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Are sustainable investments interdependent? The international evidence

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ABSTRACT

The rising concerns about climate change and environmental degradation have urged various stakeholder to focus on sustainable investments that are facing a drag from the Covid-19 pandemic. Since environmental and Covid-19 challenges are global, it is critical to assess the interlinkages of sustainable investments. In this research, we employ the dependence, centrality, and dynamic network approach to examine the interdependence and its determinants across multiple countries between January 2009 and March 2021. The findings indicate France as the lead risk transmitter while Japan and Taiwan show risk reception among international markets. We observe an increase in dependence during economic turmoil notably in Covid-19 episode. The centrality network revealed the prominent significance of sustainable investments in the European countries that can be attributed to their exceptional efforts to combat the climate change. Finally, our results suggest that the volatility in gold prices is the key driver of interdependence of sustainable investments.

1. Introduction

Issues surrounding environmental sustainability and economic development have triggered multiple arguments. Resultantly, the stakeholders concerned with sustainability have to search for ways to reduce environmental issues without negatively influencing development. Due to this, many initiatives are taken, and different agreements[1] have been signed to achieve the sustainable global transmission of the economy while taking note of social and governance issues. However, the efforts of corporations, non-governmental organizations, and governments have proven to be insufficient in addressing sustainability issues such as climate change, poverty, and inequality (Epstein and Yuthas, 2014). Thus, the word *sustainable investment* comes into play. In a way, the emergence of sustainable investment provides a means to hold companies, the financial market, and its participant more accountable for social and ecological issues. In another way, investors want their investment to significantly reflect broader values and provide solutions to social and ecological issues.

Sustainable investment entails a variety of assets classes created and selected while considering the causes of environmental, social, and governance (hereafter, ESG) issues (Jain and Sharma, 2018). Put in another way, it is an investment strategy that combines social or environmental benefits with financial returns, providing a platform for linking investors' social, ethical, ecological, and economic concerns (Naeem and Karim, 2021; Brzeszczynski and Graham, 2014). Although Croft (2009) noted that sustainable development issues could be traced back to the 18th century, they started gaining sufficient popularity in the past two decades (Capelle-Blanchard and Monjon, 2012; Bhattarai et al., 2021).

We can attribute the significant awareness of sustainable investment in recent times to two reasons. One, the United Nations Principles for Responsible Investment (UNPRI) success, which raises the alarm for integrating ESG factors in ownership and investment decisions, has caused a significant growth in sustainable investment. For instance, the Global Sustainable Investment Alliance (GSIA) noted that sustainable investment had witnessed a global growth of over 34% since 2016, with

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[1] For instance, the 17 sustainable development goals (SDGs) were established in 2012, while the Paris Agreement and European green deal was signed in 2015 and 2019, respectively.

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over $30 trillion in total assets under management as of the beginning of 2018. Also, the European Sustainable Investment Fund (EUROSIF) documents that the sustainable investment fund is becoming integral to European fund management. In addition, the ESG equity mutual funds have attracted significant net flows in recent years (Koutsokostas and Papathanasiou, 2017). Albeit different countries account for the varying proportion of the global sustainable indices. Nonetheless, there has been a significant increase over the years. Europe stands tall, being the largest market of ESG assets worldwide, totalling $14.1 trillion in 2018, followed by the US with $12 trillion in the same year after a 38% increase from 2016. Japan ranks third with an increase of 18% from 2016. Canada and Australia also have a large market for sustainable indices assets. Two, the recent integration of different markets of the world after the financial crisis of 2008/2009 and the consequent noted hedging abilities of sustainable indices (Reboredo, 2018; Naeem et al., 2021a, b; Pham, 2021; Karim et al., 2022) served as an eye-opener for most investors and researchers. Thus, investors see sustainable indices as an asset to financing climate projects and a viable investment opportunity.

In March 2020, the World health organization declared COVID-19 a global pandemic due to the sharp increase in confirmed cases and deaths worldwide. To contain the spread of the virus, most countries declared a state of emergency and have adopted numerous policies and measures (lockdown and isolation, cancelling national and international flight, border control), resulting in a stoppage in economic activities worldwide (Singh, 2020; Kim et al., 2021; Kumar et al., 2021). Precisely, this pandemic has morphed from a health crisis into an unprecedented economic crisis that harmed the stability of global financial markets. The adverse effect of the pandemic spilled over the world, as the financial markets are heavily interconnected with each other. In response to this global pandemic, many investors turned to invest more in responsible investment, showing strong resilience during this crisis (Omura et al., 2021). With the rising of investors' interests toward including environmental, social, and governance criteria in their decisions, sustainable global funds attracted more than $45.6 billion during the first quarter of2020.[2] It reported a $384.7 billion outflow for the overall global funds in the same context. These figures could prove investor confidence towards sustainable investments as they appear beneficial and have numerous advantages (e.g., lower risk-return, diversification, and hedging opportunities) for investors at crises and especially during the recent health crises. For instance, 24 out of 26 ESG-tilted index funds outperform conventional funds and show strong resilience during COVID-19 (Hale, 2020a).

Many recent studies have emerged in sustainable-related literature investigating the association between sustainable investment and conventional markets. For instance, in the frequency domain, Reboredo et al. (2020) explores the connectedness between green bonds and asset classes (i.e., energy and stock markets and corporate debt and high-yield corporate debt markets). In the same vein, Reboredo and Ugolini (2020) analyze the connectedness between the green bond market and fixed income, currency, stock, and energy commodity markets using a structural vector autoregressive (VAR) model. Likewise, Hammoudeh et al. (2020) explores the causal relationships between the green bonds and environmental and financial assets, including CO2 emission allowances price, WilderHill clean energy equity index and US conventional bonds. Arif et al. (2021) unveils the dynamic relationship between green bonds and equity, currency, commodity, and conventional bond indices during the COVID-19 outbreak. Furthermore, Umar et al. (2020) studied the co-movement between ESG equity indices and set of influential financial and environmental variables using both the granger causality (1969) approach and Diebold and Yilmaz (2012) methodology. Furthermore, additional results reported by these studies suggest the presence of strong evidence for the hedging and diversification benefits provided by these sustainable indices as they offer investors many benefits such as low risk level during turmoil periods and good management reputation.

Nevertheless, to the best of our knowledge, a lack of insight is found regarding the interdependency and co-movement among sustainable indices during the COVID-19 crisis. In this regard, this study aims to fill this void in the literature by investigating the dependence among the sustainable indices of 16 countries comprising European, North American, and Asian countries before and during the COVID-19 outbreak. Most of the selected countries in the current study significantly represent a high SRI global market capitalization percentage. Specifically, this study seeks to answer the following research questions (i) Are sustainable indices interdependent during the last decades? (ii) Are there dependence or co-movement effects among the sustainable indices of the considered countries in this study, and do they display a static or dynamic pattern? (iii) How is the dependence among sustainable indices affected during crises and especially during the COVID-19 crisis? (iv) Which market plays a leading role in the network of sustainable investment?

Based on the discussion above, this study contributes to the recent sustainable literature in several ways. First, this study provides fresh evidence on the interdependency among various countries' sustainable investments, including developed and emerging economies. Precisely, unlike the study of Umar et al. (2020) that focuses on the ESG indices of ten countries, we extend their study by utilizing the sustainable indices of sixteen countries to represent well the global workings of sustainable investment. Second, given that sustainable investment offers numerous benefits during turbulent periods (e.g., lower risk, hedging and diversification benefits), the current study also contributes to the recent sustainable finance literature by considering a large dataset that spans the last 12 years and including different challenging global events such as the European debt crisis (ESDC) 2010–2012, the Greek systemic problem, the Chinese stock market crash and the recent COVID-19 outbreak.

Third, while the adverse effects of COVID-19 pandemic on financial markets push researchers to investigate the effects of the pandemic on financial contagion (Arif et al., 2021; Naeem et al., 2021c; Corbet et al., 2020), safe haven property of precious metals and cryptocurrency (Mokni et al., 2022) to the best of our knowledge a lack of insight is found regarding the effect of this health crisis on the dependency among sustainable indexes. In other terms, this study seeks to contribute to the COVID-19 literature in finance by assessing the effects of COVID-19 outbreak on the interdependency among the sustainable indexes of sixteen countries and analyzing the driven factors of interdependence in sustainable investments.

Lastly, methodologically, this study is distinct from the noted study by Umar et al. (2020) that utilizes a mere connectedness framework and Granger causality. Precisely, our study inquiries into the dependency effect among sustainable investment indices using a network and centrality analysis. Undoubtedly, this dependence approach among series is different from the conventional connectedness and spillover methodologies. The approach helps to determine the market(s) or asset(s) with the strongest influencing power in inducing price synchronization and co-movements among other markets or assets (Wu et al., 2020). Although the dependence approach to analyzing the relationship among assets has been utilized in the literature, to the best of our knowledge, only the study of Wu et al. (2020) have applied our method of analysis to global commodity futures. Compared to the existing dependence/network approaches in the literature, this study uses partial correlations to construct the dependency network and then analyze within-system interdependence in a minimum spanning tree (MST) to evaluate the centrality of the variables. The main advantage of this approach is that the construction of the dependency network is based on correlation analysis, which is a simple and commonly applied method in portfolio construction. Given that our sample periods include challenging global events (e.g., EDSC crisis, the Greek systemic problem, the Chinese stock market crash, COVID-19 pandemic), it is expected that the correlation and dependency structures within the system of sustainable indexes is

[2] https://www.morningstar.com/products/esg-investing.

time-varying. In this regard, in addition to the centrality and dependency analyses, we account for time variation in the dependency analysis through a rolling window analysis. On the other hand, we employ a simple regression (MCO) method to investigate how the global factors considered in this study influence the interdependence in sustainable investments.

Our empirical analysis reports that France plays a central role in connecting components in the networks of sustainable investment. Nevertheless, it is found that Japan and Taiwan are least integrated with the global sustainable investment network. Results also proved evidence of time-varying within-system dependency. We found that the dependency increased drastically during crises and recession, especially during COVID-19 turmoil. Results also proved evidence of time-varying within-system dependency. We found that the dependency increased drastically during times of crises and recession. Interestingly, we found that sustainable investment dependence reached its highest level during the COVID-19 outbreak, justifying the idea suggesting that crises mostly spur the connectedness and relationship among assets. Further, findings show that European countries exhibit a good connection and form the biggest cluster, suggesting the pivotal role of geographical proximity in connecting sustainable investment among countries. Finally, results indicate that GVZ has the highest effect on the interdependence of sustainable investments.

The remainder of this paper is structured as follows. Section 2 presents the literature review. Section 3 explains the methodological approach. Section 4 describes the data and provides key characteristics of the whole sample and the two sub-periods: pre- and post-COVID-19. Section 5 reports and discusses the empirical findings, and finally, section 6 concludes the study.

2. Literature review

As noted in the previous section, issues surrounding sustainable investment have been documented in the literature. For a detailed review, the literature can be partitioned into four strands. The first strand of studies compares the performance of ESG screened mutual funds with their conventional counterpart (Renneboog et al., 2008; Derwall and Koedijk, 2009; Gi-Bazo et al., 2010; Joliet and Titova, 2018). The second strand reveals the effect of ESG disclosure on firm value (Li et al., 2018; Fatemi et al., 2018). Thirdly, some studies inquire into the portfolio performance of SRI investments (Consolandi et al., 2009; Auer and Schuhmacher, 2016; Tripathi and Bhandari, 2016; Oikonomou et al., 2018). The last strand of studies focuses on the connectedness and contagion effect among sustainable investment indices and other conventional investment series.

Starting with the first strand in the literature. This strand considers Ethical mutual funds, also called socially responsible investment (SRI), to integrate ethical, social, governance and environmental criteria in their investment portfolio (Renneboog et al., 2008). This market has experienced spectacular growth worldwide, especially since the global financial crisis (GFC) 2007–2008. For instance, the value of an investment in sustainable and responsible market stocks increased sharply and recorded $6.57 trillion in the US (Rossi et al., 2019). Numerous researchers have followed the rapid growth of the SRI industry and focus on comparing the performance of ESG screened mutual funds with their conventional peers. These studies bear mixed results. In specific terms, Renneboog et al. (2008) find that SRI funds' performance in the UK, US, and many European and Asia-pacific countries closely follows the performance of their conventional counterparts. Furthermore, it is reported that conventional indexes exhibit strong predictive power in explaining SRI fund returns than socially responsible indexes (Leite and Cortez, 2014). Derwall and Koedijk (2009) note that the SRI bond fund performance is like their conventional counterparts. Notwithstanding, SRI bond funds still outperform conventional balanced funds. Gi-Bazo et al. (2010) reveal that the US SRI funds outperform the conventional funds when the gross and net returns are considered. The study further explains that there are no significant differences in conventional and SRI funds management fees, except that SRI funds are cheaper than the conventional ones when offered by the same management company. Based on the previous studies in the field, two main arguments could be advanced to explain how SRI funds outperform conventional funds (Renneboog et al., 2008). (i)The presence of sound social and environmental performance signals the good quality of management, which might, in turn, translate into favorable financial performance. (ii) On the other hand, social, ethical, and environmental screening is an effective way to reduce the high-cost level shown during environmental disasters or corporate social crises. Thus, given that financial markets are likely to undervalue these costs, SRI funds could outperform financial markets benchmarks.

Besides, the investment styles of SRI funds can also differ from conventional funds. In this regard, Benson et al. (2006) indicate that SRI funds have different industry exposures than conventional funds. Specifically, SRI tends to be less exposed to market return volatility and more growth oriented (El Ghoul and Karoui, 2017; Humphrey and Lee, 2011).

The second strand of studies has related ESG disclosure's effect on firm value. ESG disclosure provides useful and valuable information on firms' environmental, social and governance practices (Aouadi and Marsat, 2018). Thus, implying that more diversified information (i.e., financial and non-financial information) in the economy could improve price information (Goldstein and Yang, 2015). ESG disclosure could engender many positive feedback loops such as reducing information asymmetry between firms' and related parties, enhancing transparency and visibility related to environmental, social and governance issues around the firm and further improving the internal governance mechanisms to serve the firm's stakeholders' interests, resulting in an increase in firm value in the long run (Cheng et al., 2013). How ESG disclosure influences firms' value has received much attention in the last decade. For instance, Li et al. (2018) document a positive correlation between ESG disclosure level and firm value. This means that transparency, accountability, and stakeholder trust increase the firm's values. In addition, the study uncovers that higher CEO power significantly influences the effect of ESG disclosure on firm value. This suggests that stakeholders interact with firms' ESG disclosure to a higher CEO power and greater adhesion to ESG practice. In the same vein, Fatemi et al. (2018) document that the activities and disclosure of ESG accumulate firm value while the lack of it decreases the firm value.

Studies on the portfolio performance of SRI investments are also increasing significantly. This can be hedged because investors are always searching for viable portfolios for investment purposes. For instance, Consolandi et al. (2009) compare the returns of the Dow Jones Sustainability Stoxx Index (DJSSI) with that of the Surrogate Complementary Index (SCI) to examine the possibility of divergence in performance. The study finds that DJSSI slightly underperformed the benchmark portfolio. However, the inclusion announcement produces a positive cumulated abnormal return. This significantly emphasizes the role of SRI in asset allocation. In the same vein, Auer and Schuhmacher (2016) also document that ESG performance in Asia-Pacific is similar to that of US, but lower than that of Europe. With this, the study concludes that selecting high- or low-rated stocks of ESG firms does not guarantee superior returns. Contrary to the previously noted studies, the works of Tripathi and Bhandari (2016) and Oikonomou et al. (2018) support the viability of ethical indices compared to their conventional counterparts.

The last strand of studies has gained a significant stand in the literature. These studies focus on how the sustainable indices integrate and with other conventional indices. However, most of these studies focus on green investment series (for instance, see Reboredo, 2018; Reboredo et al., 2020; Jin et al., 2020; Hammoudeh et al., 2020; Reboredo and Ugolini, 2020; Goa et al., 2021; Naeem et al., 2021a,b; Arif et al., 2021; Le et al., 2021; Nguyen et al., 2020; Ferrer et al., 2021; Saeed et al., 2021), while only the study of Umar et al. (2020) focus on the connectedness among the sustainable investment series which significantly tracks the ESG factors. The explosive popularity of green bonds is mostly attributed to their ability to channel financial resources to environment-friendly projects within the sustainability-oriented financial community (Reboredo and Ugolini, 2020). Furthermore, understanding the mechanism of price transmission between green bonds and financial markets seems very interesting to have a clear idea about the performance of these assets and their ability to act as a hedger or diversifier, especially during periods of market tensions (Reboredo et al., 2019; Reboredo and Ugolini, 2020). In clearer terms, most of the studies on green series found that green series significantly connect with most conventional series and act as a suitable hedger of risk during times of turmoil.[3] Thus, green bonds appear as substantial and useful hedging and diversification device against conventional assets.

The study of Umar et al. (2020) that utilizes the granger causality test and the spillover approach of Diebold and Yilmaz (2014) unveils that there is a significant transmission of information between the sustainable series and other conventional series used throughout the sample period. The study further credits the increased connectedness among the series during crises like the European sovereign debt crisis, the systemic Greek problem, and the COVID-19 outbreak. Lastly, the study documents that the developed markets' sustainable indices are notable shock transmitters to the Asian and other emerging markets. However, our study proves to be superior to their study in several ways. Unlike the study of Umar et al. (2020) that utilizes ten sustainable series of different countries, we utilize sixteen sustainable series, which provides a better view of the global market of sustainable investments. Two, unlike the connectedness framework that is used in the work of Umar et al. (2020) and other notable connectedness studies (see Iqbal et al., 2021) we use an advanced methodological framework that can suitably account for the dependency effect through network and centrality analysis. Three, we partition our dataset into two. This makes us provide empirical evidence for full sample and pre-COVID and post-COVID samples.

3. Methodology

To assess the global network for sustainable investments, we follow the methodology proposed by Wu et al. (2020). Combining a dependency network analysis using partial correlation and a centrality network analysis using the minimal spanning tree (MST) is considered a powerful instrument for large-scale datasets and multivariable systems. Prominently, the combined analysis allows investigating the degree and pattern of co-movements among studied markets, identifying markets with the strongest (lowest) influencing power in the sustainable investment network and exploring the potential variation in the dependence structure over time.

3.1. Dependency network

The analysis of the dependency network's main purpose is to reveal the information flow among variables in the system. To start with, the first-order partial correlation between variable i and j conditional on variable k - $PC\ (i,j|k)$ is calculated as:

$$PC\ (i,j\,/\,k) = \frac{C(i,j) - C(i,k)C(j,k)}{\sqrt{\left(1 - C^2(i,k)\right)\left(1 - C^2(j,k)\right)}} \tag{1}$$

Where: $C(i,j)$ is the unconditional correlation between variable i and j

Then, the dependency effect of variable k on the correlation between variable i and variable j is estimated as the difference between unconditional correlation and the partial correlation with respect to k:

$$d\ (i,j|k) = C(i,j) - PC\ (i,j|k) \tag{2}$$

The relationship between i and j is said to be independent of k when the value of $d\ (i,j|k)$ equals zero. In other words, the higher value of $d\ (i,j|k)$ is, the more important role of k is implied.

As we extend the number of variables to N, the total dependency effects of variable k on variable i is given as:

$$D\ (i|k) = \frac{1}{N-2}\sum_{j=1}^{N} d\ (i,j|k), j \neq k, i \tag{3}$$

It is noted that there is the presence of asymmetric dependency in the network when $D\ (i|k) \neq D\ (k|i)$.

3.2. Centrality network

Defined as an MST based on the unconditional Pearson correlation among variables, the centrality network is further constructed to depict the integration degree across countries' sustainable investment as well as to identify the role of each country in the sustainable investment network. More detail about the MST approach can be found in studies by Ji and Fan (2016); Zhang et al. (2021).

In particular, the distance linking variable i and variable j is given as $e_{ij} = \sqrt{2(1 - C(i,j)}$. Accordingly, the higher value of correlation between two variables makes the distance between them shorter.

To explore the most important variable (node) in the network, several centrality measures are then computed, including degree centrality, closeness centrality, and betweenness centrality.

$$\text{Normalized tree length} = \text{NTL} = \frac{1}{N-1}\sum_{e_{ij}\in MST} e_{ij} \tag{4}$$

$$\text{Degree centrality} = \text{DC(i)} = \sum_{j=1}^{n} f_{ij} \tag{5}$$

With f_{ij} is a dummy variable. It has a value of 1 when vertexes i and j have an edge in the MST and is zero otherwise.

$$\text{Closeness centrality} = \text{CC(i)} = \sum_{(i,j)} S_{ij} \tag{6}$$

With S_{ij} represents the shortest path from variable i to variable j in the MST. The node with a shorter distance from other nodes is noted as the center in the network.

$$\text{Between centrality} = \text{BC(i)} = \frac{2}{N(N-1)}\sum_{e_{j,q}\in MST}\frac{\sigma_{jq(i)}}{\sigma_{jq}}, i \neq j \neq q \tag{7}$$

With $\sigma_{jq(i)}$ indicates the number of shortest paths from j to q passing through i, and σ_{jq} represents the number of shortest paths from j to q.

Given all these measures, the leading countries in the sustainable investment network will be exposed as shown by the biggest nodes.

Finally, the paper applies a multi-step survival ratio of edges to validate our findings. $\vartheta(t,k)$ is the k-step survival ratio of edges in the MST and it is computed as:

$$\vartheta(t,k) = \frac{1}{N-1}\left|E(t) \cap E(t-1) \ldots E(t-k+1) \cap E(t-k)\right| \tag{8}$$

The test robustness is confirmed when a higher number of step (k) results in the larger value of $\vartheta(t,k)$.

3.3. Determinants of interdependence in sustainable investments

We employed the financial and economic factors for determining the interdependence among sustainable markets. For analyzing the impact of global factors on the interdependence, we performed regression analysis as follows:

$$CONN_t = \beta_0 + \beta_1 \sum Determinants_{it} + \varepsilon_{it}, \tag{9}$$

[3] For a detailed review of studies on green bond, readers should revert to the studies of Pham (2021) and Naeem et al. (2021b).

Table 1
Summary statistics.

Full Sample	Symbol	Mean	Std. Dev.	Skewness	Kurtosis	J-B
Canada	CAN	0.022	1.373	−0.673	18.903	33907.71***
Finland	FIN	0.004	1.877	−0.276	7.882	3213.075***
France	FRA	0.011	1.553	−0.364	10.747	8060.122***
Germany	GER	0.02	1.529	−0.442	9.911	6462.917***
India	IND	0.074	1.846	−0.087	10.241	6984.159***
Italy	ITA	0.011	1.828	−0.769	12.733	12926.31***
Japan	JAP	0.019	1.333	−0.134	6.87	2003.523***
Korea	KOR	0.03	1.664	−0.239	7.556	2793.65***
Netherlands	NET	0.041	1.449	−0.221	8.301	3766.197***
Portugal	POR	−0.018	1.589	−0.556	8.588	4321.624***
Spain	SPN	−0.007	1.748	−0.387	12.465	12005.23***
Sweden	SWE	0.029	2.007	−0.155	8.549	4111.329***
Taiwan	TAI	0.068	1.407	0.045	5.933	1145.939***
Thailand	THL	0.04	1.609	−0.047	9.074	4912.226***
United Kingdom	UKD	0.012	1.279	−0.506	10.171	6981.255***
United States	USA	0.052	1.173	−0.59	16.45	24267.87***
Pre-COVID	Symbol	Mean	Std. Dev.	Skewness	Kurtosis	J-B
Canada	CAN	0.02	1.214	−0.221	7.115	2064.486***
Finland	FIN	−0.004	1.858	−0.268	7.931	2965.528***
France	FRA	0.011	1.493	−0.065	8.245	3317.957***
Germany	GER	0.015	1.451	−0.158	6.578	1554.888***
India	IND	0.063	1.777	−0.044	10.043	5980.667***
Italy	ITA	0.008	1.785	−0.318	8.109	3195.041***
Japan	JAP	0.018	1.333	−0.167	6.741	1700.595***
Korea	KOR	0.02	1.564	−0.23	5.362	698.103***
Netherlands	NET	0.03	1.413	−0.081	8.026	3048.109***
Portugal	POR	−0.021	1.507	−0.313	5.128	593.073***
Spain	SPN	−0.007	1.689	−0.099	10.565	6902.456***
Sweden	SWE	0.026	1.95	−0.041	7.944	2946.811***
Taiwan	TAI	0.055	1.375	−0.008	5.808	950.489***
Thailand	THL	0.044	1.552	0.248	7.028	1985.38***
United Kingdom	UKD	0.016	1.227	−0.315	8.544	3752.75***
United States	USA	0.049	1.036	−0.302	7.241	2211.591***
Post-COVID	Symbol	Mean	Std. Dev.	Skewness	Kurtosis	J-B
Canada	CAN	0.037	2.419	−1.054	16.571	2373.551***
Finland	FIN	0.08	2.049	−0.349	7.376	247.055***
France	FRA	0.011	2.039	−1.465	15.607	2108.162***
Germany	GER	0.061	2.142	−1.268	14.145	1643.759***
India	IND	0.172	2.407	−0.302	8.963	452.046***
Italy	ITA	0.046	2.198	−3.08	31.015	10353.37***
Japan	JAP	0.034	1.332	0.183	8.102	329.202***
Korea	KOR	0.129	2.423	−0.301	8.952	450.305***
Netherlands	NET	0.154	1.753	−0.983	8.768	467.296***
Portugal	POR	0.012	2.233	−1.224	13.264	1401.112***
Spain	SPN	−0.006	2.236	−1.553	16.375	2372.318***
Sweden	SWE	0.066	2.489	−0.689	9.649	580.147***
Taiwan	TAI	0.196	1.685	0.245	5.813	102.559***
Thailand	THL	0.002	2.073	−1.208	13.605	1488.611***
United Kingdom	UKD	−0.022	1.698	−1.123	12.271	1144.916***
United States	USA	0.075	2.074	−0.8	13.632	1454.701***

Notes: J-B denotes the Jarque-Bera statistics for normality. *** indicates rejection of the null hypothesis at the 1% level. Full sample: January 1, 2009–March 30, 2021; pre-COVID: January 1, 2009–February 2, 2020; post-COVID: February 4, 2020–March 30, 2021.

where $CONN_t$ denotes TCI (Total Connectedness Index) and SII (System Integration Index) at time t. β_0 is the intercept whereas ε_{it} is the error term. The component $\sum Determinants_{it}$ represents the proxies of factors employed in the study. In this regard we employ five variables reflecting the major financial markets and three other variables computing the level of uncertainty. (i) The VIX index for stock market volatility is a measure of the expected change in the S&P 500 over the coming 30-days. It is computed with reference to option prices that allow investors to hedge against sharp price movements (Andrada-Félix et al., 2018). (ii) As representative of the energy market, we employ the CBOE crude oil ETF volatility index (OVX). The OVX measure the expectation of 30-day volatility in crude oil prices (Naeem et al., 2021c). As indicator of non–energy commodity markets, we use the CBOE Gold ETF volatility index (GVZ). The GVZ computes the expectations of 30-day volatility of gold prices based on the bid and ask prices of SPDR gold shares (Dimpfl and Peter, 2018). Furthermore, we use the CBOE Euro Currency VIX (EVZ), which represent the foreign exchange markets. This indicator reflects the expected 30-day volatility of the USD/EURO exchange rate, based on options on the Currency Shares Euro Trust (Kocaarslan et al., 2017). As illustrative of the Bond market, we utilize the Merrill Lynch Option Volatility estimate index (MOV), which estimates swings in the US Treasuries based on options prices (Naifar and Hammoudeh, 2016). Moreover, in this study we utilize the newly constructed infectious diseases tracking index of Baker et al. (2020). This index computes the magnitude of infectious disease pandemic. This EMV-ID index is constructed following these steps:

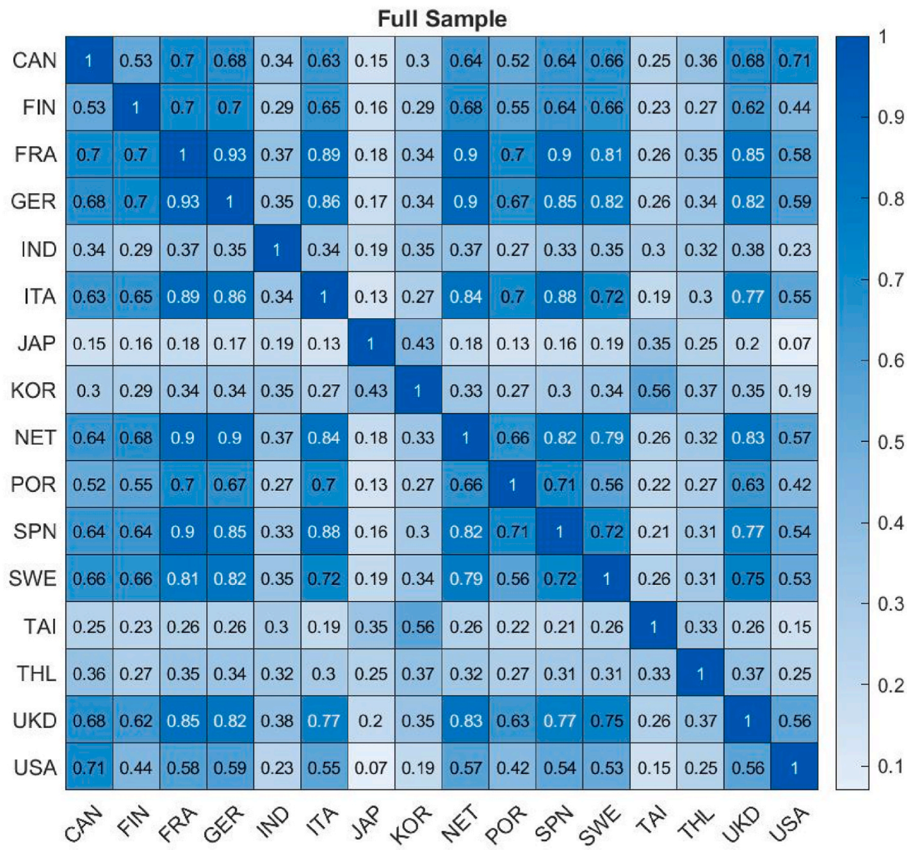

Fig. 1. Heat-map for Kendall rank correlation correlations (The darker the color is in the map, the higher the pairwise correlation is. Full sample: January 1, 2009–March 30, 2021). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

firstly, Baker et al. (2020) specify terms in four categories namely E: {economic, economy, financial}, M: {Stock market, equity, equities, standard and poors}, V: {Volatility, Volatile, uncertain, uncertainty, risk, risky}, ID: {epidemic, pandemic, virus, flu, disease, coronavirus, mers, sars, ebola, H5N1, H1N1}. Secondly, they obtain the daily counts of newspapers articles that include at least one term in each of E, M, V, and ID, based on approximately 3000 newspapers. Finally, they scaled the ID counts and multiplicatively re-scaled by the count of articles in the same day. Furthermore, as illustrative of uncertainty we employ the economic policy uncertainty (EPU) index proposed and constructed by Baker et al. (2016). Precisely, in this study, we consider the US EPU (USEPE) constructed using the Access World News Bank services by covering about 1500 US newspapers (Wang et al., 2020; Jiang et al., 2021). The first step of construction of this index involves searching the digital archives of each papers to obtain a daily count of articles which contain terms in all three categories: (i) economy (or economic), (ii) policy (or policy terms such as "legislation", "regulation", and Congress etc.), and (iii) uncertainty (or uncertain). We mention that the raw counts are scaled by the total number of articles in the newspaper, by day. Afterwards, they standardized each daily newspaper-level series to unit standard deviation and then averaged across the 1500 papers. Finally, they normalized the 1500 series to obtain the daily EPU time-series index. As for the UK EPU (UKEPU), this index is constructed based on the same approach.

4. Data

In this paper, to account for the sustainable investment performance, we employ the daily Dow Jones sustainability Indexes of 16 countries, running from January 1, 2009 to March 30, 2021. The studied period enables us to cover some major market turmoil, such as the 2010–2012 ESDC and the recent COVID-19 outbreak of 2020. Extracted from DataStream, Dow Jones Sustainability Indexes are generally recognized as the superior sustainable indices as it employs a best-in-practice assessment process, tracking the performance of companies that lead the field in terms of corporate sustainability (Searcy and Elkhawas, 2012). Hawn et al. (2018) mentioned that due to the number of questions and depth of information requests, the index's highest level of credibility is signified.

For network analysis, we obtain indices of as many countries as possible. Due to data availability, the sustainable investment indexes of 16 countries have been collected, including both developed and emerging economies. This sample includes both European countries (Finland, France, Germany, Italy, Netherlands, Portugal, Spain, Sweden, and the UK), North American countries (the US and Canada), as well as Asia countries (India, Japan, Korea, Taiwan, and Thailand). Before running the analysis, all indices are converted to returns by taking the difference in the logarithm between two consecutive price indices.

The summary statistics of the sustainable investment returns are given in Table 1. Considering the entire sample period from January 1, 2009–March 30, 2021, most countries display a positive mean of sustainable investment returns, except Portugal and Spain. India has the highest average returns in sustainable investment, accounting for 0.074, followed by Taiwan (0.068) and the US (0.052). The highest number is found in Sweden and Finland, while the US counterpart experiences the least variation in terms of standard deviation.

When we divide the studied period into pre-COVID (January 1, 2009–February 2, 2020) and post-COVID periods (February 4, 2020–March 30, 2021), the pattern holds for the pre-COVID periods in comparison with full sample statistics. However, given the outbreak of COVID, the indices appear to variate significantly. In particular, the UK sustainable investment was hit hard by the COVID pandemic as it

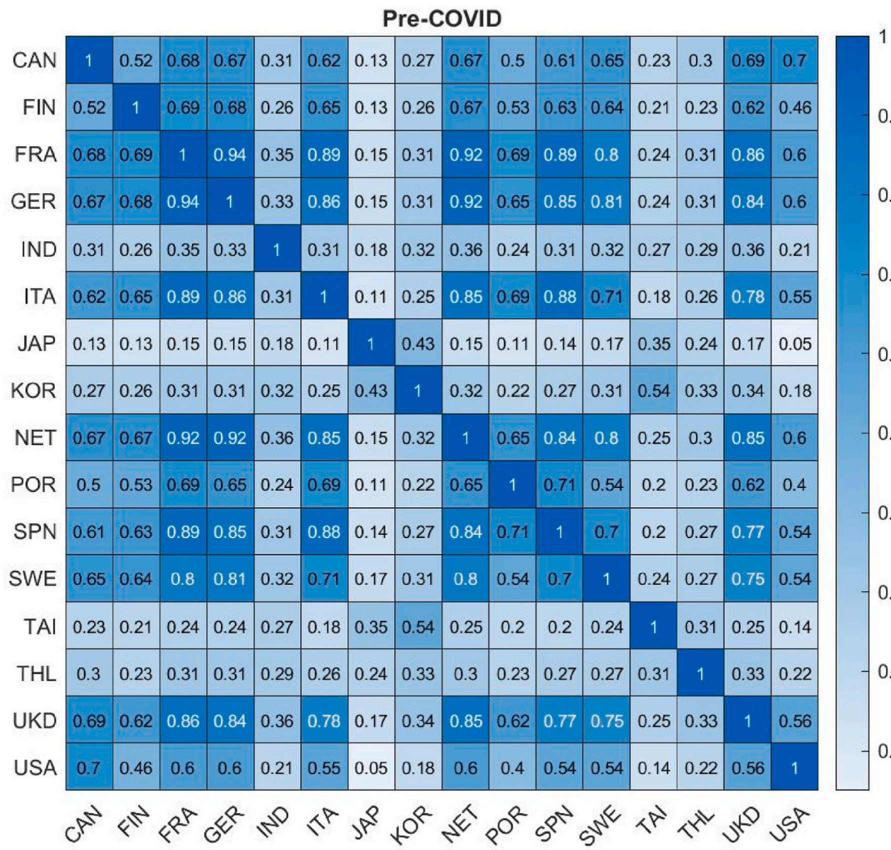

Fig. 2. Heat-map for Kendall rank correlation correlations (The darker the color is in the map, the higher the pairwise correlation is. Pre-COVID: January 1, 2009–February 2, 2020). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

exhibits negative returns at −0.022 post-COVID. Furthermore, the volatility of sustainable investment across countries is considerably higher after COVID, ranging from 1.332 to 2.489, while it was 1.036–1.95 before COVID. The impact of COVID on sustainable investment, therefore, is apparent.

Regarding the Jarque-Bera statistics, the results show the rejection of the null hypothesis at1% significant level, implying the non-normality of the sustainable investment returns.

The Heat-map for Kendall rank correlations are given in Fig 1–3 for the full sample, pre-COVID, and post-COVID periods, respectively, to have an overall picture of the linkage between markets. Generally, the map shows that France and Germany's sustainable investment is most correlated with each other and with that in other countries. The high level of correlation (showing by the darker color in the map) is especially found between France (Germany) and other European countries, such as Italy, Netherland, Spain, and the UK. Japan and Taiwan, by contrast, appear to have low correlations with others, with a correlation value of approximately 0.4 or below.

5. Empirical results

This session employs the dependency and centrality network approaches to quantify the global networks for sustainable investments. Under both approaches, we first employ static analysis in the form of networks. We further perform the dynamic version using a rolling window of 260 days (approximately one year).

5.1. Dependency network

5.1.1. Static analysis

Table 2 shows the dependency matrix depicting the impact of the sustainable investment of one country on the correlation of another country's sustainable investment with all the others. As demonstrated in the table, the value of "From" is the aggregation of each row, indicating the level of dependency of each country's suitability investment on the global network of sustainable investment. The "To" value, on the other hand, is the aggregation of each column, demonstrating the contribution of each country's sustainable investment to others. Finally, the positive (negative) value of "Net" defines the role of a country as a contributor (receiver) and is calculates as the difference between "To" and "From".

Immediately, France stands out as having the strongest influence on the global sustainable investment environment, given its highest value of To and Net dependency. France's widely recognized leading role in sustainable finance and the environment gives a plausible explanation for its highest contribution to the global sustainable investment network. In fact, France hosted the 2015 Paris Climate Change Agreement, which aimed to transition towards a climate-friendly economy. It is also the first country requesting investors to report Environmental, Social, and Governance (ESG) integration and greenhouse gas emissions. A green sovereign bond is first committed in France, and its green bond market is well recognized as the largest in Europe.[4]With the implementation of the French Energy Transition Law in January 2016, France is noted as a pioneer who requests mandatory climate and carbon risk reports from institutional investors, pension funds, and insurance companies.[5] Therefore, as Euros if (2008) mentioned, France's socially responsible investment market is the most dynamic and successful in Europe. Along with France, the top economics of Germany, the

[4] https://www.responsible-investor.com/articles/esg-country-snapshot-france.

[5] https://www.climatebonds.net/2017/06/spotlight-france-leading-green-finance-and-sustainable-investment.

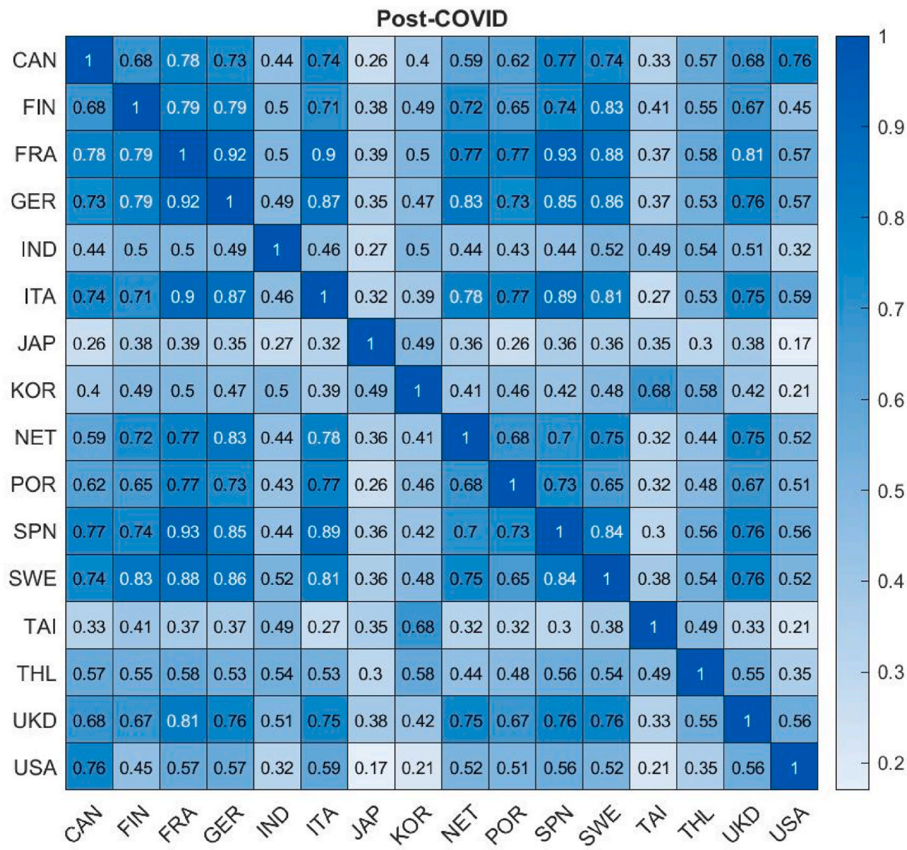

Fig. 3. Heat-map for Kendall rank correlation correlations (The darker the color is in the map, the higher the pairwise correlation is. Post-COVID: February 4, 2020–March 30, 2021). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Netherland, and the UK have notably higher dependency effects than all others. The fact that these countries are widely recognized as the leader of the European Union greatly supports the finding.

The US, in contrast, is distinguished as the country having the lowest net dependency in the sustainable investment network. It suggests that the variation in US sustainable investment is largely driven by the sustainable tenement information of the other countries. This result ties well with a previous study by Umar et al. (2020), who prove that the US is the net receiver from Europe when investigating the connectedness between ESG investment across countries. Although the US contains a large renewable energy production capacity, its share of renewable energy used in total power generation is insignificant. Additionally, the US regulation on ESG appears to be a barrier to increasing the country's share of renewables used to produce energy (Lundgren et al., 2018). The US, indeed, officially exited the Paris climate agreement on 4 November 2020when the acceleration of greenhouse gas emission was recorded. Consequently, the finding that the US lags behind European countries in terms of sustainable investment is rational to expect.[6]It is a different story turning now to Japan and Taiwan. We observe that Japan and Taiwan are two countries having the lowest contribution (To) and gain (From) from the system. The low level of integration of these two countries with the sustainable investment network is indicated subsequently.

The level of total dependency measure (Total) for the magnitude of aggregate systemic, sustainable investment linkage is found at 2.17 over the full sample. While the Pre-COVID figure is 2.07, the post-COVID dependency measure is much higher, corresponding to 2.89. As a result, the growth of sustainable investment total dependence across countries after the coronavirus outbreak is acknowledged, providing evidence of the significant impact of COVID on the dependence across countries' sustainable investment. Similar findings suggesting COVID-19 as a driving factor of the increasing linkage across markets can be found in papers by Le et al. (2021). The rising of the total dependency measure during the second sub-period underlines the fact that investors have shifted more attention towards sustainable investments after the COVID-19 pandemic outbreak. This is corroborating with the idea suggesting that during turmoil times people and particularly investors tend to shift their preferences towards a broader and holistic perspective (Talan and Sharma, 2020).

To give better observation, Figs. 4–6 demonstrate the system dependency measures for the full sample, pre-COVID, and post-COVID periods, respectively. The graphical representations showcase similar results as indicated in Table 2. France stands out as the largest contributor, followed by Netherland and the UK. It is also important to mention that the level of contribution to the system increased during the COVID-19 outbreak across most of the considered countries in this study. According to Sharma et al. (2021), the rising of sustainable investments after the COVID-19 pandemic outbreak could be due to the behavior of investors who seeking a better, fairer, and sustainable world after COVID-19 crisis. By contrast, the position of the US as the receivers, which is affected strongly by the system linkage, is observed.

Figs. 7, 9 and 11 provide information about the directed pairwise dependency across all countries' sustainable investments. For clarity, the number of outward arrows specifies the size and the weight of each node in the system. From Fig. 7 we found that France, Germany, Netherland, and UK are notably the most influential markets in the network system for the full sample. Similar results are shown when shifting our attention on the pre-COVID-19 period. Specifically, from Fig. 9, we see that France, Germany, Nederland, and UK still the most dominant markets in the network, which are also net contributor as they show

[6] https://www.raconteur.net/global-business/usa/usa-esg-investing/.

Table 2
Dependency matrix.

Full Sample

	CAN	FIN	FRA	GER	IND	ITA	JAP	KOR	NET	POR	SPN	SWE	TAI	THL	UKD	USA	From
CAN	0	0.133	0.345	0.307	0.050	0.231	0.013	0.052	0.257	0.125	0.235	0.240	0.033	0.054	0.275	0.142	2.492
FIN	0.155	0	0.360	0.337	0.044	0.258	0.015	0.053	0.305	0.140	0.251	0.253	0.032	0.042	0.238	0.086	2.567
FRA	0.135	0.111	0	0.349	0.039	0.231	0.013	0.047	0.286	0.102	0.241	0.189	0.027	0.039	0.237	0.066	2.111
GER	0.139	0.119	0.438	0	0.039	0.241	0.012	0.047	0.319	0.106	0.240	0.208	0.028	0.039	0.241	0.072	2.289
IND	0.133	0.095	0.201	0.176	0	0.146	0.023	0.085	0.185	0.085	0.143	0.153	0.056	0.072	0.189	0.059	1.800
ITA	0.146	0.131	0.452	0.369	0.041	0	0.010	0.040	0.326	0.133	0.326	0.199	0.021	0.038	0.250	0.079	2.562
JAP	0.058	0.060	0.102	0.088	0.048	0.044	0	0.126	0.091	0.044	0.075	0.092	0.075	0.064	0.106	0.008	1.081
KOR	0.114	0.103	0.187	0.174	0.077	0.099	0.041	0	0.161	0.088	0.125	0.150	0.090	0.081	0.174	0.041	1.706
NET	0.136	0.125	0.418	0.385	0.042	0.254	0.013	0.048	0	0.112	0.245	0.213	0.029	0.038	0.264	0.076	2.399
POR	0.154	0.149	0.367	0.309	0.042	0.303	0.012	0.049	0.287	0	0.319	0.183	0.031	0.043	0.250	0.082	2.580
SPN	0.147	0.128	0.468	0.355	0.040	0.319	0.013	0.045	0.305	0.135	0	0.196	0.024	0.039	0.248	0.077	2.540
SWE	0.172	0.151	0.400	0.385	0.046	0.237	0.015	0.053	0.327	0.110	0.236	0	0.031	0.042	0.272	0.084	2.561
TAI	0.101	0.085	0.139	0.135	0.073	0.062	0.041	0.148	0.137	0.078	0.087	0.117	0	0.079	0.129	0.038	1.450
THL	0.148	0.092	0.192	0.176	0.073	0.121	0.030	0.091	0.151	0.088	0.135	0.131	0.061	0	0.184	0.066	1.741
UKD	0.163	0.123	0.415	0.344	0.046	0.243	0.015	0.053	0.329	0.119	0.245	0.220	0.030	0.046	0	0.080	2.471
USA	0.298	0.127	0.300	0.297	0.039	0.227	0.004	0.034	0.269	0.113	0.218	0.203	0.023	0.043	0.238	0	2.431
To	2.199	1.732	4.783	4.186	0.739	3.018	0.269	0.970	3.737	1.577	3.121	2.748	0.592	0.758	3.296	1.055	**Total**
Net	−0.294	−0.836	2.672	1.896	−1.061	0.456	−0.812	−0.735	1.339	−1.003	0.581	0.187	−0.858	−0.982	0.826	−1.376	**2.174**

Pre-COVID

	CAN	FIN	FRA	GER	IND	ITA	JAP	KOR	NET	POR	SPN	SWE	TAI	THL	UKD	USA	From
CAN	0	0.123	0.327	0.297	0.043	0.222	0.011	0.044	0.301	0.111	0.212	0.229	0.030	0.041	0.290	0.145	2.427
FIN	0.145	0	0.348	0.329	0.036	0.254	0.011	0.044	0.318	0.130	0.240	0.233	0.028	0.032	0.239	0.092	2.479
FRA	0.123	0.101	0	0.345	0.033	0.223	0.010	0.040	0.331	0.090	0.227	0.174	0.024	0.030	0.243	0.067	2.061
GER	0.127	0.108	0.431	0	0.033	0.231	0.010	0.040	0.359	0.093	0.228	0.192	0.025	0.031	0.249	0.072	2.229
IND	0.121	0.080	0.187	0.158	0	0.137	0.020	0.072	0.191	0.070	0.134	0.135	0.048	0.057	0.179	0.053	1.641
ITA	0.135	0.122	0.444	0.363	0.035	0	0.007	0.035	0.356	0.120	0.314	0.184	0.019	0.029	0.254	0.079	2.494
JAP	0.051	0.048	0.083	0.074	0.042	0.032	0	0.115	0.083	0.036	0.061	0.081	0.071	0.056	0.094	0.005	0.933
KOR	0.099	0.088	0.164	0.154	0.065	0.090	0.036	0	0.165	0.067	0.112	0.134	0.084	0.064	0.176	0.042	1.541
NET	0.128	0.107	0.407	0.361	0.035	0.229	0.010	0.041	0	0.094	0.227	0.188	0.026	0.031	0.254	0.073	2.212
POR	0.142	0.140	0.355	0.298	0.034	0.297	0.010	0.038	0.303	0	0.318	0.172	0.028	0.032	0.250	0.076	2.492
SPN	0.131	0.118	0.453	0.352	0.035	0.314	0.010	0.038	0.348	0.124	0	0.179	0.022	0.030	0.251	0.077	2.483
SWE	0.164	0.139	0.386	0.381	0.038	0.227	0.013	0.046	0.361	0.101	0.219	0	0.028	0.033	0.279	0.088	2.502
TAI	0.092	0.072	0.125	0.120	0.060	0.058	0.037	0.130	0.141	0.069	0.080	0.104	0	0.065	0.127	0.035	1.315
THL	0.122	0.076	0.166	0.157	0.061	0.103	0.027	0.076	0.157	0.071	0.111	0.111	0.055	0	0.172	0.061	1.527
UKD	0.153	0.112	0.406	0.345	0.038	0.232	0.012	0.047	0.354	0.105	0.230	0.203	0.027	0.036	0	0.079	2.380
USA	0.268	0.126	0.305	0.297	0.032	0.220	0.002	0.031	0.298	0.095	0.209	0.200	0.020	0.034	0.237	0	2.374
To	2.000	1.560	4.587	4.032	0.621	2.870	0.226	0.837	4.065	1.377	2.923	2.521	0.534	0.601	3.294	1.045	**Total**
Net	−0.427	−0.919	2.526	1.802	−1.020	0.376	−0.708	−0.704	1.852	−1.116	0.440	0.019	−0.781	−0.926	0.915	−1.329	**2.068**

Post-COVID

	CAN	FIN	FRA	GER	IND	ITA	JAP	KOR	NET	POR	SPN	SWE	TAI	THL	UKD	USA	From
CAN	0	0.244	0.434	0.335	0.088	0.315	0.030	0.082	0.170	0.176	0.355	0.331	0.052	0.139	0.240	0.121	3.112
FIN	0.223	0	0.420	0.377	0.095	0.266	0.045	0.101	0.233	0.184	0.300	0.410	0.061	0.125	0.221	0.067	3.128
FRA	0.193	0.207	0	0.355	0.074	0.285	0.036	0.084	0.174	0.158	0.310	0.297	0.043	0.102	0.214	0.062	2.596
GER	0.195	0.230	0.484	0	0.079	0.314	0.035	0.084	0.219	0.168	0.305	0.328	0.048	0.099	0.212	0.073	2.874
IND	0.183	0.227	0.279	0.255	0	0.211	0.047	0.148	0.173	0.163	0.192	0.273	0.107	0.186	0.238	0.077	2.759
ITA	0.216	0.210	0.499	0.400	0.080	0	0.035	0.071	0.223	0.198	0.384	0.315	0.030	0.108	0.227	0.082	3.080
JAP	0.094	0.192	0.253	0.189	0.082	0.149	0	0.185	0.168	0.092	0.193	0.189	0.091	0.105	0.199	0.036	2.218
KOR	0.158	0.233	0.302	0.248	0.145	0.155	0.087	0	0.159	0.187	0.186	0.244	0.135	0.207	0.171	0.033	2.652
NET	0.177	0.267	0.408	0.460	0.087	0.354	0.046	0.086	0	0.208	0.266	0.332	0.049	0.095	0.289	0.094	3.216
POR	0.208	0.242	0.446	0.359	0.091	0.372	0.032	0.106	0.242	0	0.336	0.262	0.050	0.115	0.253	0.097	3.210
SPN	0.228	0.223	0.553	0.367	0.074	0.363	0.039	0.077	0.177	0.182	0	0.333	0.037	0.113	0.231	0.076	3.074
SWE	0.216	0.273	0.459	0.386	0.088	0.294	0.037	0.088	0.205	0.151	0.325	0	0.050	0.107	0.235	0.070	2.983
TAI	0.148	0.212	0.220	0.208	0.168	0.089	0.074	0.255	0.133	0.127	0.125	0.208	0	0.192	0.144	0.050	2.353
THL	0.250	0.240	0.328	0.251	0.143	0.237	0.048	0.161	0.147	0.167	0.272	0.257	0.094	0	0.238	0.075	2.909
UKD	0.218	0.222	0.452	0.335	0.099	0.297	0.047	0.083	0.252	0.193	0.317	0.331	0.047	0.125	0	0.095	3.113
USA	0.435	0.165	0.313	0.309	0.081	0.303	0.024	0.041	0.215	0.194	0.279	0.244	0.039	0.100	0.257	0	2.999
To	3.143	3.389	5.852	4.834	1.474	4.004	0.662	1.651	2.890	2.548	4.146	4.355	0.932	1.918	3.370	1.108	**Total**
Net	0.031	0.261	3.256	1.960	−1.285	0.925	−1.556	−1.000	−0.326	−0.662	1.072	1.372	−1.421	−0.991	0.257	−1.891	**2.892**

Note: **From** is the aggregation of each row and **To** is the aggregation of each column showing the dependency effects from the system and on the system, respectively, whereas **Net** is the simple difference between these two.

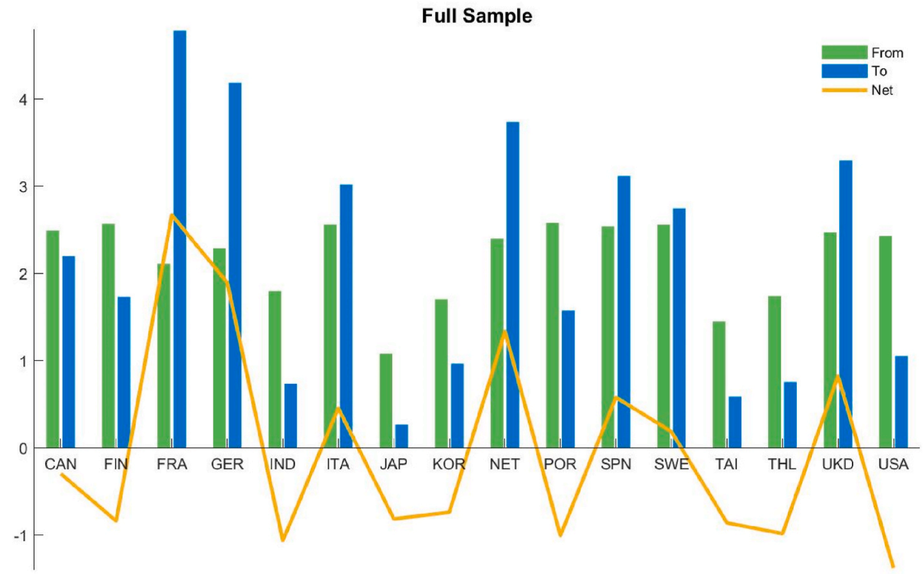

Fig. 4. System dependency measures (Full sample).

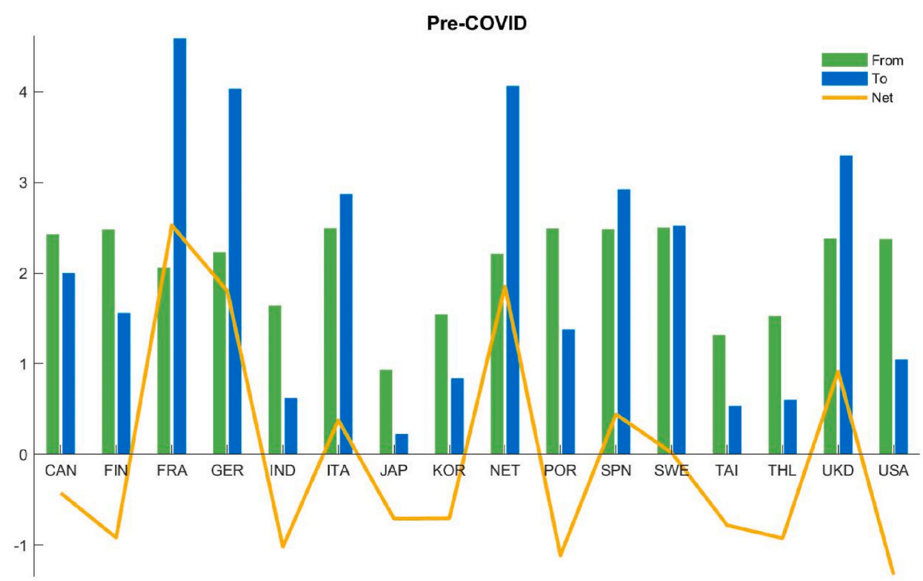

Fig. 5. System dependency measures (Pre-COVID).

stronger dependency effects than the rest of the considered countries in this study. This finding affirms the idea suggesting that Europe is one of the most dominant and advanced markets for sustainable investments (Sandberg et al., 2009). France appears as the leading market during the pre-COVID-19 period implying that its sustainable investment contains useful information that affects many other countries. According to Crifo et al. (2019), in 2018, France appears as one of the most developed socially responsible investment markets in Europe with a growth rate of 55% in the total assets under management including investments that integrated at least minimal reference to ESG criteria for the period ranging between 2011 and 2015.

Moving now to the post COVID-19 period, Fig. 11 indicates that the most dominant markets in the network are sequentially France Germany, Sweden, Spain, and Italy. Our finding affirms again the significant weight of European country especially France and Germany in sustainable investment market. It is important to mention that our finding could be since sustainable investment in Europe still gathered an even faster pace even after the COVID-19 crisis (Broom, 2020). Specifically, Europe recorded the highest number of sustainable investments worldwide by March 2020 (Hale, 2020b). Furthermore, according to Bhattacharya (2020) the recent health crisis of COVID-19 reinforces the way businesses operate globally while making them more sustainable.

To get a clear picture we plot only the top 50% connections ranked by the net pairwise dependency values in Figs. 8, 10 and 12. When focusing on the full sample period, results depict in Fig. 8 indicate that most markets considered in this study are net receivers of information coming from France, Germany, Nederland and UK. Such finding proves that France, Germany, Netherland, and UK have the larger dependency effects in the network. This evidence confirms our previous finding reported in the complete dependency network. When moving to the pre-COVID-19 period, results illustrated in Fig. 10 is in line with the results reported for the full sample period. When focusing on the post-COVID-19 period, results based on the node sizes in Fig. 12 reveal that France, Germany, and Sweden are the most dominant markets in the network. It is important to

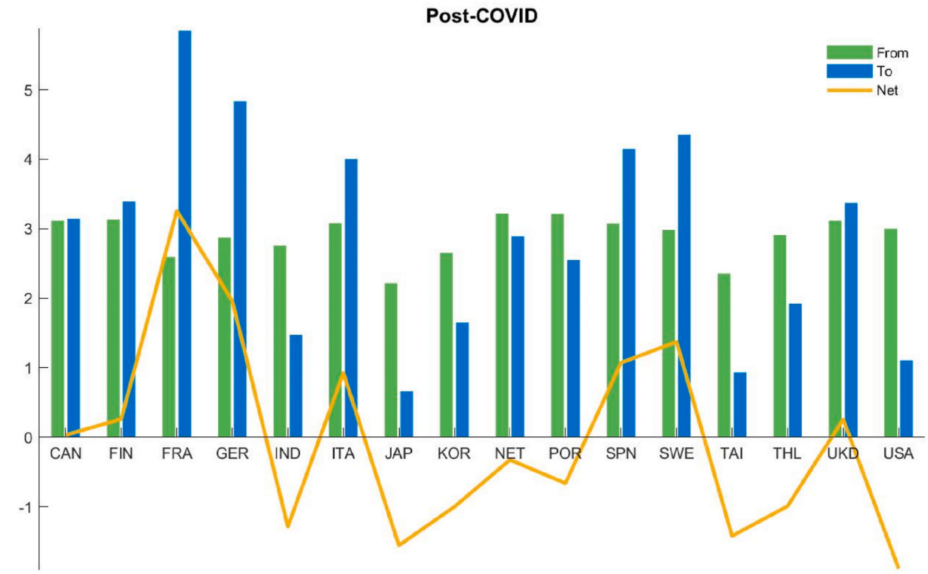

Fig. 6. System dependency measures (Post-COVID).

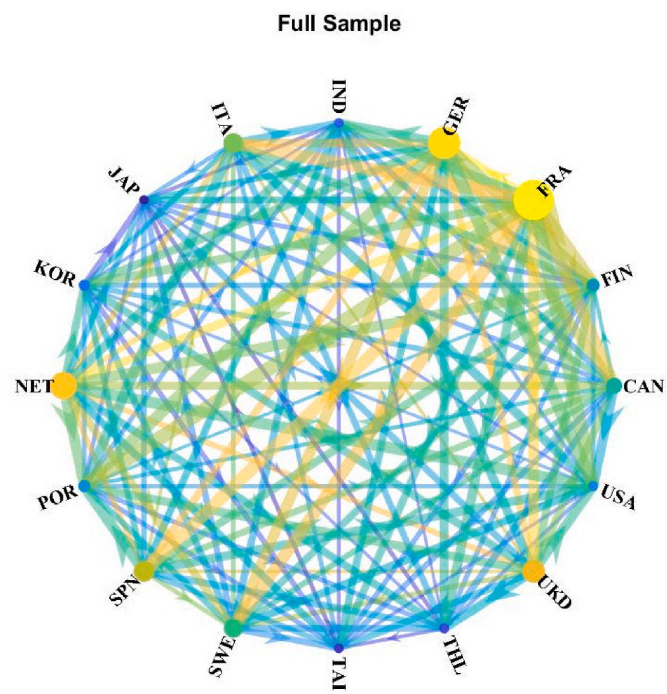

Fig. 7. Complete dependency network (Directed pairwise net dependency. Full sample).

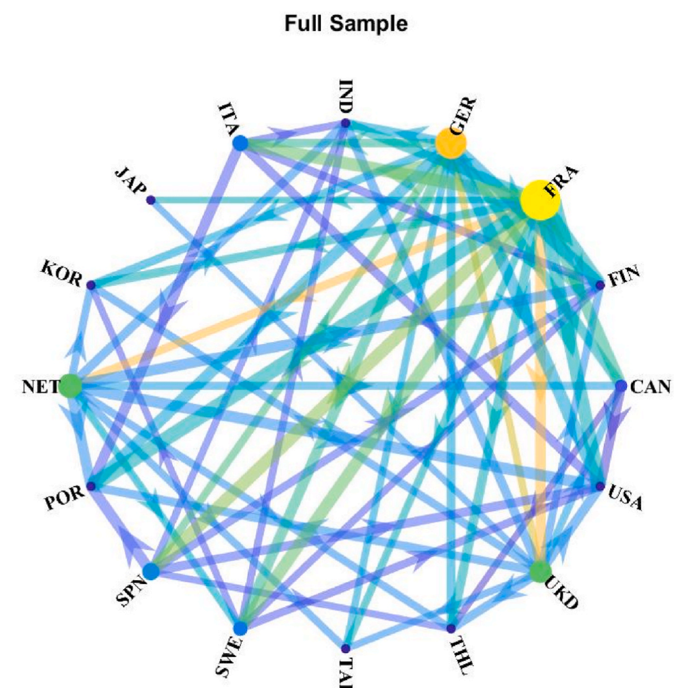

Fig. 8. Core dependency network (Top 50% pairwise net dependency. Full sample).

mention that despite the adverse effects of COVID-19 outbreak, European countries and especially France and Germany still the leading sustainable investment markets. This evidence could be attributed to the fact that investors in these countries started reinforcing their position towards sustainable projects to deal with the adverse effects of COVID-19 crisis since this pandemic accelerated the growing relevance of Environmental, Social, Governance and Economic considerations to investors and sustainable avenues became one of the most important recovery plans for numerous governments (UBS Global, 2020[7]).

[7] UBS Global, 2020. Sustainable Investing after COVID-19.

5.1.2. Dynamic analysis

Our studied period runs from January 1, 2009 to March 30, 2021, which covers both tranquil and turbulent periods. It is, therefore, necessary to explore the potential alternation in the dependence structure between countries' sustainable investments. A dynamic analysis is adopted by a rolling window approach with the window size equalling a year.

Fig. 13 reports the total dependency degree of the time-varying directed dependency network. The average value of the total dependency of sustainable investment across countries is recorded at 2, but there is a substantial variation of the overall dependency over time. In particular, the value records high (at around 2.5) at the beginning of the

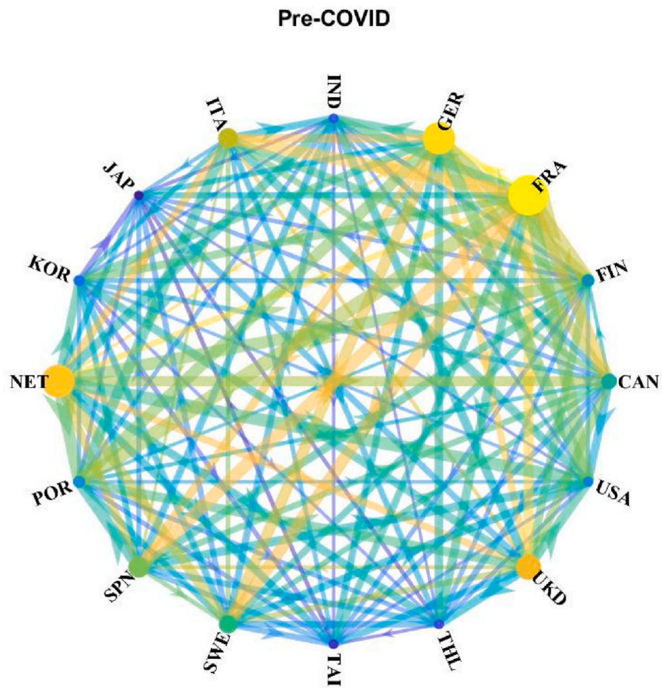

Fig. 9. Complete dependency network (Directed pairwise net dependency. Pre-COVID).

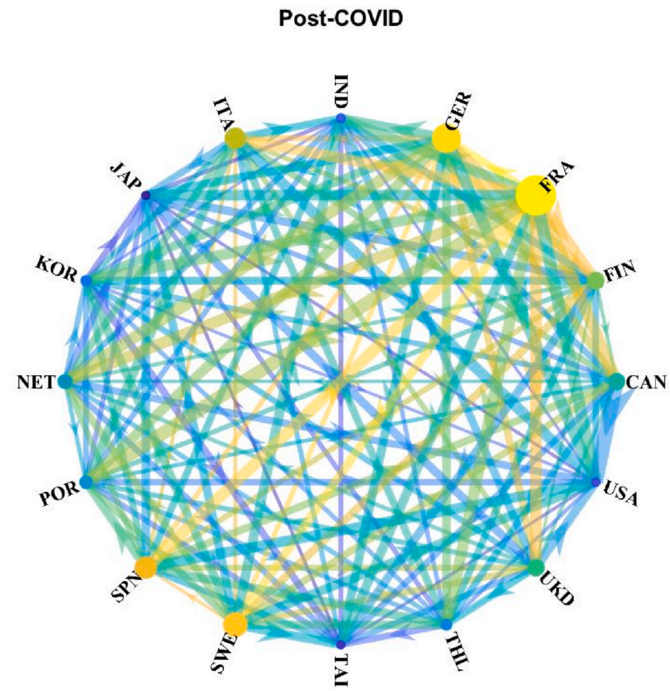

Fig. 11. Complete dependency network (Directed pairwise net dependency. Post-COVID).

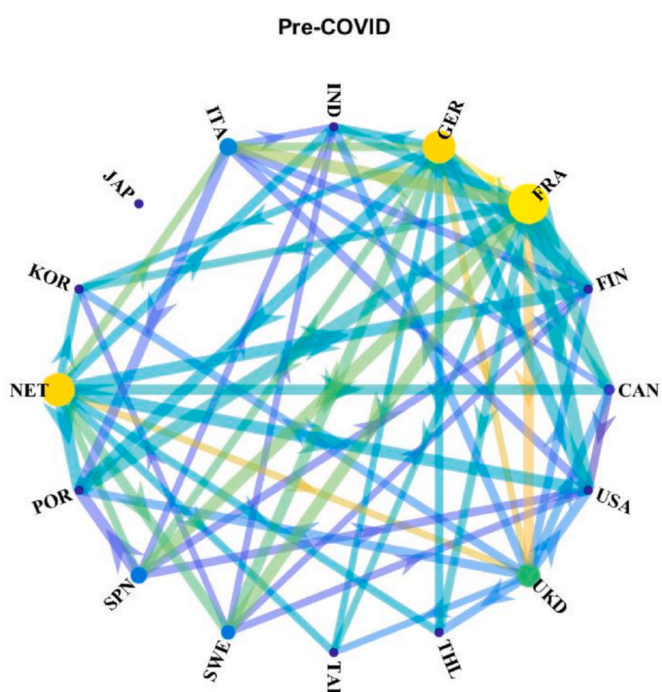

Fig. 10. Core dependency network (Top 50% pairwise net dependency. Pre-COVID).

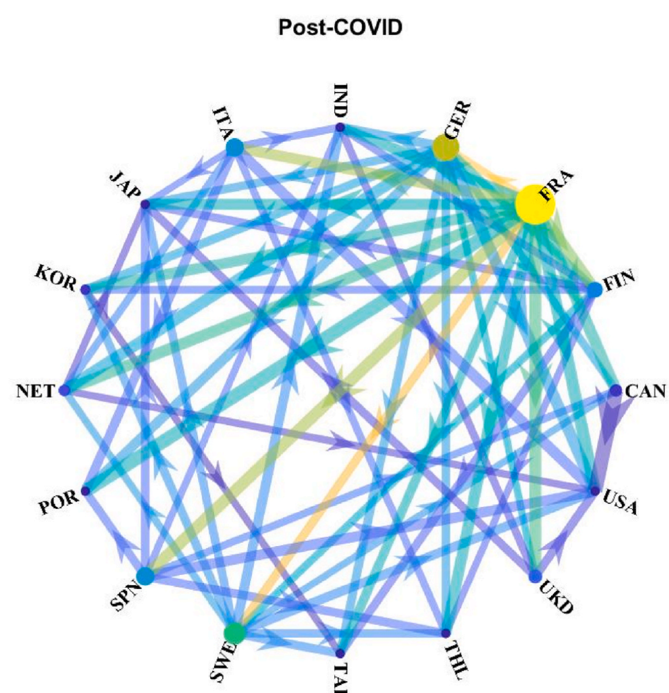

Fig. 12. Core dependency network (Top 50% pairwise net dependency. Post-COVID).

studied period (from 2010), reaching nearly 2.75 in 2012. This period corresponds to the European sovereign debt crisis (ESDC). Due to high government debt and institutional failures, the crisis peaked between 2010 and 2012 following the bank bailouts in several European countries, such as Portugal, Italy, Ireland, and Spain. Lundgren et al. (2018) shares similar findings as they observe a significant increase of connectedness across markets by the onset of ESDC.

The second strike of the dependency network is documented from 2015 to 2017, which may be associated with the failure of the Greek government when it comes to an agreement with its creditors and the Chinese stock market crash in June 2015. According to Umar et al. (2020), the Greek government's use of capital controls as a tool to regulate the banking system might put the sustainability of the Eurozone at risk, which gave rise to sustainable investment dependence across

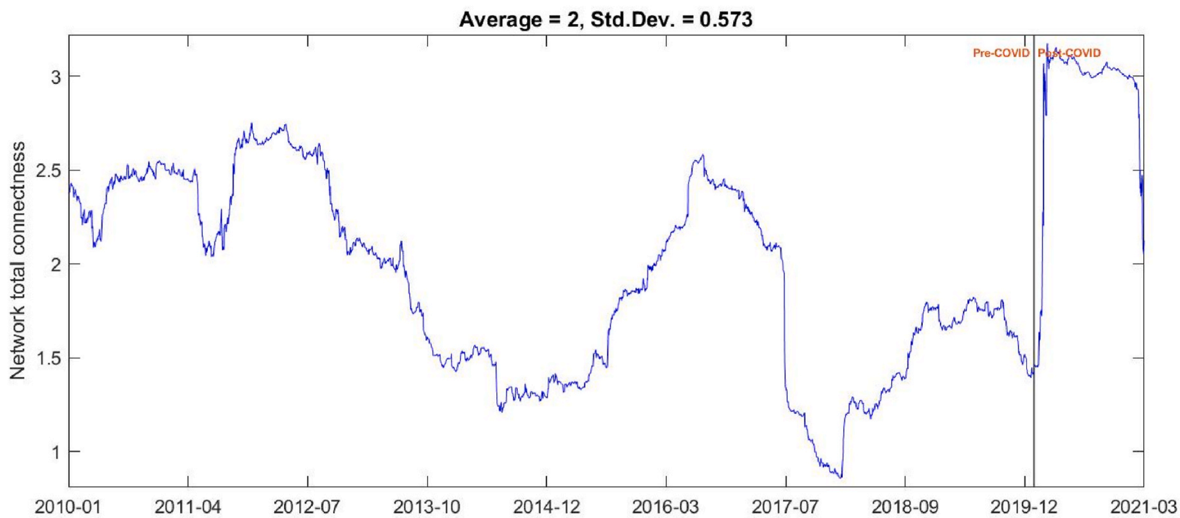

Fig. 13. Total dependency degree of the time-varying directed dependency network (**Window length: 260 approximately one year**; X-axis reports the end of the rolling windows).

Table 3
Summary statistics of the rolling-window dependency network (**Window length: 260**).

Mean	From Full Sample	Pre-COVID	Post-COVID	To Full Sample	Pre-COVID	Post-COVID	Net Full Sample	Pre-COVID	Post-COVID
CAN	2.290	2.193	2.974	1.903	1.766	2.970	−0.387	−0.427	−0.004
FIN	2.347	2.252	2.988	1.556	1.374	3.279	−0.791	−0.878	0.290
FRA	1.983	1.920	2.503	4.426	4.244	5.571	2.444	2.325	3.069
GER	2.162	2.085	2.754	3.795	3.658	4.631	1.633	1.572	1.877
IND	1.470	1.330	2.532	0.588	0.503	1.318	−0.882	−0.827	−1.214
ITA	2.375	2.285	2.950	2.739	2.631	3.854	0.364	0.346	0.904
JAP	1.044	0.936	2.112	0.273	0.247	0.668	−0.771	−0.689	−1.445
KOR	1.518	1.396	2.503	0.830	0.757	1.610	−0.688	−0.639	−0.893
NET	2.191	2.074	3.070	3.652	3.687	2.764	1.461	1.613	−0.306
POR	2.398	2.303	3.045	1.584	1.466	2.336	−0.814	−0.836	−0.709
SPN	2.375	2.302	2.958	2.874	2.708	3.913	0.499	0.406	0.955
SWE	2.371	2.299	2.835	2.445	2.233	4.278	0.074	−0.066	1.443
TAI	1.367	1.256	2.176	0.596	0.561	0.851	−0.771	−0.695	−1.325
THL	1.557	1.403	2.697	0.732	0.582	1.700	−0.825	−0.821	−0.997
UKD	2.295	2.195	2.978	2.996	2.977	3.152	0.701	0.782	0.175
USA	2.251	2.151	2.821	1.006	0.987	1.001	−1.245	−1.164	−1.820
Std. Dev	**From Full Sample**	**Pre-COVID**	**Post-COVID**	**To Full Sample**	**Pre-COVID**	**Post-COVID**	**Net Full Sample**	**Pre-COVID**	**Post-COVID**
CAN	0.657	0.608	0.307	0.709	0.596	0.392	0.263	0.244	0.126
FIN	0.656	0.609	0.318	0.719	0.464	0.312	0.460	0.390	0.099
FRA	0.404	0.365	0.205	1.166	1.059	0.604	0.794	0.730	0.403
GER	0.469	0.419	0.258	1.013	0.947	0.469	0.613	0.601	0.223
IND	0.820	0.715	0.463	0.503	0.439	0.341	0.375	0.344	0.134
ITA	0.547	0.485	0.316	1.015	1.000	0.274	0.666	0.688	0.173
JAP	0.468	0.326	0.251	0.147	0.123	0.068	0.353	0.244	0.261
KOR	0.613	0.497	0.312	0.387	0.325	0.119	0.253	0.201	0.235
NET	0.547	0.419	0.338	0.927	0.966	0.376	0.756	0.627	0.096
POR	0.664	0.616	0.362	0.564	0.435	0.489	0.537	0.559	0.134
SPN	0.594	0.573	0.265	0.810	0.639	0.479	0.620	0.573	0.229
SWE	0.569	0.545	0.287	0.955	0.724	0.357	0.640	0.498	0.122
TAI	0.566	0.459	0.372	0.267	0.253	0.145	0.352	0.266	0.232
THL	0.669	0.486	0.424	0.541	0.284	0.414	0.284	0.295	0.046
UKD	0.549	0.469	0.313	0.962	0.993	0.410	0.669	0.657	0.116
USA	0.732	0.693	0.407	0.328	0.338	0.170	0.480	0.414	0.243

Note: The summary statistics of Pre-COVID and Post-COVID remove the dependency of those rolling windows that span February 4, 2020.

European countries. From 2020 to the end of the studied period, sustainable investment dependence records the unprecedented level, reaching 3. The high interconnectedness in the system is largely attributable to the outbreak of the COVID-19 pandemic. Because COVID 19 pandemic is generally marked as the deadliest pandemics in history, its impact on system dependence is undeniable.

The literature widely supports the higher dependence between markets in time of the financial market turmoil in comparison with the tranquil period (Lundgren et al., 2018; Naeem et al., 2020; Nasreen et al., 2020; Nguyen et al., 2020; Pham, 2021). Studying the connectedness network in green investment, Lundgren et al. (2018), for instance, documents the intensification of connectedness following the

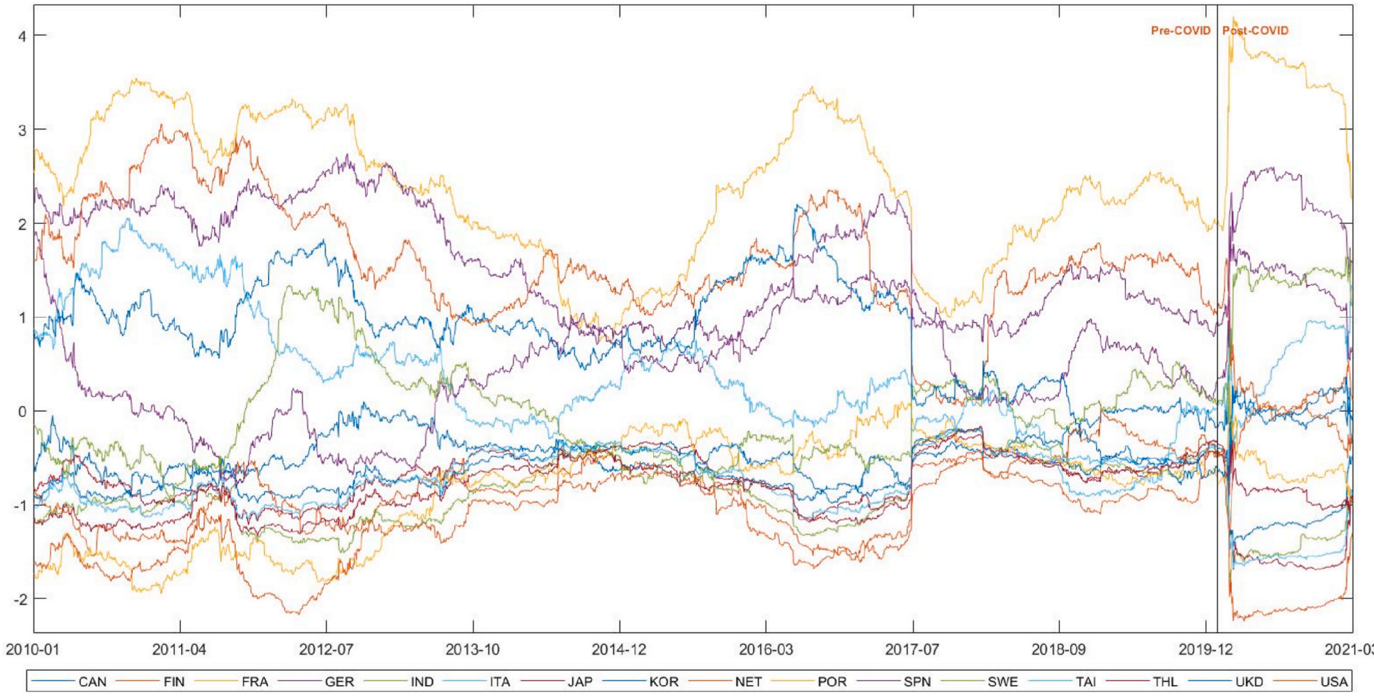

Fig. 14. Time-varying net dependency (**Window length: 260**; X-axis reports the end of the rolling windows).

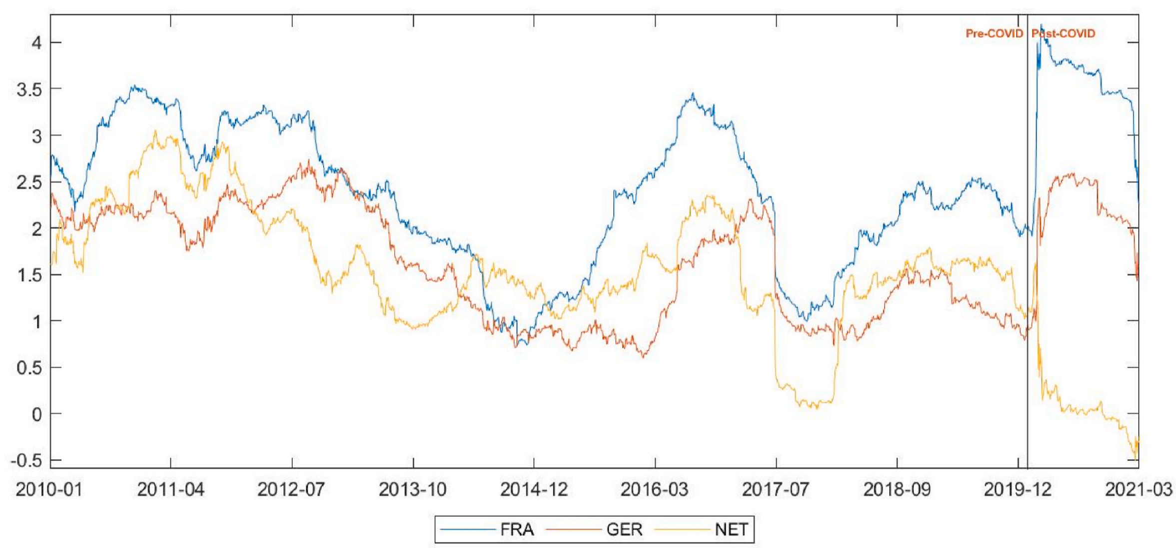

Fig. 15. Time-varying net dependency for top three contributors (**Window length: 260**; X-axis reports the end of the rolling windows).

financial crisis. Likewise, Pham (2021), investigating the connectedness between the green bond and green equity, finds that their connectedness sharply increases during extreme market conditions. The spillovers between the green equity and green bond markets reached the highest level due to the 2020 COVID-19 pandemic. The finding of dependence intensification caused by the ESDC and the subsequent COVID outbreak can be clarified by the risk aversion in the wake of the crisis. As widespread fear and uncertainty in markets contribute significantly to the higher carefulness in examining and processing new information, a higher level of market dependency is generated (Ferrer et al., 2018).

The summary statistics of the rolling window dependency network for each country's sustainable investment can be found in Table 3, containing the average value and the standard deviation of From, To, and Net measures for each country's sustainable investment. The general conclusions in accordance with the static analysis, which emphasizes that France is the top To and Net sustainable investment contributor in the system while the US is the largest net receiver.

Given the time-varying pattern of the overall dependency in the system, it is necessary to see the movement in net dependency of each country (Fig. 14), especially of the top three contributors, namely France, Germany, and Netherland (Fig. 15). France is a leader in the dependency network by having a higher level of net dependence above the other two for most of the time. Noticeably, each country's net dependency movement trend is fairly like that of the total dependency degrees of directed dependency network (Fig. 13).

5.2. Centrality network

This section is based on the MST for the centrality measure to validate the findings of the dependency approach in the previous section.

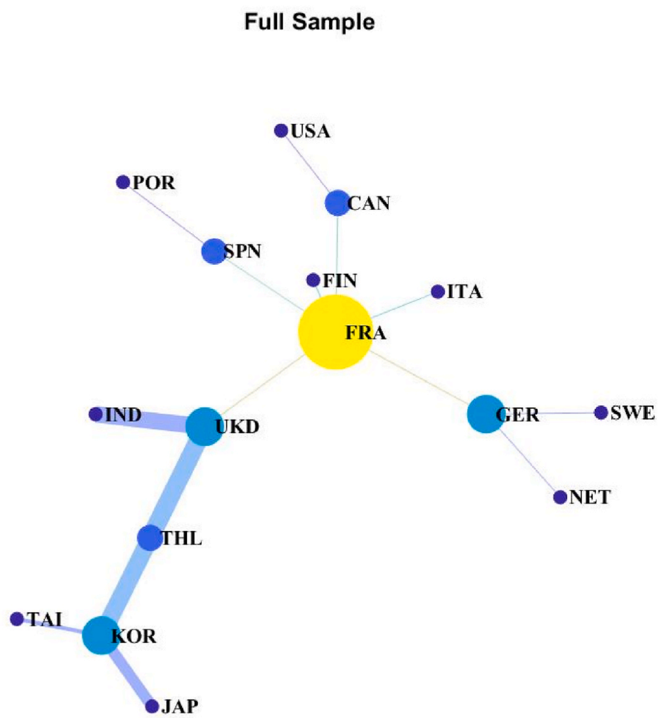

Fig. 16. Static centrality network (full sample).

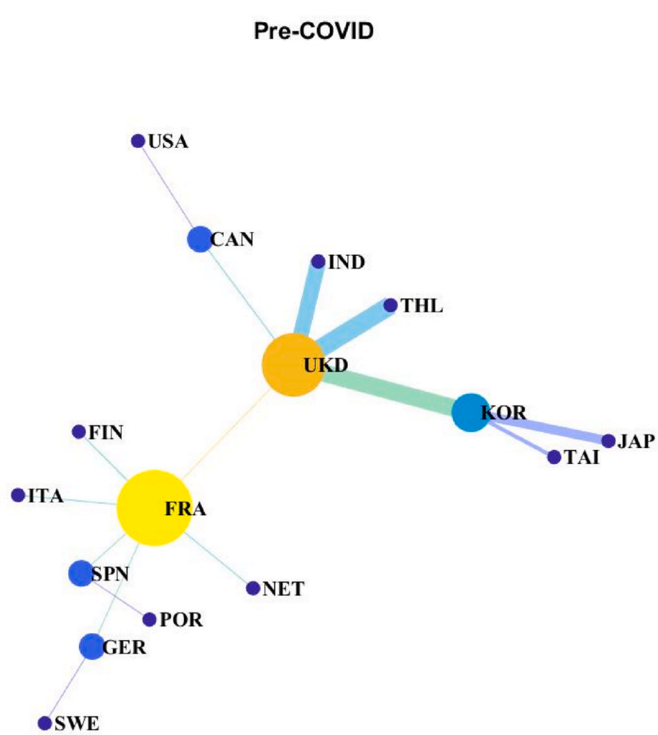

Fig. 17. Static centrality network (Pre-COVID).

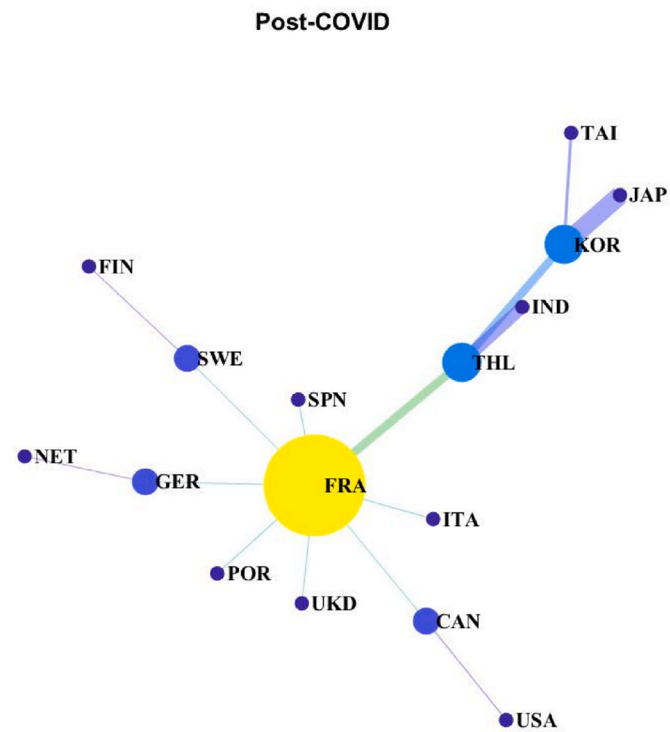

Fig. 18. Static centrality network (Post-COVID).

5.2.1. Static analysis

Fig. 16 illustrates the static centrality network among sustainable investments worldwide based on the unconditional Pearson correlation estimation. The most apparent feature that we can observe is some degree of geographical connections of the sustainable investment network. Particularly, most European and North American countries develop vital linkage to form the biggest cluster. In this cluster, resulting from having the highest number of connections with other countries, France is the top contributor to net dependence. With France playing as a central point, European countries exhibit a stronger sustainable investment synchronization and co-movements. It is also noticeable that the US sustainable investment is linked with the European counterpart via Canada. The same conclusion of interaction between Canada and the US is found in a study by Umar et al. (2020), who note the linkage between two countries owing to their shared borders, the North American Free Trade Agreement, as well as the steady and valuable mutual relationship in trade and tourism. The South Pacific countries connect and form the second biggest cluster in the sustainable investment network. Prominently, the sustainable investment of the UK seems to act as the bridge that connects the European cluster with the South Pacific cluster, generating the global sustainable investment network.

When the sample is divided into pre- and post-COVID (Figs. 17 and 18), the pattern in the pre-COVID period is consistent with the findings from the full sample analysis, emphasizing the dominant role of France and the UK. The post-COVID period also validates the central role of France on the global platform as the sustainable investment information in France propagates sustainable investment in other countries. However, the UK's sustainable investment role is significantly reduced, which can be justified by its lowest returns among studied markets after the COVID pandemic (see Table 1).

5.2.2. Dynamic analysis

Similar to the dynamic dependency network analysis, this part applies a rolling-window estimation to assess the variation of the MST over time. The system integration index is estimated based on the inverse of normalized tree length. By employing both the system integration index and the total dependency degree for the dependency network, we provide a comprehensive understanding of the overall level of connectedness within the system.

As depicted in Fig. 19, the patterns of the system integration index of the centrality network are very similar to those in Fig. 13 using the total dependency degree. The ESDC in 2012, the collapse of the Greek government and the Chinese stock market crash in 2015, and the COVID

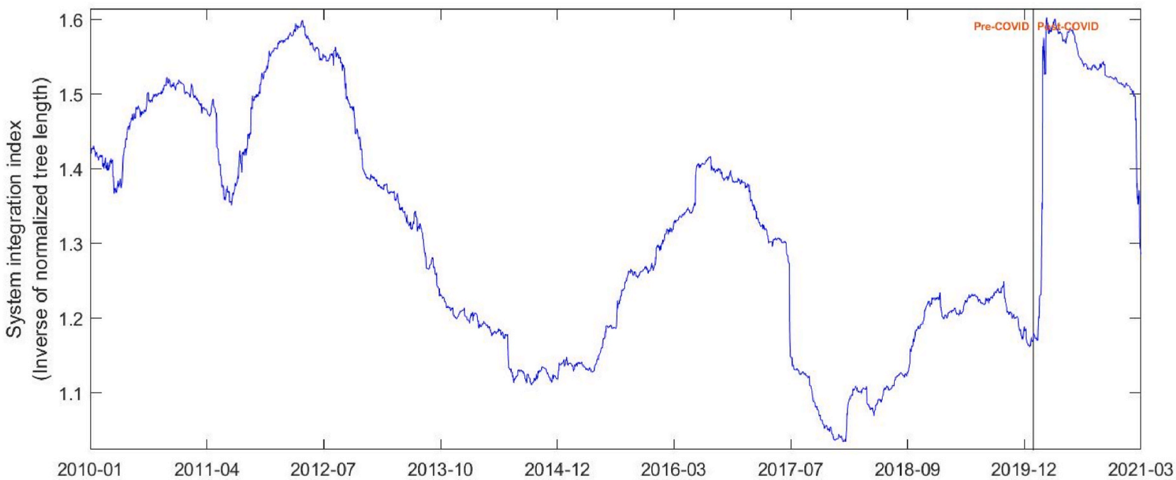

Fig. 19. System integration index of the centrality network over time (**Window length: 260**; X-axis reports the end of the rolling windows).

Fig. 20. Multi-step survival ratios of the time-varying centrality networks (**Window length: 260**; X-axis reports the end of the rolling windows).

outbreak at the end of the sample period are all associated with significantly greater levels of dependence in the sustainable investment network. The integration index began at around 1.4 in 2010 before rising to 1.6 throughout the ESDC period. Following a period of low dependence in 2013 and 2014, the number grew again in 2015 because of the failure of the Greek government and the collapse of the Chinese stock market. When the crisis' impact faded, the level of integration plummeted to its lowest point in 2017–2018. The COVID outbreak in 2020, on the other hand, results in the highest level of dependence across sustainable investment markets, with the system integration index rising dramatically from 1.2 at the end of 2019 to nearly 1.6 at the start of 2020. Afterwards, since the second quarter of 2020, the total level of dependency decreases and reaches its lowest level during the post COVID-19 period (around 1.32). This mostly due to the good news related to the official announcement of the effectiveness of COVID-19 vaccine. Generally, the results are directly in line with previous findings, highlighting the intensification of sustainable investment system integration and dependency due to the global financial crises.

Finally, to validate our results, another technique that we use in the analysis of time-varying centrality network is to compute a multi-step survival ratio of the MST for a measure of network stability. Fig. 20 indicates the survival ratios of time-varying centrality networks calculated under 2-, 6-, 12-, and 24-step. Accordingly, the survival ratio at k = 2 is 0.957 on average, while the figure drops to 0.791 at the 24-step

Table 4
Determinants of interdependence of sustainable investments.

	TCI	SII
C	−1.9757***	0.1168
	(0.4131)	(0.1062)
VIX	0.2188**	0.0648**
	(0.1015)	(0.0268)
OVX	0.1374*	−0.0084
	(0.0768)	(0.0202)
GVZ	0.5773***	0.1635***
	(0.1094)	(0.0295)
EVZ	0.1931**	0.0965***
	(0.0841)	(0.0234)
MOV	−0.2714**	−0.0487
	(0.1292)	(0.0323)
EMV	0.0070	0.0006
	(0.0056)	(0.0013)
USEPU	0.2109***	0.0722***
	(0.0285)	(0.0080)
UKEPU	0.1733***	0.0439***
	(0.0305)	(0.0077)
Adjusted R^2	54.112%	54.548%

Note: This regression is based on HAC (Newey-West) heteroscedasticity-consistent standard errors & covariance. This table presents the results for the impact of global factors, based on using the indexes for the CBOE Stock market volatility (VIX), CBOE Oil market volatility (OVX), CBOE Eurocurrency Volatility Index (EVZ), Treasury market volatility (MOVE), Gold market volatility (GVZ), US Economic Policy Uncertainty (USEPU), UK Economic Policy Uncertainty (UKEPU), and Infectious diseases tracker (EMV), respectively. TCI and SII represent Total Connectedness Index and System Integration Index, respectively. The values in () are standard errors. The asterisks ** and *** stand for significance at 10, 5 and 1% levels of significance, respectively.

interval. The survival ratio decreases with the higher number of steps imply the weakening stability of the network given a relatively long period. In other words, the finding confirms the lower connection in the global sustainable investment network as the horizon increases. These findings corroborate the studies of Zhang et al. (2021), indicating similar results of diminishing network stability due to the increase of step size.

5.3. Determinants of interdependence in sustainable investments

In this section we discuss the effects of the global factor on the sustainable investments. Results reports in Table 4 indicate that all the global factor (most of the global factors) considered in the current study have a significant impact on the total connectedness index (system integration index), except for the EMV index (OVX, MOV, and EMV index). Specifically, we found that the highest effect is shown from gold to the total connectedness index (system integration index). A 1% increase of GVZ leads to an increase of the total connectedness index (system integration index) by 57.73% (16.35%). This evidence indicates that gold market could predict the dependence between sustainability indexes by utilizing the information including in the gold prices.

According to the previous literature, this popular precious metal is considering an extraordinary opportunity for the rational investor to use gold as an effective save haven especially during periods of market tensions or uncertainty (Dutta et al., 2021). In other words, in the context of modern portfolio management, investors and fund managers viewed gold as an effective asset to store value and feel safe when they hold gold (Ji et al., 2020). Besides, recently numerous countries such as Australia used gold in green businesses. Precisely, recently many countries such as Australia and US starting employed Tiny metallic-gold particles to convert sunlight into fuel.

Furthermore, among the considered global factor, we found that the lowest and significant effect is recorded from OVX to the total connectedness index. It is revealed that a 1% increase of OVX index engenders an increase of the total connectedness index by 13.74%. This finding reveals that an increase of energy prices, crude oil influence positively the level of sustainable dependency across the countries considered in the current study. This result is not surprising given that many countries considered in the current study are heavily dependent on imported oil, which make their economy and financial assets (e.g., conventional indices, sustainability indices, cryptocurrency etc) sensitive to any variation in global energy prices (Noor and Dutta, 2017).

Dealing with the system integration index, finding proved that the lowest global factor effect on the system integration index is recorded for UKEPU, a 1% increase of EPU in UK leads to an increase of the system integration index by 4.39%. This evidence proved the ability of UKEPU to predict the dependency across the DJSI indices which is partly in line with the study by Antonakakis et al. (2016). Such finding reveals that during periods of tensions and market stress, international investors seek to invest more in sustainable stocks, which in turn might increase the level dependency in sustainable investments across countries.

6. Conclusion

The increased interest in sustainable investment due to social responsivity commitment and its potential financial benefits has stimulated the need to understand this environmentally friendly instrument. This paper, utilizing the Dow Jones Sustainability Indexes for 16 countries and the network-based approach, offers additional insights into the global networks for sustainable investment. The studied period, running from January 1, 2009 to March 30, 2021, includes major economic events, such as ESDC, the Greek systemic problem, the Chinese stock market crash, and the COVID-19 outbreak.

The results of the study have implications for market participants, including portfolio investors and policymakers. The significant degree of dependence across sustainable investment markets recommends that portfolio managers interested in sustainable investment use alternative hedging strategies to defend against risks transmitted between sustainable investments. Especially, the diversification benefit of allocating sustainable investment across countries with close geographical proximity (for example, European cluster and South Pacific cluster) is found to be limited. The rolling window-based findings further demonstrate an increase in dependency during crises and recession but a decrease in calm periods. In other words, the extreme economic movements increase sustainable investment dependency across countries, reducing the diversification effect of combining sustainable investments. Nevertheless, the integration between sustainable investments diminishes quickly over the long-term investment horizons, signalling that maintaining sustainable investments for longer periods has a higher diversification benefit. On the other hand, results show that the uncertainty in gold market (GVZ) exert the highest effect on the interdependence in sustainable investments, indicating that international investors and portfolio managers should consider this relationship when including both sustainable and gold stocks in their portfolios.

Regulators may find the study's findings valuable in assessing the nature and timing of policy responses to reduce the risk of contagion and enhance financial stability. Reduced financial impacts, which lowers market dependence during major economic crises, can encourage investors to invest in these assets. In addition, given the central position of France in the global network of sustainable investment, keeping a careful eye on the country's sustainable investments is recommended throughout both calm and stormy times.

Given the lowest level of integration of Japan and Taiwan's sustainable investment with the global network, these sustainable investment markets can be viewed as a safe haven for risks transmitted between networks. Future studies, therefore, may delve more into the sustainable investment network dependence's determinants, addressing why Japan and Taiwan do not catch a cold while other countries sneeze.

Data availability

Data will be made available on request.

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