Using green and ESG assets to achieve post-COVID-19 environmental sustainability

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Abstract

Purpose – This research explores the spillovers and portfolio implications for green bonds and environmental, social and governance (ESG) assets in the context of the rapidly expanding trend in green finance investments and the need for a green recovery in the post-COVID-19 era.

Design/methodology/approach – This study utilizes Diebold and Yilmaz's (2014) spillover method and portfolio strategies (hedge ratio, optimal weights and hedging effectiveness) for the data starting from February 29, 2012, to March 14, 2022.

Findings – The study's findings reveal that the lower volatility spillover is evidenced between the green bonds and ESG stocks during tranquil and turbulent periods (e.g. COVID-19 and Russia-Ukraine War). Furthermore, hedging costs are lower both in normal times and during economic slumps. Investing the bulk of the funds in green bonds makes it possible to achieve maximum hedging effectiveness between the S&P green bond (GB) and the S&P 500 ESG.

Practical implications – Both investors and policymakers may use these findings to make wise investment and policy choices to achieve post-COVID environmental sustainability.

Originality/value – Unlike previous research, this is the first to explore the interconnectedness among the major global and country-specific green bonds and ESG assets. The major findings of this study about the lower volatility spillovers and hedging costs between green bonds and ESG assets during the tranquil and turbulent periods may contribute to the post-COVID investment portfolio for environmental sustainability.

Keywords Green bonds, ESG, Portfolio implication, COVID-19, Environmental sustainability

Paper type Research paper

1. Introduction

The contemporary world is intensely concerned about climate change, and thus world leaders are continuously adopting several climate policies intending to achieve environmental sustainability. Global warming is heating up due to rising CO_2 emissions, with potentially devastating consequences for the planet (Naeem, Farid, Ferrer, & Shahzad, 2021; Hasan & Hossain, 2022; Hasan, Ali, Uddin, Mahi, Liu, & Park, 2022). To address climate change concerns, massive transformative initiatives are required to accelerate the transition to a low-carbon economy, requiring a large amount of capital. According to the International Energy

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Agency, between 2020 and 2050, around US$3.5tr in investments across all energy sectors would be required annually to satisfy the 2015 Paris Climate Agreement and United Nations Sustainable Development Goals (SDGs) for a sustainable global economy.

However, the adverse impacts of the recent COVID-19 pandemic on economic and financial systems have further made it a challenge to accomplish the aforesaid objectives and post-COVID-19 environmental sustainability as well. Similarly, the pandemic has adversely affected fossil fuel use, and subsequent CO_2 emissions in 32 developed and emerging countries, particularly during the first quarter of the pandemic (Smith, Tarui, & Yamagata, 2021). Furthermore, the health crisis has exacerbated (lowered) the already-low oil prices following the Russia-Saudi oil rivalry (Hasan, Hassan, Rashid, & Alhenawi, 2021). As a result of the lower oil price, green energy projects are becoming less competitive than fossil fuel-based projects, making green project funding more challenging. Consequently, these may make it harder to achieve the Paris Agreement targets and SDGs, as well as recuperate environmental sustainability following the post-COVID-19 catastrophe.

Since the launch of the United Nations Principles for Responsible Investment (PRI) in 2006, the number of signatories has grown from 734 in 2010, to 1,384 in 2015 and 3,038 in 2020, with total assets under management of $21tr (USD) in 2010, $59tr in 2015 and $103tr in 2020 [1]. In line with the increasing concerns about global warming, BlackRock CEO Larry Fink wrote in a recent annual letter that climate change will force businesses and investors to shift their strategies, leading to a "fundamental reshaping of finance" and "significant reallocation of capital [2]."

Green bonds (GB) as well as environmental, social and governance (ESG) assets are becoming increasingly important in the climate change dialogue, as they may help construct a greener economy. The GB market has grown substantially from $37bn (USD) in 2013, to $280bn in 2020 (Climate Bonds Initiative, 2020). Additionally, GB issuance hit $354.2bn at the end of Q3 in 2021, exceeding the total issuance amount for 2020, and is expected to reach half atr by the end of 2022 [3]. Similarly, the global capitalization of ESG-driven assets has surpassed $40tr, and large investors, like the World Business Council on Sustainable Development, are prioritizing ESG issues with expectation that they will generate greater future profits (Bloomberg, 2020). The recent shift in thinking has led to a shift in investment from high-risk investments to more ESG investment (Singh, 2020). According to a recent J.P. Morgan survey following the ESG implications during COVID-19, 55% of participants viewed ESG equities as having a favorable outlook over the next three years.

Previous studies (e.g. Hasford & Farmer, 2016; Gianfrate & Peri, 2019; Reboredo & Ugolini, 2020; Larcker & Watts, 2020; MacAskill, Roca, Liu, Stewart, & Sahin, 2021; Immel, Hachenberg, Kiesel, & Schiereck, 2021; Ejaz, Ashraf, Hassan, & Gupta, 2022; and inter alia) have attempted to connect GB and ESG to other financial assets, namely stocks, conventional bonds, commodities or energy assets, in order to identify hedging or diversification possibilities. Investors, particularly those not environmentally conscious, may be interested in these studies' outcomes if they demonstrate the diversification potential of the combination of environmentally friendly and non-environmentally friendly assets. However, environmentally concerned investors may be interested in portfolios that include diverse green-related assets rather than merging environment-friendly and non-environment-friendly assets. As a result, these studies on green-non-green asset connectivity may fail to attract environmentally concerned investors, hence accelerating green growth. Nonetheless, there appears to be a gap in the existing research about interconnection across green assets, particularly between GB and ESG assets.

Despite the fact that GB and ESG share a common goal—to improve environmental quality—they are distinct asset classes, as green bonds are fixed-income securities, whereas ESG equities are non-fixed-income instruments. Furthermore, ESG indices concentrate on social and governance issues in addition to the environment. The heterogeneities between these asset classes may result in their decoupling, implying a hedging or safe-haven potential. Accordingly, if there are diversification, hedging or safe-haven opportunities, lower hedging cost and higher hedging effectiveness among various green assets, especially in the aftermath of the COVID-19 pandemic, environment-conscious investors may be inspired more, and even the non-green investors may also be enticed to invest in these assets. This trend will undoubtedly attract more long-term investments, eventually leading to environmental sustainability post-COVID-19.

In the opposite view, the absence of such decoupling and hedging opportunities would fundamentally regard these assets as a homogenous asset class, with essential policy ramifications for government and policymakers to take adaptive initiatives. Despite the greater potential in the green-ESG portfolios, little attention is paid to the spillover and portfolio implications across these asset classes, especially in country-specific ESG investment aspects. However, most previous studies, for instance, Reboredo and Ugolini (2020), MacAskill *et al.* (2021) and Immel *et al.* (2021), discuss only the dependence structure between green bond and financial asset classes (e.g. stock, conventional bond, commodity, clean energy). Findings have been mixed. Additionally, as of yet, there is no evidence showing the spillover and hedging or safe haven properties through the interconnections between the global GBs and ESG assets, which are increasingly important for both investors and governments to achieve post-COVID-19 environmental sustainability.

Our study contributes in several ways to the growing green and sustainable finance literature. First, unlike previous research, we explore the interconnectedness among the major global and country-specific GBs and ESG assets. Prior studies focus on the dependence structure between the GBs and different asset classes, ignoring the green-ESG interconnection and portfolio implication aspects. Second, from a methodological viewpoint, we use Diebold and Yilmaz's (2014) (hereafter DY) dynamic spillover method and portfolio strategies (hedge ratio, optimal weights and hedging effectiveness), which are increasingly important for investors and policymakers to make investment and policy decisions in terms of different periods and optimal allocation of fund in the portfolio. Thirdly, our major findings suggest that volatility spillovers and hedging costs between GBs and ESG assets are lower during most tranquil and turbulent periods. Finally, our findings would contribute to the post-COVID investment portfolio for environmental sustainability. This study focuses on portfolio implications and spillovers of GBs and ESG assets pre- and post-COVID-19. We highlight portfolio investment strategies for both individual and institutional investors to achieve post-COVID-19 environmental sustainability through global and country-specific investment in GBs and ESG assets. In doing so, we choose several major global and country-specific GB and ESG-related assets. Utilizing several econometric methodologies, like DY's (2014) spillover method and portfolio strategies (hedge ratio, optimal weights and hedging effectiveness), our main findings unveil that volatility connectedness between GBs and ESG stocks is lower during both normal periods and periods of crisis (e.g. COVID-19 and Russia-Ukraine War). We also find that hedging costs are lower during both regular periods and periods of economic downturn periods. The optimal weight between S&P GB and S&P 500 ESG is witnessed in achieving maximum hedging effectiveness by allocating most funds to green bonds. These findings may benefit both investors and policymakers in making effective investment and policy decisions post-COVID to support investments that are environmental sustainability.

The rest of the paper is outlined as follows. Section 2 provides an overview of relevant literature. Section 3 describes the data, while the methodology is explained in Section 4. The empirical results and discussions are presented in Section 5. Section 6 concludes the study with policy implications.

2. Review of related literature

In this section, we look at three types of studies: (1) studies focusing just on GBs (2) studies focusing solely on ESG and (3) studies focusing on both GBs and ESG markets.

2.1 Studies on the GBs market

The growth of the green bond (GB) market piques the interest of investors seeking alternative eco-friendly financial products. Prior studies concentrated mostly on assessing the link between GBs and their conventional equivalents (Ejaz *et al.*, 2022). Several studies (e.g. Hachenberg & Schiereck, 2018; Gianfrate & Peri, 2019; Immel *et al.*, 2021) show that GBs have negative returns, despite the fact that investors who care about the environment are willing to sacrifice their returns to contribute to the transition to a more sustainable economy. Conversely, some researchers such as Karpf and Mandel (2018), Bachelet, Becchetti, and Manfredonia (2019), Larcker and Watts (2020) and MacAskill *et al.* (2021) note that GBs offer higher premiums and more liquidity than their "brown" bond equivalents.

The previous literature also looks at the volatility spillover and connectedness pattern of GBs with other financial markets and asset classes. Pham (2016), for example, focuses on the relationship between traditional and GBs markets. The study finds a robust volatility clustering in the GB markets than in the traditional markets. Broadstock and Cheng (2019), on the other hand, discover that different macroeconomic variables – crude oil prices, news-based sentiment for GBs and economic activity – impact the link between green and conventional bonds markets. Similarly, Reboredo (2018) examines the diversification, dependency and spillover between financial markets and GBs, revealing GBs' weaker co-movement with traditional stocks and energy markets. The study also demonstrates that GB market investors have substantial portfolio diversification opportunities, while treasury and corporate bond market investors have very few. Reboredo (2018) expands on his research in a later study (Reboredo & Ugolini, 2020), capturing multivariate co-movement patterns and revealing the existence of network connectivity between GBs and financial markets. Building on her 2018 work, his 2020 study demonstrates that the GB market is slightly correlated to the stock and energy markets.

Furthermore, Daszyńska-Żygadło, Marszałek, and Piontek (2018) investigate volatility patterns using four global GB indices with a traditional bond index. Consistent with Reboredo (2018), Daszyńska-Żygadło *et al.* (2018) find that GBs appear to be highly associated with conventional bonds due to their small market size and volatility transmission from their conventional counterparts. Huynh (2022) establishes that there is a strong association between green and triple-A-rated prime government bonds. Hassan, Hasan, Halim, Maroney, and Rashid (2022) examine the cryptocurrency environmental attention (ICEA) index's spillover effect on GB markets and discover that ICEA has no substantial influence on GB markets (except Solactive GB in the high attention regimes). To investigate the greenness, Kanamura (2020) compares the performance of GBs with the energy market and discovers a negative relationship between GBs and Brent crude oil and WTI prices.

Recently, Nguyen, Naeem, Balli, Balli, and Vo (2021) have revealed a significant link between stocks, clean energy and commodities; nevertheless, GB has a negative co-movement with stocks and commodities, indicating the diversification possibilities of GBs. Gao, Li and Wang (2021) detect a two-way asymmetric risk spillover between green and conventional bond markets, but no substantial risk spillover between GB markets is documented. Furthermore, Liu, Liu, Da, Zhang, and Guan (2021) find a significant positive relationship as well as risk spillover between GBs and clean energy equities. Naeem, Adekoya, and Oliyide (2021) analyze the effect of the GBs on several commodity asset classes, including precious metals, agricultural commodities and energy markets. They find a significant spillover effect between GBs and commodities from the same asset class over time.

2.2 Studies on the ESG markets

Investors have increasingly focused on sustainability over the last decade, with money pouring into assets that have strong environmental, social and governance (ESG) credentials (Ferriani & Natoli, 2021). The rising interest in ESG assets and their influence on investment decisions have increased the openness of traditional funds to investing in ESG assets (Armstrong & Green, 2013; Hasford & Farmer, 2016). Furthermore, due to the COVID-19 outbreak, investors' investment behavior in ESG-integrated stocks has significantly increased in their portfolio selection (Rubbaniy, Khalid, Rizwan, & Ali, 2021). As a consequence, portfolio choice reappraisal has resulted in capital migration from high-risk assets to ESG assets (Singh, 2020) and has improved portfolio returns in ESG and ETF (exchange-traded fund) indices during COVID-19 (Albuquerque, Koskinen, Yang, & Zhang, 2020; Broadstock, Chan, Cheng, & Wang, 2021; Singh, 2020).

Several studies, such as Singh (2020), Ferriani and Natoli (2021) and Omura, Roca, and Nakai (2021), discover that higher ESG rating firms are prone to minor risk and maintain stability amid turbulence. Similarly, Verheyden, Eccles, and Feiner (2016), Díaz, Ibrushi, and Zhao (2021) and Omura *et al.* (2021) show that ESG screening equities yield higher returns with lower volatility and tail risk. Previous research has also compared the performance of ESG-driven assets to market-wide performance under various economic scenarios. Some studies, for example, look at green funds (Silva & Cortez, 2016), socially responsible investment (SRI) funds (Muñoz, Vargas, & Marco, 2014; Nofsinger & Varma, 2014; Zhu, Yang, Lv, & Zhuang, 2021) and ESG stocks (De & Clayman, 2015; Alessandrini & Jondeau, 2020; Cunha *et al.*, 2020) and show that ESG assets outperform their conventional counterparts under stressful times. However, other studies (e.g. Leite & Cortez, 2015; Auer, 2016) reveal that ESG screens result in lower portfolio performance of ESG assets relative to benchmarks when diversity is lower.

To disclose the hedge and safe-haven role, Rubbaniy *et al.* (2021) employ the wavelet coherence approach and find a positive coherence between ESG stocks and the global COVID-19 fear index, indicating ESG stocks' hedging and safe-haven opportunities. Conversely, several studies portray ESG investments as similar alternatives to traditional safe-haven assets, for example, stocks (Akhtaruzzaman, Boubaker, & Sensoy, 2021; Hasan, Mahi, Hassan, & Bhuiyan, 2021; Yousaf & Ali, 2021; Ashraf, Rizwan, & Ahmad, 2022), gold (Baur & Hoang, 2021; Yousaf, Bouri, Ali, & Azoury, 2021), commodities (Bouri, Shahzad, Roubaud, Kristoufek, & Lucey, 2020; Ji, Zhang, & Zhao, 2020; Rubbaniy *et al.*, 2021), cryptocurrencies (Goodell & Goutte, 2021; Rubbaniy *et al.*, 2021; Yousaf & Ali, 2021) and bonds (Hassan, Djajadikerta, Choudhury, & Kamran, 2021; Yarovaya, Elsayed, & Hammoudeh, 2021).

2.3 Studies on the ESG and GB markets

We have discussed recent research on the relationship between ESG and GBs. Few studies have investigated the link between ESG and GB markets. Wang and Wang (2022), for example, investigate the relationship between the performance of ESG parameters and GB issuance from the perspective of Chinese listed companies and find that good ESG standards boost public firms' willingness to issue GBs. More specifically, they see ESG as being supportive of sustainable activities; nevertheless, they find financial performance negatively impacts GB issuance. Cheng, Sharma, and Broadstock (2022) study the impacts of brand reputation and ESG on international GB issuance and discover a robust beneficial influence of ESG disclosure score and its interaction with a brand reputation on GB issuance, arguing that ESG might be a critical driver of successful GB issuance.

2.4 Studies on the GBs and ESG markets using DY's (2014) methodology

Finally, this section examines empirical research that used DY's (2014) technique to determine the dynamic volatility spillover connectivity of green and/or ESG assets. For instance, using a

TVP-VAR connectedness framework of the Diebold and Yilmaz approach, Broadstock, Chatziantoniou and Gabauer (2022) show that investing in GB provides optimum portfolios; the portfolio with the fewest connections has the best Sharpe ratio and significantly lower risk. Reboredo and Ugolini (2020) use a structural VAR model to show that the GB market is highly correlated to the fixed-income and currency markets, which experience significant price spillovers that send minimal reverse effects while being poorly connected to the stock, energy and high-yield corporate bonds markets. Pham (2021) discovers that the spillover effects between GBs and green equities are short-lived across all market situations, as the degree of connection diminishes in the medium- and long-term investment horizons. Likewise, Umar, Abrar, Zaremba, Teplova, and Vo (2022) use the dynamic connectedness technique to identify the major transmitter of return spillover between filthy bonds and equities, and find that the key transmitter of volatility spillovers are dirty stocks.

The DY approach is also used in the case of ESG research. For example, Akhtaruzzaman, Boubaker, and Umar (2022) investigated the relationship between the media coverage index (MCI) and ESG leader indices using the TVP-VAR framework of the DY technique and discovered a strong association during the peak of the COVID-19 pandemic when the US was a net receiver of shocks, confirming that the US was the most affected region during the pandemic. According to Shaik and Rehman (2022), ESG stock indices in the Middle East, Africa and Latin America are net shock transmitters, but those in the United States and Asia-Pacific are net volatility receivers. Furthermore, Gao, Li, Zhao, and Wang (2022) use the DY technique to discover that, in most situations, the developed North American market is at the heart of outward risk spillover in global ESG stock markets. Their overall system has a small-world structure, with various risk spillover aspects in the interior locations. The empirical findings widen the conceptual framework of the ESG stock market and provide a foundation for investors and governments looking to reduce ESG investing risk.

Some key points from the literature addressed above are highlighted. First, previous research has mainly focused on the link between green and conventional bonds, GBs and other financial asset classes, ESG assets and equities or other assets, or ESG assets themselves. These studies primarily sought to investigate how GBs and ESG equities perform compared to their traditional equivalents or other traditional financial assets. Second, very little research has been conducted on the hedging or safe-haven possibilities of ESG assets and GBs, particularly as they relate to other financial assets. Additionally, remarkably few studies have looked at the safe-haven possibilities that ESG assets provide in the face of global turbulence, like the COVID-19 crisis. In fact, these studies look at the alternative asset characteristics in GBs and ESG assets.

Finally, to the best of our knowledge, only two studies have been conducted that analyze the impact of ESG assets on GBs issuance. Research investigating this seems to be absent in both global and country-specific contexts. Although these two asset classes serve the same purpose, namely to increase environmental sustainability, they may not co-move owing to asset class heterogeneity (e.g. GBs are fixed-income securities, whereas ESG stocks are non-fixed-income securities). As a result, GBs and ESG assets may provide diversification opportunities, and, if so, they would be of interest to all investors as well as environmentally conscious investors. Therefore, given the importance of ESG and GBs in selecting sustainable and eco-friendly portfolios, this study intends to bridge the aforementioned literature gaps.

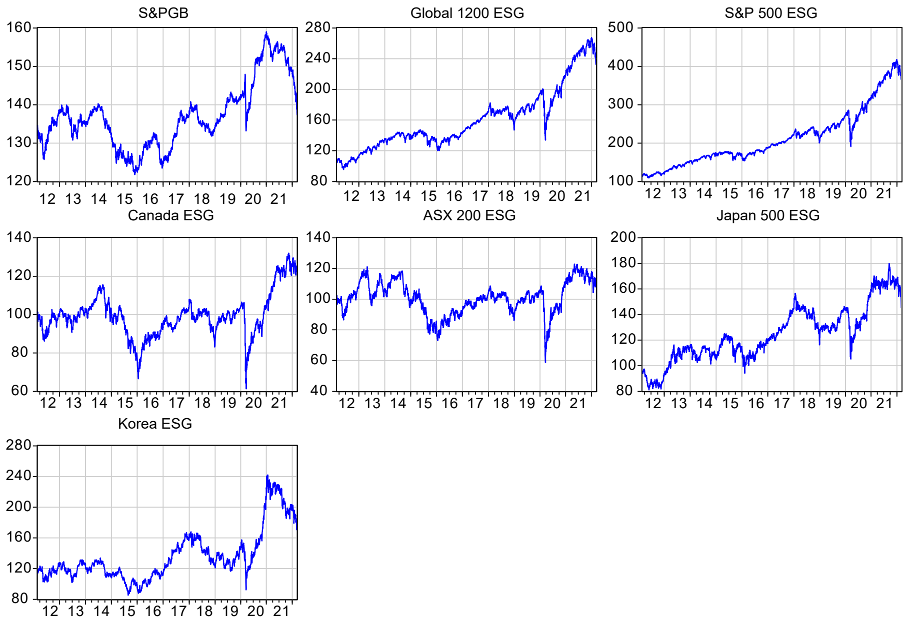
3. Data and preliminary analysis

This study looks into the dynamic spillover and portfolio strategies across global and country-specific green and ESG assets to achieve post-COVID economic sustainability by investing in such assets. The study uses one global GBs index to proxy green assets and six major global and country-specific ESG indices to proxy sustainable financing instruments. These include

(1) the Dow Jones S&P Green Bond Index (S&P GB), which is a market-weighted index that attempts to reflect the global green bond market and is used to fund environmentally beneficial projects; (2) the S&P Global 1200 ESG Index (Global 1200 ESG), which is designed to track the performance of companies in global clean energy-related businesses from both developed and emerging markets, with a target constituent count of 100; (3) the S&P 500 ESG Index, which is a broad-based market-cap-weighted index to measure the performance of securities meeting sustainability criteria; (4) the S&P Canada LargeMidCap ESG Index (Canada ESG) is a broad-based, market-cap-weighted index that is designed to quantity the performance of securities meeting sustainability criteria, while maintaining similar overall industry group weights; (5) the S&P/ASX 200 ESG Index (ASX 200 ESG) is developed to measure the performance of securities by satisfying the sustainability criteria, while maintaining similar overall industry group weights; (6) the S&P Japan 500 ESG Index (Japan 500 ESG) is a broad-based, market-cap-weighted index that is meant to monitor the performance of securities toward filling the sustainability norms; (7) the S&P Korea LargeMidCap ESG Index (Korea ESG) is a broad-based, market-cap-weighted index that is designed to measure the performance of securities meeting sustainability criteria, while maintaining similar overall industry group weights.

In this study, the daily closing prices of the indices mentioned above are used, and the sample period ranges from February 29, 2012, to March 14, 2022. The entire sample is divided into two sub-samples: pre-COVID-19 crisis and post-COVID-19 crisis. The pre-COVID-19 period spans from February 29, 2012, to December 30, 2019, while the post-COVID-19 period is from December 31, 2020, to March 14, 2022. The starting date of the post-COVID-19 sample is based on the study of Yarovaya *et al.* (2021). The data period and frequency are determined by data availability. All the data are amassed from http://us.spindices.com. We transform the prices of these assets into logarithmic first difference (returns) for analysis.

Figure 1 depicts the daily closing price dynamics of global and country-specific GBs and ESG assets during the full data period. The prices of most of the assets evaluated in



Source(s): Figure by authors

Figure 1. Price dynamics of GB and ESG indices

this study are rising and have experienced some dramatic swings between 2012 and 2022. However, from mid-2014 to late 2015, the prices of the S&P GB, Canada ESG, ASX 200 ESG and Korea ESG indices fell gradually, then progressively increased up to 2020 (except for Korea ESG). Nonetheless, all assets fell dramatically in early 2020 due to the adverse effects of the COVID-19 pandemic, which had a detrimental influence on the global economic and financial system (Sharif, Aloui, & Yarovaya, 2020; Hasan, Hassan *et al.*, 2021, Hasan, Mahi, Sarker, & Amin, 2021, Hasan, Hossain, Junttila, Uddin, & Rabbani, 2022). At the same time, the prices of all assets (except Global 1200 ESG, S&P 500 ESG and Canada ESG) rose consistently from early 2020 to late 2020, before falling precipitously up to the sample period. Interestingly, the Global 1200 ESG and S&P 500 ESG indices have comparable price trends.

Table 1 exhibits the descriptive statistics together with the results of normality and stationarity tests for three sample periods: pre-COVID-19, post-COVID-19 and 2012-2022 (the entire sample period). However, we witness that all ESG indices outperform GBs indices in terms of mean returns across all samples and have higher volatility as assessed by standard deviations than GBs indices. In addition, the S&P 500 ESG Index has the highest mean returns, whereas the Korea ESG has the most volatility throughout all samples. Additionally, negative skewness values suggest a longer or fatter left-sided tail for all series returns.

Variables	Mean	Std. Dev	Skewness	Kurtosis	Jarque-Bera	ADF	PP
Panel A: entire sample							
Δln(S&P GB)	0.001	0.337	−0.474	8.278	2939.29***	−47.42***	−47.41***
Δln(Global 1200 ESG)	0.032	0.912	−1.324	23.200	42423.41***	−31.47***	−50.47***
Δln(S&P 500 ESG)	0.047	1.057	−1.085	24.880	49412.20***	−34.83***	−58.66***
Δln(Canada ESG)	0.008	1.158	−1.441	30.811	79904.00***	−32.63***	−51.92***
Δln(ASX 200 ESG)	0.003	1.245	−0.956	12.017	8682.93***	−32.53***	−50.19***
Δln(Japan 500 ESG)	0.018	1.163	−0.099	6.272	1098.01***	−54.27***	−55.00***
Δln(Korea ESG)	0.015	1.466	−0.310	7.345	1969.20***	−48.18***	−48.17***
Panel B: Pre-COVID-19							
Δln(S&P GB)	0.003	0.323	−0.179	6.652	1076.92***	−45.59***	−44.55***
Δln(Global 1200 ESG)	0.031	0.718	−0.639	6.743	1251.01***	−37.47***	−30.32***
Δln(S&P 500 ESG)	0.044	0.801	−0.537	6.219	920.74***	−34.55***	−33.16***
Δln(Canada ESG)	0.001	0.926	−0.241	5.445	496.46***	−44.58***	−24.84***
Δln(ASX 200 ESG)	0.002	1.067	−0.383	5.121	406.81***	−43.63***	−27.92***
Δln(Japan 500 ESG)	0.021	1.126	−0.169	5.849	658.36***	−34.72***	−41.29***
Δln(Korea ESG)	0.012	1.320	−0.529	5.843	735.98***	−28.27***	−39.82***
Panel C: Post-COVID-19							
Δln(S&P GB)	−0.006	0.382	−1.087	10.670	1414.21***	−26.52***	−28.53***
Δln(Global 1200 ESG)	0.035	1.405	−1.367	17.345	4744.74***	−31.47***	−50.47***
Δln(S&P 500 ESG)	0.056	1.683	−1.042	16.711	4279.42***	−26.87***	−47.60***
Δln(Canada ESG)	0.033	1.757	−1.804	25.391	11444.89***	−35.73***	−54.76***
Δln(ASX 200 ESG)	0.010	1.742	−1.297	11.866	1898.72***	−28.59***	−41.27***
Δln(Japan 500 ESG)	0.004	1.287	0.080	6.907	340.25***	−44.95***	−39.99***
Δln(Korea ESG)	0.027	1.900	−0.025	7.074	369.31***	−38.91***	−38.15***

Note(s): The table reports the descriptive statistics and unit root test results of all return series for all samples. Std. Dev. stands for standard deviation. ADF and PP are the empirical statistics of the Dickey and Fuller (1979) and Phillips and Perron (1988) unit root tests, respectively. Δln refers to natural logarithm returns. The asterisk *** denotes the rejection of the null hypotheses at the 1% significance level
Source(s): Estimated by authors

Table 1.
Descriptive statistics and unit root test

High kurtosis levels suggest extreme returns are more likely than a normally distributed return series. The non-normality of the return series is further confirmed by the Jarque-Bera test statistics, as the test rejects the null hypothesis of normality.

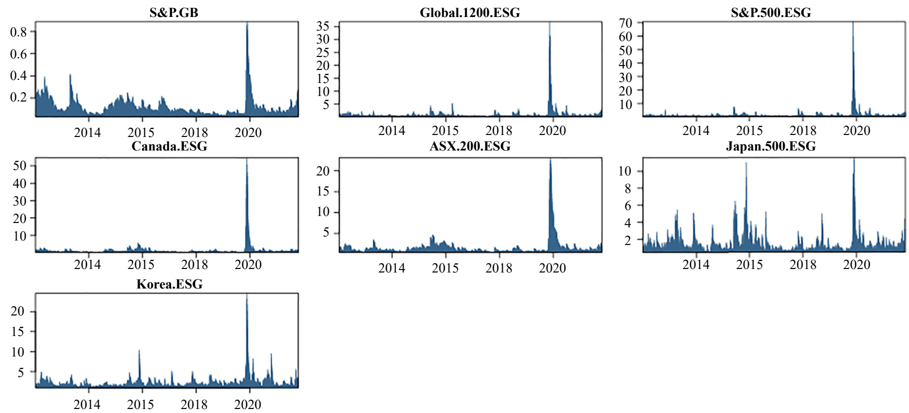
Finally, the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests (at both the trend and constant levels) showed no stationarity flaws in any of the variables.

Figure 2 depicts the conditional volatility results for all variables. This result is estimated based on the generalized autoregressive conditional heteroskedasticity (GARCH (1,1)) model. The results show that the conditional volatility of the S&P GB grew somewhat in 2012 and 2013, and then dropped in 2014 before rebounding in 2015 and 2016. The entry of corporations, municipalities and banks into the GBs market bolstered growth in 2015; however, in the following year (2016), GBs were strived to dive deeper into reporting on trends and market states (Climate Bonds Initiative, 2015), which could explain the volatility in these periods. Furthermore, in early 2020, the volatility of all factors intensified. It is unsurprising given how hard the COVID-19 pandemic hit the global economic and financial markets at that time. Consistent with descriptive statistics, the Korea ESG Index has the highest volatility throughout most time periods.

4. Methodology

4.1 Connectedness measures

In this study, we utilize the variance decomposition of the forecast error technique developed by Diebold and Yilmaz (2014) (DY) to capture the dynamic spillover connectedness between the GBs and ESG indices. There are some obvious advantages for employing this method. The one potential advantage of this technique is that no arbitrarily selected window size has to be chosen to retrieve dynamic connectedness measures (Bouri, Gabauer, Gupta, & Tiwari, 2021). Furthermore, the DY approach for pairwise connectedness is more appealing than other methods, such as Granger causality, because it is directional but completely pairwise and unweighted, evaluating zero versus nonzero coefficients with arbitrary significance levels and without monitoring the size of nonzero coefficients (Diebold & Yilmaz, 2014). Besides, it avoids the need to uncover unavoidable assumptions in variance decomposition and impulse response analyses. Furthermore, contrary to Antonakakis (2012) and Hoesli and Reka (2013), only one rather than two models are required to estimate the conditional



Source(s): Figure by authors

Figure 2.
Conditional volatility

volatility transmission mechanism. Thus, we start by taking into account the k-th order, N variable vector error correction (VAR):

$$R_t = \sum_{i=1}^{K} \Phi_i R_{t-i} + \varepsilon_t, \tag{1}$$

where R_t indicates the returns of the $N \times 1$ vector of GBs and ESG assets. Φ_i, $i = 1, 2\ldots, i$ denotes the $N \times N$ parameters' matrix and ε_t refers to the vector of the error terms, which can be assumed to be subsequently interconnected. We also employ the modified VAR decomposition approach developed by Koop, Pesaran, and Potter (1996) and Pesaran and Shin (1998), which is ordering-independent for variance decompactions. The $\dot{\mathrm{D}}^{H.} = [d_{ij}^H]$ signifies the H-step generalized variance decomposition matrix that is represented below:

$$d_{ij}^H = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (\acute{e}_i \Phi_h \sum ej)^2}{\sum_{h=0}^{H-1} (\acute{e}_i \Phi_h \sum \Phi_h ej)}, \tag{2}$$

where σ_{jj} denotes the j-th diagonal element of Σ, and the covariance matrix of the vectors' shock in the non-orthogonalized VAR is indicated by Σ. Φ_h signifies the coefficient matrix multiplying the h-lagged shock vector in the infinite moving-average description of the non-orthogonalized VAR, and e_j indicates the selection vector with a (jth) element equal to one and zeros in other places. Each entry in the d_{ij}^H matrix is normalized by the row sum to ensure that the row sum is equivalent to 1.

The off-diagonal entries of $\dot{\mathrm{D}}^{H.}$ are the net directional pairwise volatility spillover among the GB indices and the ESG indices. The gross pairwise directional spillover connectedness from others, j to i, becomes $C_{i\leftarrow j}^H = d_{ij}^H$. The net directional pairwise spillover is $C_{ij}^H \neq C_{i\leftarrow j}^H - C_{i\leftarrow j}^H$ as $C_{ij}^H \neq C_{i\leftarrow j}^H$. Therefore, the total connectedness from others to i and from j to others is $C_{i\leftarrow \bullet}^H = \sum_{\substack{j=1 \\ j\neq 1}}^N d_{ij}^H$ and $C_{\bullet\leftarrow j}^H = \sum_{\substack{i=1 \\ j\,\vert \neq i}}^N d_{ji}^H$, respectively. Accordingly, the net total directional connectedness becomes $C_i^H = C_{\bullet\leftarrow i}^H - C_{i\leftarrow \bullet}^H$, and $C^H = \frac{1}{N}\sum_{\substack{i,j=1 \\ j\neq i}}^N d_{ij}^H$ is the total connectedness measure.

4.2 Hedge ratio, optimal portfolio weights and hedging effectiveness

We use the hedge ratio (HR), optimal portfolio weights and hedging effectiveness (HE) to offer a superior hedging strategy and portfolio implications to investors and portfolio managers with a better estimation (Antonakakis, Chatziantoniou, & Gabauer, 2019). Some researchers (e.g. Yousaf & Yarovaya, 2022; Hasan, Rashid, Shafiullah, & Sarker, 2022) also utilize these calculations in their studies to do the same. However, we estimate the HR, introduced by Kroner and Sultan (1993), based on the conditional variance and covariances of the DCC-GARCH t-copula. The HR evaluates the hedging cost of a \$1 long position in asset i (GBs) with a β_{ijt} USD short position in asset j (ESG assets), in this case, several GB and ESG assets. The specification is expressed as follows:

$$\beta_{ijt} = \frac{h_{ijt}}{h_{jjt}}, \tag{3}$$

where h_{ijt} is the conditional covariance of variables i and j. It indicates that higher conditional variances lead to lower long-position hedging costs, whereas greater conditional covariances lead to higher long-position hedging costs.

We estimate the optimal portfolio weights (proposed by Kroner and Ng (1998)), W_{ijt}, based on the DCC-GARCH t-copula approach. The optimal portfolio weights between the GB and ESG indices pairs can be estimated through the following specification:

$$W_{ijt} = \frac{h_{jjt} - h_{ijt}}{h_{iit} - 2h_{ijt} + h_{jjt}}, \tag{4}$$

where W_{ijt} may be more than 1 or less than zero. We establish the following constraints to capture this drawback:

$$W_{ijt} = \begin{cases} 0, & \text{if } W_{ijt} < 0 \\ W_{ijt} & \text{if } 0 \leq W_{ijt} \leq 1 \\ 1 & \text{if } W_{ijt} > 1 \end{cases}.$$

Finally, Ederington's (1979) HE approach is employed in measuring the effectiveness of hedging and different portfolio strategies between the GB and ESG indices. It can be expressed as follows:

$$HE_i = 1 - \frac{V(r_{\beta,w})}{V(r_{unhedged})}, \tag{5}$$

where the $r_{\beta,w}$ can be computed as

$$\begin{cases} r_\beta = y_{it} - \beta_{ijt} y_{jt} \\ r_w = w_{ijt} y_{it} + (1 - w_{ijt}) y_{jt} \end{cases}.$$

HE_i denotes the percent decrease in the unhedged position's variance. The variance of the unhedged position of asset i is denoted by $V(r_{unhedged})$. $V(r_{\beta,w})$ suggests the hedged portfolio variance either from the optimal HR or the optimal weight strategy. y_{it} is the return of hedging asset i at time t. Accordingly, y_{jt} is the return of asset j at time t. The higher risk reduction in the portfolio is linked with a greater HE_i.

5. Empirical results analysis

5.1 Pearson correlation matrix

Table 2 displays the correlation matrix's outcome. The findings indicate that all of the assets included in this analysis are positively associated with one another, indicating that they are likely to move in tandem.

5.2 Results of DY estimation

The values of the directional, pairwise and total connectedness index (TCI) among the S&P GB and ESG indices are presented in Table 3. The outcomes reveal that TCI, reported in the bottom right corner, is 58.26% on average, demonstrating that the variables are strongly linked. The penultimate "TO others" row exhibits that Global 1200 ESG transmits the highest volatility spillover (110.37%) to other variables, followed by the Canada ESG (84.08%). On the other hand, the last "FROM others" column suggests that the Japan 500 ESG (68.31%) and Global 1200 ESG (68.13%) are the largest volatility spillover recipients from others in the system. Interestingly, the S&P GB Index is the lowest receiver and spreader of spillover in the system. In the last row, "NET," we notice that the Global 1200 ESG, S&P 500 ESG and Canada ESG are the net transmitters of spillover (positive), whereas the rest of the assets are the net receivers of spillover (negative).

Table 2.
Correlation matrix

Variables	Δln(S&P GB)	Δln(Global 1200 ESG)	Δln(S&P 500 ESG)	Δln(Canada ESG)	Δln(ASX 200 ESG)	Δln(Japan 500 ESG)	Δln(Korea ESG)
Δln(S&P GB)	1						
Δln(Global 1200 ESG)	0.228***	1					
Δln(S&P 500 ESG)	0.079***	0.933***	1				
Δln(Canada ESG)	0.255***	0.831***	0.753***	1			
Δln(ASX 200 ESG)	0.348***	0.574***	0.404***	0.567***	1		
Δln(Japan 500 ESG)	0.231***	0.315***	0.128***	0.214***	0.470***	1	
Δln(Korea ESG)	0.204***	0.360***	0.207***	0.296***	0.459***	0.455***	1

Note(s): The table presents the correlation matrix among GB and ESG assets during the entire study period. Δln refers to natural logarithm returns as the first difference of the variables
Source(s): Estimated by authors

The aforementioned row and column of Table 3 are now dynamically depicted in Figures 3–6. These plots can be deemed as directional spillover plots. Figure 3 illustrates the directional volatility spillovers from the others to GB and ESG indices (corresponding to the last "*From others*" column in Table 3). The directional spillovers from all the assets vary considerably over time. The S&P GB Index obtains around 60% volatility spillover from other variables from 2012 to 2014. Spillovers began to reduce after 2014 and remained around 40% until late 2019. Accordingly, this volatility further fell below 10% during early to mid-2020, when the COVID-19 pandemic hit the world economy. This result implies that GBs received the least amount of volatility spillovers from other variables during the turbulence period, manifesting the S&P GB Index as a portfolio diversifier, which is aligned with Naeem, Karim, Uddin, and Junttila (2022).

In contrast, most ESG indices (excluding the Korea ESG) received more than 60% volatility spillovers from the system during most of the periods. However, in terms of receiving from others, the directional spillover of the Japan 500 ESG dips abruptly during COVID-19 and then swiftly climbs to 80% in late 2020 to early 2021. It suggests that the Japan 500 ESG might give a hedging advantage during turbulent periods like pandemics. Furthermore, the spillover of the Korea ESG Index substantially varies significantly over time, starting at 80% in 2012 and then declining drastically to roughly 25% until early 2016, before increasing back up to experiencing spillover from others, approximately 80% in early 2018.

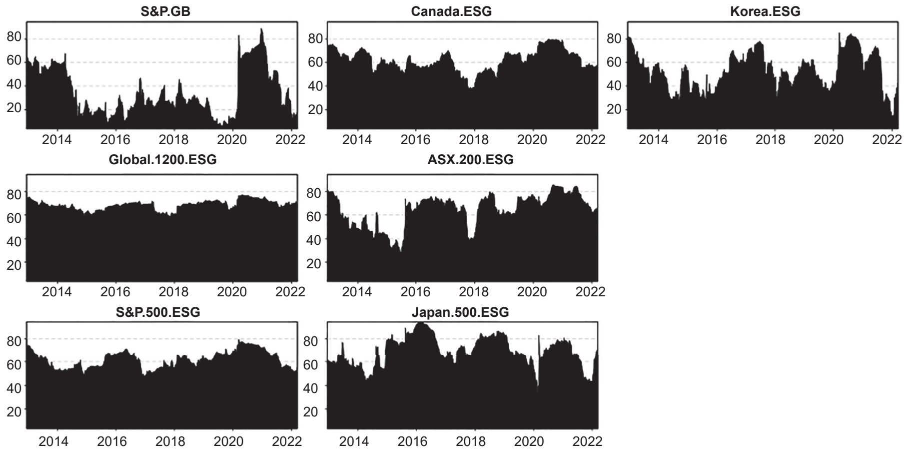
Figure 4 illustrates the volatility spillovers from one asset class to the other asset classes (referring to the penultimate "*To others*" row in Table 3). The findings reveal that volatility spillovers change with time. The S&P GB Index began transmitting more than 100% spillovers in early 2012, and rapidly declined to around 25% in mid-2014, and then varied until the end of the study period (2022). The Global 1200 ESG, S&P 500 ESG and Canada ESG indices are the key transmitters of volatility spillover to others with some swings. The ASX 200 ESG and Korea ESG indices disseminate mild volatility spillovers to others, while the Japan 500 ESG transmits the least amount of spillovers, ranging from 10% to 30% from 2012 to 2020, before escalating to more than 70% volatility spillover in 2021.

Table 3. Volatility spillover connectedness

Variables	Δln(S&P GB)	Δln(Global 1200 ESG)	Δln(S&P 500 ESG)	Δln(Canada ESG)	Δln(ASX 200 ESG)	Δln(Japan 500 ESG)	Δln(Korea ESG)	FROM others
Δln(S&P GB)	66.50	6.69	4.74	7.26	9.11	3.37	2.33	33.50
Δln(Global 1200 ESG)	2.63	31.87	29.35	20.35	7.02	3.83	4.96	68.13
Δln(S&P 500 ESG)	1.86	31.31	38.62	18.04	3.98	2.91	3.28	61.38
Δln(Canada ESG)	4.07	21.97	16.98	38.78	10.22	3.08	4.90	61.22
Δln(ASX 200 ESG)	7.05	16.56	10.66	17.77	36.38	5.01	6.57	63.62
Δln(Japan 500 ESG)	4.94	20.43	13.87	11.37	8.39	31.69	9.30	68.31
Δln(Korea ESG)	4.51	13.41	7.40	9.30	9.94	7.10	48.33	51.67
TO others	25.07	110.37	83.00	84.08	48.66	25.30	31.34	407.81
NET	−8.43	42.24	21.62	22.86	−14.96	−43.00	−20.33	TCI *58.26*

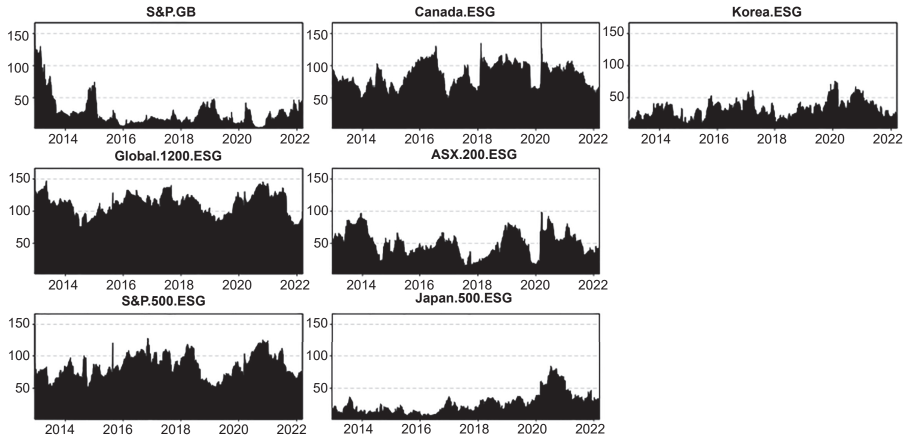
Note(s): The table presents the pairwise directional connectedness between GB and ESG indices. The "TO others" row and the "FROM others" column correspond to the total directional connectedness to others, and the total directional connectedness from others, respectively. The labels NET and TCI relate to the net directional connectedness and total connectedness index, respectively. Δln refers to natural logarithm returns as the first difference of the variables. All the values are in percentage (%) form

Source(s): Estimated by authors



Source(s): Figure by authors

Figure 3.
Volatility spillovers FROM others

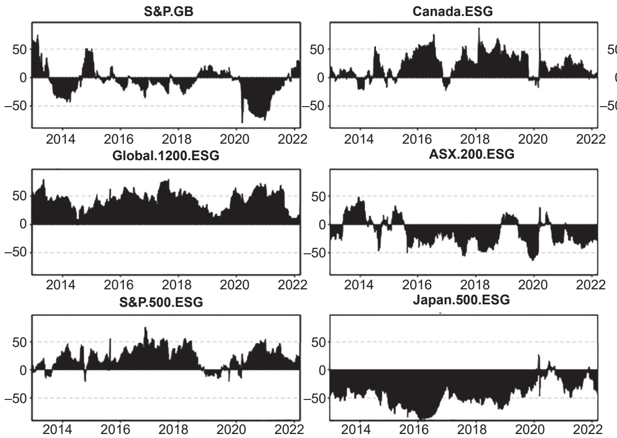


Source(s): Figure by authors

Figure 4.
Volatility spillovers TO others

The net total dynamic volatility spillovers from/to other variables are depicted in Figure 5. The results reveal that volatility spillovers alter over time in terms of both spreading and receiving. During early to late 2012, the S&P GB spread volatility around 50% to others; after that, it began to accept volatility from others until 2014, before transmitting approximately 50% in 2015. During COVID-19, the S&P GB Index transferred a little volatility to others, but then began to receive heavily (about 75%) from late 2020 to 2021.

When we look at the directional spillovers of ESG indices, we see that the Global 1200 ESG, S&P 500 ESG and Canada ESG indices are the dominant transmitters of volatility to others. In contrast, the Japan 500 ESG and Korea ESG indices are net recipients of volatility from others. During COVID-19, however, the S&P 500 ESG and Canada ESG received minor volatility spillovers from other variables, while the Japan 500 ESG and Korea ESG transferred marginal directional spillovers to others. The ASX 200 ESG received volatility spillovers from other variables during most of the sample time periods.



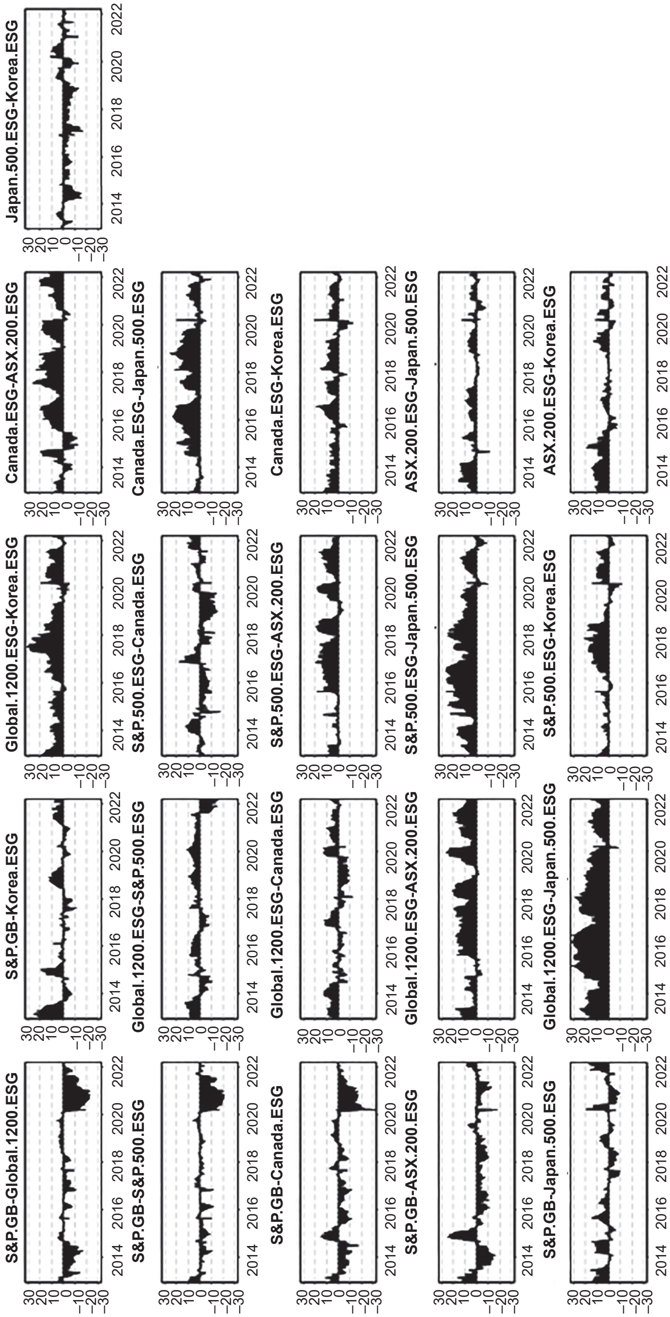
Source(s): Figure by authors

Figure 5.
Net total directional volatility spillovers

The dynamic pairwise net volatility connectedness of each pair of GBs and ESG indices is shown in Figure 6. Overall, we see the time-varying nature of volatility spillover across several assets, as well as varying forms of net transmitter and receiver for the majority of the assets across the study period. The results demonstrate that the S&P GB Index is the net recipient of volatility spillovers from the Global 1200 ESG, S&P 500 ESG, Canada ESG and ASX 200 ESG for most of the time, with these spillovers being somewhat higher (except for the ASX 200 ESG) from late 2020 to late 2021, at around 20%. However, during turbulence periods such as the COVID-19 pandemic in early 2020 and the Russia-Ukraine invasion in February-March 2022 [4], there is little or no volatility transmitter or receiver to or from S&P GB and Global 1200 ESG, S&P 500 ESG, Canada ESG and ASX 200 ESG, implying that there is diversification and safe-haven opportunities between these assets during the crises periods, which is consistent with Arif, Hasan, Alawi, and Naeem (2021), Nguyen *et al.* (2021), Rubbaniy *et al.* (2021), Hasan, Uddin, Ali, Rashid, Park, and Kang (2022) and Naeem *et al.* (2022). Furthermore, the volatility connection between GBs and the Japan 500 ESG and Korea ESG swings with time, with less closeness identified during the pandemic.

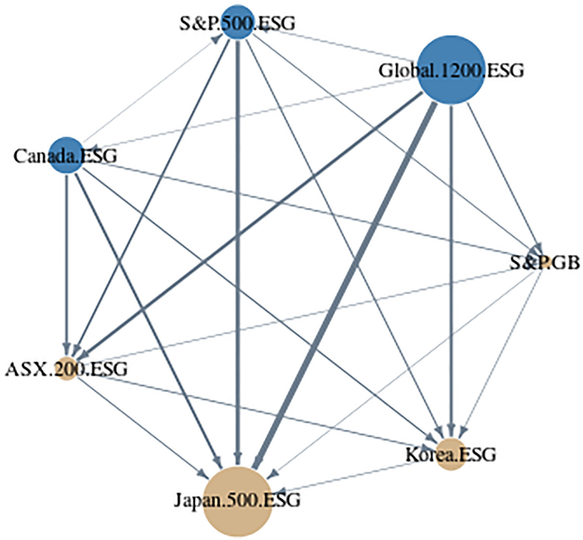
On the other hand, the Global 1200 ESG Index is the dominant spreader of volatility toward ASX 200 ESG, Japan 500 ESG and Korea ESG across the whole sample period, while the volatility connectedness between the Global 1200 ESG Index and S&P 500 ESG and Canada ESG is exchanged with each other, regardless of the tranquil and turbulence times. Furthermore, in most periods, S&P 500 ESG receives directional spillover of roughly 10% from Canada ESG, whereas ASX 200 ESG, Japan 500 ESG and Korea ESG are the top recipients of volatility from S&P 500 ESG. Similarly, Canada ESG and ASX 200 ESG are the major transmitters of volatility to ASX 200 ESG, Japan 500 ESG and Korea ESG, and Japan 500 ESG and Korea ESG, respectively, but, throughout the sample period, Korea ESG transfers the majority of its volatility to the Japan 500 ESG.

We also use Diebold and Yilmaz's (2014) connectedness network technique to investigate pairwise directional connectivity for the entire sample period. Figure 7 illustrates the plot. The connectedness map provides critical information about senders and receivers, as well as the degree of linkage. We also utilize a range of colors to identify the interrelationships inside the network. The color of a node in the system represents the role of a certain market in the system. For example, the blue color nodes denote the major transmitter, while the yellow color nodes illustrate the major receiver. The node size also reflects how economically



Source(s): Figure by authors

Figure 6.
Net pairwise directional volatility spillovers



Note(s): The figure illustrates pairwise connectedness among the variables. Blue and yellow nodes denote the net shock transmitter and receiver, respectively. Averaged net pairwise directional connectedness dimensions are utilized to weight vertices. The size of nodes indicates the weighted average net total directional connectivity. Arrows indicate positive net directional connectivity from a source to the arrow's edge. Bold arrows suggest stronger connectivity

Source(s): Figure by authors

Figure 7.
Network plot

interrelated the assets under consideration are. The arrow thickness also indicates the degree of directional connection. As seen in Figure 7, the Global 1200 ESG Index is the highest transmitter of spillover toward other ESG indices and the S&P GB, while the Japan 500 ESG Index is the greatest net recipient of spillover from other ESG indices and the S&P GB. S&P GB and S&P 500 ESG are the lowest receivers and transmitters of spillover from and to other variables among all assets.

5.3 Portfolio implications: hedge ratios, optimal weights and hedging effectiveness

Table 4 displays the hedge ratio (HR) (long/short), optimal weights and hedging effectiveness (HE) for GB and ESG assets over three sample periods. The HR and optimal weights are reported on the left and right sides of Table 4, respectively. According to HR, a $1 long position in a GB can be hedged with the average value of the hedging ratio percentage of a short position in the ESG stock indices (Tiwari, Abakah, Gabauer, & Dwumfour, 2022). The results show that HRs are lower between S&P GB and all ESG assets ranging from 2%–10% across the entire sample period. These outcomes suggest that investors need to invest 2–10 cents in a short position in ESG stocks to hedge a $1 USD long position in the S&P GB. The highest and most significant hedging effectiveness is detected between S&P GB/ASX 200 ESG, implying that this combination would minimize the S&P GB Index's 12% return variation in the portfolio.

Hedging costs are also lower prior to COVID, ranging from 2%–11%, and considerable HE is found in the S&P GB/Global 1200 ESG, S&P GB/Canada ESG and S&P GB/ASX 200 ESG

Variables	β	Hedge ratio HE	p-value	w	Optimal weights HE	p-value
Panel A: Entire sample						
Δln(S&P GB)/Δln(Global 1200 ESG)	0.10	0.03	0.45	0.88	0.05	0.22
Δln(S&P GB)/Δln(S&P 500 ESG)	0.02	−0.04	0.33	0.86	0.09***	0.01
Δln(S&P GB)/Δln(Canada ESG)	0.09	0.03	0.39	0.95	0.01	0.76
Δln(S&P GB)/Δln(ASX 200 ESG)	0.10	0.12***	0.00	0.99	0.00	0.98
Δln(S&P GB)/Δln(Japan 500 ESG)	0.07	0.04	0.33	0.97	0.00	0.97
Δln(S&P GB)/Δln(Korea ESG)	0.04	0.04	0.31	0.98	0.00	0.95
Panel B: Pre-COVID-19						
Δln(S&P GB)/Δln(Global 1200 ESG)	0.11	0.10**	0.02	0.87	0.07	0.12
Δln(S&P GB)/Δln(S&P 500 ESG)	0.02	0.03	0.48	0.84	0.14***	0.00
Δln(S&P GB)/Δln(Canada ESG)	0.10	0.11***	0.01	0.94	0.03	0.54
Δln(S&P GB)/Δln(ASX 200 ESG)	0.10	0.13***	0.00	0.99	0.00	0.96
Δln(S&P GB)/Δln(Japan 500 ESG)	0.07	0.02	0.64	0.96	0.01	0.84
Δln(S&P GB)/Δln(Korea ESG)	0.04	0.03	0.50	0.97	0.01	0.74
Panel C: Post-COVID-19						
Δln(S&P GB)/Δln(Global 1200 ESG)	0.07	0.01	0.87	0.93	0.02	0.48
Δln(S&P GB)/Δln(S&P 500 ESG)	0.03	−0.04	0.66	0.89	0.09**	0.03
Δln(S&P GB)/Δln(Canada ESG)	0.07	0.01	0.93	0.97	0.01	0.91
Δln(S&P GB)/Δln(ASX 200 ESG)	0.09	0.11*	0.09	1.00	0.00	0.97
Δln(S&P GB)/Δln(Japan 500 ESG)	0.09	0.11	0.18	0.99	−0.03	0.75
Δln(S&P GB)/Δln(Korea ESG)	0.05	0.08	0.35	1.00	0.00	0.99

Note(s): The table presents the hedge ratio, optimal weights and hedging effectiveness between the green bond and ESG assets. The hedge ratio and optimal weights are indicated by β and w, respectively. HE represents hedging effectiveness. Δln refers to natural logarithm returns as the first difference of the variables. ***, **, * indicate the significance at the 1%, 5% and 10% levels, respectively
Source(s): Estimated by authors

Table 4. Hedge ratio and optimal portfolio weights

portfolios. During the post-COVID-19 period, only the S&P GB/ASX 200 combination provides a lower hedging cost and significant HE, implying that investors only need to invest 9 cents in a short position in the ASX 200 ESG to hedge a $1 long position in the S&P GB. This is an attractive portfolio combination that aligns with our earlier findings in the DY estimations.

The findings of optimal portfolio weights are shown on the right side of Table 4. The results indicate that the optimal weights between S&P GB and S&P 500 ESG (S&P GB/S&P 500 ESG) during the entire, pre- and post-COVID-19 sample periods are 0.86, 0.84 and 0.89, respectively. To attain the optimum hedging effectiveness across all three periods (pre-COVID, post-COVID and the entire sample), investors should invest 86%, 84% and 89% of their money in the S&P GB Index, and 14%, 16% and 11% in the S&P 500 ESG Index, respectively. However, the remaining optimal weights between the GB and ESG assets are negligible during all three sample periods.

6. Conclusions and policy implications

The green bond (GB) and environmental, social and governance (ESG) markets have emerged as alternative financial markets that have grown significantly over the last decade. The growth of green investments stems from the escalation of socially responsible investing trends, country-level and global requirements, such as the Paris Climate Accord, the European Green Deal and, more recently, rising interest in environmental sustainability following the COVID-19 pandemic. In light of this, this research focuses on the spillovers and portfolio implications for GBs and ESG assets during and before the COVID-19 pandemic. This study also underscores the need of attaining post-COVID-19 environmental sustainability by investing in global and country-specific GBs and ESG assets. This study chooses several major global green and ESG-related assets: the S&P Dow Jones Green Bond Index, the S&P Global 1200 ESG Index and some country-specific ESG assets. Additionally, we perform a subsample analysis for the ongoing COVID pandemic crisis period to ascertain the connectedness forms and portfolio implications. To this end, we utilize Diebold and Yilmaz's (2014) spillover method and portfolio strategies (hedge ratio, optimal weights and hedging effectiveness).

Our findings show that the S&P GB Index receives the least amount of directional spillovers from ESG assets. These spillovers were lower during periods of turbulence such as the COVID-19 pandemic and the Russia-Ukraine War. Furthermore, in most time periods, the S&P GB and Japan 500 ESG are the lowest transmitters of volatility spillovers to other assets. Regarding pairwise volatility spillovers, green bond and ESG assets exchanged little or no spillovers during the pandemic and Russia-Ukraine catastrophes, implying their diversification and safe-haven potential in investors' portfolios. However, the evidence of portfolio implications suggests that the cost of hedging is lower between GB and ESG portfolios during entire, pre- and post-COVID-19 periods. On the other hand, based on the analysis of the optimal weight, the highest and most significant hedging effectiveness is observed between the S&P GB Index and the S&P 500 ESG Index through investing 84–89% of investors' funds in green bonds throughout all sample periods.

The findings in this research offer some important policy implications. Investors and portfolio managers may build portfolios for greater diversification and safe-haven benefits by adding global and country-specific GBs and ESG assets to their portfolios. The lower connectivity between GBs and ESG assets, in particular, demonstrates that environmentally conscious investors may diversify their portfolios across asset classes without jeopardizing their environmental and economic sustainability goals. Furthermore, because GB and ESG stocks are less intertwined, investors may diversify their risk by establishing green bond-ESG portfolios. Furthermore, the cheaper hedging cost and investing most of the funds in green bonds allow investors to achieve the best hedging effectiveness. These investment techniques may act as a catalyst in the post-COVID period for bridging the gap between economic recovery programs and the transition to a green financial environment. Policies that minimize the economic and financial effects of the COVID-19 pandemic can reduce the volatility spillover between GB and ESG stocks, prompting investors to participate in both environmentally friendly assets simultaneously. Specifically, policymakers should be conscious of the high volatility transmission of ESG assets, especially the volatility of the Global 1200 ESG Index, to other country-specific assets and take suitable measures to tackle these phenomena. Finally, there is a need to foster the creation of green financial mechanisms and a green financial environment that meets the diversified financial needs of investors while also boosting issuer and investor trust.

Nonetheless, our research has some limitations that provide opportunities for future researchers. We restrict our investigation to broader GB and ESG indices. Future research might expand this sample to include other financial markets. Furthermore, future research can use sectoral assets to conduct a more in-depth examination of the dynamics of traditional and green financial tools. This analysis may yield more specific findings about the relationship between green and traditional investments at the sectoral level. In a similar vein, a more thorough examination of interconnection will be possible by looking more closely at GB and ESG Indices at the business or industry level. Because ESG indices include firms and industries that are not directly tied to environmental sustainability, future research may look into whether ESG firms and industries defined as environmentally sustainable differ in their connection to GBs. These observations, however, would have an impact on portfolio strategy guidance.

Notes

1. See, https://www.unpri.org/pri
2. https://www.blackrock.com/corporate/investor-relations/larry-fink-ceo-letter
3. https://www.climatebonds.net/resources/reports/sustainable-debt-summary-q3-2021
4. The Russia-Ukraine invasion has taken place on February 24, 2022 (Boubaker, Goodell, Pandey, & Kumari, 2022). The intensity of invasion between Russia and Ukraine war is covered up to 14 March, 2022, as we select the ending date based on the availability of data.

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