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Asymmetric relationship between green bonds and Sukuk markets: The role of global risk factors

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ABSTRACT

This study investigates the asymmetric connectedness and spillover effects between two ethical fixed-income assets (Sukuk and green bonds) with regard to global risk factors using a sample of 15 Sukuk markets and green bond indices. This complex network allows us to examine the extreme risk spillover and interlinkages across green bonds and Sukuk under different market conditions, captures sudden upward changes in the total and net spillover indices and hence, serves as an alerting system for any impending crisis in relation to global risk factors. Empirical results indicate a persistency feature in the connectedness between Hong Kong and Malaysian, and UK and Nigerian Sukuk markets under different market conditions. More importantly, Sukuk and green bond markets are not largely affected by global risk factors in the middle, upper and lower quantiles. Findings from the portfolio analysis show that Sukuk is effective in hedging the risks of green bonds and global factors. These results of potential diversification characteristics and risk reduction benefits are robust and hold during the Covid-19 pandemic period. Finally, our findings are of paramount importance for investors who are interested in ethical investments as well as policymakers in order to maintain a stable and sound financial system.

1. Introduction

Since the global financial crisis, investors, researchers, and policymakers have been interested in studying patterns of financial connectedness and risk transmissions across financial markets and assets (e.g., Belke and Dubova, 2018; Tiwari et al., 2018; Malik and Umar, 2019; Kang et al., 2019). During turbulent and stressful periods, the investigations of cross-market interlinkages are not only of major importance for policymakers to reduce the impact of systemic risks on the economy but also for investors and portfolio managers to adjust their decisions and maximize benefits from portfolio diversification. Previous literature has asserted the fact that financial contagion and cross-market interlinkages tend to increase during turbulent and stressful periods (Forbes and Rigobon, 2002; Elsayed and Helmi, 2021).

In this regard, green bond has emerged as a novel financial instrument that not only provides opportunities for portfolio diversification but is also designed to cope with the global impendence of environmental hazards by funding environmentally friendly projects (Coston et al., 2014; Heine et al., 2019; Mensi et al., 2022). This type of investments has attracted a wide range of investors,

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both institutional and individual, and has reached a level of $2 trillion in 2022. Several studies have examined the differences between conventional and green bonds in terms of financial aspects (e.g., Baker et al., 2018; Hachenberg and Schiereck, 2018; Nanayakkara and Colombage, 2019; Wang et al., 2020; Kapraun et al., 2021; Löffler et al., 2021). Some others have studied the connectedness between green bonds and other asset classes such as conventional bonds (e.g., Pham, 2016; Nanayakkara and Colombage, 2019; Huynh et al., 2020; Reboredo et al., 2020; Pham and Nguyen, 2021; Elsayed et al., 2022), stock markets (e.g., Reboredo, 2018; Kanamura, 2020; Reboredo et al., 2020; Nguyen et al., 2021; Yousaf et al., 2022) and energy markets (e.g., Ferrer et al., 2021; Liu et al., 2021; Naeem et al., 2021). These studies have highlighted some sizeable diversification benefits for investors by comprising green bonds into their portfolios.

Similarly, previous studies highlighted the advantages of including Islamic financial instruments in investment portfolios as they are less volatile and outperform their conventional counterparts during tension periods due to their distinct characteristics such as risk-sharing, low leverage, and close connection with the real economic activities (Ajmi et al., 2014; Yarovaya et al., 2021). In particular, sukuk are *Shariah*-compliant instruments and are defined by the Auditing and Accounting Organization of the Islamic Financial Institutions (AAOIFI) as certificates designated to finance particular projects or investment activities and to the ownership of tangible assets or services. A great deal of studies has reported the main similarities and differences between sukuk and conventional bonds (e.g., Ahmed and Elsayed, 2019; Naifar and Hammoudeh, 2016). Particularly, similarities are essentially linked to the fixed term maturity, the guarantee of payment of the principal at maturity and the stream of income entitled by the holders of the two assets, while differences are mainly related to their ownership, issuance and pricing procedures. In recent years, and just like green bonds, sukuk have transitioned from being a niche market to one of the most noteworthy market developments with a 164 % increase in annual issuance volume between 2014 and 2020 (World bank, 2021). In 2021, the total issuance of sukuk is estimated to more than $1.35 trillion, with around 55 percent of which were issued in the past five years (Fitch Rating, 2021). A large body of the literature has examined the connection between sukuk and Islamic stock markets (Aloui et al., 2015; Aloui et al., 2018; Godlewski et al., 2013; Mensi et al., 2020; Naifar et al., 2016), between sukuk and conventional stock markets (e.g., Akhtar et al., 2017; Sclip et al., 2016) and sukuk and conventional bonds (e.g., Ariff et al., 2017; Kenourgios et al., 2016; Maghyereh and Awartani, 2016; Samitas et al., 2021; Yarovaya et al., 2021). Despite the multitude of studies on the interrelationship between asset classes, the number of studies that have investigated the interaction between sukuk and green bonds is scarce. Particularly, we focus on these two assets for several reasons. First, academic evidence shows that investors prefer green bonds over other conventional financial instruments due to the earmarked sustainable growth associated with them (Broadstock et al., 2021; Nguyen et al., 2021; Ferrat et al., 2022; Ielasi et al., 2018). Second, sukuk, as Islamic instruments, have gained interest by a wide range of investors due to their safe-haven properties against conventional financial instruments (e.g., Abbes and Trichilli, 2015; Arif et al., 2021) and the diversification opportunities that they offer in times of economic uncertainties owing to their distinctive features (Billah et al., 2022). Hence, taking together, investment in sukuk and green bonds could be seen, by investors, as an effective way to mitigate the risk related to economic downturns and environmental hazards. Therefore, the question would be, do these two unconventional markets experience spillovers and can be used for diversification and hedging purposes?

This study aims to extend the literature on the interrelationship between financial assets to the case of sukuk and green bonds to provide further insights for international investors and those interested in ethical investments. Karim and Naeem (2022) is the only study, to date, that has examined the interconnectedness among green, conventional, and Islamic markets using data on sukuk and green bonds. Our study differs from theirs in two major ways. First, unlike Karim and Naeem (2022) who use data on sukuk and green bonds within a wide system encompassing stock, energy and commodity indices, our study focuses on green and Islamic bonds only and examine the bidirectional connectedness between these two assets which could be more insightful for investors interested in these instruments. Second, the authors use data on the Dow Jones Global Sukuk and S&P Green Bond Index. Unlike their study, we opt for a disaggregated analysis using a large sample of both sukuk and green bond indices from different regions to explore the potential differences in the reactions of the different markets which could be more useful for investors in formulating their investment strategies at both a regional and international levels.

More formally, this study investigates the asymmetric dynamic linkages and spillover effects between these two types of financial assets. In addition, we examine the impact of global risk factors on connectedness and risk transmission between sukuk and green bonds. Using a sample of 15 sukuk markets from different regions of the world (i.e., GCC, Asia, Europe and Africa) and four continental green bond indices, we evaluate the dynamic connection and transmission of information among and between these two markets as well as the way these could be affected by global factors. Then, we investigate the implications on portfolio management by assessing the risk associated to two assets-portfolios regarding risk reduction gains and diversification benefits. In doing so, we study the interconnectedness using a network analysis framework, based on the volatility spillover approach. Diebold and Yilmaz (2009; 2012) were the first to develop an index that measures return and volatility spillovers based on a forecast error variance decomposition function in a Vector Autoregressive (VAR) model. Due to its several econometric advantages over other traditional approaches, that mainly rely on its simplicity and ability to capture spillovers among multiple assets and markets, their intuitive methodology has been extensively used by numerous financial and economic studies (e.g., Awartani and Maghyereh, 2013; Basher and Sadorsky, 2016; Mensi et al., 2018; Yoon et al., 2019, Elsayed et al., 2021, among others).

In the light of the above background, the current study is novel in its contribution by empirically examining the quantile return connectedness of sukuk and Green bond markets at median, upper, and lower quantiles to quantify the connectedness structures and time-varying attributes. Methodologically, previous studies employed quantile connectedness approach to examine extreme dependence between financial and non-financial sukuk markets (Billah et al., 2022), time-varying approach of Diebold and Yilmaz (2012) for configuring connectedness among sukuk and Islamic equity markets (Balli et al., 2022), BEKK-GARCH technique to examine volatility between sukuk and conventional bond indices (Ghaemi Asl & Rashidi, 2021), DCC-GARCH to measure uncertainty between sixteen commodities and sukuk markets (Naifar, 2018). However, evidence lacks studies employing the quantile connectedness approach to analyze the return connectedness of sukuk and green bond markets and highlight their diversification potentials during normal and turbulent periods. Moreover, this methodology allows us to capture extreme dependencies in the return distribution tails, which are not captured by the average connectivity method. In this case, the added value of our new methodology lies in its ability to capture connectivity in the upper and lower quantiles and, thus, the relative dependencies of the quantiles. This complex network allows us to examine the extreme risk spillover and interconnectedness across green bond and sukuk markets under different market conditions, captures sudden upward changes in the total and net spillover indices and hence, serves as an alerting system for any impending crisis in relation to global risk factors. In fact, our quantile-based connectivity approach allows us to provide the first empirical evidence for different extreme spillovers between the upper and lower extreme quantiles, helping to explain tail risk dispersion in sukuk and the green bond indices.

Our study extends the related literature on financial contagion and portfolio allocation of financial assets in, primarily, four ways, making our contribution four-folded. First, given the limited available research on the connectedness between sukuk and green bonds, and to fill this gap in the literature, this study examines the connectedness and risk transmission between these two bond markets alongside with global risk factors by taking advantage of high frequency (i.e., daily). Specifically, since we focus on socially responsible investing in fixed income (i.e., sukuk and green bonds), this study could be of interest to ethical investors who need to understand the dynamic connection and transmission of information between these two ethical products. Second, by applying a quantile spillover approach, our study not only provides valuable information about how sukuk and green bonds react to risk innovations and how their *comovement* is affected by global risk factors, but also shows how they behave under different market conditions and to what extend these reactions are persistent over time. Third, some insights for investors in terms of risk reduction and portfolio allocation are highlighted in our study with respect to risk factors for green bonds and sukuks. Finally, the sample period encompasses the Covid-19 pandemic episode. Consequently, this study is the first to test the bidirectional dynamic connectedness between sukuk and green bonds during the period of the COVID-19 pandemic which may have important implications for investors.

Empirical findings are interesting, and can be summarized as follows: First, we find a persistency feature in the connectedness between Hong Kong and Malaysian, and UK and Nigerian sukuk markets under different market conditions. Second, the results of the dynamic spillovers show that the degree and intensity of dependency varies over time for all assets and variables under consideration. Thirdly, and more importantly, our results indicate that sukuk and green bond markets are not largely affected by global risk factors in the middle, upper and lower quantiles. Fourth, portfolio analysis indicates that sukuk are effective in hedging risk of holding green bonds and vice versa. The same conclusion of high hedging effectiveness is confirmed for sukuk with regard to the global risk factors. Finally, these results of the potential diversification characteristics and risk reduction benefits are robust and hold during the Covid-19 pandemic period.

The remainder of the study is structured as follows. Section 2 describes methodology used, data and the preliminary analysis. The discussion of the estimated results is presented in Section 3. Section 4 concludes the study.

2. Methodology and data

2.1. The regression model of quantile

The standard least-square approach is utilized with high conditions, including the linear regression model needs to fulfill the conditions of homoskedasticity and uncorrelated random errors. Specifically, whenever the distribution is thick-tailed or has outliers, the robustness of the results is poor. Consequently, to overcome the shortcomings mentioned above, the quantile regression is chosen as the basis model of this paper. Conceding to the principle of linear quantile regression initially designed by Koenker and Bassett Jr. (1978), in linear conditions, provided the dependent variables x_t, the quantile τ of y_t is:

$$Q_\tau(y_t|x_t) = x_t\beta(\tau)\tau \in (0,1) \tag{1}$$

Q_τ is represented in different quantile functions; the quantile τ between 0 and 1; x_t is the vector that explains the variable; $\beta(\tau)$ is called the quantile regression coefficient. So, this paper defines the estimators of different quantile coefficient $\widehat{\beta}(\tau)$ by the following minimization problem:

$$\widehat{\beta}(\tau) = \underset{\beta(\tau)}{argmin} \sum_{\beta(\tau)_{t=1:y_t \geq x_t\beta(\tau)}}^{T} \tau|y_t - x_t\beta(\tau) + \sum_{\beta(\tau)_{t=1:y_t < x_t\beta(\tau)}}^{T} (1-\tau)|y_t - x_t\beta(\tau)| \tag{2}$$

$\widehat{\beta}(\tau)$ describes the dependence between the explanatory variable x_t and the conditional quantile function y_t at the τ_{th}. By solving the above, we can fit well the estimates of $\beta(\tau)$ at different quantile points.

2.2. The quantile VAR (QVAR) model

The quantile structure is next constructed into the VAR (p) model as follows:

$$y_t = \lambda(\tau) + \sum_{i=1}^{p} B_i(\tau)y_{t-i} + e_t(\tau), \tau \in (0,1) \tag{3}$$

where y_t is the n-dimensional vector dependent variable of period t; $\lambda(\tau)$ signifies the intercept term at the quantiles τ; $e_t(\tau)$ is the N-dimensional residual vector at the quantiles τ; $B_i(\tau)$ displays the lagged coefficient matrix at different quantiles. The model nicely combines the VAR with the quantile structure and clarifies the dependence between the two model.

To estimate the values of two variables $\lambda(\tau)$ and $B_i(\tau)$, this paper assumes that the residuals $e_t(\tau)$ satisfy the population quantile restrictions, $Q_\tau(e_t(\tau)|F_{t-1}) = 0$; F_{t-1} represents the information set at time $t-1$. The population τ_{th} conditional quantile of y is:

$$Q_\tau y_\tau F_{t-1} = \lambda(\tau) + \sum_{i=1}^{p} \widehat{B}_i(\tau) y_{t-i} \tag{4}$$

2.3. Quantile spillover indices based on the Diebold–Yilmaz framework

Ando et al. (2022) improved the spillover index in each quantile that can be established by outlining the quantile variation, in accordance with the spillover approach developed by Diebold and Yilmaz (2012, 2014). Hence, equation (1) is modified in respect of the moving average process of an infinite-order vector, resulting in equation (3):

$$y_t = \mu(\tau) + \sum_{s=0}^{\infty} A_s(\tau) e_{t-s}(\tau),\ t = 1, \cdots, T \tag{5}$$

With,

$$\mu(\tau) = \left(I_n - B_1(\tau) - \cdots - B_p(\tau)\right)^{-1} c(\tau),$$

$$A_s(\tau) = \begin{cases} 0, s < 0 \\ I_n, s = 0 \\ B_1(\tau)A_{s-1}(\tau) + \cdots + B_p(\tau)A_{s-p}(\tau), s > 0 \end{cases}$$

where y_t is given by the sum of the residuals $e_t(\tau)$; I_n and $A_s(\tau)$ are N × Ncoefficients vectors. The coefficient matrix $A_s(\tau)$ rewritten from the moving average model is the key factor to identify the forecast error variance decomposition.

Consequently, the Generalized Variance Decomposition function of Koop et al. (1996) and Pesaran and Shin (1998) is applied to overcome the problem of Cholesky-factor ordering. Thus, for the forecasting horizon H, equation (4) can be applied to estimate a variables' Generalized Forecast Error Decomposition of Variance (GFEVD) due to shocks from other variables:

$$\theta_{ij}^{g}(\mathrm{H}) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i^{'} h_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i^{'} h_h \sum e_i\right)} \tag{6}$$

where $\theta_{ij}^{g}(\mathrm{H})$ represents the input of the jth variable to the variance of the i-th variables' forecast error on the H horizon. $\sum$ indicates the error vectors' variation matrix while σ_{jj} represents the Σ matrix' j th diagonal element. e_{i} signifies a vector with either a 1 or 0 value for the i-th element or others, respectively. Consequently, each variance decomposition matrix entry is normalised as set out in equation (5):

$$\widetilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{7}$$

The Diebold-Yilmaz framework (2012, 2014) can be utilised to ascertain connectivity measures in the τth conditional quantile. Its foundation is a generalised decomposition of the error variance in the quantile forecast. To be more specific, the total connectivity index for the quantiles τ can be calculated via equation (8):

$$TSI(\tau) = \frac{\sum_{i=1,}^{N} \sum_{j=1, i \neq j}^{N} \omega_{ij}^{h}(\tau)}{\sum_{i=1,}^{N} \sum_{j=1}^{N} \omega_{ij}^{h}(\tau)} \times 100 \tag{8}$$

For quantiles τ, equation (9) shows the calculation for the directional spillover index of all indices to index i, which is referred to as 'TO':

$$S_{i\bullet}(\tau) = \frac{\sum_{j=1, i \neq j}^{N} \omega_{ij}^{h}(\tau)}{\sum_{j=1}^{N} \omega_{ij}^{h}(\tau)} \times 100 \tag{9}$$

Conversely, for quantiles τ, equation (10) presents the calculation for the directional spillover index from index i to all indices, which is referred to as 'FROM':

$$S_{\bullet i}(\tau) = \frac{\sum_{j=1, i \neq j}^{N} \omega_{ij}^{h}(\tau)}{\sum_{j=1}^{N} \omega_{ij}^{h}(\tau)} \times 100 \tag{10}$$

Based on equations (9) and (10), the net spillover index (NS) for the quantiles τ can be presented as shown in equation (11):

$$NSi(\tau) = S_{\bullet i}(\tau) - S_{i\bullet}(\tau) \tag{11}$$

Likewise, the pairwise spillover index in quantiles τ is expressed as shown in equation (12):

$$Sij = \omega_{ji}^{h}(\tau) - \omega_{ij}^{h}(\tau) \tag{12}$$

A VAR lag of order 1 was the foundation of the connectedness system, which was selected on the basis of Bayesian information criteria. The forecast error variance of the forward decomposition (ten steps) was also utilised. Finally, the dynamic spillover measures were estimated using a rolling-window strategy (Diebold & Yilmaz, 2014; Shahzad et al., 2018).

2.4. Hedge ratios and portfolio weights

This research segment uses results from a DCC-GARCH model of Guhathakurta et al. (2020) to determine the best possible portfolio weights and hedge ratios for variables under consideration. This method is accorded to the conjecture that investors are open to take a long (short) position in Sukuk (green bonds) whenever the forthcoming volatility is anticipated to become increased (decreased) in contrast to its existing level. This would protect investors against the risk associated with unfavourable market movements. Equation (13) shows the calculation for the hedge ratios between Sukuk and green bonds or global factors:

$$\beta_{greenbonds,sukuk,t} = h_{greenbonds,sukuk,t} \Big/ h_{sukuk,sukuk,t} \tag{13}$$

where β stands for the hedge ratio to get one-dollar long position within green bonds (Sukuk) as well as one-dollar short position within Sukuk (green bonds). Moreover, $h_{greenbonds,sukuk,t}$ stands for the conditional covariance in between green bonds and Sukuk returns while $h_{sukuk,sukuk,t}$ exemplifies the conditional variance regarding Sukuk returns.

When estimating the hedge ratio for one-dollar long position in Sukuk and one-dollar short position in green bonds, $h_{sukuk,sukuk,t}$ is replaced with $h_{greenbonds,greenbonds,t}$. Essentially, when the associated ratio is near zero, green bond is an inexpensive hedge for Sukuk, and vice versa. The optimal weight for investing in a minimal risk portfolio consisting of Sukuk and green bonds is calculated as stated in equations (14) and (15) (Kroner & Ng, 1998):

$$\omega_{greenbonds,sukuk,t} = \frac{h_{sukuk,t} - h_{greenbonds,sukuk,t}}{h_{greenbonds,t} - 2h_{greenbonds,sukuk,t} - h_{sukuk,t}} \tag{14}$$

$$\omega_{greenbonds,sukuk,t} = \left\{ \begin{array}{c} 0, \omega_{greenbonds,sukuk,t} < 0 \\ \omega_{greenbonds,sukuk,t}, 0 \leq \omega_{ij,t} \leq 1 \\ 1, \omega_{greenbonds,sukuk,t} > 1 \end{array} \right\} \tag{15}$$

where $\omega_{greenbonds,sukuk,t}$ represents the weight of green bonds in a one-dollar portfolio of green bonds and Sukuk at time t. Subsequently, the optimum weight for green bonds would be $(1 - \omega_{ij,t})$. Finally, the hedging effectiveness (HE) of a portfolio containing green bonds and Sukuk could be calculated as follows:

$$HE = \frac{h_{unhedged} - h_{greenbonds,sukuk,\omega}}{h_{unhedged}} \tag{16}$$

where $h_{unhedged}$ signifies the variance of green bonds or Sukuk returns' variance with no diversification whereas $h_{greenbonds,sukuk,\omega}$ indicates the hedged portfolio variance with most advantageous optimal investment in green bonds and Sukuk markets.

2.5. Data and preliminary analysis

In order to examine the dynamic connectedness and spillover effects between sukuk and green bond markets, we constructed Sukuk indices based on a daily dataset obtained from Bloomberg Professional Service for fifteen countries. The sample includes data for the GCC countries, namely Bahrain, Kuwait, Oman, Qatar and Saudi Arabia, United Arab Emirates; Turkey from West Asia; Hong Kong, Indonesia, Malaysia, and Singapore from Southeast Asia; Pakistanis from South Asia; Nigerians from Africa; and Europe, Ireland and the United Kingdom. The reason for choosing this period is to study the impact of global shocks on the integration of the Sukuk market. Using a large sample of countries also allows researchers to study the effects of proliferation within and between regions.

This data is only used for liquid Sukuk, which contains regular daily data because they are fully tradable and can also be traded on the secondary market. The availability of data from Sukuk is an essential factor in choosing a country. Therefore, we built the sovereign Sukuk index for this tool using the Bloomberg methodology,[1] developed by Billah et al. (2022) and Balli et al. (2022) and criteria for minimising selection bias. The standards required for the Bloomberg index justify the choice of Sukuk instruments: first, a minimum maturity of 12 months; Second, the amount owed is more than $200 million. And third, it must have at least a rating from S&P, RAM, MARC, or Moody's. It was decided to focus exclusively on US dollar denominated Sukuk, which represents the majority in this market,

[1] The technical document is available at:https://www.bloombergindices.com/content/uploads/sites/2/2016/01/633470877 INDX GFI WP 151022.pdf.

to limit currency effects. Specifically, we collected data on 153 highly liquid Sukuk, and Table 1 shows the number of Sukuk in each country that contributed to the formulation of the aggregated Sukuk indices.[2]

In addition, the sample used consists of the daily closing prices of the four green bond indices. The Bloomberg Barclays MSCI Green Bond Index (GB GL) is used to track financial performance in the global green bond market (Reboredo, 2018; Reboredo & Ugolini, 2020). The GB GL index was launched in November 2014 and has become the leading green bond index. The securities that make up this index have a fixed coupon and are worth investing in. In addition, the performance of green bonds in China, the US and the EU is monitored using the FTSE Green Bond Index (Onshore CNY) (CH GB), the MSCI Bloomberg Barclays Euro Green Bond Index (EU GB) and the MSCI Bloomberg Barclays US Green Bond Index (US GB). The index consists of investment-grade green bonds with fixed-rate coupons issued by companies and governments in euros or US dollars, as well as securitised bonds. To study the impact of global risks on Sukuk, we also use a volatility index developed by the Chicago Board Options Exchange (CBOE). The CBOE volatility index estimates the expected market volatility over 30 days. We use volatility indices of three main assets, namely oil (CBOE Crude Oil ETF Volatility Index, OVX), gold (CBOE Gold Volatility Index, GVZ) and stocks (CBOE SPDR ETF Volatility Index, VIX). Thomson Reuters Eikon, DataStream, and Bloomberg Databases were used as data sources, with an indicative timeframe from January 1, 2016, to April 1, 2022. The start date is based on data available in the Sukuk market. The daily return is calculated as the first difference between the natural logarithms of each index multiplied by $100(r = ln(Pt/Pt-1) \times 100)$, where p represents the closing price.

Table 2 reports the descriptive statistics for all sukuk indices, green bonds indices and global risk factors used in our study. The average sukuk return ranges from −0.002 for Ireland, Malaysia, and Singapore, to 0.030 for Turkey. The mean return green bond is higher than that of sukuk and ranges from 0.014 for FTSE Chinese Green bond index to 0.067 for Bloomberg Barclays MSCI US Green bond index during the sample period. The standard deviation, minimum and maximum values show a moderate variability of all indices, with heavy-fatter-tailed distributions as indicated by the skewness and kurtosis values. The statistics of the global risk factors reflect the severity of shocks that have hit the global markets during the sample period. These results justify the choice and the use of the quantile analysis given its ability to capture tail relationships and stability with extreme observations. The Augmented Dickey-Fuller (ADF) and Phillip-Perron (PP) test results reject the null hypothesis of non-stationarity of all series at the 1 % significance level indicating that all variable sunder consideration are level-stationary.

3. Empirical results

3.1. Static quantile connectedness analysis between Sukuk, green bonds and global factors

We begin by studying the connectedness of the middle, lower and upper information quantiles as reported in Tables 3–5, respectively. This study highlights the direction and strength of the information *spillovers* between sukuk and green bonds indices, as well as global risk factors.

Results in Table 3 depict the return connectedness for the middle quantile (50th) total, net and pairwise *spillover* indices. The conditional median (50th quantile) represents the normal market conditions. Findings reveal that the highest own-share *spillover* occurs in the case of the CH GB with 99.11 %. This means that all the others account for 0.89 % of the CH GB forecast error variance. For the other green bond indices, the own-share *spillovers* account for 55.64 %, 58.09 % and 53.48 % for EU GB, GL GB and US GB, respectively. For sukuk, the own portion ranges from 49.97 % for Hong Kong to 89.84 % for Singapore. These findings confirm previous claims on the cross-country disparities in the level of financial integration for sukuk (Naifar et al., 2016; Balli et al., 2022). In the event of sukuk indices, we find that the highest impact is caused by UK on the Nigerian sukuk market with 31.87 %, followed by Hong Kong on Malaysian sukuk market with 27.94 %. For GB indices, the impact is lower with the highest ones originating from US GB on the EU GB (19.01 %) and on the GL GB (18.80 %), followed by EU GB which has an impact of 18.05 % on the US GB. Hence, US GB and EU GB are a two-way transmitters and receivers, followed by EU GB and GL GB. Similarly, the same result is found for Malaysia and Hong Kong, with higher bidirectional backlinks for these two markets than for green bonds. We also find that neither used sukuk indices nor used green bonds indices are largely affected by global risk factors, with moderate *spillovers* from global risk factors to sukuk and green bond indices, ranging between 0.01 and 0.93 %. This finding seems to be in line with previous studies which claim that green bonds and sukuk carry risk mitigating features and efficiently protect investments from unexpected shocks (e.g., Arif et al., 2021; Ferrer et al., 2021; Yousaf et al., 2021).

In total, results show that Hong Kong sukuk index influences the most the market by 65.17 % and is influenced by 50.03 % indicating that it is a net transmitter of shocks. While, for green bond indices, we find that US GB influences the market by 54.01 % against 44.36 % received. Among all investigated series, Hong Kong, UK and the Indonesian and Malaysian sukuk indices, EU GB and US GB indices as well as VIX appear to be the only net transmitters of shocks. The main net receiver is the Pakistani sukuk market (-6.04 %) followed by the Irish sukuk market (-5.15 %). Regarding the level of TSI within the overall return connectedness system, a value of 26.67 % implies a relatively moderate level of intensity in the return *spillovers* across used assets.

Table 4 reports the results for the lower (5th) quantile, which represents the bear market conditions. Results show that the own-share *spillovers* are lower than those experienced in normal market conditions, with the highest value occurring for Singapore (88.10 %) with respect to sukuk, and 17.14 % for CH GB with respect to green bonds. Regarding sukuk indices, findings reveal that the highest impact still originates from UK to the Nigerian sukuk market (30.36 %), followed by Hong Kong on the Malaysian sukuk market (26.03

[2] For Sukuk prices, we use the Bloomberg generic price (BGN), a market consensus price for corporate and government bonds calculated using prices from several sources in order to obtain highly accurate quotes.

Table 1
Composition of the Sukuk Index.

	Country	Sukuk
	Bahrain	4
	Kuwait	5
GCC Countries	Oman	4
	Qatar	7
	Saudi Arabia	5
	United Arab Emirates (UAE)	16
Asian Countries	Hong Kong	1
	Indonesia	35
	Malaysia	47
	Pakistan	5
	Singapore	5
African countries	Nigeria	3
European Countries	Ireland	1
	Turkey	12
	United Kingdom (UK)	3

Note: We used the daily return of Sukuk data available on the Bloomberg database, for the period from 01 January 2016 to 01 April 2022. To construct country sukuk indices we use the same methodology of Bloomberg Index.

Table 2
Descriptive statistics of Sukuk, green bonds and global factor returns.

	Mean	Max	Min	SD	Skew	Kurt	ADF	PP
Sukuk markets								
BAHRAIN	0.001	0.538	−0.538	0.026	−0.354	288.748	−15.36***	−15.39***
HONG KONG	0.001	0.130	−0.208	0.019	−1.913	28.888	-22.28***	-22.07***
INDONESIA	0.001	1.524	−1.086	0.186	0.559	12.188	−8.49***	−16.85***
IRELAND	−0.002	0.623	−1.015	0.128	−0.564	9.209	-23.23***	-26.32***
KUWAIT	0.001	0.707	−1.025	0.095	−0.812	17.558	−10.51***	−16.71***
MALAYSIA	−0.002	1.014	−1.002	0.157	−0.066	10.482	−13.90***	−20.49***
NIGERA	0.002	0.501	−1.024	0.079	−1.638	36.484	−15.94***	−15.65***
OMAN	0.001	0.085	−0.079	0.008	0.023	30.962	−17.85***	−17.82***
PAKISTAN	0.013	2.246	−1.805	0.175	4.078	63.149	−12.32***	−13.97***
QATAR	0.001	0.269	−0.441	0.020	−6.242	249.059	−19.72***	−19.73***
SAUDI ARABIA	0.001	0.065	−0.052	0.006	1.215	40.993	−17.76***	−17.79***
SINGAPORE	−0.002	0.623	−1.015	0.128	−0.564	9.209	−13.06***	−12.70***
TURKEY	0.030	6.387	−2.813	0.427	2.856	49.426	−19.69***	−19.71***
UAE	0.001	0.007	−0.008	0.001	0.089	9.002	−19.04***	−19.05***
UK	−0.002	1.400	−3.610	0.284	−1.420	24.165	−28.61***	−28.73***
Green bonds								
FTSE Chinese (Onshore CNY) Green Bond Index (CH GB)	0.014	0.006	−0.010	0.001	−1.228	35.991	−18.639***	−38.461***
Bloomberg Barclays MSCI Euro Green Bond Index (EU GB)	0.062	0.020	−0.032	0.005	−1.263	10.859	−18.730***	−19.23***
Bloomberg Barclays MSCI Green bond index (GL GB)	0.032	0.035	−0.059	0.009	−1.162	11.242	−19.734***	−20.34***
Bloomberg Barclays MSCI US Green Bond Index (US GB)	0.067	0.022	−0.039	0.005	−1.791	17.369	−21.695***	−22.67***
Global factors								
GVZ	0.015	0.298	−0.266	0.052	0.584	6.418	−44.159***	−44.819***
OVX	0.009	0.858	−0.622	0.068	1.946	32.645	−31.282***	−42.376***
VIX	0.005	0.768	−0.300	0.082	1.431	11.371	−43.833***	−45.725***

Note: This table provides the descriptive statistics for the Sukuk, Green bonds and Global factors of the sample under study. Max, Min, SD, Skew, Kurt and JB represents Maximum, Minimum, Standard Deviation, Skewness, Kurtosis, and Jarque-Bera, respectively. *** Indicates significance at 1%.

%). For GB indices, the highest recorded impacts are from US GB to GL GB (10.42 %) and EU GB (10.15 %), and from EU GB to US GB (10.16 %). Similar to the results of the (50th) quantile, US GB and EU GB, and Malaysia and Hong Kong sukuk markets are found to be two-way transmitters and receivers of shocks, respectively. Considering global risk factors, their impact on sukuk and green bond indices is higher than that reported for normal market conditions (Table 3) albeit moderate. The highest shares are displayed by the Irish, Saudi and UAE sukuk markets, regarding sukuk indices. The range is between 0.02 and 6.71 % with respect to GVZ, 0.33–6.41 % with respect to OVX, and between 0.05 and 6.38 % with respect to VIX. Results for VIX do not corroborate those of Sclip et al. (2016) who find a strong correlation between the volatilities of sukuk and US stock market.

Among all series, the Pakistani, the Saudi and the Emirati sukuk markets as well as all used GB indices and risk factors are net transmitters of shocks, displaying the highest *spillovers* to the other markets (more than 92 %). The main receivers are the Kuwaiti, Bahraini and Indonesia sukuk markets with net *spillover* values of −38.30 %, −29.40 % and −29.40 %, respectively. The average TCI is of 68.23 % which indicates a high level of strength in return *spillovers*.

Table 5 summarizes the complete sample of the upper quantile (95th) connectedness, which represents bull market conditions.

Table 3
Middle quantile (50th) spillover index between Sukuk, Green bonds and Global factors.

	BAH	HK	IND	IRL	KUW	MAL	NIG	OMA	PAK	QAT	SAU	SIN	TUR	UAE	UK	CHGB	EUGB	GLGB	USGB	GVZ	OVX	VIX	FROM
BAH	80.94	3.49	6.8	0.36	0.13	1.65	0.01	3.47	0.64	0.07	0.35	0.22	0.01	0.39	0.24	0.02	0.21	0.24	0.24	0.22	0.07	0.23	**19.06**
HK	2.16	49.97	0.01	5.5	2.63	25.69	0.07	0.06	0.12	0.37	0.79	2.09	8.78	0.73	0.08	0.02	0.22	0.28	0.28	0.07	0.01	0.09	**50.03**
IND	6.72	0.01	79.99	0.01	0.67	0.01	0.01	7.6	0.07	0.03	0.1	0.01	1.46	0.93	1.51	0.01	0.01	0.27	0.01	0.07	0.45	0.09	**20.01**
IRL	0.35	8.74	0.01	79.33	0.81	6.35	0.01	0.01	0.01	0.1	0.41	0.6	3.09	0.05	0.01	0.02	0.01	0.04	0.01	0.01	0.02	0.06	**20.67**
KUW	0.14	4.22	0.68	0.82	80.2	3.08	0.01	0.22	1.81	0.01	0.99	0.8	0.28	2.42	4.22	0.02	0.01	0.02	0.07	0.01	0.01	0.01	**19.80**
MAL	1.11	27.94	0.01	4.35	2.09	54.32	0.04	0.01	0.01	0.26	0.88	1.79	6.98	0.11	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.03	**45.68**
NIG	0.01	0.09	0.01	0.01	0.01	0.05	67.83	0.01	0.01	0.03	0.01	0.01	0.03	0.01	31.87	0.01	0.02	0.01	0.01	0.01	0.02	0.01	**32.17**
OMA	3.68	0.11	8.15	0.02	0.24	0.02	0.01	85.99	0.02	0.05	0.37	0.01	0.99	0.01	0.06	0.01	0.08	0.08	0.02	0.01	0.1	0.01	**14.01**
PAK	0.61	0.16	0.07	0.06	1.75	0.05	1.22	0.04	77.24	2.77	1.43	0.07	0.64	1.51	0.62	0.01	2.34	2.78	4.35	0.53	0.93	0.83	**22.76**
QAT	0.13	0.67	0.07	0.15	0.01	0.43	0.34	0.05	2.65	87.24	0.91	0.04	0.01	0.12	0.71	0.02	1.08	1.93	1.92	0.48	0.68	0.37	**12.76**
SAU	0.33	1.17	0.09	0.39	0.95	1.22	0.04	0.4	1.39	0.72	75.52	0.16	1.84	0.21	2.33	0.01	7.07	2.12	4.02	0.02	0.01	0.01	**24.48**
SIN	0.24	3.48	0.01	0.68	0.9	2.97	0.01	0.01	0.06	0.04	0.19	89.84	1	0.34	0.01	0.05	0.04	0.05	0.05	0.01	0.03	0.03	**10.16**
TUR	0.01	12.1	1.26	2.69	0.24	8.86	0.03	0.79	0.37	0.01	1.69	0.77	68.97	0.02	0.58	0.01	0.62	0.58	0.32	0.01	0.01	0.1	**31.03**
UAE	0.44	1.19	0.97	0.07	2.4	0.17	0.2	0.01	1.54	0.05	0.17	0.31	0.13	79.3	8.36	0.02	2.18	0.73	1.59	0.09	0.02	0.09	**20.70**
UK	0.18	0.1	1.11	0.01	3.11	0.02	27.79	0.04	0.08	0.23	1.7	0.01	0.5	5.74	59.14	0.01	0.12	0.05	0.06	0.01	0.01	0.01	**40.86**
CH GB	0.06	0.07	0.01	0.12	0.06	0.03	0.01	0.01	0.04	0.02	0.03	0.07	0.02	0.05	0.01	99.11	0.01	0.01	0.1	0.07	0.1	0.04	**0.89**
EU GB	0.18	0.67	0.01	0.02	0.02	0.11	0.02	0.13	1.73	0.67	5.32	0.09	0.52	1.67	0.15	0.01	55.64	13.64	19.01	0.08	0.16	0.17	**44.36**
GL GB	0.19	0.42	0.23	0.08	0.07	0.01	0.04	0.09	2.35	1.18	1.92	0.03	0.64	0.73	0.1	0.01	14.13	58.09	18.8	0.14	0.29	0.44	**41.91**
US GB	0.14	0.32	0.01	0.01	0.07	0.01	0.08	0.02	3.04	1.09	2.94	0.04	0.29	1.13	0.27	0.03	18.05	16.55	53.48	0.74	0.32	1.4	**46.52**
GVZ	0.2	0.1	0.27	0.01	0.02	0.03	0.23	0.02	0.05	0.38	0.12	0.09	0.01	0.02	0.01	0.26	0.02	0.2	0.89	77	5.88	14.22	**23.00**
OVX	0.13	0.01	0.47	0.14	0.01	0.07	0.09	0.16	0.7	0.57	0.01	0.03	0.01	0.01	0.02	0.09	0.23	0.02	0.49	6.13	80.53	10.09	**19.47**
VIX	0.19	0.13	0.14	0.06	0.04	0.04	0.22	0.02	0.03	0.28	0.01	0.07	0.1	0.05	0.03	0.01	0.14	0.08	1.77	13.68	9.24	73.67	**26.33**
TO	**17.19**	**65.17**	**20.31**	**15.53**	**16.20**	**50.86**	**30.46**	**13.15**	**16.72**	**8.90**	**20.30**	**7.26**	**27.31**	**16.24**	**51.16**	**0.60**	**46.58**	**39.69**	**54.01**	**22.33**	**18.38**	**28.33**	**26.67**
NET	**−1.87**	**15.14**	**0.30**	**−5.15**	**−3.59**	**5.18**	**−1.71**	**−0.86**	**−6.04**	**−3.86**	**−4.18**	**−2.90**	**−3.72**	**−4.46**	**10.30**	**−0.30**	**2.21**	**−2.22**	**7.49**	**−0.67**	**−1.09**	**2.00**	

Note: The above table illustrate the Quantile VAR spillovers for Total, net and pairwise at the middle quantile (0.50) which represent the normal market condition.

Table 4
Lower quantile (5th) spillover index between Sukuk, Green bonds and Global factors.

	BAH	HK	IND	IRL	KUW	MAL	NIG	OMA	PAK	QAT	SAU	SIN	TUR	UAE	UK	CHGB	EUGB	GLGB	USGB	GVZ	OVX	VIX	FROM
BAH	41.2	0.07	0.26	1.82	1.36	0.25	0.01	2.34	5.62	3.67	5.31	0.22	1.88	4.18	1.05	4.13	5.47	5.32	5.34	3.44	3.57	3.45	**58.80**
HK	0.36	29	1.01	6.85	0.09	13.81	0.06	0.04	3.48	4.22	2.94	0.42	1.23	5.73	0.87	3.57	4.98	4.87	4.93	4.13	3.51	3.88	**71.00**
IND	0.21	1.34	37.36	3.2	2.1	0.09	0.01	1.74	4.93	4.05	4.57	0.06	4.24	2.54	0.04	4.61	5.44	6.09	5.18	4.38	3.61	4.24	**62.64**
IRL	0.95	5.02	2	21.31	0.69	1.97	0.05	0.13	5.71	4.81	6	0.05	1.2	4.77	0.76	5.72	6.91	6.69	6.75	6.71	5.42	6.38	**78.69**
KUW	1.57	0.58	2.32	2.01	37.57	0.71	0.09	0.42	6.93	3.95	6.46	0.68	2.4	1.84	0.61	3.69	4.75	5.14	5.32	4.24	4.04	4.66	**62.43**
MAL	0.3	26.03	0.13	5.25	1	54.99	0.04	0.01	0.85	1.41	0.09	1.62	2.81	0.94	0.06	0.49	0.92	0.81	0.75	0.53	0.5	0.49	**45.01**
NIG	0.01	0.07	0.01	0.02	0.04	0.05	68.7	0.01	0.04	0.05	0.05	0.01	0.02	0.04	30.36	0.13	0.04	0.04	0.1	0.02	0.16	0.05	**31.30**
OMA	4.52	0.07	3.69	0.48	0.71	0.01	0.01	79.41	0.93	0.92	1.57	0.03	0.06	0.74	0.01	0.89	1.31	0.65	1.07	0.81	1.19	0.94	**20.59**
PAK	2.12	1.81	1.94	4.14	2.04	0.34	0.14	0.2	15.38	6.16	7.65	0.13	3.03	6.33	0.85	5.78	8.45	8.3	8.34	5.88	5.13	5.86	**84.62**
QAT	1.75	2.58	2.11	4.41	1.43	0.5	0.02	0.2	7.51	15.75	7.28	0.11	2.91	6.01	1.1	6.17	7.63	8.52	7.99	5.44	5.05	5.54	**84.25**
SAU	1.96	1.51	1.71	3.81	1.9	0.04	0.02	0.28	7.69	5.83	13.87	0.13	3.38	5.27	0.71	6.25	9.21	8.25	8.61	6.6	6.41	6.56	**86.13**
SIN	0.47	1.04	0.12	0.11	1.44	2.66	0.01	0.03	0.17	0.2	0.73	88.1	1.52	0.33	0.55	0.33	0.39	0.5	0.51	0.27	0.33	0.18	**11.90**
TUR	1.3	0.41	3.29	1.45	1.45	1.52	0.03	0.03	5.52	3.81	7.09	0.54	29.65	3.83	1.52	5.14	6.52	6.43	6.1	5.08	4.76	4.53	**70.35**
UAE	1.96	3.61	1.16	3.91	0.34	0.55	0.02	0.18	6.92	4.91	5.87	0.26	2.94	18.19	3.33	5.52	7.8	7.5	7.42	6.04	5.69	5.87	**81.81**
UK	1.17	0.51	0.02	1.3	0.44	0.11	19.57	0.02	2.63	1.1	1.06	0.18	2.42	6.43	44.28	2.51	2.94	2.67	3.1	2.31	2.69	2.53	**55.72**
CH GB	1.69	1.97	2.08	4.16	1.29	0.14	0.06	0.19	6.17	5.09	7.15	0.07	2.99	5.05	0.93	17.14	7.73	7.39	7.77	7.16	7	6.77	**82.86**
EU GB	1.72	2.29	2.19	4.05	1.3	0.28	0.01	0.24	7.38	5.5	8.18	0.07	2.96	5.87	0.86	5.83	12.96	9.5	10.15	6.25	6.12	6.3	**87.04**
GL GB	1.72	2.22	2.17	4.08	1.34	0.2	0.01	0.12	7.25	5.56	7.39	0.07	3.08	5.73	0.83	6.1	9.8	13.74	10.42	6.47	5.61	6.09	**86.26**
US GB	1.68	2.08	1.82	3.72	1.34	0.18	0.05	0.19	7.19	5.47	7.5	0.09	2.91	5.52	1.01	6.08	10.16	9.99	13.44	6.64	6.13	6.8	**86.56**
GVZ	1.26	2.13	1.8	4.38	1.27	0.14	0.01	0.16	6.11	4.51	6.87	0.05	2.57	5.16	0.74	6.45	7.59	7.41	7.73	15.5	8.35	9.79	**84.50**
OVX	1.45	1.9	1.6	4.02	1.27	0.15	0.07	0.26	5.6	4.37	6.83	0.07	2.66	5.14	0.97	6.78	7.78	6.85	7.6	8.81	16.47	9.34	**83.53**
VIX	1.23	1.98	1.79	4.41	1.27	0.13	0.03	0.16	5.94	4.49	6.82	0.04	2.38	5.15	0.85	6.51	7.73	7.12	8.24	9.87	8.92	14.95	**85.05**
TO	**29.40**	**59.23**	**33.24**	**67.59**	**24.12**	**23.83**	**20.30**	**6.95**	**104.6**	**80.09**	**107.4**	**4.91**	**49.58**	**86.59**	**48.01**	**92.67**	**123.5**	**120.1**	**123.4**	**101.08**	**94.19**	**100.24**	**68.23**
NET	**−29.4**	**−11.8**	**−29.4**	**−11.1**	**−38.3**	**−21.2**	**−11.0**	**−13.6**	**19.95**	**−4.16**	**21.31**	**−6.99**	**−20.8**	**4.79**	**−7.71**	**9.81**	**36.51**	**33.78**	**36.86**	**16.58**	**10.66**	**15.19**	

Note: The above table illustrate the Quantile VAR spillovers for Total, net and pairwise at the lower quantile (0.05) which represent the bear market condition.

Table 5
Upper quantile (95th) spillover index between Sukuk, Green bonds and Global factors.

	BAH	**HK**	**IND**	**IRL**	**KUW**	**MAL**	**NIG**	**OMA**	**PAK**	**QAT**	**SAU**	**SIN**	**TUR**	**UAE**	**UK**	**CHGB**	**EUGB**	**GLGB**	**USGB**	**GVZ**	**OVX**	**VIX**	**FROM**
BAH	39.44	0.27	0.29	2.2	1.24	0.29	0.08	2.05	5.64	3.26	4.83	0.46	1.44	4.52	1.55	4.26	5.19	5.14	4.34	4.62	4.27	4.62	**60.56**
HK	0.06	32.59	1.28	7.64	0.08	16.66	0.06	0.01	2.65	3.5	1.92	0.68	0.88	4.08	0.15	3.4	4.12	4.21	4.39	4.22	3.41	4.01	**67.41**
IND	0.21	1.11	29.39	3.73	2.38	0.09	0.04	1.28	5.22	4.34	5.09	0.17	4.03	3.33	0.06	5.58	5.63	6.31	5.48	6.27	4.52	5.75	**70.61**
IRL	0.87	4.83	2.36	20.52	0.92	1.9	0.02	0.1	5.7	5.02	5.55	0.05	0.83	5.04	0.57	6.08	6.47	6.82	6.12	7.64	5.94	6.67	**79.48**
KUW	1.33	0.2	3.16	1.97	38.25	0.59	0.04	0.3	5.59	3.41	6.09	0.84	2.24	1.35	0.56	4.21	4.46	4.93	4.6	5.62	4.89	5.38	**61.75**
MAL	0.36	26.84	0.14	4.95	0.79	52.52	0.11	0.01	0.87	1.15	0.15	1.41	3.39	0.96	0.28	0.8	1.1	1.08	0.82	0.77	0.69	0.81	**47.48**
NIG	0.01	0.12	0.03	0.04	0.01	0.08	80.45	0.01	0.02	0.14	0.01	0.01	0.02	0.04	18.96	0.01	0.01	0.02	0.01	0.01	0.02	0.01	**19.55**
OMA	4.22	0.06	3.63	0.43	0.67	0.02	0.01	81.11	0.82	0.71	1.36	0.05	0.17	0.67	0.1	0.7	1.05	0.55	0.8	0.85	1.06	0.97	**18.89**
PAK	2	1.02	2.42	3.9	2.01	0.33	0.31	0.12	14.31	4.8	6.49	0.25	2.77	5.91	2.51	6.3	7.89	7.45	7.69	7.41	6.69	7.41	**85.69**
QAT	1.45	2.1	2.66	4.79	1.51	0.46	0.13	0.14	6.75	18.97	7.04	0.16	2.17	5.17	0.41	6.55	6.99	7.53	7.27	6.33	5.01	6.4	**81.03**
SAU	1.74	1.01	2.34	4.5	2.21	0.05	0.04	0.25	6.53	5.67	15.31	0.26	3.19	4.68	0.16	6.41	8.63	7.75	8.23	7.86	6.19	7	**84.69**
SIN	0.96	1.62	0.41	0.06	1.69	2.49	0.01	0.05	0.59	0.51	1.34	80.6	2.06	0.46	0.2	0.65	1.14	1.43	1.16	0.86	0.7	1.01	**19.40**
TUR	1.21	0.81	3.78	1.31	1.68	2.08	0.02	0.07	5.26	3.77	6.76	0.75	31.69	3.48	1.33	4.77	5.99	5.59	5.37	5.42	4.32	4.52	**68.31**
UAE	1.66	2.38	2.25	4.37	0.67	0.32	0.02	0.13	6.83	4.82	5.56	0.37	2.02	17.92	2.75	6.05	7.27	7.08	7.17	7.09	6.2	7.08	**82.08**
UK	1.07	0.18	0.06	1.2	0.77	0.03	17.67	0.05	2.9	0.67	0.63	0.13	1.77	7	48.6	2.11	2.81	2.66	2.39	2.14	2.75	2.42	**51.40**
CH GB	1.45	1.68	2.77	4.85	1.66	0.25	0.02	0.14	6.36	5.29	6.54	0.15	2.38	5.17	0.72	16.3	7.09	7.26	7.09	8.08	7.11	7.62	**83.70**
EU GB	1.55	1.66	2.26	4.47	1.31	0.23	0.15	0.15	6.89	4.77	7.38	0.22	2.45	5.6	1.43	6	13.57	9.46	9.45	7.29	6.69	7.03	**86.43**
GL GB	1.6	1.75	2.66	4.46	1.57	0.24	0.15	0.08	6.87	5.31	6.5	0.25	2.34	5.3	1.21	6.04	9.65	13.76	9.67	7.14	6.26	7.19	**86.24**
US GB	1.37	2.11	2.36	4.07	1.42	0.27	0.02	0.12	6.92	5.25	6.83	0.2	2.26	5.55	0.69	6	9.7	9.76	13.62	7.47	6.54	7.46	**86.38**
GVZ	1.23	1.78	2.59	5.23	1.76	0.16	0.01	0.13	6.09	4.66	6.79	0.15	2.38	5.23	0.67	6.96	7.23	7.31	7.56	14.06	8.16	9.87	**85.94**
OVX	1.16	2.01	2.21	4.55	1.78	0.23	0.33	0.17	6.02	4.31	6.14	0.21	1.99	5.09	1.21	6.61	7.5	7.04	7.36	9	15.41	9.67	**84.59**
VIX	1.32	1.69	2.56	4.73	1.91	0.16	0.02	0.13	5.9	4.85	6.51	0.18	2	5.32	0.75	6.79	7.27	7.4	7.54	10.11	8.82	14.04	**85.96**
TO	**26.82**	**55.21**	**42.21**	**73.44**	**28.05**	**26.92**	**19.25**	**5.48**	**100.4**	**76.22**	**99.51**	**6.94**	**42.78**	**83.96**	**36.27**	**96.26**	**117.2**	**116.8**	**114.5**	**116.18**	**100.26**	**112.89**	**68.00**
NET	**–33.8**	**−12.2**	**−28.4**	**−6.04**	**–33.7**	**−20.6**	**−0.29**	**−13.5**	**14.7**	**−4.81**	**14.8**	**−12.5**	**−25.5**	**1.88**	**−15.1**	**12.6**	**30.8**	**30.5**	**28.1**	**30.2**	**15.7**	**26.1**	

Note: The above table illustrate the Quantile VAR spillovers for Total, net and pairwise at the upper quantile (0.95) which represent the bull market condition.

Reported results indicate that the highest own-share *spillover* happens in the case of Oman with 81.11 %, followed by Nigeria with 80.45 % with regard to sukuk indices, and in the case of CH GB with 16.30 % with regard to green bonds. For sukuk, the highest impact is caused by Hong Kong on Malaysian market (26.84 %), with the two markets being main two-way transmitters and receivers of shocks (with 16.66 % from Malaysia to Hong Kong). The same conclusion is found for UK and Nigeria with respective values of 18.96 % and 17.67 % of pairwise *spillover*.

For global risks, the same conclusions as for the lower information quantile are drawn. Specifically, *spillover* from risk factors to global financial markets is moderate and ranges from 0.01 % to 8.08 % with respect to GVZ, from 0.02 % to 7.11 % with respect to OVX, and from 0.01 % to 7.62 % with respect to VIX. Results also indicate that CH GB is the main receiver of shocks from global factors. Regarding sukuk, the Irish, Pakistani, Saudi as well as Emirati markets tend to be the main receivers of shocks from the same factors. Results also reveal that Pakistani, Saudi and Emirati sukuk indices are the only net transmitters of shocks among all used sukuk indices. In addition, all used green bonds indices as well as global risk factors appear to be net transmitters, with EU GB (30.80 %), GL GB

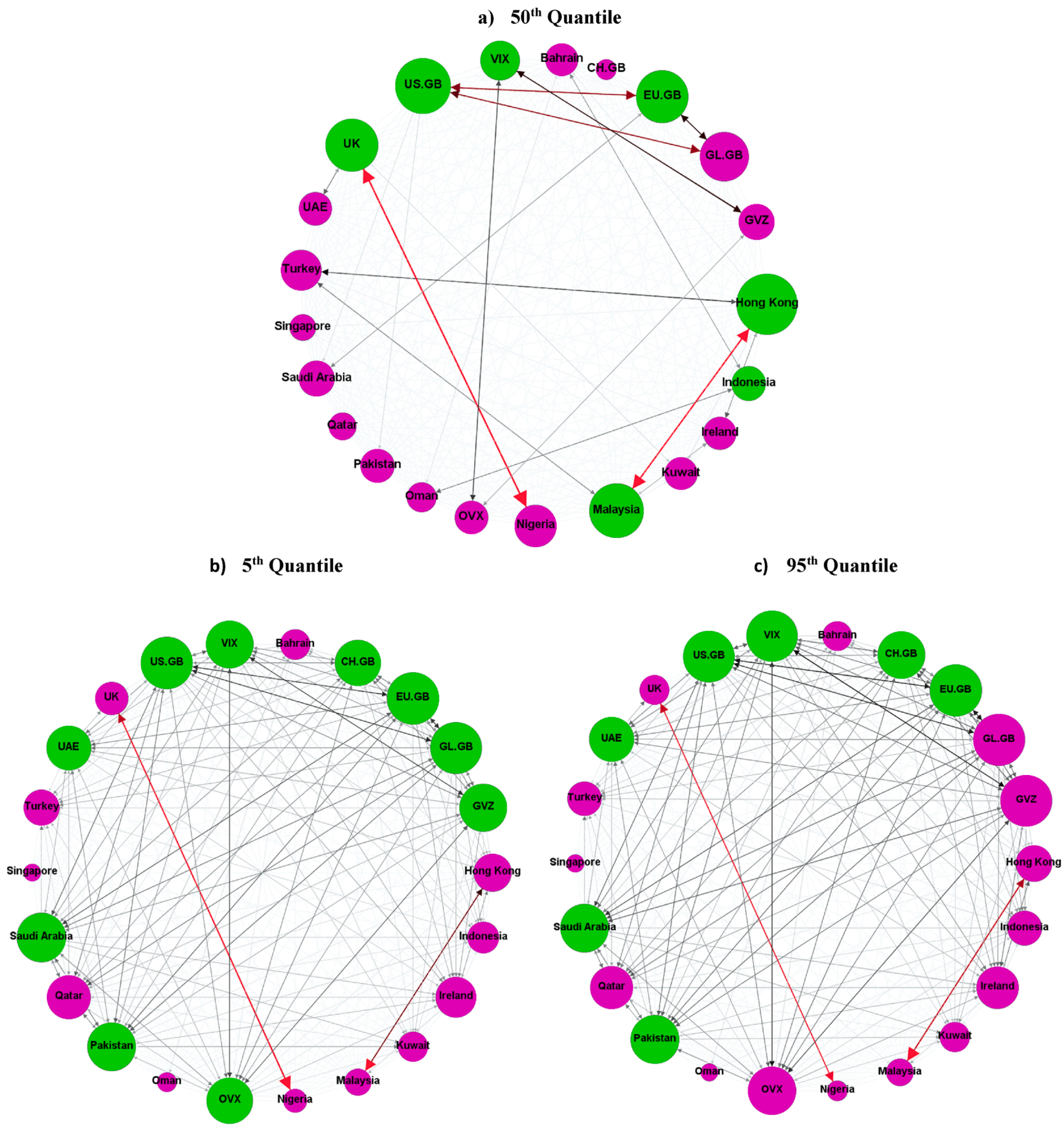

Fig. 2. The above graphs depict the Network Connectedness between Sukuk, Green bonds and Global factors. The Lag 1 has been used and 10 days have been taken for Forecast horizon. Note: The size of the node shows the magnitude of contribution of each variable to system connectedness, while the colour indicates the origin of connectedness. Node size signifies the extent of spillovers effect and colour specifies whether a market is a net transmitter (green) or recipient (pink) of spillovers. The forced directed layout algorithm set node location where the sum of the vectors set the node route. Arrow width signifies the strength of the pair-wise spillovers and colour specifies strongest (red) to weakest (black) directions of spillovers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

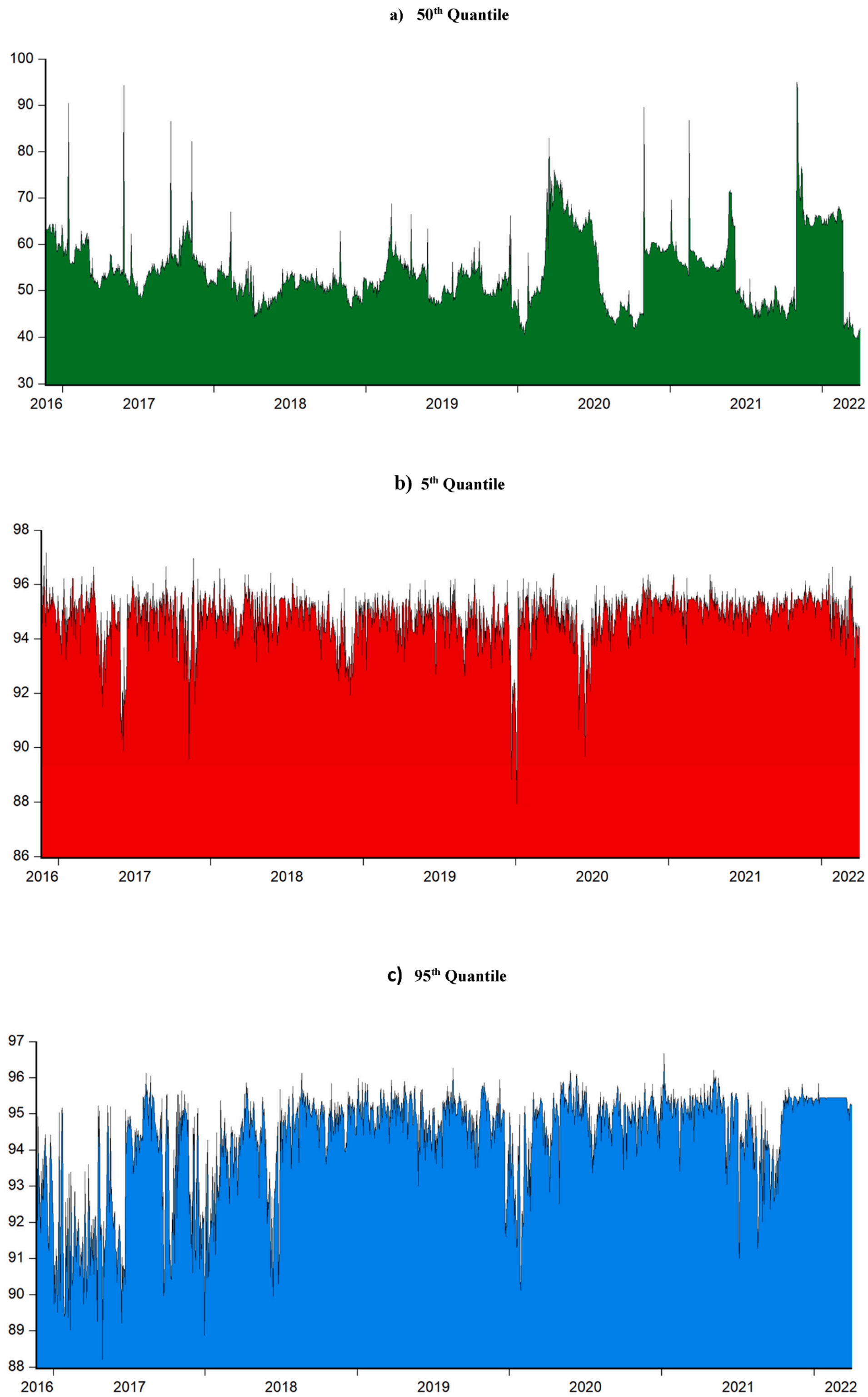

Fig. 3. The above graph depicts the Time-Varying spillovers between Sukuk, Green bonds and Global factors at the middle, lower and upper quantiles. The rolling window has been considered 200 days and 10 days forecast horizon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a) 50th Quantile

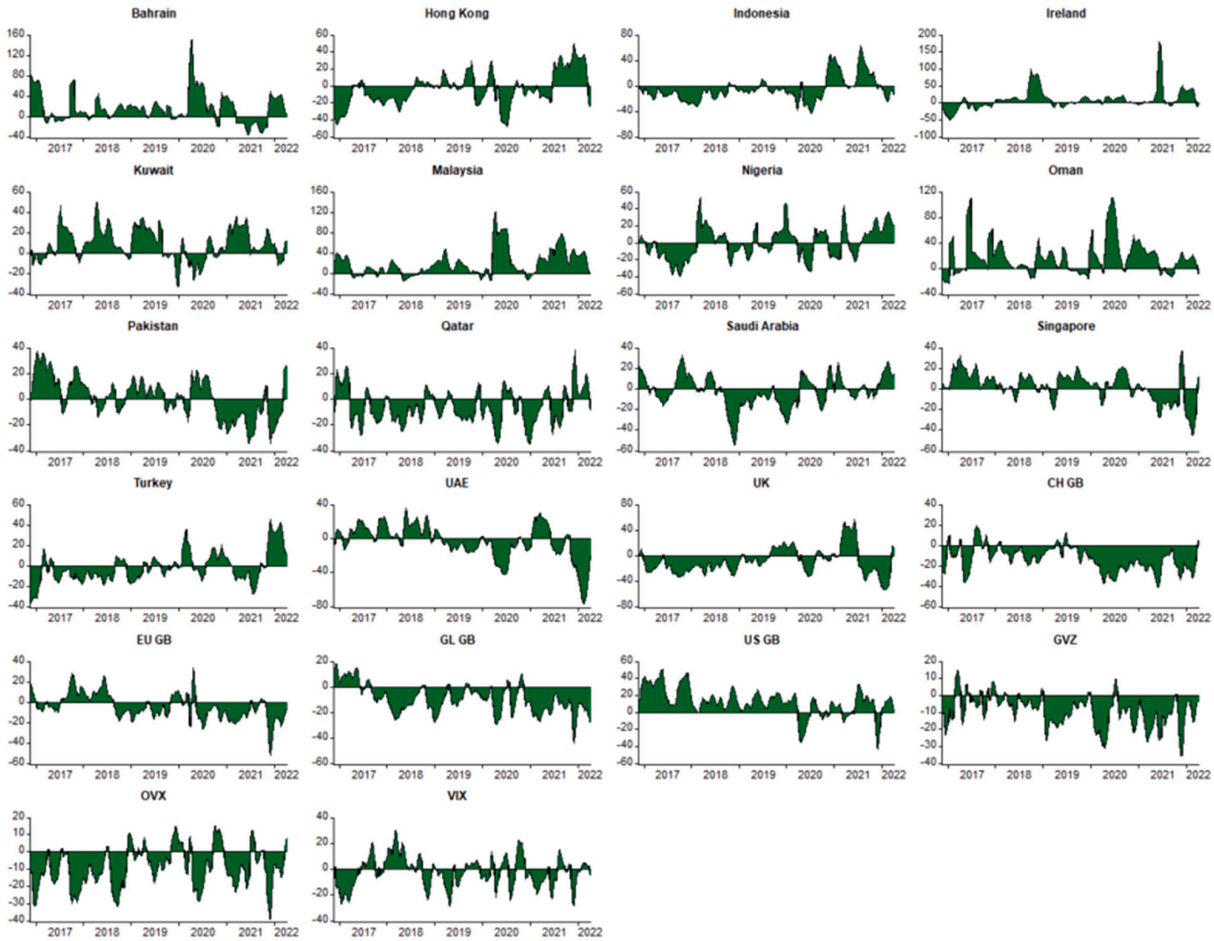

Fig. 4. The above graph depicts the Time-Varying Net spillovers between Sukuk, Green bonds and Global factors at the middle, lower and upper quantiles. The rolling window has been considered 200 days and 10 days forecast horizon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(30.50 %), and GVZ (30.20 %) being the main risk transmitters. The main net receivers are the Bahraini (-30.80 %) and the Kuwaiti (-30.70 %) sukuk markets.

The level of TSI within the overall return connectedness is of about 68.00 % implying a strong level of return spillover across used variables. This average value demonstrates the average connectedness which might hide time-specific and time-varying effects. We examine, in section 3.3, the dynamic connectedness between the variables.

3.2. Direction and strength of the spillover in quantiles between Sukuk, green bonds and global factors

To better elucidate the direction and intensity of *spillover* between sukuk, green bonds and global factors, Fig. 2 depicts the network of directional connectedness among used markets and risk factors under normal (graph a), bearish (graph b) and bullish (graph c) market periods. The direction of the arrow from one market or factor to another denotes the average *spillover* interaction between the pair. That is, an arrow from *x* to *y* indicates that *y* is a receiver of shocks from *x*. The width of the arrow designates the strength of the pairwise *spillover*, with colours red and black specifying the strongest and weakest *spillover* directions, respectively. The size of nodes shows the magnitude of contribution of each variable to the system connectedness, and colours pink and green specify net receivers and net transmitters of shocks, respectively.

The graphs show some interesting and complementing results to those derived from Tables 3–5. Specifically, we find that the strongest pairwise *spillovers*, for the median (50th) quantile (panel a), are between Hong Kong and Malaysia, and between UK and Nigerian sukuk markets. A lower but substantial connection is also found between US and EU green bonds, and between US and GL green bonds. The logical explanation of this result is that these sukuk and green bond markets are highly integrated into the global

b) 5th Quantile

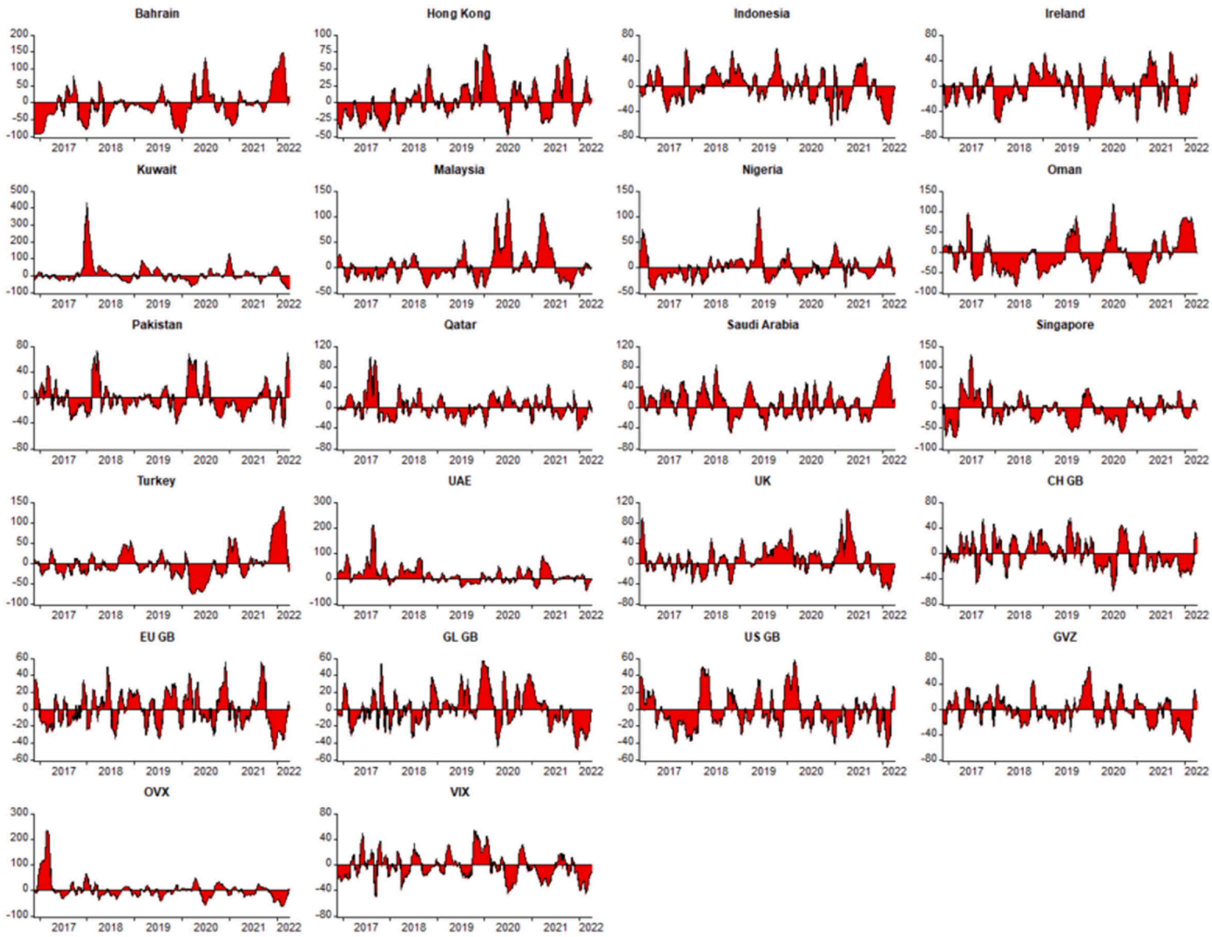

Fig. 4. (*continued*).

sukuk and green bond systems, respectively.

Apart from these connections, the graph shows interesting diversification opportunities for sukuk and green bonds for investors and hedging of the risk of dramatic fluctuations in global risk factors. This results are aligned with previous empirical findings (see for example, Albuquerque et al., 2020; Ferrer et al., 2021; Karim and Naeem, 2022; Mensi et al., 2022, among others).

Graphs (b) and (c) of Fig. 2 depict the connectedness system for the lower (5th) and upper (95th) quantiles, respectively. The strongest pairwise connections appear to be between UK and Nigerian, and between Hong Kong and Malaysian sukuk markets. This complements the results in Tables 4 and 5, which show that these markets are net receivers of shocks. The results also imply that, in both bearish and bullish market conditions, all other sukuk and green bond markets are not significantly affected by shocks from other asset markets and global risks in our sample. This finding does not seem to be consistent with previous literature findings on the strong volatility linkages between Islamic countries (Bley and Chen, 2006; Akhtar et al., 2017; Sclip et al., 2016). The results are rather not strongly significant for sukuk of Islamic countries in our study.

In summary, Fig. 2 demonstrates an important aspect of stability in the connection between Hong Kong and Malaysian, and UK and Nigerian sukuk markets in the middle, lower and upper quantiles. Investors' awareness of these connections helps diversify their risk with other ethical assets. Also, the negligible importance of global risks as transmitters of shocks in this connectedness system demonstrates the sizeable risk mitigation properties of these asset markets.

3.3. Time-varying in-quantile total and net connectedness between Sukuk, green bonds and global factors

Market interconnections and relationships tend to vary over time and the level of connectedness among them is recognizably associated to market conditions (e.g., Baumöhl, 2019; Bouri et al., 2020; Bouri et al., 2021; Mensi et al., 2021; Billah et al., 2022). In line with this evidence highlighting tail-based dependencies between markets and given that our sample period encompasses several important events that may affect the degree of connectedness among markets, we examine the dynamic total *spillover* between our used

c) 95th Quantile

Fig. 4. (*continued*).

variables as depicted by Fig. 3, at the middle (graph a), lower (graph b), and upper (graph c) quantiles. We consider a 200-day rolling window and a 10-day forecast horizon to assess this time-varying *spillover*.

Looking at graph (a), fluctuations in the total connectedness over the sample period in the middle quantile (40 to 95) indicate the high volatility of used markets and factors. More specifically, under the middle quantile, the total *spillover* reached more than 90 in 2016, 2017, and 2020 to 2022. These findings align with expectations, as the period under consideration includes several crisis events. Indicatively, the high total spillover in 2016 and 2017 can be attributed to the long-term effects of the Euro Debt Crisis that started in 2013 and the slow recovery of the global economy (Shahzad et al., 2017). After a relatively smooth period between 2018 and 2019, the dynamic *spillover* shows many other peaks in 2020 to 2022 attributable to the Covid-19 led crisis.

Spillovers of the lower (graph b) and the upper (graph c) quantiles reached between 88 and 97. In both quantiles, there was a relative decline in return *spillover* in 2017 and 2020. This result is somehow surprising. Particularly, amid the outbreak of the Covid-19 pandemic, the dynamics of interdependence between financial markets are expected to increase, as argued by several studies (e.g., Aslam et al., 2020; Zhang et al., 2020; Adekoya and Oliyide, 2021; Guo et al., 2021). The outcome of the declining *spillover* between sukuk, green bonds and global risk factors, in these times of crisis, validates the hedging properties of these assets during the early period of the pandemic (Naeem et al., 2021; Arfaoui et al., 2022).

In conclusion, our findings show significant albeit high fluctuations in *spillover* over the entire sample period between used variables. Importantly, while we find a decline in the overall *spillover* of sukuk, green bonds and global risk factors during certain periods of time, inducing increased potential diversification benefits, investors should remain aware of the subsequent increases that tend to increase the interdependence between these assets, in relation to global risks. In other words, our results indicate that sukuk and green bonds are not immune to external shocks during the sample period, and investors are advised to continuously rebalance their portfolios and adjust structure accordingly.

Fig. 4 shows the connectedness of the rolling net spillovers in the middle (graph a), lower (graph b) and the upper (graph c) quantiles. The figure depicts the timely contribution of each market or factor to the connectedness system as obtained from the net

Table 6
Hedge ratios, portfolio weights and hedging effectiveness of Sukuk and green bonds.

Panel A: Long position in green bonds and individual sukuk markets are in short position

Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (CH.GB/SUKUK)	*HR*	*OPW*	*HE (%)*	*Pairs (CH.GB/SUKUK)*	*HR*	*OPW*	*HE (%)*	*Pairs (EU.GB/SUKUK)*	*HR*	*OPW*	*HE (%)*	*Pairs (EU.GB/SUKUK)*	*HR*	*OPW*	*HE (%)*
CH.GB/Bahrain	1.73	0.62	52.0	*CH.GB/Bahrain*	−0.75	0.58	11.36	*EU.GB/Bahrain*	0.48	0.78	6.1	*EU.GB/Bahrain*	−0.23	0.62	4.37
CH.GB/Hong Kong	10.4	0.08	98.0	*CH.GB/Hong* Kong	−1.18	0.45	39.50	*EU.GB/Hong* Kong	4.45	0.29	4.0	*EU.GB/Hong* Kong	−0.82	0.3	10.50
CH.GB/Indonesia	1.6	0.2	97.0	*CH.GB/Indonesia*	0.21	0.88	9.96	*EU.GB/Indonesia*	−0.96	0.39	20.0	*EU.GB/Indonesia*	−0.34	0.69	6.63
CH.GB/Ireland	7.88	0.4	96.0	*CH.GB/Ireland*	−8.05	0.36	32.02	*EU.GB/Ireland*	8.4	0.65	19.7	*EU.GB/Ireland*	−4.43	0.28	13.80
CH.GB/Kuwait	−5.52	0.39	93.0	*CH.GB/Kuwait*	−0.07	0.67	11.14	*EU.GB/Kuwait*	0.97	0.25	33.0	*EU.GB/Kuwait*	−0.28	0.68	3.23
CH.GB/Malaysia	2.44	0.31	94.0	*CH.GB/Malaysia*	1.15	0.58	23.58	*EU.GB/Malaysia*	0.5	0.42	20.0	*EU.GB/Malaysia*	2.06	0.58	13.22
CH.GB/Nigeria	1.96	0.42	94.0	*CH.GB/Nigeria*	−1.28	0.65	2.62	*EU.GB/Nigeria*	0.43	0.58	50.0	*EU.GB/Nigeria*	1.21	0.69	2.03
CH.GB/Oman	8.04	0.5	28.0	*CH.GB/Oman*	−0.21	0.72	13.96	*EU.GB/Oman*	0.88	0.56	18.7	*EU.GB/Oman*	−0.03	0.84	1.48
CH.GB/Pakistan	4.41	0.2	97.0	*CH.GB/Pakistan*	−1.41	0.41	15.00	*EU.GB/Pakistan*	−0.35	0.34	32.0	*EU.GB/Pakistan*	−0.04	0.31	8.58
CH.GB/Qatar	0.74	0.14	97.0	*CH.GB/Qatar*	−1.8	0.4	8.22	*EU.GB/Qatar*	3.79	0.35	14.0	*EU.GB/Qatar*	1.02	0.29	8.70
CH.GB/Saudi Arabia	2.71	0.11	97.0	*CH.GB/Saudi* Arabia	0.03	0.27	15.66	*EU.GB/Saudi* Arabia	0.44	0.52	9.0	*EU.GB/Saudi* Arabia	0.85	0.24	5.03
CH.GB/Singapore	0.69	0.39	20.0	*CH.GB/Singapore*	0.47	0.67	91.44	*EU.GB/Singapore*	−0.06	0.7	24.2	*EU.GB/Singapore*	−0.06	0.74	69.94
CH.GB/Turkey	−0.39	0.41	87.0	*CH.GB/Turkey*	−0.38	0.61	9.10	*EU.GB/Turkey*	0.22	0.65	16.5	*EU.GB/Turkey*	−0.37	0.63	2.98
CH.GB/UAE	7.05	0.2	97.0	*CH.GB/UAE*	0.66	0.29	15.24	*EU.GB/UAE*	2.09	0.23	31.0	*EU.GB/UAE*	1.43	0.37	10.22
CH.GB/UK	1.97	0.32	95.0	*CH.GB/UK*	−0.86	0.39	12.80	*EU.GB/UK*	0.66	0.78	61.0	*EU.GB/UK*	1.69	0.28	8.73
GL.GB/Bahrain	0.49	0.89	12.0	*GL.GB/Bahrain*	0.49	0.57	23.00	*US.GB/Bahrain*	0.7	0.61	26.5	*US.GB/Bahrain*	−0.47	0.62	7.66
GL.GB/Hong Kong	5.75	0.29	95.0	*GL.GB/Hong* Kong	0.72	0.18	39.00	*US.GB/Hong* Kong	7.26	0.27	82.0	*US.GB/Hong* Kong	−2.38	0.39	20.58
GL.GB/Indonesia	−0.23	0.34	90.0	*GL.GB/Indonesia*	−0.41	0.59	11.00	*US.GB/Indonesia*	−0.9	0.38	83.0	*US.GB/Indonesia*	−0.46	0.7	7.35
GL.GB/Ireland	10.54	0.6	45.0	*GL.GB/Ireland*	−1.07	0.21	53.00	*US.GB/Ireland*	13.82	0.58	30.0	*US.GB/Ireland*	−7.26	0.33	21.80
GL.GB/Kuwait	−0.13	0.22	82.0	*GL.GB/Kuwait*	0.47	0.66	26.00	*US.GB/Kuwait*	1.29	0.25	83.0	*US.GB/Kuwait*	−0.42	0.67	7.27
GL.GB/Malaysia	0.18	0.44	85.0	*GL.GB/Malaysia*	−1.43	0.56	55.00	*US.GB/Malaysia*	0.55	0.38	85.0	*US.GB/Malaysia*	1.9	0.6	21.46
GL.GB/Nigeria	0.9	0.5	42.0	*GL.GB/Nigeria*	3.46	0.6	92.00	*US.GB/Nigeria*	0.3	0.42	61.0	*US.GB/Nigeria*	0.69	0.73	4.10
GL.GB/Oman	1.17	0.55	98.8	*GL.GB/Oman*	−0.09	0.85	9.00	*US.GB/Oman*	0.8	0.53	75.8	*US.GB/Oman*	0.02	0.87	3.68
GL.GB/Pakistan	−0.87	0.32	97.0	*GL.GB/Pakistan*	2.06	0.14	1.00	*US.GB/Pakistan*	−1.27	0.33	89.0	*US.GB/Pakistan*	0.3	0.4	21.78
GL.GB/Qatar	3.36	0.35	97.0	*GL.GB/Qatar*	2.83	0.34	60.00	*US.GB/Qatar*	5	0.36	88.0	*US.GB/Qatar*	1.04	0.28	13.70
GL.GB/Saudi Arabia	−1.22	0.37	91.0	*GL.GB/Saudi* Arabia	1.26	0.17	50.00	*US.GB/Saudi* Arabia	0.38	0.48	87.0	*US.GB/Saudi* Arabia	0.97	0.28	11.86
GL.GB/Singapore	−0.32	0.6	15.0	*GL.GB/Singapore*	0.04	0.68	24.77	*US.GB/Singapore*	−0.17	0.62	13.2	*US.GB/Singapore*	−0.11	0.69	87.00
GL.GB/Turkey	0.45	0.62	27.0	*GL.GB/Turkey*	−0.01	0.47	80.00	*US.GB/Turkey*	0.62	0.44	33.0	*US.GB/Turkey*	−0.75	0.62	4.95
GL.GB/UAE	2.27	0.15	91.0	*GL.GB/UAE*	0.4	0.3	13.00	*US.GB/UAE*	3	0.26	87.0	*US.GB/UAE*	0.92	0.55	17.98
GL.GB/UK	0.42	0.62	46.0	*GL.GB/UK*	1.92	0.3	20.00	*US.GB/UK*	0.37	0.73	8.0	*US.GB/UK*	1.43	0.25	12.21

Panel B: Long position in individual sukuk markets and green bonds are in short position

Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (SUKUK/CH.GB)	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/CH.GB)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/EU.GB)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/EU.GB)*	*HR*	*OPW*	*HE (%)*
Bahrain/CH.GB	2.72	0.38	39.0	*Bahrain/CH.GB*	−3.43	0.42	1.10	*Bahrain/EU.GB*	4.35	0.22	60.9	*Bahrain/EU.GB*	−1.29	0.38	3.10
Hong Kong/CH.GB	0.16	0.92	27.6	*Hong Kong/CH.GB*	0.81	0.55	36.12	*Hong Kong/EU.GB*	−0.35	0.71	60.9	*Hong Kong/EU.GB*	0.41	0.7	19.15
Indonesia/CH.GB	−0.41	0.8	15.4	*Indonesia/CH.GB*	1.21	0.12	1.42	*Indonesia/EU.GB*	−0.19	0.61	16.0	*Indonesia/EU.GB*	0.19	0.31	3.17
Ireland/CH.GB	−0.46	0.6	10.1	*Ireland/CH.GB*	−0.42	0.64	2.58	*Ireland/EU.GB*	0.81	0.35	18.6	*Ireland/EU.GB*	0.03	0.72	2.81
Kuwait/CH.GB	−0.11	0.61	11.0	*Kuwait/CH.GB*	−6.22	0.33	1.80	*Kuwait/EU.GB*	−0.15	0.75	65.0	*Kuwait/EU.GB*	1.25	0.32	8.80
Malaysia/CH.GB	−0.97	0.69	75.0	*Malaysia/CH.GB*	15.91	0.42	1.84	*Malaysia/EU.GB*	−0.41	0.58	87.0	*Malaysia/EU.GB*	0.14	0.42	8.40
Nigeria/CH.GB	0.17	0.58	−24.0	*Nigeria/CH.GB*	2.6	0.35	1.52	*Nigeria/EU.GB*	1.05	0.42	22.0	*Nigeria/EU.GB*	2.32	0.31	4.00
Oman/CH.GB	3.36	0.5	12.9	*Oman/CH.GB*	−6.77	0.28	1.72	*Oman/EU.GB*	1.8	0.43	16.5	*Oman/EU.GB*	0.79	0.16	9.10
Pakistan/CH.GB	0.43	0.8	21.7	*Pakistan/CH.GB*	−0.6	0.59	30.80	*Pakistan/EU.GB*	−0.35	0.66	22.2	*Pakistan/EU.GB*	−0.08	0.69	34.30
Qatar/CH.GB	0.19	0.86	37.4	*Qatar/CH.GB*	−0.54	0.6	36.28	*Qatar/EU.GB*	−0.05	0.65	45.8	*Qatar/EU.GB*	0.06	0.71	68.31

(*continued on next page*)

Table 6 (*continued*)

Panel B: Long position in individual sukuk markets and green bonds are in short position															
Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (SUKUK/CH.GB)	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/CH.GB)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/EU.GB)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/EU.GB)*	*HR*	*OPW*	*HE (%)*
Saudi Arabia/CH.GB	0.14	0.89	22.6	*Saudi Arabia/CH.GB*	0.12	0.73	36.68	*Saudi Arabia/EU.GB*	0.77	0.48	28.8	*Saudi Arabia/EU.GB*	−0.03	0.76	95.98
Singapore/CH.GB	−0.97	0.61	66.3	*Singapore/CH.GB*	3.17	0.33	42.48	*Singapore/EU.GB*	−0.95	0.3	58.5	*Singapore/EU.GB*	−0.1	0.26	9.94
Turkey/CH.GB	0.32	0.59	40.0	*Turkey/CH.GB*	1.47	0.39	2.40	*Turkey/EU.GB*	−0.24	0.36	26.0	*Turkey/EU.GB*	−0.35	0.37	4.00
UAE/CH.GB	0.15	0.8	52.7	*UAE/CH.GB*	0.08	0.71	36.46	*UAE/EU.GB*	0.14	0.77	43.0	*UAE/EU.GB*	0.41	0.63	46.77
UK/CH.GB	−0.08	0.68	55.0	*UK/CH.GB*	−0.84	0.61	7.20	*UK/EU.GB*	1.59	0.22	33.0	*UK/EU.GB*	1.58	0.72	6.00
Bahrain/GL.GB	2.1	0.11	66.0	*Bahrain/GL.GB*	0.94	0.43	78.00	*Bahrain/US.GB*	1.14	0.39	13.0	*Bahrain/US.GB*	0.97	0.38	2.70
Hong Kong/GL.GB	0.3	0.71	57.0	*Hong Kong/GL.GB*	−0.17	0.82	13.30	*Hong Kong/US.GB*	0.57	0.73	15.3	*Hong Kong/US.GB*	−0.26	0.61	23.64
Indonesia/GL.GB	0.4	0.66	60.0	*Indonesia/GL.GB*	−0.99	0.41	5.00	*Indonesia/US.GB*	0.5	0.62	4.0	*Indonesia/US.GB*	−1.36	0.3	1.97
Ireland/GL.GB	0.48	0.4	33.0	*Ireland/GL.GB*	0.82	0.79	15.00	*Ireland/US.GB*	0.00	0.42	30.0	*Ireland/US.GB*	1.5	0.67	2.82
Kuwait/GL.GB	−0.11	0.78	88.0	*Kuwait/GL.GB*	1.47	0.34	95.00	*Kuwait/US.GB*	−0.07	0.75	83.0	*Kuwait/US.GB*	1.7	0.33	8.40
Malaysia/GL.GB	0.44	0.56	97.0	*Malaysia/GL.GB*	−1.62	0.44	96.00	*Malaysia/US.GB*	0.72	0.62	95.0	*Malaysia/US.GB*	−7.72	0.4	8.30
Nigeria/GL.GB	0.9	0.5	40.0	*Nigeria/GL.GB*	−1.05	0.4	97.00	*Nigeria/US.GB*	0.71	0.58	39.0	*Nigeria/US.GB*	−0.81	0.27	3.40
Oman/GL.GB	1.33	0.45	83.0	*Oman/GL.GB*	1.41	0.15	93.00	*Oman/US.GB*	2.18	0.47	12.2	*Oman/US.GB*	2.52	0.13	8.90
Pakistan/GL.GB	0.19	0.68	80.0	*Pakistan/GL.GB*	0.23	0.86	70.90	*Pakistan/US.GB*	0.58	0.67	3.0	*Pakistan/US.GB*	0.35	0.6	53.63
Qatar/GL.GB	0.13	0.65	77.0	*Qatar/GL.GB*	0.06	0.66	23.70	*Qatar/US.GB*	0.59	0.64	54.0	*Qatar/US.GB*	0.12	0.72	67.37
Saudi Arabia/GL.GB	0.34	0.63	49.0	*Saudi Arabia/GL.GB*	−0.03	0.83	16.35	*Saudi Arabia/US.GB*	0.78	0.52	5.0	*Saudi Arabia/US.GB*	−0.1	0.72	33.70
Singapore/GL.GB	0.56	0.4	43.8	*Singapore/GL.GB*	−0.25	0.32	76.10	*Singapore/US.GB*	−0.5	0.38	63.8	*Singapore/US.GB*	−0.4	0.31	11.86
Turkey/GL.GB	0.86	0.38	57.0	*Turkey/GL.GB*	−0.34	0.53	88.00	*Turkey/US.GB*	0.6	0.56	38.0	*Turkey/US.GB*	−0.83	0.38	2.00
UAE/GL.GB	0.34	0.85	18.0	*UAE/GL.GB*	0.16	0.7	70.20	*UAE/US.GB*	0.51	0.74	93.0	*UAE/US.GB*	0.66	0.45	51.65
UK/GL.GB	1.1	0.38	72.0	*UK/GL.GB*	0.95	0.7	57.00	*UK/US.GB*	0.63	0.27	26.0	*UK/US.GB*	2.33	0.75	4.20

Notes: This table illustrate the hedge ratios (HR), the optimal portfolio weights (OPW) and the hedging effectiveness (HE %) among the green bonds and the fifteen sukuk markets within full sample.

Table 7
Hedge ratios, portfolio weights and hedging effectiveness of Sukuk and global factors.

Panel A: Long position in global factors and individual sukuk markets are in short position

Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (GVZ/SUKUK)	*HR*	*OPW*	*HE (%)*	*Pairs (GVZ/SUKUK)*	*HR*	*OPW*	*HE (%)*	*Pairs (OVX/SUKUK)*	*HR*	*OPW*	*HE (%)*	*Pairs (OVX/SUKUK)*	*HR*	*OPW*	*HE (%)*
GVZ/Bahrain	0.35	0.77	21.57	*GVZ/Bahrain*	0.32	0.58	23.19	*OVX/Bahrain*	0.98	0.61	20.00	*OVX/Bahrain*	0.6	0.3	52.20
GVZ/Hong Kong	0.95	0.29	49.05	*GVZ/Hong Kong*	1.59	0.32	18.22	*OVX/Hong Kong*	−2.11	0.14	37.00	*OVX/Hong Kong*	4.58	0.12	16.30
GVZ/Indonesia	0.1	0.39	43.41	*GVZ/Indonesia*	0.07	0.72	10.60	*OVX/Indonesia*	1.27	0.18	45.00	*OVX/Indonesia*	1.47	0.3	51.10
GVZ/Ireland	0.86	0.58	32.33	*GVZ/Ireland*	4.59	0.27	14.00	*OVX/Ireland*	7.48	0.44	43.00	*OVX/Ireland*	11.9	0.14	28.80
GVZ/Kuwait	1.36	0.41	53.99	*GVZ/Kuwait*	0.16	0.68	18.08	*OVX/Kuwait*	6.06	0.24	17.00	*OVX/Kuwait*	0.73	0.4	68.60
GVZ/Malaysia	−0.04	0.47	54	*GVZ/Malaysia*	−1.56	0.55	22.70	*OVX/Malaysia*	−0.15	0.3	46.00	*OVX/Malaysia*	−2.23	0.49	89.20
GVZ/Nigeria	−0.08	0.62	41.93	*GVZ/Nigeria*	1.53	0.66	28.49	*OVX/Nigeria*	−0.51	0.39	55.00	*OVX/Nigeria*	2.58	0.51	21.50
GVZ/Oman	0.55	0.6	10.88	*GVZ/Oman*	−0.15	0.8	4.72	*OVX/Oman*	1.21	0.43	72.00	*OVX/Oman*	−0.39	0.49	29.50
GVZ/Pakistan	−0.69	0.32	36.51	*GVZ/Pakistan*	−0.32	0.37	13.13	*OVX/Pakistan*	−1.38	0.12	61.00	*OVX/Pakistan*	−3.22	0.11	26.70
GVZ/Qatar	0.7	0.35	61.94	*GVZ/Qatar*	−0.39	0.36	10.43	*OVX/Qatar*	1.34	0.14	7.00	*OVX/Qatar*	−5.12	0.11	3.60
GVZ/Saudi Arabia	1.26	0.49	63.97	*GVZ/Saudi Arabia*	−1.09	0.21	4.00	*OVX/Saudi Arabia*	11.57	0.33	70.00	*OVX/Saudi Arabia*	−3.52	0.06	5.50
GVZ/Singapore	0.54	0.6	2.22	*GVZ/Singapore*	0.17	0.81	3.75	*OVX/Singapore*	0.78	0.42	86.00	*OVX/Singapore*	0.87	0.36	6.30
GVZ/Turkey	0.27	0.68	50.03	*GVZ/Turkey*	0.42	0.59	22.22	*OVX/Turkey*	0.85	0.47	83.00	*OVX/Turkey*	1.36	0.26	67.00
GVZ/UAE	0.54	0.33	51.67	*GVZ/UAE*	−0.51	0.41	12.89	*OVX/UAE*	3.11	0.13	25.00	*OVX/UAE*	−0.23	0.13	5.10
GVZ/UK	−0.1	0.56	51.33	*GVZ/UK*	−0.25	0.29	11.36	*OVX/UK*	0.09	0.42	73.00	*OVX/UK*	−3.19	0.16	35.50
VIX/Bahrain	0.09	0.77	8.35	*VIX/Bahrain*	0.65	0.36	57.44								
VIX/Hong Kong	2.45	0.26	11.44	*VIX/Hong Kong*	4.09	0.17	35.85								
VIX/Indonesia	−0.04	0.32	9.8	*VIX/Indonesia*	0.29	0.47	49.27								
VIX/Ireland	6.89	0.57	17.38	*VIX/Ireland*	14.65	0.17	31.08								
VIX/Kuwait	1.05	0.32	16.73	*VIX/Kuwait*	−0.13	0.44	58.38								
VIX/Malaysia	0.21	0.38	17.08	*VIX/Malaysia*	−6.41	0.51	72.15								
VIX/Nigeria	0.51	0.52	21.74	*VIX/Nigeria*	0.83	0.53	91.97								
VIX/Oman	0.97	0.51	5.08	*VIX/Oman*	−0.26	0.57	28.13								
VIX/Pakistan	−0.9	0.3	9.05	*VIX/Pakistan*	−1.55	0.15	10.62								
VIX/Qatar	1.75	0.29	15.7	*VIX/Qatar*	−1.21	0.14	5.93								
VIX/Saudi Arabia	1.94	0.46	19.75	*VIX/Saudi Arabia*	−2.46	0.08	2.39								
VIX/Singapore	−0.31	0.56	5.9	*VIX/Singapore*	0.38	0.5	1.56								
VIX/Turkey	−0.21	0.65	16.71	*VIX/Turkey*	0.6	0.36	66.43								
VIX/UAE	0.85	0.25	12.66	*VIX/UAE*	0.01	0.17	18.46								
VIX/UK	0.19	0.55	24.58	*VIX/UK*	−1.38	0.19	35.35								

Panel B: Long position in individual sukuk markets and global factors are in short position

Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (SUKUK/GVZ)	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/GVZ)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/OVX)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/OVX)*	*HR*	*OPW*	*HE (%)*
Bahrain/GVZ	2.56	0.23	55.00	*Bahrain/GVZ*	−0.13	0.42	1.92	*Bahrain/OVX*	1.49	0.39	25.00	*Bahrain/OVX*	−0.19	0.7	68.20
Hong Kong/GVZ	0.3	0.71	20.53	*Hong Kong/GVZ*	0.2	0.68	21.57	*Hong Kong/OVX*	0.12	0.86	57.59	*Hong Kong/OVX*	0.05	0.88	87.94
Indonesia/GVZ	−0.12	0.61	79.04	*Indonesia/GVZ*	0	0.28	3.85	*Indonesia/OVX*	−0.05	0.82	21.41	*Indonesia/OVX*	0.24	0.7	63.22
Ireland/GVZ	−0.41	0.42	16.78	*Ireland/GVZ*	0.71	0.73	2.35	*Ireland/OVX*	0.11	0.56	16.36	*Ireland/OVX*	−0.12	0.86	87.50
Kuwait/GVZ	−0.02	0.59	14.85	*Kuwait/GVZ*	−0.84	0.32	2.57	*Kuwait/OVX*	0.19	0.76	6.7	*Kuwait/OVX*	−0.36	0.6	12.30
Malaysia/GVZ	−1.58	0.53	4.06	*Malaysia/GVZ*	6.07	0.45	7.60	*Malaysia/OVX*	−0.6	0.7	2.05	*Malaysia/OVX*	2.42	0.51	1.10
Nigeria/GVZ	0.5	0.38	18.26	*Nigeria/GVZ*	1.89	0.34	3.75	*Nigeria/OVX*	0.4	0.61	14.87	*Nigeria/OVX*	0.48	0.49	43.72
Oman/GVZ	3.27	0.4	12.00	*Oman/GVZ*	−1.68	0.2	1.30	*Oman/OVX*	1.66	0.57	52.00	*Oman/OVX*	−0.56	0.51	3.40
Pakistan/GVZ	−0.01	0.68	98.08	*Pakistan/GVZ*	−0.02	0.63	32.80	*Pakistan/OVX*	0.05	0.88	22.21	*Pakistan/OVX*	−0.06	0.89	51.22
Qatar/GVZ	0.5	0.65	27.45	*Qatar/GVZ*	−0.06	0.64	50.66	*Qatar/OVX*	0.25	0.86	76.16	*Qatar/OVX*	−0.06	0.89	87.38
Saudi Arabia/GVZ	0.51	0.51	15.37	*Saudi Arabia/GVZ*	−0.05	0.79	44.43	*Saudi Arabia/OVX*	0.3	0.67	91.07	*Saudi Arabia/OVX*	−0.02	0.94	90.51

(*continued on next page*)

Table 7 (*continued*)

Panel B: Long position in individual sukuk markets and global factors are in short position															
Full Sample				During COVID-19				Full Sample				During COVID-19			
Pairs (SUKUK/GVZ)	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/GVZ)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/OVX)*	*HR*	*OPW*	*HE (%)*	*Pairs (SUKUK/OVX)*	*HR*	*OPW*	*HE (%)*
Singapore/GVZ	2.05	0.4	52.00	*Singapore/GVZ*	1.29	0.19	5.10	*Singapore/OVX*	0.96	0.58	54.00	*Singapore/OVX*	0.21	0.64	4.40
Turkey/GVZ	2.24	0.32	12.36	*Turkey/GVZ*	0.3	0.41	3.85	*Turkey/OVX*	0.99	0.53	9.91	*Turkey/OVX*	0.28	0.74	37.38
UAE/GVZ	0.4	0.67	22.13	*UAE/GVZ*	−0.04	0.59	37.24	*UAE/OVX*	0.26	0.87	71.01	*UAE/OVX*	−0.03	0.87	86.59
UK/GVZ	0.13	0.44	11.15	*UK/GVZ*	0.7	0.71	1.17	*UK/OVX*	0.47	0.58	8.14	*UK/OVX*	−0.23	0.84	63.20
Bahrain/VIX	1.75	0.23	90.00	*Bahrain/VIX*	−0.38	0.64	14.54								
Hong Kong/VIX	−0.05	0.74	49.84	*Hong Kong/VIX*	0.13	0.83	32.41								
Indonesia/VIX	−0.21	0.68	56.63	*Indonesia/VIX*	0.12	0.53	55.75								
Ireland/VIX	0.36	0.43	28.02	*Ireland/VIX*	0.41	0.83	16.05								
Kuwait/VIX	0.15	0.68	14.13	*Kuwait/VIX*	−1	0.56	2.57								
Malaysia/VIX	−0.92	0.62	3.92	*Malaysia/VIX*	1.91	0.49	7.30								
Nigeria/VIX	0.5	0.48	29.2	*Nigeria/VIX*	0.55	0.47	37.26								
Oman/VIX	1.81	0.49	33.00	*Oman/VIX*	−1.24	0.43	1.08								
Pakistan/VIX	−0.18	0.7	77.6	*Pakistan/VIX*	−0.06	0.85	87.37								
Qatar/VIX	0.06	0.71	17.84	*Qatar/VIX*	−0.08	0.86	97.10								
Saudi Arabia/VIX	0.2	0.54	14.53	*Saudi Arabia/VIX*	−0.06	0.92	53.11								
Singapore/VIX	1.27	0.44	30.00	*Singapore/VIX*	0.8	0.5	−0.18								
Turkey/VIX	0.97	0.35	12.73	*Turkey/VIX*	0.44	0.64	35.48								
UAE/VIX	0.15	0.75	17.06	*UAE/VIX*	0.01	0.83	85.08								
UK/VIX	0.56	0.45	16.58	*UK/VIX*	0.42	0.81	11.35								

Notes: This table illustrate the hedge ratios (HR), the optimal portfolio weights (OPW) and the hedging effectiveness (HE %) among the global factors and the fifteen sukuk markets within full sample.

directional spillover, and its transitions from a transmitter to a receiver of shocks over time and vice versa.

In the median quantile (graph a), risk factors (i.e., GVZ, OVX and VIX) appear to, generally, be net recipients of shocks in the whole sample period, with a relatively low degree of *spillover* that does not exceed 30. We find a neutral trend in *spillover* patterns indicating equal reciprocity until 2019 (2021) for Hong Kong, Malaysia, Indonesia (Ireland). However, in the late sample period, a more significant *spillover* positions are observed for all markets. Specifically, during this period of time, sukuk indices of Bahrain, Hong Kong, Indonesia, Ireland, Kuwait, Malaysia, Nigeria and Oman appear to be net transmitters of shocks. Sukuk markets of Pakistan, Qatar, and UAE, as well as all green bond indices (CH GB, EU GB, GL GB, US GB) appear to be net receivers in the period of the pandemic, while an equal reciprocity in net *spillover* positions is noticeable for the Saudi Arabian, Singaporean, Turkish and UK sukuk indices. The highest risk transmissions are recorded for Bahrain and Ireland in the early-period of the pandemic reaching more than 150. These findings indicate that sukuk and green bonds have been significantly affected by the global economic slowdown induced by the Covid-19 pandemic and stimulated by increased interest rates, decreased stock market prices and economic turmoil.

Patterns of net *spillover* estimates in the lower and upper quantiles are shown in graphs b and c of Fig. 4, respectively. Typically, extreme net spillover models fluctuate in the full period. The only exceptions are Kuwaiti and Emirati sukuk indices in bearish market conditions (graph b), which implies that these two markets seem to be well monitored by regulators against extreme events and will continue in the future.

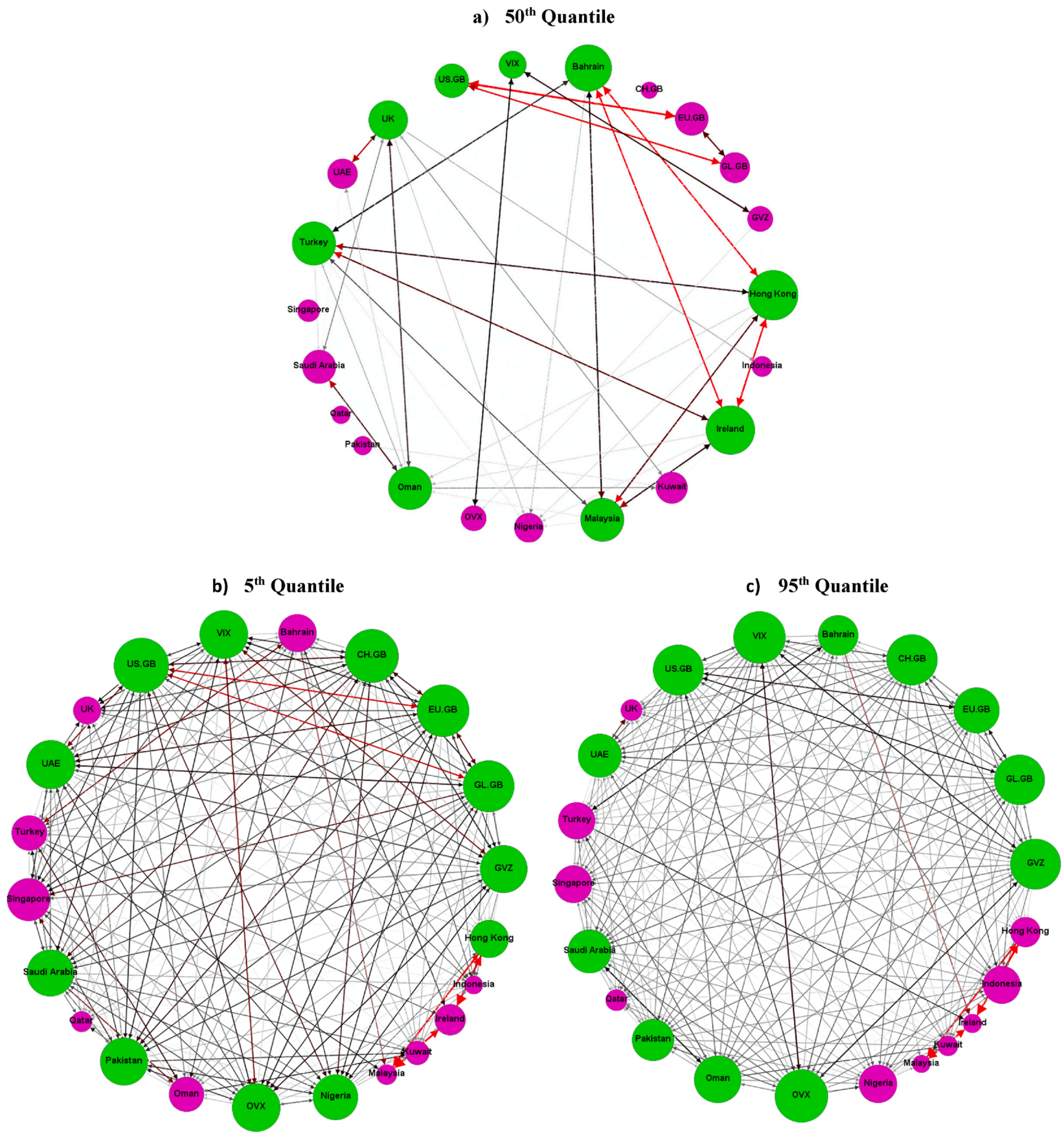

Fig. 5. The above graphs depict the Network Connectedness between Sukuk, Green bonds and Global factors, during COVID-19. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.4. Portfolio management and risk analysis implications

Table 6 presents the hedge ratios (*HR*), optimal portfolio weights (*OPW*), and hedging effectiveness (*HE*) of different portfolios consisting in longing (shorting) green bonds and shorting (longing) sukuk as reported in Panel A (Panel B) of the table. *OPW* in Panel A (B) refers to the optimal weight of Green bonds (Sukuk) in the one-dollar Sukuk (Green bonds) index. For example, the optimal weight of CH.GB in a one-dollar Bahraini sukuk index is 62 %, indicating that an investor could minimize risk by holding 38 % of Bahraini sukuk in her CH.GB-Bahrain sukuk portfolio. The findings of the optimal weights in green bonds-sukuk portfolios in the full sample period show that investors should hold more *Sukuk* than *Green bonds* in their portfolios in order to minimize risk while keeping the expected return unchanged for the majority of the pairs. The exceptions are Bahrain and Oman sukuk markets with respect to CH.GB, Bahrain, Ireland, Nigeria, Oman, Singapore, Turkey and UK with respect to EU.GB and GL.GB, and Bahrain, Ireland, Oman, Singapore and UK with respect to US.GB.

The results of the optimal hedge ratios (*HR*) in panel A (B) indicate that an investor would minimize risk from *Green bonds-Sukuk* portfolio if a one-dollar long position in Green bonds (Sukuk) is hedged by a short position of the value of *HR* in Sukuk (Green bonds). Accordingly, findings in Table 6 suggest that an investor in the *CH.GB-Hong Kong sukuk* portfolio could minimize risk if US$ 100 long position in CH.GB (Hong Kong sukuk) is hedged by a short position of US$ 173 (US$ 272) in Hong Kong sukuk market (CH.GB) in the full sample period. The same reasoning holds for the other pairs.

Considering the hedge effectiveness ratios (*HE*) in panel A, we find consistent *HE* for green bonds in all sukuk markets, with high-risk reductions of more than 50 % for the majority of markets, reaching above the 90 % level with respect to CH GB and GL GB. This result confirms the effectiveness of sukuk in reducing risk of holding green bonds. Also, results in panel B support the good performance of green bonds in terms of risk reduction for an investment in sukuk.

Panels A and B of Table 7 summarize the characteristics of portfolios consisting in longing (shorting) global factors and shorting (longing) sukuk, respectively. The table reports the hedge ratios (*HR*), optimal portfolio weights (*OPW*), and hedging effectiveness (*HE*) of the different portfolios.

The results of the optimal weights in global risk-Sukuk portfolios show that an investor could minimize global risks by holding sukuk. The average optimal weight of sukuk varies from 12 % for Pakistan to 77 % for Bahrain in the full sample period. This finding indicates that investing in sukuk seems to provide some sizeable diversification benefits. Risk evaluation results, as measured by the hedge ratios (*HR*) and hedging effectiveness (*HE*), show that sukuk are effective in reducing global risks with *HE* is reaching above 50 % in the majority of cases.

3.5. Sub-sample analysis: The Covid-19 pandemic period

We focus, in this section, on the period of Covid-19 and we examine the connectedness and risk analysis between sukuk, green bonds and global factors. Fig. 5 shows the network connectedness between our underlying variables for the 50th (graph a), 5th (graph b), and the 95th quantiles. Results found are different from those corresponding to the full sample period. Specifically, for the median quantile, we find that the strongest *spillovers* with respect to sukuk are between Bahrain and Ireland, Bahrain and Hong Kong and Ireland and Hong Kong, which appear to be transmitters of shocks in the period of the pandemic. A lower but material connection is also found from Hong Kong and Ireland to Turkey. For green bonds, the strongest pairwise connections are between US GB and GL GB and US GB and EU GB. In the upper and lower quantiles (graphs b and c), more connections are established between used assets and factors in period of Covid-19. The strongest ones are between Hong Kong and Malaysia, Hong Kong and Ireland, and Ireland and Malaysia with respect to sukuk in both quantiles. For green bonds, the most intense *spillovers,* in bearish market conditions, are between US GB and GL GB and US GB and EU GB. These relations seem to weaken when the market is bullish.

Overall, Fig. 5 shows some interesting diversification opportunities for investors in sukuk and green bonds during the period of Covid-19. Specifically, apart from the connections established between some of them, both assets do not seem to be affected by fluctuations of global risk factors nor by risks transmitted from their peers in the normal, bearish and bullish market conditions.

These conclusions of risk mitigation properties and diversification benefits of these asset markets are confirmed by the results of risk analysis reported in Tables 6 and 7. More particularly, the economic uncertainty and fragility associated to the pandemic did not hinder the diversification characteristics of green bonds and sukuk. For portfolios comprising green bonds and sukuk, we find consistent hedging effectiveness that reach more than 50 % for some portfolios. The findings are useful for investors in their investment decision-making to take long (short) positions in sukuk and green bonds in order to maximise *HE*. Negative values of *HR* occur when pairs are negatively correlated, which is the case of several portfolios during the pandemic period. In this case, investors could hedge risk by either longing or shorting both assets. Results in Table 7 for the Covid-19 period show that sukuk appear to be effective hedge with respect to the three used global risk factors with *HE* exceeds 35 % for most cases. *HR* results show that a fraction of $100 long position in global risks could be hedged by incorporating sukuk in the hedging strategy. These findings have important implications for investors as they provide some hedging opportunity perspectives, especially, in periods of economic turmoil.

4. Conclusion

In this study, we investigate the spillover effects as well as portfolio implications for two ethical fixed-income assets (i.e., sukuk and green bonds) in presence of global risk factors. We use a large sample of the main sukuk disaggregated in 15 countries, and four main regional green bonds for the period that goes from January 1, 2016 to April 1, 2022. We, specifically, use an in-quantile spillover approach to study the interdependency between used assets and factors giving the increased focus of existing literature on connectedness analysis. Hence, we contribute to the literature by providing a detailed analysis of the linkages between sukuk and green bonds, which is the first such study.

Our analysis unveils interesting findings. Although we find some similarities in the connectedness in the left, middle and right tails of the conditional distribution, some differences are also discerned. First, the results of the static directional spillover analysis show a salient stability feature in the connectedness between Hong Kong and Malaysian, and UK and Nigerian sukuk indices in the middle, lower and upper quantiles. This finding implies that investors in these markets should be cautious and diversify the risk by comprising other assets in their portfolios. Second, our findings also suggest some differences in the spillover structures between the upper and lower tails and the middle quantile. More particularly, we find a significant connection between US green bonds and European green bonds under normal market conditions. This connection weakens in both bullish and bearish market conditions. Considering global risk factors, we find that used sukuk and green bond indices are not largely affected by global factors in the middle quantile. The impact becomes higher in both the lower and upper quantiles albeit moderate.

These differences support the use of quantile-based analysis since the evolution of the tail dependence structure is veiled by the estimates of the average-based connectedness models. Third, the results of the rolling spillover analysis indicate that the degree of dependency of the tail varies over time. We find significant albeit high fluctuations in both total and net spillover over the entire sample period. This result implies that investors should remain alert to the timely changes in the interdependence between used assets and continuously rebalance their portfolios. Fourth, with regards to risk management and portfolio implications, our results stipulate the effectiveness of sukuk in reducing risk of holding green bonds and vice versa. Findings also indicate that sukuk are effective in reducing global risks with hedging effectiveness ratios reaching more than 50 % for the majority of pairs. Finally, empirical results from the Covid-19 pandemic period show that the majority of used sukuk and green bond indices do not seem to be affected by fluctuations of global risk factors nor by risk transmitted from their peers in the different quantiles. These findings of diversification characteristics and risk mitigation properties of used assets is confirmed through the risk evaluation analysis that shows high levels of hedging effectiveness in a two-assets portfolio, exceeding 35 % in most cases.

Our findings are particularly important for both investors and regulators in order to identify the risk transmission between Sukuk and green bond markets. More specifically, the findings of this paper provide helpful insights for investors, and more particularly the ethical ones, in terms of portfolio structure and risk management. These results should also be insightful for market regulators, who are continually seeking financial stability, in their formulation of predictions under extreme events, in view of the nature of the underlying dynamics between sukuk and green bonds, in relation to global factors. To this extent, companies and financial institutions are also encouraged to issue ethical products such as green and Islamic bonds to manage their financial risks. As a possible future direction of this research, scholars could investigate the robustness of these results using different methodological techniques to examine the interconnectedness of green bonds and sukuk and recommend some portfolio diversification strategies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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