to seasonal vulnerabilities. Therefore, ESG uncertainty is not a fixed risk factor or one priced uniformly in every period. Rather, it should be considered a dynamic risk transmission mechanism that changes depending on market conditions. The finding that the ESG–market link has weakened over time, particularly since 2016, does not contradict the increasing importance of ESG. On the contrary, this finding may be related to the calculation of the index followed in this study or the methodology chosen, or it may stem from a narrowing of risk premiums related to ESG and mispricing, differences in ESG ratings, greenwashing, and noisy signals. (Yue, 2023; Lin et al., 2023; Yang et al., 2024; Tian et al., 2025). Future studies comparing ESG indicators with alternative measures (e.g., green bond indices, carbon prices) and testing them with micro-level firm-specific data will make significant contributions to the literature.

Author contributions

The authors declare to have contributed equally to the manuscript. All authors have read and approved the final manuscript.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflict of interest.

References

- Agustin IN, Safitri D, Hesniati H, et al. (2025) Navigating market volatility: ESG and Islamic stock performance amidst Covid-19 stringency. *ETIKONOMI* 24: 69–84. <https://doi.org/10.15408/etk.v24i1.38475>
- Aldieri L, Amendola A, Candila V (2023) The impact of ESG scores on risk market performance. *Sustainability* 15: 7183. <https://doi.org/10.3390/su15097183>
- Alnafrah I (2024) ESG practices mitigating geopolitical risks: Implications for sustainable environmental management. *J Environ Manage* 358: 120923. <https://doi.org/10.1016/j.jenvman.2024.120923>
- Alnafrah I, Alqararah K, AlJaradin M (2025) From linear to circular: Evaluating the effects of circular economy on sustainable development progress in the EU economies. *J Environ Manage* 382: 125383. <https://doi.org/10.1016/j.jenvman.2025.125383>
- Ando T, Greenwood-Nimmo M, Shin Y (2018) Quantile Connectedness: modelling tail behaviour in the topology of financial networks. *Available at SSRN* 3164772. <http://dx.doi.org/10.2139/ssrn.3164772>
- Baruník J, Křehlík T (2018) Measuring the frequency dynamics of financial connectedness and systemic risk. *J Financ Economet* 16: 271–296. <https://doi.org/10.1093/jjfinec/nby001>
- Chairani C, Siregar SV (2021) The effect of enterprise risk management on financial performance and firm value: the role of environmental, social and governance performance. *Meditari Account Res* 29: 647–670. <https://doi.org/10.1108/MEDAR-09-2019-0549>
- Chatziantoniou I, Abakah EJA, Gabauer D, et al. (2022) Quantile time–frequency price connectedness between green bond, green equity, sustainable investments and clean energy markets. *J Clean Prod* 361: 132088. <https://doi.org/10.1016/j.jclepro.2022.132088>
- Chen S, Song Y, Gao P (2023) Environmental, social, and governance (ESG) performance and financial outcomes: Analyzing the impact of ESG on financial performance. *J Environ Manage* 345: 118829. <https://doi.org/10.1016/j.jenvman.2023.118829>

- Dechezleprêtre A, Sato M (2017) The impacts of environmental regulations on competitiveness. *Rev Environ Econ Policy*. <https://doi.org/10.1093/reep/rex013>
- Diebold FX, Yilmaz K (2012) Better to give than to receive: Predictive directional measurement of volatility spillovers. *Int J Forecast* 28: 57–66. <https://doi.org/10.1016/j.ijforecast.2011.02.006>
- Frambo MB, Kok CJ (2022) ESG score, stock valuation, and stock performance during the 2020 COVID-19 stock market crash. *J Impact ESG Invest* 2: 69–77. <https://doi.org/10.3905/jesg.2022.1.046>
- Gaies B (2025) Risky finance, riskier climate: when financial instability meets climate risks on the bridge of sustainability uncertainty. *North Ame J Econo Financ*, 102492. <https://doi.org/10.1016/j.najef.2025.102492>
- Ge H, Zhang X (2025) From uncertainty to sustainability: How climate policy uncertainty shapes corporate ESG? *Int Rev Econ Financ* 98: 104011. <https://doi.org/10.1016/j.iref.2025.104011>
- He F, Feng Y, Hao J (2023) Corporate ESG rating and stock market liquidity: Evidence from China. *Econ Model* 129: 106511. <https://doi.org/10.1016/j.econmod.2023.106511>
- Hu Y, Bai W, Farrukh M, et al. (2023) How does environmental policy uncertainty influence corporate green investments? *Technol Forecast Soc* 189: 122330. <https://doi.org/10.1016/j.techfore.2023.122330>
- Huang DZ (2021) Environmental, social and governance (ESG) activity and firm performance: A review and consolidation. *Account Financ* 61: 335–360. <https://doi.org/10.1111/acfi.12569>
- Kushwaah P, Symss J (2025) Asymmetric connectedness between economic policy uncertainty of selected countries and Indian equity market. *J Financ Econ Policy* 18: 325–346. <https://doi.org/10.1108/JFEP-10-2024-0299>
- Kyaw K (2022) Effect of policy uncertainty on environmental innovation. *J Clean Prod* 363: 132645. <https://doi.org/10.1016/j.jclepro.2022.132645>
- Li T, Ma F, Zhang X, et al. (2020) Economic policy uncertainty and the Chinese stock market volatility: Novel evidence. *Econ Model* 87: 24–33. <https://doi.org/10.1016/j.econmod.2019.07.002>
- Lin X, Zhu H, Meng Y (2023) ESG greenwashing and equity mispricing: evidence from China. *Financ Res Lett* 58: 104606. <https://doi.org/10.1016/j.frl.2023.104606>
- Liu EX, Song Y (2025) ESG performance, environmental uncertainty, and firm risk. *J Int Financ Manage Account* 36: 292–322. <https://doi.org/10.1111/jifm.12227>
- McDonald J (2011) The role of law in adapting to climate change. *Wires Clim Change* 2: 283–295. <https://doi.org/10.1002/wcc.96>
- Nakhli MS, Gaies B, Hemrit W, et al. (2024) Twenty-year tango: Exploring the reciprocal influence of macro-financial instability and climate risks. *J Econ Behav Organ* 220: 717–731. <https://doi.org/10.1016/j.jebo.2024.02.017>
- Neo JRD, Sing TF, Wang W (2025) Doing good and doing well: The relationships between ESG and stock returns of REITs. *Real Estate Econ* 53: 1105–1137. <https://doi.org/10.1111/1540-6229.12534>
- Olanrewaju VO, Adebayo TS, Uzun B (2025) Navigating the impact of ESG sustainability uncertainty on fossil fuel prices: Evidence from wavelet cross-quantile regression. *Appl Econ*, 1–17. <https://doi.org/10.1080/00036846.2025.2535552>
- Ongan S, Gocer I, Işık C (2025) Introducing the new ESG-based sustainability uncertainty index (ESGUI). *Sustain Dev* 33: 4457–4467. <https://doi.org/10.1002/sd.3351>

- Potì V, Dell'Atti S, Di Martino G, et al. (2024) ESG and stock market performance at times of economic and market-wide stress: Evidence from US-listed firms during the COVID-19 pandemic. *Available at SSRN 5326659*.
- Qing L, Alnafrah I (2025) Environmental attention in cryptocurrency markets: A catalyst for clean energy investments. *Int Rev Econ Financ* 99: 104063. <https://doi.org/10.1016/j.iref.2025.104063>
- Sassen R, Hinze AK, Hardeck I (2016) Impact of ESG factors on firm risk in Europe. *J Bus Econ* 86: 867–904. <https://doi.org/10.1007/s11573-016-0819-3>
- Šević A, Nerantzidis M, Tampakoudis I, et al. (2024) Sustainability indices nexus: Green economy, ESG, environment and clean energy. *Int Rev Financ Anal* 96: 103615. <https://doi.org/10.1016/j.irfa.2024.103615>
- Sun Y, Zhao Z (2024) Responsible investment: Institutional shareholders and ESG performance. *Pacific-Basin Financ J* 85: 102357. <https://doi.org/10.1016/j.pacfin.2024.102357>
- Tian Y, Feng J, Ma J, et al. (2025) ESG rating divergence and stock market mispricing: empirical evidence from China: Tian et al. *Environ Dev Sustain*, 1–28. <https://doi.org/10.1007/s10668-025-06359-1>
- Xu Z, Liu D, Li Y, et al. (2025) ESG and stock price volatility Risk: Evidence from Chinese A-share market. *North Am J Econ Financ* 75: 102277. <https://doi.org/10.1016/j.najef.2024.102277>
- Yang Z, Song P, Xu M, et al. (2024) Environmental, social and governance performance and equity mispricing: Does embedded information mediation matter? *Financ Res Lett* 67: 105922. <https://doi.org/10.1016/j.frl.2024.105922>
- Yu S, Zheng Y, Hu X (2022) How does climate change affect firms' investment efficiency? Evidence from China's listed renewable energy firms. *Bus Strateg Environ* 32: 3977–3996. <https://doi.org/10.1002/bse.3349>
- Yue W (2023) ESG information disclosure and asset mispricing. *Highlights Bus Econ Manage* 16: 166–183. <https://doi.org/10.54097/hbem.v16i.10555>
- Yung K, Root A (2019) Policy uncertainty and earnings management: International evidence. *J Bus Res* 100: 255–267. <https://doi.org/10.1016/j.jbusres.2019.03.058>
- Zhang Q, Zhang C (2026) ESG Ratings, Financial Performance and Stock Returns. *Financ Res Lett* 109907. <https://doi.org/10.1016/j.frl.2026.109907>
- Zhao Y, Ramzan M, Brika SK, et al. (2025) Uncertainty in climate and ESG policies: implications for renewable energy investments. *Appl Econ*, 1–15. <https://doi.org/10.1080/00036846.2025.2516836>
- Zhou Y, Alnafrah I (2025) Leveraging AI and green finance for cleaner energy production: A sustainability framework for ESG integration and climate action. *J Clean Prod* 525: 146595. <https://doi.org/10.1016/j.jclepro.2025.146595>
- Zumenté I, Bistrova J (2021) ESG importance for long-term shareholder value creation: Literature vs. practice. *J Open Innov Technol Market Complex* 7: 127. <https://doi.org/10.3390/joitmc7020127>



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