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Exploring the dynamic links, implications for hedging and investment strategies between Sukuk and commodity market volatility: Evidence from country level analysis

Mabruk Billah [a], Sinda Hadhri [b], Faruk Balli [c,d,*], Mohammad Sahabuddin [e]

[a] Department of Accounting and Finance, College of Business Administration, Prince Mohammad Bin Fahd University, Al Khobar, Saudi Arabia
[b] Institute of Sustainable Business and Organizations, Sciences and Humanities Confluence Research Center- UCLy, ESDES, Lyon, France
[c] School of Economics and Finance, Massey University, Auckland, New Zealand
[d] Al-Farabi Kazakh National University, Almaty, Kazakhstan
[e] Department of Business Studies, State University of Bangladesh, Bangladesh

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A B S T R A C T

This research paper examines the influence of spillovers between volatility of commodities (including soft commodities, precious metals, industrial metals, along with energy) and returns of sukuk. Using a notable sample of fifteen sukuk country indices and sixteen products, we examine the time-varying criterion vector autoregression (TVP-VAR) based extended joint connectedness method and contribute to the correlation analysis literature by supplying a comprehensive as well as policy-oriented analysis of the connection between sukuks and also commodities. Our results disclose that the system-wide dynamic connectedness is slowly heterogeneous and driven by financial occasions. Next, we look at the potential determinants of connectivity between sukuk and commodity markets, we find that global risk factors significantly impact the degree of spillovers between markets. In particular, the negative impacts of risk factors on spillovers suggest that some risk-mitigating properties may be related to market leverage in the composite portfolio in bear market conditions. In addition, our results, using hedging efficiency and the Sharpe ratio, confirm the hypothesis of diversification opportunities between markets that leverage dynamic connectivity networks.

1. Introduction

Market fluctuation has become a central theme for realizing the portfolio gain and minimizing the risk. It plays vital roles to understand the volatility connectedness and spillover effects in different financial markets and asset classes (El-Sayed et al., 2024). The presence of the market volatility will not encourage growing assets in the portfolio lines. Moreover, the strong correlation between asset classes always diminishes the diversification benefits and implies risk transmission mechanism (Tiwari et al., 2022). Particularly, commodity markets have raised questions regarding their portfolio optimization benefits during the crises, pandemic, and vulnerable periods. For that reason, economical supervisors, investors, and policymakers might have a spotless understanding of the deep connectedness between commodities and other market volatility (Wen et al., 2021). They could evaluate the optimum weight and also

* Corresponding author: Al-Farabi Kazakh National University, Almaty, Kazakhstan.
E-mail addresses: sbillah@pmu.edu.sa (M. Billah), shadhri@univ-catholyon.fr (S. Hadhri), F.balli@massey.ac.nz (F. Balli), sahabuddingme@gmail.com (M. Sahabuddin).

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hedge ratio to lower the risk exposure of unpredictable markets or rate volatility without compromising expected returns.

However, the recent Ukraine-Russia crisis and the COVID-19 pandemic have shed light on the safe haven and resilience asset categories in considering the systemic risks (Mahran, 2022). This trend has made up the importance of evaluation for the financial assets and commodity market that grow the dynamic network connectedness among them in the crises (Trabelsi, 2019). Moreover, financial integration has become an essential ingredient across countries and different assets class for seeking portfolio diversification and hedging optimization. Interestingly, financialization of the different commodity and equity markets encourages investors to evaluate their safe haven features properties during the crises period (Hood et al., 2013; Billah et al., 2022; Silvennoinen et al., 2013). Relatedly, an increasing trend of volatility and/or correlation would discourage investors to select commodities as a refuge asset and a diversification tool during the turmoil.

Regarding Islamic finance, many investors and firms have become more confident to turn and invest their fund into the Islamic segments of products and services. Islamic finance based products and services comply the Shariah rules, and it can play a vital role to satisfy the ethical and religious criteria. It encourages finding innovative logistics and support partnership and risk-sharing products and services. Particularly, sukuk, commonly known as Islamic bonds, have become more popular and widely used financiers. Moreover, it is a Riba (interest) free financial equity, which substantially differ from the conventional bonds. Therefore, Muslim stakeholders might comfort to invest their massive fund in these alternative bonds that comply with their morals and plays a vital role in maintain the financial stability (Sial et al., 2022). As these innovative assets have experienced a huge growth (Naifar & Hammoudeh, 2016), the study of their risk hedging properties and diversifications potential has emerged in the recent year (Mensi et al., 2020; Samitas et al., 2021). In this vein, as commodity markets have also experienced a dramatic movement and shown a strong co-movement pattern in recent year (Hoque et al., 2023), we attempt to study the dynamic linkages between commodity and equity markets for providing portfolio hedging and investment strategies insights.

Previous numerous studies have focused on volatility and spillover linkages in financial markets (Charfeddine & Al Refai, 2019; Corbet et al., 2021, Uludag & Khurshid, 2019; Yoon et al., 2021). These studies have received attention by many researchers that examined the volatility and return connectedness among both similar and different asset classes or such as equity, bond, commodity, and foreign exchange markets (Charfeddine & Al Refai, 2019; Corbet et al., 2021; Yoon et al., 2021; Billah et al. 2023). However, exploring the dynamic connectedness, implications for hedging and investment strategies between sukuk and commodity markets volatility have received little attention yet (Samitas et al., 2021).

The purpose of this study to explore the return connectedness among fifteen commodities and sukuk markets in the GCC, Asian, Africa and European countries. Particularly, we investigate the return and volatility linkages along with hedging implications and portfolio strategies between sukuk and commodity markets in dynamic environment. This portfolio strategy supports the multi-asset approach including resilience and refuge assets that provides better exposure to minimize the risk and maximize growth of the total portfolio. A wide-range of diversifiable assets will help investors in making decisions promptly and adopt policy to face crises and uncertainties (Deligonul, 2020). Moreover, financial investors are facing challenges in making optimum benefits from their investment due to rapid changing the global financial environment (Pirgaip et al., 2021). Therefore, they searched for resiliency assets for minimize the loss during the turbulent period. Resilience assets are often described the ability for the particular assets that can absorb and adopt in a dynamic changing environment to survive, add value, and proper (Fox O'Mahony et al., 2023; Swaminathan et al., 2022). In contrast, amid the financial and geopolitical crises, investors want to invest their funds in safer projects or assets, not to leave all money in a bank or stock portfolio. A Refuge asset contains a real intrinsic value that can retain purchasing power for the future, for example gold (Mensi et al., 2021).

However, sukuk is an instrument of Islamic social finance that comply the Shariah principles (Billah et al., 2023). It not only ensures the safe-haven properties but also provide ethical, socially responsible investment opportunities. Moreover, it contributes to the environmental wellbeing, infrastructure development and socio economic development. The current study investigates the hedging implications and investment strategies between sukuk and commodity markets. These instrument of investments has drawn attention in both individual and international investors in recent decade (Billah et al., 2023). Unlike, the development of green bond market, sukuk market has transmitted into a new height from the niche market segment to a noteworthy market in recent year. Annual market development rate is tremendous, it reached 164% from 2014 to 2020 (Billah et al., 2024). Total volume of global sukuk market is estimated 2.276 trillion by 2028, with maintaining compound annual growth rate (CAGR) 16.2% (Global Sukuk Market Dashboard: 3Q23, 2023).

The contributions of this present study are the following: First, we explore total net connectedness and pairwise directional connectedness in return, so we understand the movement of each commodity, energy and sukuk markets as a net receiver or transmitter of shocks. Second, we perform the same analysis of net directional and dynamic connectedness in volatility linkages between used markets. Third, we study the net pairwise spillovers in subsamples such as during and pre COVID-19 pandemic period. Fourth, we investigate how do the spillover response to the global markets? Finally, we explore portfolio implication in dynamic environment of our connectedness analysis.

From the empirical viewpoint, we use the dynamic connectedness approach that has widely used in methodology introduced by Diebold and Yilmaz (2009; 2012; 2014). This approach contains time frequency based dynamic characteristics and develops a network connectedness among variables. Moreover, in absence of the economic theory, this approach might explain network connectedness, and/or particular variables ordering and suitably fit how does the transmission mechanism works inside a pre-determined network (Wiesen et al., 2018). However, this approach has received considerable attention to the policymakers to regulate economic and political measures for minimizing the negative impact of shocks in a certain or particular group of variables (Chatziantoniou & Gabauer, 2021). Traditional connectedness techniques have addressed significant flaws in recent time. These are (1) it is based on rolling window VAR model, required to select appropriate size of rolling window. There is no appropriate or pre-determined size for the rolling window model, and (2) generalized FEVD, which is inefficient for normalization (Caloia et al., 2019). However, TVP-VAR[1] model is based on network connectedness time frequency domain properties. It is suitable to overcome the limitation of proper size (Antonakakis et al., 2020). Moreover, this approach carries on some benefits, like (1) it monitors the variation of the parameters more precisely, (2) it avoids the losing of observations, (3) it has less impacts by outliers, and (4) it has no arbitrary window size for selection. According to Lastrapes and Wiesen (2021), the second limitation relapses as they recommended a connectivity technique that stabilizes the model based on the fitting matrix (R2). Later on, Balcilar et al. (2021) took on the concept of Antonakakis et al. (2020) as well as Lastrapes and Wiesen (2021) and also suggested an innovative version of the primary connection technique. Balcilar and others. (2021) allows the measurement of two-way network connectivity to be considered in general connectivity scenarios, which has not been done before. In addition, the traditional connectivity method by Diebold and Yilmaz (2009, 2012, 2014)'s advantages have been used in the TVP-VAR-based augmented co-connectivity method.

Our findings could be potted as follows. First, volatility pairwise connections are more pronounced than return connections in the full sample. However, some diversification opportunities between used markets could also be highlighted as suggested by weak or inexistent spillover linkages between the majorities of indices. Second, the time-varying analysis shows that used sukuks and commodities are highly responsive to external shocks induced by economic downturns. Third, the sub-sample analysis indicates that connections in return (volatility) are more significant during the COVID-19 rather than pre-pandemic period. Fourth, we observe a significant explanatory power of global risk variables on the magnitude of spillover across used markets. Finally, using the hedge effectiveness and Sharpe ratios of dynamic connectedness network-based portfolios, we demonstrate some risk reduction and profitability potential of used commodities and sukuks.

We could structure for the rest part of this paper as follows. Section 2 of this paper presents the related literature, section 3 exhibits the data and methodology, section 4 presents the results and discussion part, and section 5 highlights the conclusion, limitation, and recommendation for future direction of research.

2. Literature review

The growth of Islamic finance has substantially increased in recent decades. Interestingly, the assets or market capitalization of the Islamic finance industry has increased from 2.75 trillion to 3.06 US dollars amidst the COVID-19 pandemic in 2021 (IFSB, 2022). Particularly, Islamic banking and Sukuk markets have contained the major segments of the Islamic finance industry. These two segments sustained up to 90% of the market shares or capitalization of the Islamic finance industry (Ledhem, 2022). The global new Sukuk issuances have gradually increased and reached 195.5 billion US dollars in 2021, having recorded 181.6 billion US dollars in 2020 ((Global Sukuk Issuance Is Set To Increase In 2021, 2021).

Financial markets encompass with bond, equity, debt, mortgage and derivative markets. However, the importance of equity and bond markets is significant among these markets. Hence, the dynamic links between equity and bond markets in terms of volatility transmission and portfolio implications with other markets or asset classes have been conceded as the most important topic for researchers and financial market participants. For instance, Al Maghyereh et al. (2019) explores the hedging and portfolio implications among sukuks, gold and Islamic stocks in a dynamic environment using the wavelet-based GARCH-DCC method. The findings indicate that gold plays a stable role in terms of hedging and diversification benefits indifferent investment horizons that could ensure better portfolio gains, especially, during the short-term holding period. Meanwhile, Ahmed and Elsayed (2019) test the dynamic interdependencies between equities and Sukuk markets in Malaysia and find that both equity markets such as Islamic and conventional stock markets are highly integrated. Their findings also indicate that the Sukuk market plays a robust role as a main receiver of spillover effects, while conventional stock and bond markets play the role of a net transmitter of spillover effects.

Moreover, Danila et al. (2021) have examined the co-integration relationship between conventional bonds and Sukuk in GCC and ASEAN countries using the GARCH-DCC model. Similarly, Samitas et al. (2021) have investigated the network connectedness between the traditional bond and Sukuk markets using the TVP-VAR model in developed and emerging countries. They find that the Malaysian bond and Sukuk markets are strongly correlated and Dow Jones Sukuk indices play a key role as transmitters of shocks to other markets. Mensi et al. (2022) employ a multi-scales-based frequency spillover and investigate portfolio implications between Sukuk and equity markets using wavelet analysis. They find dynamic time-frequency varying linkages that suggest that sukuks offer relatively better diversification opportunities for BRICS countries than stock markets.

Considering the interdependence with commodity markets, a number of well-documented studies have investigated the transitive relationship between commodities and equity markets (Chen et al., 2022; Kannadhasan et al., 2020; Ready, 2018), bond markets (KangMcIverYoon, 2016; Tule et al., 2017), and banking institutions (Saif-Alyousfi et al., 2020; Tabash et al., 2022). The empirical findings suggest that a unit or single segment market (e.g. equity, bond, financial and non-financial entities) may not exhibit reliable results when examining the relationship in different dimensions (Chen et al., 2014). Therefore, the dynamic linkages along with hedging and portfolio implication between Sukuk and commodity markets volatility should be further explored.

Particularly, during turbulent economic and financial periods such as the ongoing Ukraine- Russia crisis and the COVID-19 pandemic, moreover, adverse external shocks can largely influence economic growth, financial stability, social safety and portfolio management strategies (Albulescu, 2021; Bitler et al., 2020; Balli et al., 2020; Balli et al., 2021). In this same line, commodity price fluctuations in different sectors can show a significant co-movement pattern, which is very important for portfolio implications (Hoque

[1] The details formula for the TVP-VAR variation with heteroscedastic variation and also covariances is outside the variety of this study; however, interested site visitors should describe Antonakakis et al. (2020).

et al., 2023). Prior studies typically examine the linkages in return and volatility in an aggregate, single-unit setting or for similar types of asset classes (Billah et al., 2023), few studies have been given focused on dynamic linkages between used commodities (Khalfaoui et al., 2021; Mo et al., 2022). In addition, it has been given less attention on Sukuk in empirical research. However, our study attempts to provide practical insights for both investors and regulators by examining the dynamic linkages between Islamic sukuks and commodity markets.

2.1. Data and preliminary analysis

Acquired from Bloomberg, the dataset made use of in this research makes up daily returns from 15 nations of Sukuk indices of 6 GCC nations, viz., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, as well as the United Arab Emirates; one West Asian nation (Turkey), four Southeast Eastern areas (Hong Kong, Singapore, Malaysia, Indonesia), one South Eastern state (Pakistan), an African country (Nigeria) and also lastly two European nations (the U.K. as well as Ireland), through January 1, 2016 to September 15, 2022. The research period was picked because it makes it hassle-free to evaluate just how the Sukuk can be incorporated with the Asset markets. Using a massive example of different countries allows us to examine spillover impacts inside and throughout regions.

The liquid Sukuk with normal daily data are made use of as they are completely tradable and also can additionally be traded retrospectively on the additional market. The accessibility of Sukuk information is a vital factor to consider causing nation selection. Consequently, the researchers created a sovereign Sukuk index for the tool, embracing the Bloomberg method[2] from Billah et al. (2022) and Balli et al. (2022) and also criteria for lessening selection predisposition. The requirements needed for the Bloomberg index figured out the option of Sukuk instruments: initially, a minimal maturation of one year; secondly, the outstanding balance is greater than $200 million; and also 3rd, at least a score from S&P, RAM, MARC, or Moody's. To restrict currency results, the choice was made to focus specifically on US dollar denominated Sukuk, which consists of the majority of this market. The countries that have taken in this paper, 178 Sukuk were evaluated, and the variety of Sukuk in each nation that contributed to the make-up of the Sukuk is given in Table 1.[3]

In addition, our research study uses daily spot price log results for 16 commodities from the Dow Jones Commodity Index from January 1, 2016 to September 15, 2022 to estimate the dynamic relationship between Sukuk and commodity markets. Spot yields are the main reason for short-term fluctuations in commodity yields while rolling yields (average annual returns) are the main contributor to long-term excess commodity yields (Nagayev et al., 2016). The S&P GSCI is the first significant commodity index to invest in and is one of the most comprehensive and weighted known benchmarks for production. The index includes a commodity index for precious metals (gold and silver), an energy commodity index (crude oil and natural gas), Soft Agricultural Commodity Index (cocoa, coffee, cotton, sugar, grains, livestock, corn, soybeans and wheat) and Industrial Metal Commodity Index (aluminum, copper and zinc). The selection of commodities made use of in this study supplies possible understandings into sector direct exposure in determining the risk and return of the Sukuk index.

In this research, the detailed data for all the Sukuk, energy market, and commodity indices have been shown in Table 2. The typical sukuk return varies from −0.170 for Singapore to 0.039 for Malaysia. The mean return for the power markets ranges from 0.025 for Gold to 0.073 for Gas during the example period. For agriculture commodities, imply return arrays from −0.014 for Cocoa to 0.037 for Corn. The standard deviation, minimum as well as maximum worth's reveal a moderate irregularity of all markets, with heavy-fatter-tailed distributions as shown by the skewness as well as kurtosis worths for Sukuk markets. The results of the Augmented Dickey-Fuller (ADF) and Jarquet-Bera (JB) tests rejected the null hypothesis of the non-stationarity of all series at the 1% level, indicating that all variables considered at the 1% level were stationary.

2.2. Return estimation

To calculate the return and of sukuk and commodities, we took the first difference of the logarithm of the daily 100 indexes. Therefore, the formula would be written to get the return of the sukuk and commodities as below:

$$R_t = log\left(P_t/P_{t-1}\right) \times 100 = (log\ P_t - log\ P_{t-1}) \times 100 \tag{1}$$

here the returns show by R_t, and at time t and $t-1$, the index levels signify by P.

2.3. Volatility estimation

By utilizing a vector of return series $r_t = [r_{1,t}, \ldots.., r_{n,t}]$, the following mean formula is approximated:

$$r_t = \mu_t + \gamma r_{t-1} + \varepsilon_t. \tag{2}$$

[2] In below link, we may find the document regarding the Bloomberg methodology: http://www.bloombergindices.com/content/uploads/sites/2/2016/01/633470877 INDX GFI WP 151022.pdf.

[3] The price of the sukuk, we utilize the Bloomberg common rate (BGN), a market agreement rate for corporate as well as federal government bonds calculated using prices from a number of resources in order to obtain highly exact quotes.

Table 1
Composition of the sukuk index.

	Country	Sukuk
	Bahrain	4
	Kuwait	7
GCC Countries	Oman	5
	Qatar	7
	Saudi Arabia	8
	United Arab Emirates (UAE)	16
Asian Countries	Hong Kong	5
	Indonesia	35
	Malaysia	55
	Pakistan	5
	Singapore	5
African countries	Nigeria	5
European Countries	Ireland	4
	Turkey	12
	United Kingdom (UK)	5

Note: We used the daily return of Sukuk data available on the Bloomberg database, for the period from January 01, 2016 to September 15, 2022. To construct country sukuk indices we use the same methodology of Bloomberg Index which has been implemented by Billah et al. (2022) and Balli et al. (2022).

In Eq. (2) the constant term vector is denoted by μ, while $\varepsilon_t = [\varepsilon_{1,t}, \ldots.., \varepsilon_{n,t}]$ denotes the error term vector. Then the conditional volatility estimates $h^2_{i,t}$ from Bollerslev's (1986) one-dimensional GARCH (1,1) process is as follows:

$$h^2_{i,t} = \omega + \alpha\varepsilon^2_{i,t-1} + \beta h^2_{i,t-1}. \tag{3}$$

where $h^2_{i,t}$ is the quote of the difference for day t, $\varepsilon^2_{i,t-1}$ *and* $h^2_{i,t-1}$ are respectively the return and also the difference of the previous day. γ is the weight provided to the long-run difference v_l.

After setting $\gamma v_l = \omega$, the specifications ω, α *and* β can be approximated making use of the optimum chance technique presented in formula (4) in the below area. γ can after that be computed as:

$$\gamma = 1 - \alpha - \beta. \tag{4}$$

The v_l is the long-run variance and it will equal to:

$$v_l = \omega/\gamma \tag{5}$$

To ensure a stable GARCH process and also make certain that the weight provided to the long-term variance v_l stays positive, it is called for that $\alpha + \beta < 1$.

3. Methodology

3.1. TVP-VAR connectedness approach

This part explains the TVP-VAR connection technique and Diebold and Yilmaz's (2012) initial method. Utilizing the Bayesian information standard (BIC), we approximate a TVP-VAR design with a lag period of order one:

$$Y_t = \beta_t Y_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \sum\nolimits_t\right) \tag{6}$$

$$vec(\beta_t) = vec(\beta_{t-1}) + \nu_t \quad \nu_t \sim N(0, R_t) \tag{7}$$

where Y_t as well as Y_{t-1} are vectors of $N \times 1$ dimension endogenous variables; ε_t is a dimensional decay term $N \times 1$ with a time varying variance-covariance matrix $N \times N$, $\sum_t$; β_t is the $N \times N$ matrix of VAR coefficients; ν_t is an $N^2 \times 1$ intercept vector with $N^2 \times N^2$ dimensions of the time varying variance-covariance matrix, R_t; $vec(\beta_t)$ is a vectorization of β_t.

Then the TVP-VIMA model is written as follows: $y_t = \sum_{h=0} N_{h,t}\varepsilon_{t-1}$ where $N_0 = I_Z$ and ε_t denotes symmetric white noise, where $Z \times Z$ varies Matrix time covariance $E(\varepsilon_t\varepsilon_t^{'}) = \sum_t$ varies with time. Therefore, the L-step prediction error is as follows:

Table 2
Descriptive statistics and unit-root test.

	ABR	Mean	Max	Min	SD	Skew	Kurt	JB	ADF
Energy, Precious & Industrial metals									
GOLD	GOLD	0.025	0.056	−0.051	0.009	−0.148	5.226	11679.15***	−15.159***
SILVER	SILV	0.018	0.089	−0.123	0.018	−0.650	7.361	44808.10***	−19.932***
CRUDE OIL	COIL	0.049	0.438	−0.569	0.034	−2.103	71.193	72754.07***	−18.730***
NATURAL GAS	NGAS	0.073	0.166	−0.192	0.032	−0.254	4.008	1787605.00***	−19.783***
ALUMINIUM	ALUM	0.026	0.054	−0.077	0.012	−0.251	2.975	4325.94***	−15.345***
COPPER	COPP	0.029	0.046	−0.081	0.013	−0.268	1.949	4392.08***	−16.870***
ZINC	ZINC	0.041	0.074	−0.072	0.015	−0.091	1.489	570085.30***	−15.364***
Soft Agriculture Commodities									
COCOA	COCO	−0.014	0.064	−0.065	0.017	−0.028	0.469	190889.20***	−15.841***
COFFEE	COFF	0.032	0.096	−0.090	0.019	0.175	1.573	1249.35***	−19.785***
COTTON	COTT	0.029	0.058	−0.058	0.015	−0.120	1.523	36223.68***	−18.592***
SUGAR	SUG	0.012	0.086	−0.058	0.017	0.122	1.005	72754.07***	−17.873***
GRAINS	GRAIN	0.035	0.062	−0.063	0.013	−0.080	2.340	14762.65***	−18.675***
LIVESTOCK	LIVE	0.010	0.053	−0.062	0.011	−0.339	2.593	13457.86***	−17.78***
CORN	CORN	0.037	0.069	−0.070	0.015	−0.249	2.774	1438.44***	−16.439***
SOYBEANS	SOYB	0.030	0.064	−0.070	0.012	−0.255	3.295	1919.39***	−15.657***
WHEAT	WHEA	0.036	0.078	−0.085	0.018	0.150	1.706	6843.45***	−15.847***
Sukuk Markets									
BAHRAIN	BAH	0.031	0.241	−0.158	0.010	9.101	272.073	6.43E+06***	−15.36***
HONG KONG	HK	−0.001	0.077	−0.041	0.004	6.328	144.454	1.95E+06***	−22.28***
INDONESIA	IND	−0.012	0.071	−0.160	0.007	−11.927	273.723	5.93E+06***	−8.49***
IRELAND	IRL	0.000	0.035	−0.160	0.004	−32.557	1246.168	1.52E+08***	−23.23***
KUWAIT	KWT	−0.002	0.377	−0.416	0.014	−3.896	782.595	4.26E+07***	−10.51***
MALAYSIA	MAL	0.039	1.134	−0.571	0.037	16.163	569.212	2.26E+07***	−13.90***
NIGERA	NGR	0.006	2.986	−2.985	0.101	0.015	858.787	5.12E+07***	−15.94***
OMAN	OMN	0.032	0.511	−0.424	0.024	3.971	302.441	6.36E+06***	−17.85***
PAKISTAN	PAK	−0.005	0.040	−0.063	0.004	−3.399	59.408	2.64E+05***	−12.32***
QATAR	QAT	−0.005	0.051	−0.052	0.003	−2.354	209.006	3.40E+06***	−19.72***
SAUDI ARABIA	SAR	−0.004	2.297	−2.301	0.078	−0.083	869.472	2.09E+08***	−17.76***
SINGAPORE	SIN	−0.170	1.099	−2.303	0.085	−11.720	364.507	9.76E+06***	−13.06***
TURKEY	TUR	−0.004	0.088	−0.268	0.009	−13.805	423.746	1.29E+07***	−19.69***
UAE	UAE	0.002	0.022	−0.053	0.002	−8.223	232.989	3.97E+06***	−18.11***
UK	UK	0.005	0.189	−0.137	0.008	5.195	365.217	1.06E+07***	−19.19***

Note: This table gives the definitive stats for the sixteen commodities and fifteen Sukuk markets under research study. ABR, Max, Min, SD, Skew, Kurt, JB, and ADF represents Abbreviation, Maximum, Minimum, Standard Deviation, Skewness, Kurtosis, Jarque-Bera, and Augmented Dicky-Fuller test, respectively. *** Indicates significance at 1%.

$$\varphi_t(L) = y_{t+L} - E(y_{t+L}|y_t, y_{t-1}, \ldots) = \sum_{l=0}^{L-1} N_{l,t}\varepsilon_{t+L-l} \tag{8}$$

A matrix of forecast error covariance be able to be recorded as below:

$$E\left(\varphi_t(L)\varphi_t^{'}(L) = N_{l,t}\Sigma_t N_{h,t}^{'}\right), \tag{9}$$

The suggested structure counts on Pesaran and Shin's (1998) L-step in advance generalized forecast error variance decomposition (GFEVD). The GFEVD, $gST_{ij,t}$, stands for an effect of a shock originating from variable j on variable i and also can be written as follows:

$$\varphi_{ij,t}^{gen}(L) = \frac{E\left(\varphi_{i,t}^2(L)\right) - E\left[\varphi_{i,t}(L) - E\left(\varphi_{i,t}(L)\right)\left|\varepsilon_{j,t+1,\ldots,}\varepsilon_{j,t+1}\right.\right]^2}{E(\varphi_{it}^2(L))} \tag{10}$$

$$= \frac{\sum_{l=0}^{L-1}\left(e_i^{'}N_{lt}\Sigma_t e_j\right)^2}{\left(e^{'}\Sigma_t e_j\right)\cdot\sum_{l=0}^{L-1}\left(e_i^{'}N_{lt}\sum_t N_{lt}^{'}e_i\right)} \tag{11}$$

$$gST_{ij,t} = \frac{\varphi_{ij,t}^{gen}(L)}{\sum_{j=1}^{L}\varphi_{ij,t}^{gen}(L)} \tag{12}$$

where e_i represents the $Z \times 1$ unselected vector that has one in the $i - th$ position, and $\varphi_{ij,t}^{gen}(L),(L)$, which is a symmetric reduction in Variance from denotes the forecast error of variable i due to the shock state of variable j in the future.

$\sum_{j=1}^{Z} \varphi_{ij,t}^{gen}(L) \neq 1$ normalizes to one, which gives the value $gST_{ij,t}$. We collect these metrics as follows:

$$X_{i\leftarrow\bullet,t}^{gen,from} = \sum_{j=1,i\neq j}^{Z} gST_{ij,t,} \tag{13}$$

$$X_{i\rightarrow\bullet,t}^{gen,to} = \sum_{j=1,i\neq j}^{Z} gST_{ij,t}. \tag{14}$$

We then present the total net directional connectivity: $X_{i,t}^{gen,net} = X_{i\rightarrow\bullet,t}^{gen,to} - X_{i\leftarrow\bullet,t}^{gen.\ from}$. If $X_{i,t}^{gen,net} < 0(X_{i,t}^{gen,net} > 0)$, variable i implies a net receiving (sending) shock. In other words, variable i is controlled by other variables in the network.

In addition, we present the Total Connectivity Index (TCI), which clarifies the network within the network. TCI can be defined as:

$$gST_t = \frac{1}{z}\sum_{i=1}^{Z} X_{i\leftarrow\bullet,t}^{gen,from} = \frac{1}{z}\sum_{i=1}^{Z} X_{i\rightarrow\bullet,t}^{gen,to} \tag{15}$$

where higher level network overflow has greater value.

Finally, the spillovers of the net pairwise directions can be represented as:

$X_{i,t}^{gen,net} = gST_{ij,t}^{gen,to} - gST_{ij,t}^{gen,from}$. If $X_{ij,t}^{gen,net} > 0$, which implies that row i has a stronger influence over row j.

3.2. Extended joint connectedness approach

The $gST_{ij,t}$ and $jST_{ij,t}$ are assumed:

$$X_{i\leftarrow\bullet,t}^{jnt,from} = \sum_{j=1,i\neq j}^{Z} jST_{ij,t,} \tag{16}$$

$$X_{\bullet\leftarrow i,t}^{jnt,to} = \sum_{j=1,i\neq j}^{Z} jSTji,t, \tag{17}$$

$$jSI_i = \frac{1}{z}\sum_{i=1}^{Z} X_{i\leftarrow\bullet,t}^{jnt,from} = \frac{1}{z}\sum_{i=1}^{Z} X_{i\rightarrow\bullet}^{jnt,to}. \tag{18}$$

To generalize a scaling approach, we used Lastrapes and Wiesen (2021) approach where the scaling factor $\boldsymbol{\eta}$ differs for each order as follows:

$$\eta_i = \frac{X_{i\leftarrow\bullet,t}^{jnt,from}}{X_{i\leftarrow\bullet,t}^{gen,from}} \tag{19}$$

$$\eta = \frac{1}{z}\sum_{i=1}^{Z} \eta_i \tag{20}$$

Our scaling and the one derived from the joint connectivity method are the same; the method that we have chosen which offers greater suppleness since each row has its very own scaling element. Ultimately, the complying with activities need to be coded:

Lastly, we can obtain.

(1) $jST_{ij,t} - \eta_i gST_{ij,t,}$.
(2) $jST_{ii,t} = 1 - X_Z^{j\ jnt,from}$,.
(3) $X_{i\rightarrow\bullet,t}^{jnt,to} = \sum_{j=1,j\neq i}^{Z} jST_{ij,t}$..

At last, permitting the scaling parameter to differ by row enables to calculate the net total and pairwise directional connectedness steps as follows:

$$X_{i,t}^{jnt,net} = X_{i\rightarrow\bullet,t}^{jnt,to} - X_{i\leftarrow\bullet,t}^{jnt,from}, \tag{21}$$

$$X_{ij,t}^{jnt,net} = gST_{ji,t} - gST_{ij,t}. \tag{22}$$

Even if the interpretations are identical to the initial connectivity method, the results are much more accurate since the shortcomings of the row count normalization method have been overcome (Caloia et al., 2019).

This strategy is much less distortion-sensitive, does not call for differing window sizes, and also spots criterion changes extra precisely (Antonakakis et al., 2020). On top of that, we have not just made use of the joint connectivity technique suggested by Lastrapes and Wiesen (2020), which gives much more precise results because of different normalization strategies to Diebold as well as Yilmaz (2009, 2012, 2014), however we have additionally extended this structure. This proposed standard permit boosted adaptability and also even enables the calculation of metrics for paired connectivity networks, which was formerly unattainable.

3.3. Determinants of return and volatility spillovers

Return and volatility spillovers are dispersed and mostly heterogenous among samples. A further analysis is needed to identify the drivers of the differences among the spillovers. We adhere to the traditional spillovers model used in international finance modified into the property market returns. We expect that spillovers might be much less in larger markets. Furthermore, global factors are thought about as other gravitational variables.

The idea was created that a variety of variables would most definitely affect the influence of shocks on Sukuk along with commodities at the complete return and volatility spillovers, consisting of (1) CLMT, (2) EMV, (3) EPU, (4) GFS, (5) GMNS, (6) GVZ, (7) OVX, as well as (8) VIX.[4] In line with recently published studies for example Balli, de Bruin, and Chowdhury (2019) as well as Balli et al. (2021), a recognized regression formula for the sukuk in addition to asset markets has in fact been specified. Therefore, based on the basic gravity model we used the regression model; nonetheless, it adjusted to comprise of the variables gotten in touch with worldwide statistics, taking these variables right into account as gravity elements:

$$X_{i,t}^{jnt,net} = \alpha_0 + \alpha_1 X_{it} + \varepsilon_{it} \tag{23}$$

where the reliant variable $X_{i,t}^{jnt,net}$ is produced within three ways. Initially, it describes the total spillovers at the return and volatility in between sukuk i as well as asset markets j (Tables 2–4). The data of these variables have been collected from Data-stream. The term X_{it} has the drivers of connectedness consisting of variables $EPU_{i,j}, VIX_{i,j}, OVX_{i,j}, GVZ_{i,j}, GFS_{i,j}, EMV_{i,j}, GMNS_{i,j}, CLMT_{i,j}$.

We have actually identified the heteroskedasticity as well as autocorrelation dealt with standard errors (HAC) in the analyses. We likewise have tested normality of the error terms, misspecification of the versions (RESET) as well as managed for the fixed and arbitrary results with Hausmann tests as well as used fixed result versions in our estimates.[5] It should be kept in mind that; we use the MCoP which is the minimum connectedness portfolio technique recommended by Broadstock et al., 2022 to take a look at the hedging efficiency (HE). We additionally use the Sharpe Ratio to rank the products based upon the productivity of the financial investment against the prospective risks.

4. Discussion of the results

From now, we talk about the outcomes of balanced and time-varying connectedness analyses. We start by offering the outcomes of the net overall connectedness as well as net pairwise directional connectedness in returns, so we understand the responsibility of every commodity, energy as well as sukuk market as a net transmitter or net recipient of shocks. We additionally highlight the results of the time-varying development of the TCI to examine its reaction to the various financial, economic as well as political occasions throughout our research duration. Secondly, we provide the exact outcomes of net directional and vibrant connectedness in volatility between used markets. Thirdly, the net pairwise spillovers are being presented in subsamples (i.e., pre- and during the Covid-19 pandemic period). Fourth, we discuss the results of the different basic gravity models for both return and volatilities. Finally, we interpret the results of the multivariate portfolio analysis.

4.1. Return connectedness between used commodities and sukuk markets

4.1.1. Pairwise net directional connectedness results

To take a look at the instructions and also the strength of return overflow between sukuk, energy and commodity markets, Fig. 1 shows the network of directional return connectedness amongst sukuk, energy and commodity markets. The instructions of the ar from one market to another suggest the ordinary spillover interconnected among the sets. The arrow's width shows the strength of the pairwise overflow, with colors black and red denoting the weakest as well as most full spillover instructions, specifically. The dimension of nodes shows the level of impact of each market to the system connectedness, as well as pink colors and also green designate the recipients of net as well as net transmitters of shocks, specifically.

Graph 1 shows that sukuk indices of India, Ireland, Nigeria, Oman, Pakistan, and UAE are net receivers of shocks, while sukuk indices of UK, Hong Kong, Bahrain, Kuwait, Qatar, Malaysia, Saudi Arabia, Singapore, and Turkey are net transmitters of shocks. For commodity and energy markets, with the exception of coffee, grain and aluminium markets, all the markets appear to be net receivers of shocks in the network system. The strongest pairwise *spillovers* are between UK and Nigerian sukuk markets, and from Grain to

[4] To understand each independent variable for our paper we have created a table in Appendix A.1 which will explain the definitions of each variable. Additionally, these variables have been used in previous studies, (such as Lundgren et al., 2018; Kocaarslan & Soytas, 2019; Batten, Kinateder, Szilagyi, & Wagner, 2021; Ji et al., 2019; Bouri et al., 2021; Saeed al., 2020, 2021).

[5] To check the correlation between the independent variables that we have, we have created correlation matrix table and it is in Appendix A.2. We may observe from the table that their multicollinearity among the variables as the correlation's ranges from −0.25 to 0.47.

Table 3
Determinants of dynamic total connectedness for Sukuk and Commodity returns.

Coefficient	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
EPU	−0.023*** (0.003)								0.057*** (0.003)
VIX		0.261*** (0.033)							0.170*** (0.033)
OVX			−0.113*** (0.013)						−0.064*** (0.015)
GVZ				0.466*** (0.047)					0.416*** (0.080)
GFS					−7.469*** (0.355)				−3.174*** (0.404)
EMV						0.309*** (0.022)			0.163*** (0.019)
GMNS							0.088 (0.082)		0.055 (0.066)
CLMT								0.014*** (0.001)	0.008*** (0.001)
R^2(%)	17.34	19.20	18.00	19.3	17.07	18.80	17.00	16.29	36.69
N	1746	1746	1746	1746	1746	1746	1746	1746	1746

Note: Standard errors are printed in parenthesis. *, ** and *** show that the relevant coefficient is significant at the 10%, 5% and 1% level respectively.

Table 4
Determinants of dynamic total connectedness for Sukuk and Commodity volatilities.

Coefficient	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
EPU	−0.037*** (0.002)								−0.028*** (0.002)
VIX		−0.343*** (0.024)							−0.214*** (0.022)
OVX			−0.098*** (0.008)						−0.087*** (0.010)
GVZ				−1.008*** (0.036)					−1.238*** (0.054)
GFS					3.299*** (0.262)				1.801*** (0.275)
EMV						0.059*** (0.016)			0.055*** (0.013)
GMNS							−0.103* (0.062)		−0.088** (0.045)
CLMT								−0.004*** (0.007)	−0.005*** (0.001)
R^2(%)	15.07	17,67	23.00	30.23	8.07	9.80	15.23	27.50	49.00
N	1746	1746	1746	1746	1746	1746	1746	1746	1746

Note: Standard errors are printed in parenthesis. *, ** and *** show that the relevant coefficient is significant at the 10%, 5% and 1% level respectively.

Wheat markets. The strong connection between sukuk markets of the two countries corroborates the findings of Billah et al. (2023) and may reflect investor demand and economic ties coupled with the boarder context of global financial integration that allow the two sukuk markets to be linked through cross-boarder investments, financial flows and investor preferences. A lower but substantial connection is also established between gold and silver metals and from Grain to Corn. These relations between Grain and Wheat and, Grain and Corn are natural and unsurprising giving that Wheat and Corn are ones of the major types of grain, with Wheat being one of the most important and widely cultivated grains globally, making it a significant component of the overall grain market. As a result, their shared characteristics, common agricultural practices, staple role in the global food industry as well as market dynamics are factors explaining the spillover effects between them. For gold and silver, their connection is mainly driven by their common status as precious metals. Other factors such as market sentiment, common investment strategies, and their safe-haven properties during times of economic uncertainty may contribute to the spillover effects between the two markets (e.g., Baur & McDermott, 2010; Cheong & Chong, 2018; Raza et al., 2018). Despite this linkage, given the weak integration of all other markets into the global sukuk or commodity system, the chart suggests attractive diversification opportunities for investors in these markets (Antonakakis et al., 2018; Basher et al., 2016).

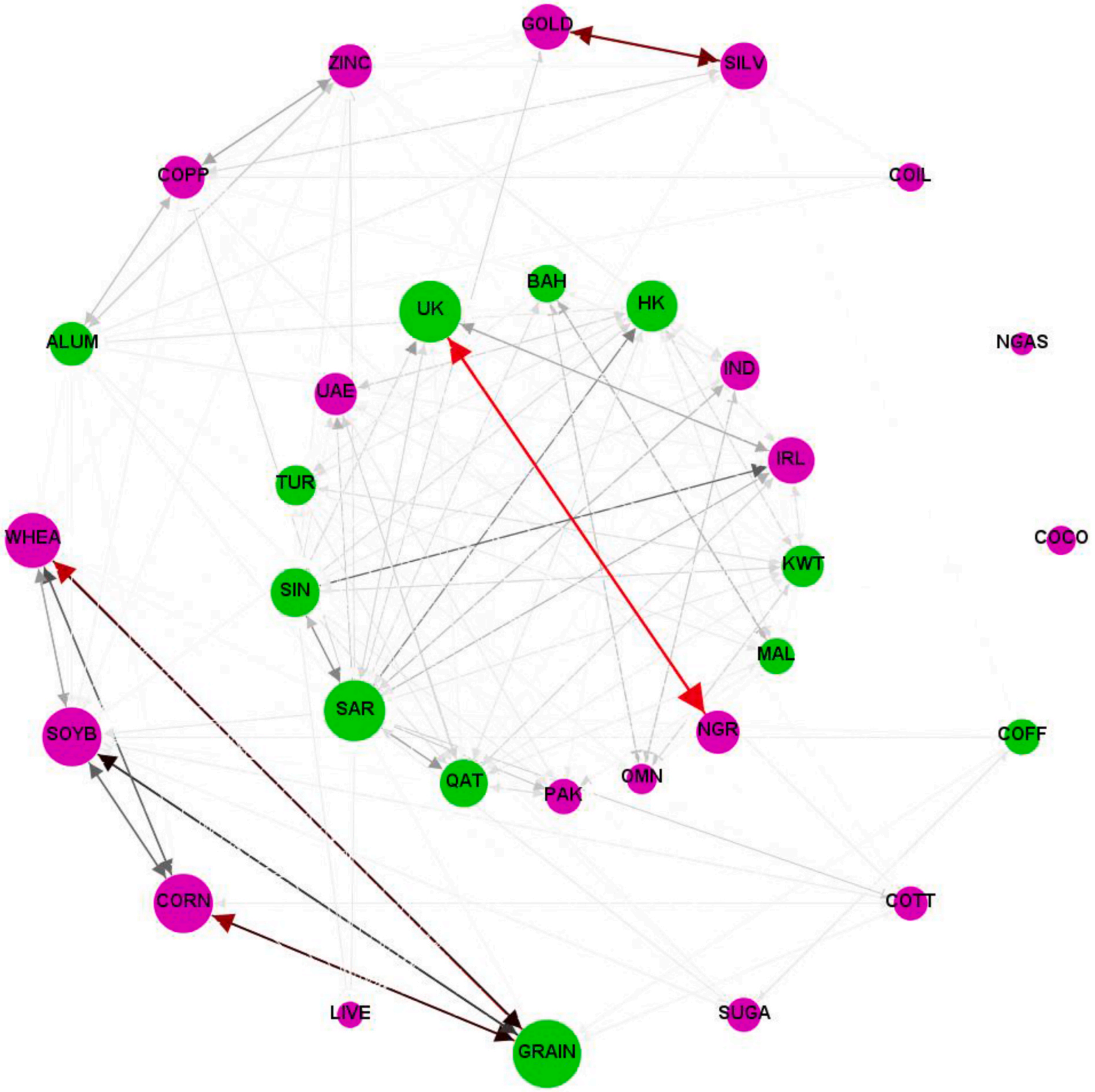

Fig. 1. A complete example of a reverse connection network between the Sixteen Commodity and Fifteen Sukuk markets. The overall system-wide dynamic connectivity index is based on first-order TVP-VAR with first-order delay length and 28-level GFEVD.
Note: This network graph shows the overall connectedness level in a system consisting of Sixteen commodities and Fifteen Sukuk market returns over the complete example duration. The dimension of the node shows the size of the contribution of each variable to system connectedness, while the shade suggests the beginning of connectedness. Node dimension indicates the level of spillover impact as well as color defines whether a market is an internet transmitter (green) or recipient (pink) of overflows. The forced guided layout formula established node place where the amount of the vectors set the node course. Arrow width represents the strength of the pairwise overflows, and color specifies the best (red) to weakest (black) instructions of spillovers. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4.1.2. Dynamic spillover of returns

We, now, examine the time-varying total return spillovers among sukuk, energy and commodity markets as described by Fig. 2. In particular, our sample period includes several important events that can affect the size of the spillovers between markets (e.g., Baumöhl, 2019; Bouri et al., 2020; Mensi et al., 2021). To assess the time-varying spillovers, we use the first order TVP-VAR with a one-delay length and a 28-level GFEVD, which is based on a dynamic connectedness index.

Fig. 2 shows a large variability in the return spillover index over the sample period (45–95). More specifically, we note a relatively high *spillover* in the early-sample period (up to 70%) that can be ascribed to the slow recovery of the entire economic and financial

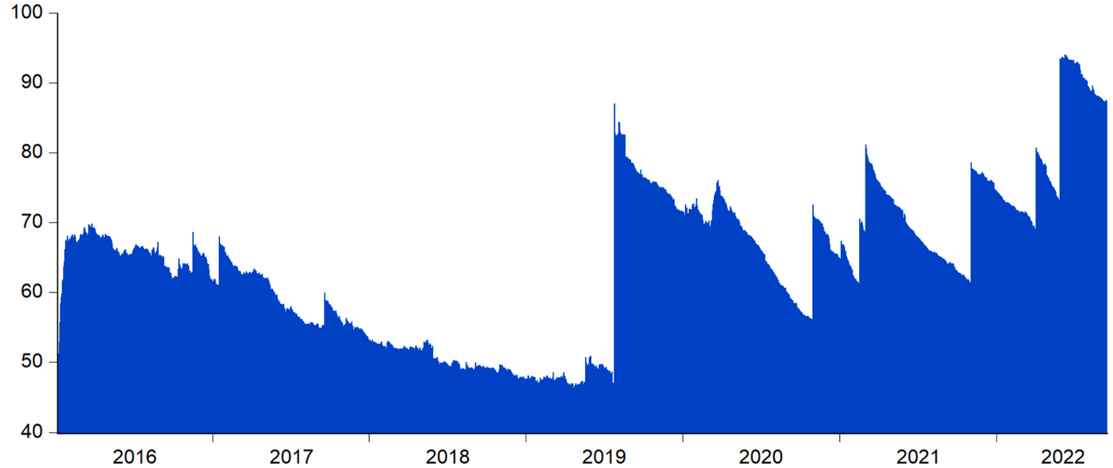

Fig. 2. Total time-varying Return connectedness between Sixteen Commodities and Fifteen Sukuk markets.
Notes: System-wide total dynamic connectedness index is based on a 1st-order TVP-VAR with a 1st-order delay length and a 28-level GFEVD.

systems from the effects of the global financial crisis and the subsequent Euro debt crisis (Stracca, 2015; Shahzad et al., 2017; Billah et al., 2022)[6] as well as to the political instabilities in the late 2016 (Ahmed & Elsayed, 2019). In 2018 and early 2019, *spillovers* of returns exhibit a significant decline and reach between 54 and 45. This trend could be attributable to several elements such as the recovery of world economy from trade tensions between China and the United States that has largely impacted Islamic, energy and commodity markets (Liow et al., 2020; Billah et al., 2022). Subsequently, and amid the outbreak of the Covid-19 pandemic, the return *spillover* index start to increase to reach more than 90 by the end of the sample period. This finding of increased interdependence between markets is expected as argued by a number of studies (e.g., Aslam et al., 2020; Guo et al., 2021). The total return *spillover* varies between 56 and 87 between late 2019 and 2021. This outcome of increased *spillover* between sukuk, commodities and energy markets suggest declining diversification benefits between these markets during the pandemic period. Our empirical findings do not align those of Naifar (2018) who find a time-varying negative correlation between commodity prices and GCC sukuk returns.

Fig. 3 portrays the prompt contribution of each market to the connectedness system as derived from the web total amount spill-overs, and their transitions from a recipient to a transmitter of shocks over time, and vice versa. The figure shows that precious metals (gold and silver) appear to, mainly, be net receivers of shocks in the entire sample period. The degree of *spillover* is high and exceeds 80 at some points of time (in 2019 and 2022). For energy commodities (crude oil and natural gas), industrial metals (Aluminium, Copper and Zinc) and some soft agriculture commodities (Coffee, Cotton, and Sugar), a peer reciprocity in net *spillover* positions is observed until late 2019. In the late example period, more substantial overflow positions are prominent for these markets. For the rest of agriculture commodities (Cocoa, Livestock, Corn, Soybeans and Wheat), they appear to be net receivers of shocks in most sample period, while results show the opposite for Grain. For sukuk indices, results indicate a neutral trend in *spillover* patterns for Bahrain, India, Ireland, Kuwait, Nigeria and Oman with some significantly high net *spillovers* at some points of time reaching more than 300. The peaks occur after 2019 for these markets with noticeable high transmission positions for Bahrain and Oman occurring in 2017 that could be associated to the OPEC price reduction agreement. Sukuk markets of Hong Kong, Saudi Arabia, Singapore, Turkey, UAE, and UK appear to be net transmitters of shocks in most sample period, while sukuk markets of Malaysia, Nigeria, Pakistan and Qatar exhibit an equal reciprocity of net return *spillover*. These findings indicate potential diversification benefits of sukuks in the whole sample for the majority of markets.

4.2. *Volatility connectedness between used commodities and sukuk markets*

4.2.1. *Pairwise net directional connectedness results*

Fig. 4 depicts the volatility connectedness system and the strength and direction of the information spillovers in the full sample. Correlations of mean spillover between pairs are identified by the direction of arrows from one market to another, and the width of the arrows indicates the intensity of pairwise spillovers. The black and red color arrows indicate the weakest and strongest overflow directions, respectively. Node size indicates the level of contribution of each market to system connectivity. The pink and green colors indicate the network transmitter and network hit receivers, respectively.

Results reveal that sukuk markets of Qatar and Ireland carry significant volatility to the other markets and that they are critical players in the connectedness network. Specifically, findings indicate strong connections between Qatari sukuk market and agriculture (cotton, sugar, cocoa), energy (gold, zinc) and sukuk (Pakistan and Oman) markets. A strong risk transmission is also found from Irish sukuk index to sukuk markets of Singapore, Kuwait, Malaysia, and Nigeria. A moderate but substantial connection is also found from

[6] These effects include, among other, falling asset prices, decline in trade and raw materials prices, and decelerated international capital flows.

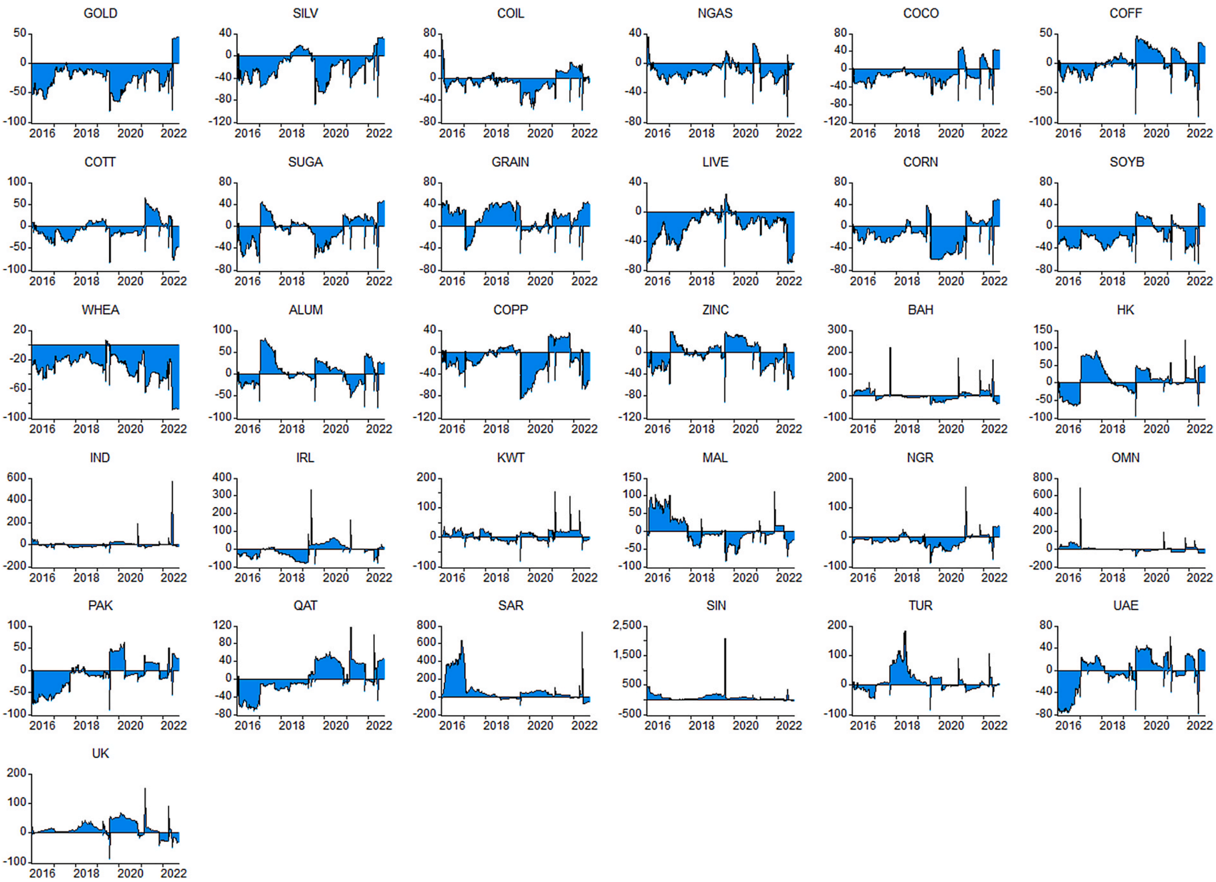

Fig. 3. Spillovers of net total return.
Notes: See Fig. 2.

UK to Malaysian sukuk indices. These findings seem to be consistent with the empirical findings of previous studies on the strong volatility linkages between Islamic indices (e.g., Akhtar et al., 2017; Hkiri et al., 2017; Balli et al., 2022).

4.2.2. Dynamic spillover of volatility between used markets

In this section, we explore the dynamics of the total volatility *spillover* between sukuks and used energy and commodity markets. Fig. 5 presents the system-wide total time-varying *spillover* index based on a TVP-VAR model with a one-delay length and a 28-level GFEVD.

Outcomes reveal significant albeit high changes in the overall connectedness over the whole example period. Specifically, the volatility *spillover* index is higher than 70 for most the sample period and reaches more than 85% between 2017 and 2020. This result indicates that volatility shocks spill over among used markets and that the total *spillover* index is very responsive to extraneous shocks as well as economic turbulences. This result seems to be consistent with some previous empirical studies which find a positive correlation between Islamic securities and some energy and precious metals (e.g., Boubaker & Rezgui, 2020; Godil et al., 2022; Zaighum et al., 2021).

Fig. 6 provides a visualization of the contribution of each market to the overall net *spillover* system over time. Typically, the figure shows that extreme net *spillovers* fluctuate in the full period for all markets. The only exceptions are sukuk markets of Bahrain, Ireland, Qatar, UAE and UK that, generally, show a neutral trend in the most sample period which suggests that these markets are well monitored by regulators against extreme events. For the rest of sukuk indices, they appear to, mostly, be net transmitters of shocks in the full sample. The greatest risk transmissions are taped for Ireland, Bahrain and Qatar in the early-sample duration, reaching greater than 2000. These findings could be attributed to the political uncertainty induced by the US presidential election and the UK referendum on EU membership in 2016. For commodities, a general trend could be noted between 2017 and 2020. Specifically, precious metals (gold and silver), energy commodities (oil and gas), industrial metals (Copper and Zinc) and the majority of agricultural commodities (Cocoa, Coffee, Cotton, Sugar, Grain, Livestock, Soybeans, and Wheat) exhibit a significant net transmitter position between 2017 and 2020, while Corn and Aluminium show a significant net receiver position during the same period. In the late-sample period (after 2020), all commodities (except Cocoa, Livestock, Wheat and Copper) appear to be net transmitter of shocks. This finding is consistent with previous empirical results that find more pronounced trends in *spillovers* for commodities during crisis periods (e.g.,

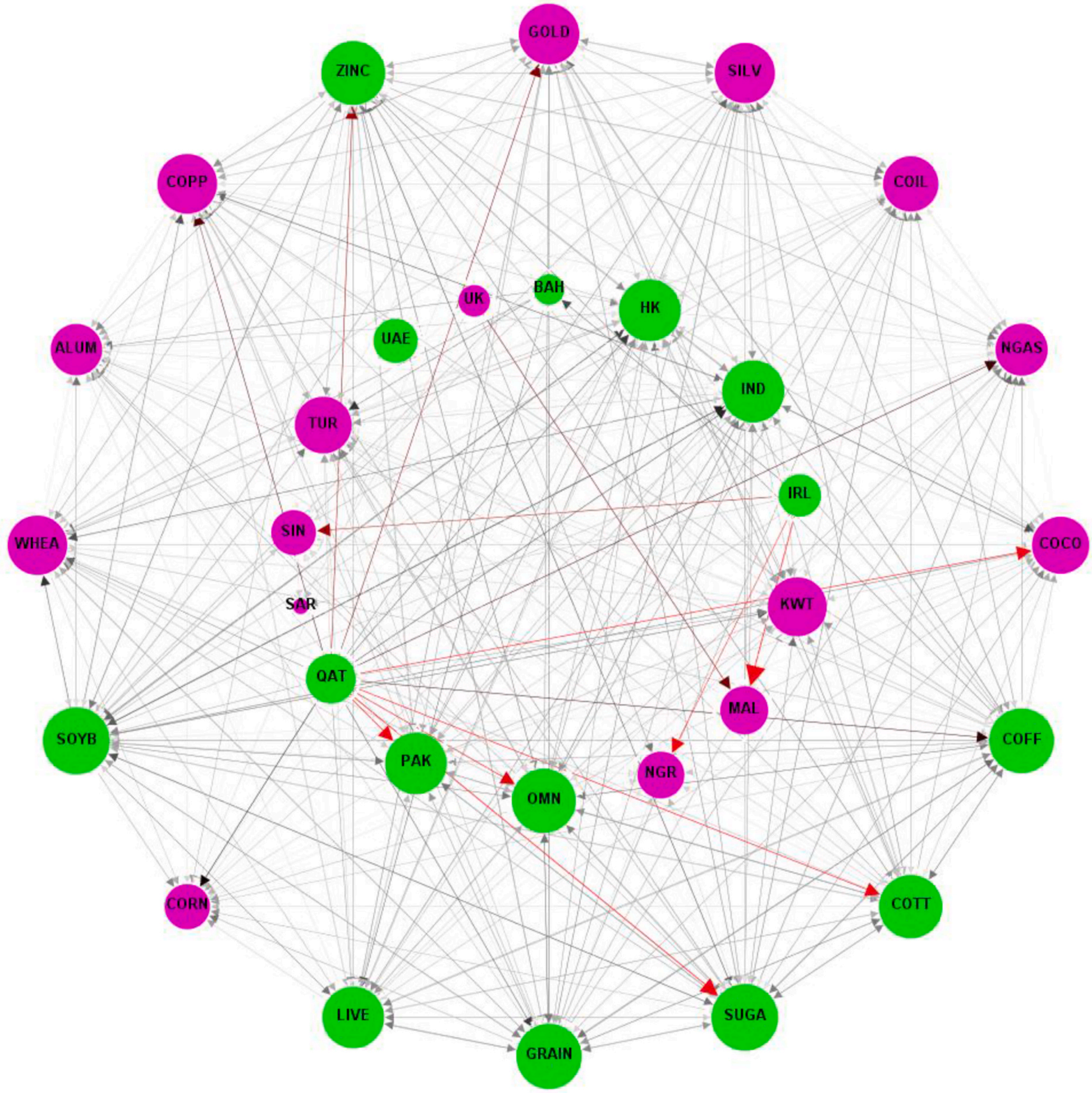

Fig. 4. A complete example of a reverse connection network between the Sixteen Commodity and Fifteen Sukuk markets. The overall system-wide dynamic connectivity index is based on first-order TVP-VAR with first-order delay length and 28-level GFEVD.
Notes: See Fig. 1.

Balli, Naeem, et al., 2019; Chevallier & Lelpo, 2013; Du et al., 2011; Kang et al., 2017).

4.3. Return and volatility connectedness in subsamples

In this section, we examine the connectedness between markets in two sub-samples – before and during the Covid 19 pandemic period. Figs. 7 and 8 show the network connectedness in returns and volatility, respectively. Results found for the Covid period are unalike to those corresponding to the pre-pandemic sample period.

For return connectedness, Fig. 7 demonstrates that, during the pre-pandemic, the connections appear to be weak or inexistent for most commodities and sukuk markets. The only strong connection is between Nigerian and UK sukuk markets. For the pandemic period, more significant connections are found between used markets. Primarily, the results show that the greatest overflows concerning sukuks are from Bahrain to Oman, from Singapore to Ireland, as well as from Saudi Arabia to Pakistan and also the UK. A lower

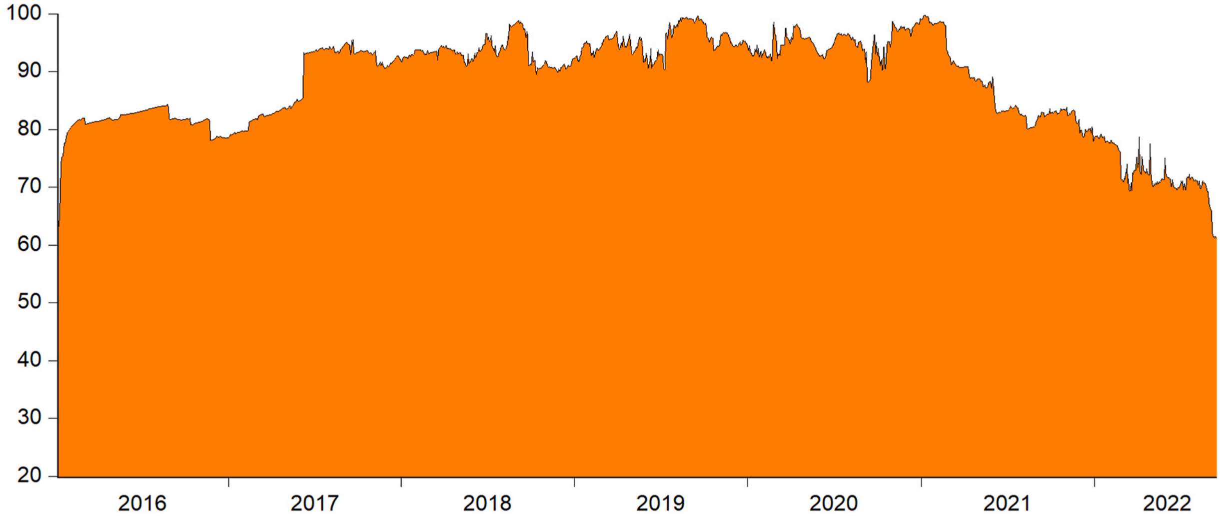

Fig. 5. Total time-varying Volatility connectedness between Sixteen Commodities and Fifteen Sukuk markets.
Notes: System-wide total dynamic connectedness index is based on a 1st-order TVP-VAR with a 1st-order delay length and a 28-level GFEVD.

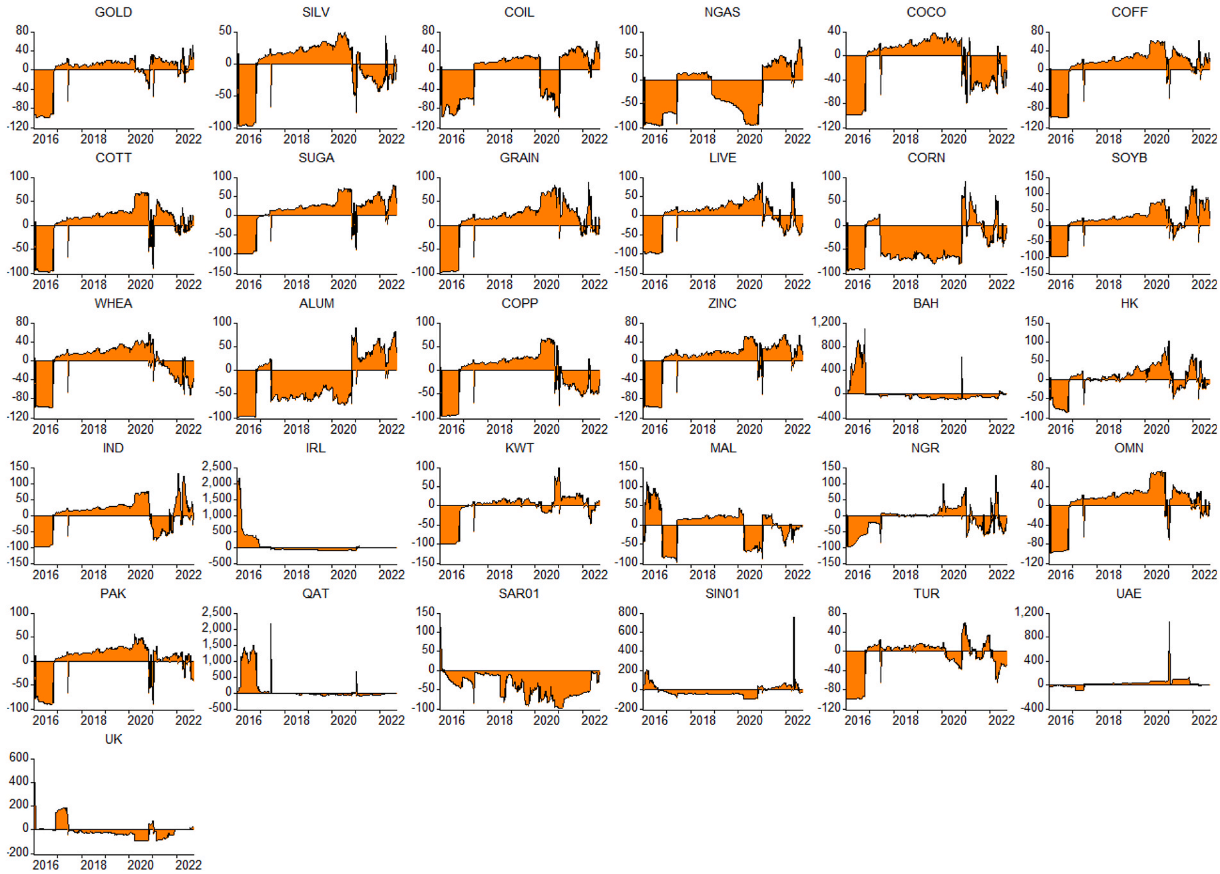

Fig. 6. Spillovers net total volatility.
Notes: See Fig. 2.

but material connection is also set-up from Oman to Bahrain, and between India and Oman. For commodities, results show a strong *spillover* between Gold and Silver, between Grain and Wheat, Corn and Soybeans, respectively. This finding corroborates those of some previous studies on the global financial crisis period that demonstrate that commodities display higher *spillovers* during crisis episodes

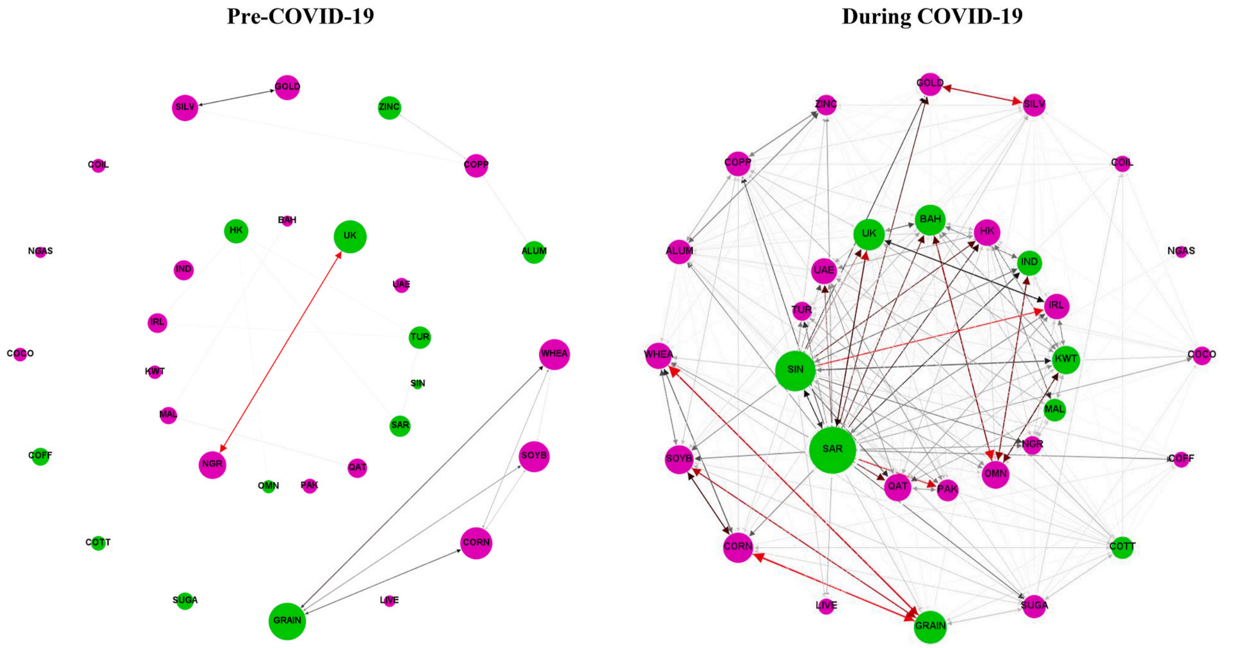

Fig. 7. Return Dispersion Connectivity Network between sixteen commodity and fifteen Sukuk markets before and during COVID-19.
Notes: See Fig. 1.

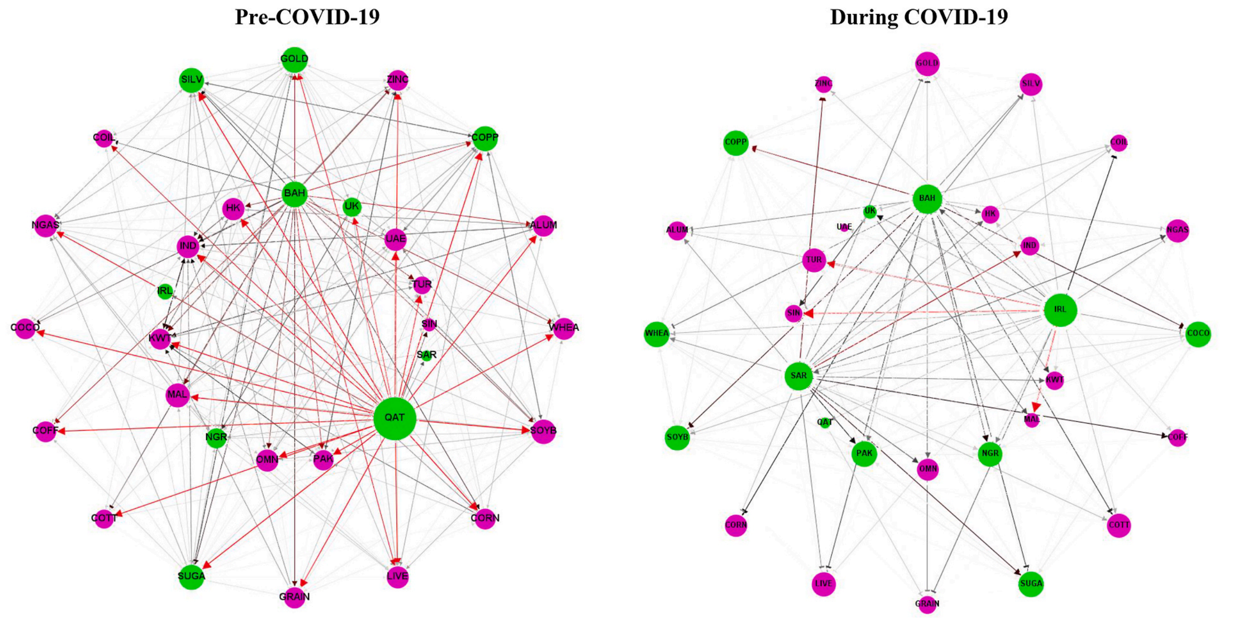

Fig. 8. Volatility Dispersion Connectivity Network between sixteen commodity and fifteen Sukuk markets before and during COVID-19.
Notes: See Fig. 1.

(Grosche & Heckelei, 2016; Kang et al., 2017).

For volatility connectedness, Fig. 8 shows that the connections between used sukuks and commodities are more pronounced during the pre-pandemic period. Interestingly, strong connections are established from Qatar sukuk market to nine other sukuk markets (Turkey, UAE, UK, Hong Kong, India, Kuwait, Malaysia, Oman, and Pakistan) and all used commodities. This result of the major role of Qatar as a transmitter of shocks among Islamic markets is congruous with the results of some previous studies (e.g., Naeem et al., 2021; Billah et al., 2022). A possible explanation is that this market is a major issuer of sukuks in both financial and non-financial co-operations which could have broader implications (Billah et al., 2022). For the pandemic period, the most intense pairwise connections

Table 5
Dynamic multivariate portfolio weights.

Minimum Connectedness Portfolio (MCoP) based on TVP-VAR model

Panel A: FULL SAMPLE

	MEAN	STD.D	5%	95%	HE	P-VALUE	SHARPE RATIO
GOLD	0.03	0.03	0.00	0.08	−1.10	0.00	2.773
SILV	0.02	0.02	0.00	0.07	0.44	0.00	1.043
COIL	0.03	0.02	0.00	0.07	0.85	0.00	1.440
NGAS	0.03	0.02	0.00	0.05	0.83	0.00	2.309
COCO	0.03	0.02	0.00	0.06	0.39	0.00	−0.855
COFF	0.02	0.02	0.00	0.06	0.52	0.00	1.697
COTT	0.02	0.02	0.00	0.05	0.22	0.00	1.912
SUGA	0.02	0.02	0.00	0.07	0.38	0.00	0.698
GRAIN	0.16	0.09	0.00	0.29	−0.03	0.47	2.692
LIVE	0.03	0.03	0.00	0.08	−0.41	0.00	0.883
CORN	0.01	0.03	0.00	0.08	0.18	0.00	2.561
SOYB	0.01	0.03	0.00	0.08	−0.13	0.01	2.426
WHEA	0.01	0.04	0.00	0.10	0.46	0.00	2.025
ALUM	0.03	0.03	0.00	0.08	−0.13	0.01	2.084
COPP	0.02	0.03	0.00	0.07	−0.11	0.03	2.335
ZINC	0.02	0.02	0.00	0.06	0.27	0.00	2.645
BAH	0.03	0.03	0.00	0.08	−0.71	0.00	3.059
HK	0.03	0.03	0.00	0.08	−10.19	0.00	−0.257
IND	0.04	0.04	0.00	0.10	−2.50	0.00	−1.628
IRL	0.03	0.04	0.00	0.10	−9.02	0.00	−0.038
KWT	0.03	0.02	0.00	0.07	0.09	0.05	−0.148
MAL	0.03	0.03	0.00	0.09	0.88	0.00	1.041
NGR	0.07	0.07	0.00	0.20	0.98	0.00	0.057
OMN	0.04	0.04	0.00	0.12	0.69	0.00	1.325
PAK	0.03	0.03	0.00	0.08	−7.97	0.00	−1.123
QAT	0.03	0.04	0.00	0.12	−25.51	0.00	−1.817
SAR	0.03	0.03	0.00	0.09	0.97	0.00	−0.054
SIN	0.04	0.05	0.00	0.17	0.98	0.00	−2.001
TUR	0.03	0.03	0.00	0.07	−1.04	0.00	−0.433
UAE	0.03	0.03	0.00	0.08	−36.60	0.00	0.766
UK	0.04	0.06	0.00	0.18	−1.93	0.00	0.584

Panel B: Pre-COVID-19

	MEAN	***STD.D***	***5%***	***95%***	***HE***	***P-VALUE***	***SHARPE RATIO***
GOLD	0.02	0.04	0.00	0.11	0.63	0.00	4.343
SILV	0.04	0.05	0.00	0.13	0.87	0.00	1.873
COIL	0.02	0.02	0.00	0.05	0.95	0.00	2.381
NGAS	0.03	0.02	0.00	0.07	0.97	0.00	−0.225
COCO	0.03	0.02	0.00	0.05	0.93	0.00	−1.021
COFF	0.02	0.02	0.00	0.05	0.92	0.00	0.305
COTT	0.03	0.02	0.00	0.07	0.87	0.00	0.731
SUGA	0.03	0.04	0.00	0.10	0.93	0.00	−0.463
GRAIN	0.16	0.10	0.00	0.30	0.83	0.00	0.988
LIVE	0.03	0.02	0.00	0.07	0.81	0.00	−0.238
CORN	0.01	0.02	0.00	0.06	0.87	0.00	0.714
SOYB	0.01	0.03	0.00	0.07	0.83	0.00	0.933
WHEA	0.01	0.03	0.00	0.07	0.91	0.00	0.932
ALUM	0.03	0.03	0.00	0.10	0.82	0.00	1.839
COPP	0.02	0.03	0.00	0.08	0.83	0.00	2.438
ZINC	0.02	0.02	0.00	0.04	0.91	0.00	2.384
BAH	0.03	0.02	0.00	0.06	0.76	0.00	4.290
HK	0.02	0.02	0.00	0.05	−6.12	0.00	0.589
IND	0.02	0.03	0.00	0.09	−3.22	0.00	3.594
IRL	0.03	0.02	0.00	0.05	−16.57	0.00	1.162
KWT	0.03	0.02	0.00	0.05	−2.72	0.00	0.304
MAL	0.02	0.03	0.00	0.11	−1.18	0.00	3.715
NGR	0.09	0.07	0.00	0.23	1.00	0.00	0.116
OMN	0.04	0.02	0.00	0.08	0.96	0.00	0.778
PAK	0.03	0.03	0.00	0.11	−2.85	0.00	1.582
QAT	0.03	0.03	0.00	0.10	−10.29	0.00	−0.067
SAR	0.04	0.04	0.00	0.14	−4.62	0.00	3.074
SIN	0.02	0.02	0.00	0.05	0.95	0.00	−1.015
TUR	0.03	0.03	0.00	0.08	−0.60	0.00	−0.786

(*continued on next page*)

Table 5 (*continued*)

Minimum Connectedness Portfolio (MCoP) based on TVP-VAR model

Panel A: FULL SAMPLE

	MEAN	STD.D	5%	95%	HE	P-VALUE	SHARPE RATIO
UAE	0.03	0.02	0.00	0.06	−8.57	0.00	3.341
UK	0.02	0.05	0.00	0.11	0.41	0.00	3.909

Panel C: During COVID-19

	MEAN	***STD.D***	***5%***	***95%***	***HE***	***P-VALUE***	***SHARPE RATIO***
GOLD	0.02	0.03	0.00	0.08	−0.53	0.00	1.248
SILV	0.04	0.04	0.00	0.11	0.65	0.00	0.446
COIL	0.03	0.03	0.00	0.08	0.92	0.00	0.988
NGAS	0.03	0.02	0.00	0.06	0.88	0.00	4.877
COCO	0.03	0.02	0.00	0.07	0.28	0.00	−0.589
COFF	0.02	0.02	0.00	0.07	0.62	0.00	3.282
COTT	0.01	0.02	0.00	0.06	0.42	0.00	3.212
SUGA	0.02	0.02	0.00	0.07	0.32	0.00	2.479
GRAIN	0.11	0.10	0.00	0.32	0.20	0.00	4.629
LIVE	0.03	0.03	0.00	0.08	−0.31	0.00	2.375
CORN	0.02	0.04	0.00	0.11	0.37	0.00	4.639
SOYB	0.02	0.03	0.00	0.07	0.07	0.31	4.205
WHEA	0.02	0.03	0.00	0.08	0.58	0.00	3.282
ALUM	0.03	0.03	0.00	0.10	0.12	0.08	2.399
COPP	0.02	0.03	0.00	0.07	0.11	0.13	2.254
ZINC	0.03	0.03	0.00	0.07	0.29	0.00	3.009
BAH	0.02	0.04	0.00	0.13	−0.48	0.00	1.554
HK	0.02	0.03	0.00	0.09	−4.36	0.00	−0.688
IND	0.03	0.04	0.00	0.11	−0.58	0.00	−3.749
IRL	0.03	0.03	0.00	0.10	−3.44	0.00	−3.393
KWT	0.04	0.06	0.00	0.19	0.61	0.00	−0.285
MAL	0.05	0.04	0.00	0.13	0.95	0.00	1.347
NGR	0.03	0.03	0.00	0.08	0.10	0.15	−0.565
OMN	0.06	0.06	0.00	0.19	0.73	0.00	2.022
PAK	0.02	0.03	0.00	0.08	−3.59	0.00	−2.808
QAT	0.03	0.04	0.00	0.11	−12.58	0.00	−3.102
SAR	0.04	0.05	0.00	0.16	0.99	0.00	−0.158
SIN	0.04	0.04	0.00	0.13	0.99	0.00	−2.968
TUR	0.03	0.03	0.00	0.09	0.04	0.55	−0.409
UAE	0.03	0.04	0.00	0.13	−21.39	0.00	−1.148
UK	0.06	0.07	0.00	0.20	−0.96	0.00	−2.447

Notes: This table illustrate the hedge ratios, among fifteen Sukuk and sixteen commodity markets in full sample, pre and during Covid-19.

are from Ireland to Turkey, Singapore, and Malaysia, and from Saudi Arabia to India. Lower but material connections are shown from sukuk indices to industrial materials. More particularly, these connections are from Saudi Arabian sukuk market to Zinc market and from Bahraini sukuk market to Copper market. The connections between commodities are materially weak.

Overall, Figs. 7 and 8 indicate some sizeable risk mitigation properties of some used markets. Specifically, the weak or inexistent return and volatility *spillovers* between sukuks and commodities during the pandemic period suggest some interesting diversification opportunities between them.

4.4. Determinants of spillovers

We focus, in this section, on the determinants of *spillover* between used commodities and sukuk markets among some risk variables namely related to economic policy uncertainty (EPU), volatilities of the stock (VIX and EMV), oil (OVX), and gold (GVZ) markets, global financial stress (GFS), macroeconomic news surprises (GMNS) and climate change (CLMT). Results reported in Tables 3 and 4 are for determinants of the return and volatility connectedness, respectively. Risk variables are given in regressions singly, followed by estimates for the complete model that uses all the variables in the last column.

Results in Table 3 show that most variables are statistically significant at the 1% level (Models 1–8), which indicates a strong explanatory power of used risk factors on the dynamic total return connectedness between sukuks and commodities. The only exception is GMNS. The relation is statistically negative (positive) for EPU, OVX, GVZ and GFS (VIX, EMV and CLMT). For EPU (Model 1), for example, results suggest that an increase in economic policy uncertainty is associated to a decrease in the degree of total *spillover* among used markets. The same reasoning holds for the other factors. These results could be explained through several factors such as flight-to-safety and risk aversion phenomenon. Specifically, during periods of high uncertainty and stress, as evidenced by high EPU, OVX, GVZ and GFS, investors often seek safe-haven assets. This flight to safety can lead to reduced cross-market spillovers (Baele et al., 2020; Bekaert et al., 2009). Similarly, as uncertainty in the stock markets increases, as evidenced by higher VIX and EMV, investors may become more risk averse and seek other investment opportunities such as commodities and Islamic financial products to mitigate potential risk, leading to higher spillover effects among these two assets. This result aligns those of Naifar et al. (2017) who find that, as volatility and uncertainty in the stock market increases, investors expect higher returns in sukuk markets. The result of the positively significant effect of climate change (CLMT) supports empirical evidence of its role in shaping financial markets' dynamics (Venturini, 2022).

The highest coefficient is related to GFS and suggests that a one-unit increase in global financial stress is associated to a 7.469 decrease in the magnitude of return connectedness between sukuk and commodity markets. When using all risk factors together (Model 9), we note some differences in the sign of the relation between used factors and total connectedness as compared to the individual testing results. Specifically, the results become significantly positive for EPU and GVZ. The sign of the coefficients holds for the other factors. These empirical results of Model 9 on EPU, VIX and GFS partially align those of Naifar and Hammoudeh (2016) who find that sukuk markets are influenced by global stress and uncertainty factors which indicates integration with the global environment. Particularly, the authors find that higher (lower) GFS (EPU and VIX) is associated with a higher possibility of subsequent negative returns of sukuks. Our empirical results suggest the effectiveness of global risk factors in explaining the degree of *spillover* between commodities and sukuks.

Findings in Table 4 are for the determinants of connectedness in volatility between used markets. Results of the individual testing indicate a significantly positive (negative) relation between GFS and EMV (EPU, VIX, OVX, GVZ, GMNS and CLMT) and the magnitude of the *spillover* between markets at the 10% level or higher. When used together (Model 9), risk factors show no difference in sign and significance with respect to the results of the individual models (1–8). As for the results of return connectedness in Table 3, results of volatility connectedness show also that the highest coefficient is related to GFS. A general increase in this proxy would significantly increase volatility *spillovers* between sukuk and commodity markets, which confirms its non-trivial role as a determinant of total connectedness between used markets. The negative coefficients associated to the other risk factors could suggest that, in bearish market conditions, sukuks and commodities could present some risk mitigation properties when combined in investment portfolios.

The relation is statistically negative (positive) for OVX and GFS (EPU, GSV, VIX, EMV and CLMT).

Results of the individual testing indicate a significantly positive (negative) relation between GFS and EMV (EPU, VIX, OVX, GVZ, GMNS and CLMT) and the magnitude of the *spillover*.

4.5. Multivariate portfolio analysis results

In this section, we dig deeper into the implications for portfolio diversification and risk management using the minimum connectedness portfolio (MCoP) approach that minimizes pairwise connectedness across markets. We focus on examining the hedging effectiveness scores *(HE)* and Sharpe ratios to rank sukuks and commodities based on their risk hedging and profitability. The results are given in Table 5 Panel A for the full sample period, Panel B for the pre-Covid-19 pandemic period and in Panel C for the period of the pandemic.

Prior to considering hedge effectiveness and Sharpe ratios, we take a look at the average portfolio allocations in the full sample (Panel A). The mean portfolio weights for sukuks suggest some similar country-level characteristics with weights, typically, ranging between 3% and 4%. The highest weight is for Nigeria (7%). For commodities, average portfolio weights, typically, range between 1% and 3%. The largest weight is recorded for Grain (16%) giving commodities a combined time averaged approximative weight of 49% against 51% for sukuks. The combined time averaged weight is 51% for commodities and 49% for sukuks in the pre-Covid-19 period (Panel B) and of 47% for commodities and 53% for sukuks, approximatively, during the pandemic period (Panel C). It is also noteworthy that Grain market has the largest single weight in the three sample periods among all markets. This result suggests the important role of this commodity in a fixed-income investment portfolio.

Regarding the hedge effectiveness scores (*HE*), results in Panel A indicate that, in the basis of the average portfolio weights, an investor could statistically and significantly lower the volatility of each market in her portfolio by about 9% with respect to an investment of 3% in Kuwait sukuk market and to 98% when investing 4% of her portfolio in Singapore sukuk market. Reported results also show that volatility reductions are only financially meaningful for some commodity markets. These are Silver, crude oil, natural gas, Cocoa, Coffee, Cotton, Sugar, Corn, Wheat and Zinc. For the other markets, results of negative *HE* suggests that they are associated with increased portfolio volatility. For sukuks, only Kuwait, Malaysia, Nigeria, Oman, Saudi Arabia and Singapore are associated with statistically meaningful volatility reductions in the portfolio. For the period of the pandemic (Panel C), the hedging effectiveness of commodities seems to be more pronounced than that of the full-sample period. Specifically, all commodities except Gold and Livestock seem to, significantly, contribute to a much lower level of volatility. For sukuks, we note a stability feature in risk reduction properties for sukuk markets of Kuwait, Malaysia, Nigeria, Oman, Saudi Arabia and Singapore in the period of the pandemic. Findings suggest that if we invest, for example, on average 4% in Saudi Arabian and Singaporean sukuk markets, we would be able to reduce the volatility of each asset by up to 99%. Overall, these findings seem to validate the hypothesis of presence of diversification opportunities among markets using the dynamic connectedness network.

We move to the results of the Sharpe ratios. We find that among commodities, Gold market exhibits the strongest reward-to-risk ratio (2.773). Natural gas market appears to display the strongest combined risk reduction and reward-to-risk properties with a HE of 83% and a Sharp ratio of 2.309. This result of the strong performance of natural gas market is also valid for the period of the pandemic. More particularly, all commodities (with the exception of Cocoa) seem to be highly performant during the pandemic period based on the Sharpe ratio. For sukuks, we find that, for the full sample period, the highest Sharpe ratio is for Bahrain (3.059). The risk-adjusted performance of the majority of sukuks is negative except for Bahrain, Malaysia, Nigeria, Oman, UAE and UK, suggesting a low remuneration of returns to risk in the full sample. Turning to the results of the pandemic period, all sukuks (with the exception of Oman) exhibit uniformly negative Sharpe ratios suggesting that the inclusion of sukuks is unlikely to lead to substantially higher returns and/or lower risks.

5. Conclusion

In the past two decades, Islamic finance sector has witnessed remarkable expansion, capturing the interest of investors, researchers and experts worldwide. This development has prompted a fundamental query regarding the potential of these assets for optimizing portfolio allocation, especially in times of uncertainty. Comparably, over the few last decades, commodity markets have experienced significant growth and evolution due to increased global demand for commodities and their financialization. Notably, commodities have become increasingly attractive for investors and emerge as an asset class for diversification and risk management. To understand the linkages among different types of commodities (i.e., metal, industrial, energy and agricultural) and Islamic sukuks, we propose to investigate the effects of the spillovers as well as portfolio implications in this research study. This exercise makes our study the first to focus on these two types of assets all together. Therefore, we collected 15 countries sukuk markets and 16 commodities for the period that goes from January 01, 2016 to September 15, 2022. We employ the time-varying parameter vector autoregression (TVP-VAR) based extended joint connectedness approach of Balcilar et al. (2021), which contributed to the literature on connectedness analysis by delivering a comprehensive and policy-oriented analysis of the interdependence between sukuks and commodities.

Our study unveils some interesting findings. First, the return *spillover* analysis shows strong connections between UK and Nigerian sukuk indices, between Gold and Silver metals, and from Grain to Wheat markets. Second, we find strong pairwise volatility connectedness between Qatar sukuk index and sukuk indices of Pakistan and Oman and some commodity markets (i.e., Cotton, Sugar, Cocoa, Gold, and Zinc). We also find strong volatility *spillovers* from Ireland to sukuk markets of Singapore, Kuwait, Malaysia and Nigeria. These results state that capitalists in these markets must diversify the risk by consisting of other assets in their portfolios. Apart from these connections, our analysis unveils some interesting diversification opportunities between sukuks and commodities in the full-sample period. Third, the time-varying analysis indicate high return and volatility *spillovers* between used markets in the early-sample period. The *spillover* index reaches up to 70 for the return network and up to 85 for volatility connectedness. This result indicate that used sukuks and commodities are highly responsive to external shocks and economic downturns. The analysis also shows declining diversification benefits in the period of the pandemic as suggested by increased return *spillovers*. However, from an individual contribution viewpoint, our results show some potential diversification benefits in two-asset portfolios between used markets over time. Fourth, we divide our sample into two sample periods (i.e., the pre – Covid19 pandemic period and the Covid19 pandemic period). When comparing between the two subsamples, we find more significant connections in return (volatility) during the pandemic (pre – pandemic) period. Overall, our subsample analysis results indicate some sizeable risk mitigation properties between some used markets due to weak or inexistent linkages. Fifth, looking at the potential determinants of this connectedness between used markets, we find a significant effect of global risk factors on the degree of *spillover* among markets. Specifically, the negative significant coefficients related to some risk factors suggest that, in bearish market conditions, some risk mitigation properties could be attributed to used markets in a combined portfolio. Finally, these findings are confirmed through a multivariate portfolio analysis that shows some risk reduction properties of some markets in both the full-sample and during the Covid-19 pandemic period. Specifically, using both the hedge effectiveness and Sharpe ratios, our results validate the hypothesis of presence of diversification opportunities among markets using the dynamic connectedness network.

The implications of this study for both investors and market regulators are important. First, our findings suggest that including these markets in a portfolio can provide significant diversification and risk reduction benefits. Precisely, we demonstrate that a pre–set portfolio technique in which the weights of various markets are selected based on the connectedness network could yield some risk hedging benefits and profitability. Second, our findings complement previous results on connectedness analysis and suggest that during the Covid19 pandemic period, return connections between commodities and fixed-income Islamic assets become more significant. Third, in the severe times of the Covid19 pandemic, commodities tend to, typically, be net directional return and volatility receivers. Sukuks are shown to behave as both transmitters and receivers of shocks. Investors should, hence, be cautious about the direction and the magnitude of shocks between these markets to maximize diversification benefits. Fourth, when financial stress is increased, the magnitude of total return (volatility) spillover is shown to decrease (increase), demonstrating the important role of this risk factor as a determinant of financial connectivity patterns across markets. Therefore, rational investors are advised to closely monitor movements of this factor to effectively determine when and how they should take short or long positions accordingly.

As a future direction for this research, scholars could extend our analysis and include other ethical products (i.e., green bonds, green stocks, Islamic stocks) to examine the interconnectedness between commodities and ethical assets and recommend some connectedness-based diversification strategies.

Table A.1
Variables to Determine the Spillovers

Variable	Description
EPU	EPU index shows the relevant consistency of own-country newspaper information in which consist of a threesome of conditions referring to the economy (E), policy (P) and uncertainty (U). Former investigations indicate an inverted connection among transformations in EPU and Sukuk returns (Balli et al., 2020). Therefore, the negative sign will be expecting from EPU.

(*continued on next page*)

Table A.1 (*continued*)

Variable	Description
VIX	The VIX is a real-time market index that meets market assumptions for volatility over the next 30 days. Considering the bond attributes of Sukuk and green bonds, rises in the degree of the VIX possess an adverse effect on (Sukuk and green) bonds, which decreases the TSI. As a result, we anticipate. an adverse indication for the VIX.
OVX	OVX is the expected 30-day crude oil volatility estimate since the US Oil Fund (USO) set the price. Rises in the degree of the OVX may come with a negative effect on sukuk and commodity prices (Saeed et al., 2021), which results in a decrease in the degree of the TSI. Therefore, the negative sign will be expecting from OVX.
GVZ	GVZ is an estimation regarding the anticipated 30-day volatility of returns on the SPDR Gold Shares ETF (GLD).
GFS	Anticipated through Bank of America Merrill Lynch, the Global Financial Stress Index is a method regarding cross-market risk, demand protection, and financial investment flows in the worldwide financial process.
EMV	Baker et al. (2020) developed an index which is called Equity Market Volatility (EMV) tracker, and it is being based on the eleven major U.S. newspapers. Moreover, this index closely moves with the VIX and with realized volatility on the S&P 500.
GMNS	We have another interesting variable that we have taken, which is called global macroeconomic news surprises and has been developed by Scotti (2016). As we know the aggregate demand and supply conditions may have higher uncertainty through macroeconomic news surprises. Therefore, considered that sukuk and commodity prices, are strongly sensitive to demand and supply conditions, a rise in the uncertainty encompassing the macroeconomy may cause a higher volatility in sukuk and commodity prices.
CLMT	The MSCI World Climate Change Index (CLMT) is accorded to the MSCI World Index, it is relative index, and consists of substantial and mid-cap securities across 23 Developed regions. The index aims to represent the efficiency of an investment strategy that re-weights securities based upon the opportunities and risks connected with the transition to a lower carbon economy, although looking for to reduce exemptions from the relative index.

Table A.2
Correlation Coefficients of Explanatory Variables

Explanatory variables	EPU	VIX	OVX	GVZ	GFS	EMV	GMNS	CLMT
EPU	1.00							
VIX	0.16	1.00						
OVX	0.12	0.47	1.00					
GVZ	0.12	0.44	0.26	1.00				
GFS	−0.17	0.02	0.34	0.12	1.00			
EMV	0.22	−0.07	0.29	−0.25	−0.11	1.00		
GMNS	0.09	0.10	−0.06	0.10	−0.31	0.13	1.00	
CLMT	0.02	0.52	0.21	0.23	0.39	−0.03	−0.13	1.00

Credit statement: contribution of the authors

All authors contributed equally to the paper.

Data availability

Data will be made available on request.

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