The Causal Relationship Between Green Finance and Geopolitical Risk: Implications for Environmental Management

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Abstract

This study investigates the time-varying causal relationship between geopolitical risk and green finance during the period of 1 March 2012- 16 February 2022. By using the novel time-varying causality testing framework, our findings shed light on the nexus between geopolitical risk and green finance in informing environmental management decisions. First, we find that time heterogeneity does exist in the causal relations between geopolitical risk and green finance. Second, geopolitical risk has a more prolonged impact on the volatility of green bonds and renewable energy than the return. Yet, geopolitical risk tends to influence the return of clean energy more persistently than volatility. Third, we observe that geopolitical risk has a more sustained impact on the return and volatility of renewable energy than clean energy. This might be due to the distinct nature of the production of clean energy and renewable energy, thereby providing implications for effective environmental management. Lastly, this paper demonstrates that the impact of geopolitical risk on the return of European clean energy has diminished since the onset of 2015. The volatility of the European clean energy sector is not affected by global geopolitical risk, underscoring the necessity of promoting the development of this sector to reduce the dependence on fossil fuels and enhance energy independence.

Keywords: Green finance; Geopolitical risk; Time-varying causality; Clean energy; Renewable energy; Environmental management; Sustainable Development Goals.

JEL Classifications: Q01, Q20, Q50, G10

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Highlights:

- Geopolitical risk has a more prolonged impact on the volatility of green bonds and renewable energy than their return.
- The return of clean energy is influenced more persistently by geopolitical risk than volatility.
- Geopolitical risk poses a more sustained effect on the return and volatility of renewable energy than clean energy.
- The impact of geopolitical risk on the return of European clean energy has diminished since the onset of 2015.
- Promoting clean energy transition is necessary in securing energy security.

1. Introduction

Green finance directs the flow of capital from the public and private sectors to green initiatives that address sustainable development and provide environmental benefits. As climate change accelerates, it becomes increasingly necessary to promote green finance in order to channel investments toward green projects and activities that are environmentally friendly (Alkathery et al., 2022; Zhang et al., 2021; Yousaf et al., 2021). In this way, we will be able to transition into a net zero economy. The need to utilise green financing will continue to increase in order to facilitate a resilient economic recovery from Covid-19 in a sustainable way. In the meantime, geopolitical risk has been gaining more and more attention from businesses, investors, and policymakers (Caldara and Iacoviello, 2022; Balli et al., 2022). This is because heightened geopolitical tension is associated with lowered investment and greater financial instability. Since green investing can face exposures to both systematic and idiosyncratic geopolitical risk, it is essential to take into account the impact exerted by geopolitical events on green financial instruments.

The transmission mechanism from geopolitical risk to the green finance market originates from geopolitical stress inducing downward pressure on green investment decisions and stock prices, which leads to increased risk exposure faced by the underlying green financial assets and a higher probability of green finance market turbulence. Therefore, geopolitical risk may undermine the efforts to embrace sustainable environmental management practices. It is documented that geopolitical risk has diverse effects on return and volatility of equity markets and energy commodities (Balcilar et al., 2018; Bouri et al., 2019; Caldara & Iacoviello, 2022; Qin et al., 2020). Moreover, Lee et al. (2021) show that the geopolitical risk Granger causes the volatility of the green bond index at the distribution of lower quantiles. Zhang et al. (2021) find that green finance by means of green credit policy enhances environmental quality in China by altering the pattern of corporate investment and financing.

However, there are few studies examine the dynamics between green finance and geopolitical risk from a time-varying perspective. Given the frequent fluctuations in geopolitical tensions (Balli et al., 2022; Hasan et al., 2020) and the volatility and return of green financial products (Arif et al., 2021; Zhu et al., 2021), the causal relations between geopolitical risk and green finance may be sensitive to time periods. To account for the possible change points and time heterogeneity in the causality between geopolitical risk and green finance, this study employs the novel time-varying Granger causality testing framework (Nasir et al., 2021; Nasir et al., 2019; Shi et al., 2020) that consists of forward expanding, rolling window, and recursive-evolving algorithms. We select a range of green financial instruments including the NASDAQ OMX Clean Energy Focused Europe Index, NASDAQ OMX Renewable Energy Generation Index S&P Global Clean Energy Index, and S&P Green Bond Index to provide a comprehensive picture pertaining to green finance. The utilisation of the time-varying lag-augmented VAR models (Shi et al. 2020) allows for the detection of the time-varying changes in the causal relationship and the identification of specific dates with respect to the existence of causality.

The main aim of this study is to investigate the time-varying causality dynamics between geopolitical risk and green finance over the period from 1 March 2012 to 16 February 2022. By disentangling the causal relationships from geopolitical risk to the return and volatility of green financial products, we provide new insights into the role of green finance in environmental management amid geopolitical uncertainty. It is worth noting that green financing is an integral part of supporting the delivery of the United Nations Sustainable Development Goals (UN, 2015). In particular, green finance aligns with the UN Sustainable Development Agenda by matching the financial needs of environmentally friendly projects with the financial flows from public and private sector organizations.

This study contributes to the literature in a range of important ways. First, by using novel time-varying algorithms based on the lag-augmented VAR models (Shi et al., 2020), we find unidirectional Granger causality from geopolitical risk to the return and volatility of green finance. which is not detected by the traditional pairwise Granger causality test. Lee et al. (2021) examine the causal relation between geopolitical risk and green bond by using the Granger-causality in quantile and find that there exists causality from geopolitical risk to green bond in the lower quantiles. We extend the current literature by demonstrating the time heterogeneity in the time-varying causality between geopolitical risk and green finance. Second, geopolitical risk has a more prolonged impact on the volatility of green bonds and renewable energy than that of return whilst geopolitical risk exerts a more significant influence on the return of clean energy than volatility. Existing studies (e.g., Su et al., 2021) find the bidirectional causality between global geopolitics risks and renewable energy. Our results add to the literature by further investigating the impact of geopolitical risk on both the return and volatility of renewable energy. Third, we document that geopolitical risk has a more sustained effect on the return and volatility of renewable energy than clean energy, which offers policy implications for effective environmental management. Vakulchuk et al. (2020) show that the literature investigate the effects of geopolitics do not distinguish between different energy sources. To fill this void, we include both clean energy and renewable energy in this study. Fourth, existing green finance studies in the context of Europe (Jakubik & Uguz, 2021; Sangiorgi & Schopohl, 2021) focus on the role of green bond rather than the financial instruments that provide financing for clean and renewable energy development. In this sense, we contribute to the literature by taking an distinct perspective and exhibiting that the volatility of European clean energy is immune from global geopolitical risk. This highlights the need to nurture the clean energy sector in Europe in an attempt to reduce the reliance on fossil fuels and enhance energy independence. Lastly, our novel findings on the heterogenous impacts of geopolitical risk on the return and volatility of green finance can be used to improve environmental risk management, which enhances energy independence and green transformation (Alkathery et al., 2022). In light of the fact that significant causal relationships between geopolitical risk and green finance tend to occur during periods of geopolitical crises and financial market turmoil, investors and businesses can use our findings to optimise portfolio diversification. Given that geopolitical risk contains the predictive content for the return and volatility of green finance products, it is prominent for policymakers to strengthen the green finance regulatory environment in ensuring the stabilisation of the green financial market, especially during turmoil times. In addition, this paper provides practical implications on how the development of green finance can pave the way for sustainable environmental management.

The remainder of this paper is structured as follows. Section 2 reviews the literature on the development of green finance and its association with environmental management and geopolitical risk. Section 3 explains the research methodology and presents the data. Section 4 discusses the results. Section 5 concludes the paper with policy implications, research limitations and recommendations.

2. Literature review

2.1 The role of green finance in promoting environmental management

According to the literature, there is considerable pressure on traditional energy sources, such as coal, steel, and high-carbon assets, to make the transition to a greener economy. A large number of non-performing assets may be created to expose the economy to the risk of stagflation (Demary and Hüther, 2022). Eventually, all high-carbon industries may face large amounts of bad debt, which may result in high default rates for companies in high-carbon industries (e.g., steel, cement, aluminium, and petrochemical). Nevertheless, Jakubik and Uguz (2021) see this as a very large area and a major risk that all countries should guard against during the process of the low-carbon transition. As well, Fatica et al. (2021) demonstrate that banks that issue green bonds reduce their lending to carbon-intensive industries and point out that the green transition will affect the credit structure for financial institutions. Due to the large number of non-performing manufacturing loans resulting from environmental pollution, banks should be very cautious when lending to industries and companies with high carbon emissions. Should banks choose to support the development of coal-fired power companies despite high-carbon assets (i.e., coal-fired power), they must consider the problem of excess capacity caused by changes in green policies or renewable technologies. In the future, the production capacity of new high-carbon assets may require 100% purchase of emission allowances when put into production, and the cost will be greatly increased (Bebbington and Larrinaga-González, 2008; Wu et al., 2021). Therefore, banks would need to perform stress tests on stock assets and take carbon emissions into account in the future green credit business and make forward-looking judgments. As a result, traditional high-carbon industries may face a variety of issues, such as rising financing costs and rising emissions costs (Alkathery et al., 2022). The future operation and transformation pressure on high-carbon industries is likely to be significant.

Carbon emissions in a country are directly influenced by its energy structure, economic aggregate, and population (Gao et al., 2022). Furthermore, it is crucial to accelerate the development of green finance and to provide continuous financial support for the low carbon, the green transition of the economy (Wu et al., 2021; Smeets, 2018). The goal of carbon peaking and carbon neutrality will inevitably result in substantial changes to the energy structure, the industrial structure, and the way of life of many countries. For example, using panel data from 30 Chinese provinces between 2009 and 2019, Gao et al. (2022) find that green financing can improve access to renewable energy and environmental protection industries in local provinces. Based on panel data of E7 and G7 countries during the period from 2010 to 2018, Wu et al. (2021) report that an increase in the green financing index of 1% purifies E7 countries' environment by 0.3920%, while it improves the quality of the environment in G7 countries by 0.375%. Taking into consideration both resource-geographic and constraining factors in Russia, Smeets (2018) suggests that the establishment of renewable energy industries should be treated as a policy priority to prevent future technological import dependence. Therefore, financial institutions should provide more financial products and direct social funds towards the development of renewable energy sources and green technologies (Huynh et al., 2020; Zhu et al., 2021).

2.2 Optimize energy structure and the development of green finance

When developing a green financial system, financial institutions will face increased risks from existing high carbon industries as well as new industrial models and investment strategies (Yousaf et al., 2022; Hafner et al., 2020). Green development is becoming the main focus of sustainability in the post-COPID-19 period (Madaleno et al., 2022; Yearsley, 2020). Yousaf et al. (2022) investigate the hedging benefits and the diversification of green investments throughout COVID-19 and state that it is imperative to promote the green transformation of the global economy and clean energy investments. According to existing studies, the green transformation of the financial system will create a carbon trading market (Elsayed et al., 2022; Madaleno et al., 2022; Ye et al., 2022) and promote ESG investments (Sharma et al., 2021; Yoo et al., 2021). Further, research has also been conducted on new green investment models (Chen and Ma, 2021; Lundgren et al., 2018) and new risk assessments for the financial system (Zhang et al., 2019; Nasir et al., 2021; Nguyen et al., 2021) in order to develop green goals and suggest industrial adjustments that are suitable to one's own green financial system.

In the context of the COVID-19 crisis, Madaleno et al. (2022) find that green bonds are the only assets that acted as safe havens against volatile market conditions. They note that the most important role of green finance is to change the allocation of resources, particularly financial resources. As a result, investment credit is further inclined toward low-carbon development. Climate risks have been better understood over time, and renewable energy is increasingly commercially viable. Investment also plays an influential role. Several investors have announced that their portfolio companies will address climate change as part of the COVID-19 response (Yearsley, 2020). While others investors engage in policymaking and measure the carbon footprint of their investment portfolios (Sangiorgi and Schopohl et al., 2021). Furthermore, an increasing number of investors are beginning to finance the transition to a lower-carbon economy. Investments in renewable energy sources (Ye et al., 2022), green technologies (Madaleno et al., 2022), and energy efficiency (Chen and Ma, 2021; Yoo et al., 2021). Therefore, in order to establish or transition to a green financial system, there are many factors that should be taken into consideration.

Financial institutions and investors are expected to gradually lose interest in traditional energy fields and high-carbon industries. Fatica et al. (2021) and Zhang et al. (2021a) find that the cliff-like declines in investment in these industries and the revaluation of asset values will stagnate the industry and transfer risks to the financial field, causing the spread of risk. As an example, institutions such as the Central Bank of China, the China Banking and Insurance Regulatory Commission, and other regulatory bodies conduct stress tests to ensure that financial institutions are prepared to withstand the risks of this greener transformation in China (Rehman et al., 2021; Zhu et al., 2021). According to Fatica et al., (2021), none of the green bonds issued by financial institutions are directly related to specific green investment activities. Thus, future research should investigate this further. In order to develop green industries, it is necessary to invest in science and technology, as well as to establish new industrial development models. Besides the choice of technical direction, there is also the issue of survival of the fittest. Sangiorgi and Schopohl (2021) state that unclear disclosures and poor reporting are the main barriers to the success of green bonds, and that regulatory bodies and market financial institutions should monitor the fairness of the greener financial market transition (Wu et al., 2021).

2.3 Green finance and energy commodities under heightened geopolitical risk

The concept of green bonds was first introduced by the World Bank in 2007. As defined by the World Bank, green bonds are debt instruments issued specifically to support climate-related or environmental projects. About 33% of the 750-billion-euro recovery plan launched by the European Union in response to COVID-19 is financed by green bonds (Staff, 2020). In a survey of European asset managers, Sangiorgi and Schopohl (2021) show that European investors are highly interested in green bond investments. They refer to green bonds as investments in renewable energy infrastructure, low-emission transportation, and low-energy consumption housing (Huynh et al., 2020). However, the EU does not currently have a standard for evaluating the environmental attributes of green investments.

Hedging functions of green bonds attract many market players to participate in green debt governance. As discussed by Yousaf et al. (2021), green bonds have a similar performance to gold as a strong hedge against extreme financial downturns in the S&P (Standard and Poor) 500 index during COVID-19. According to them, with the rapid growth of green bond issuance, more market institutions are allocating their investments based on the green bond index. As a disaster event study, Tiwaei et al. (2022) also consider COVID-19 as the research context and find that investing in the green bond index is a safe hedging strategy. They show that green bond index investments may be used as a strategy for asset diversification and risk-hedging effects on stock investments over the medium and long term (Huynh et al., 2020).

Furthermore, Madaleno et al. (2022) investigate the nexus between green technology and green finance and advocate for investment in forward-looking areas, including green and digital. Jakubik and Uguz (2021) examine the effects of green bond policies on equity prices among European insurance companies using monthly data from 2012 to 2019. They observe an increase in bond prices after introducing green bond policies. Jakubik and Uguz (2021) propose that establishing a European green bond standard may serve as a benchmark for the financial market and provide investors with a rigorous, reliable method of evaluating the bonds. This will enable investors within and outside of the EU to issue bonds against this standard. Furthermore, green bond buyers can verify that their investments are sustainable and environmentally friendly.

In addition to the low level of commodity inventories during COVID-19, and the slow recovery of the global supply chain, geopolitical risk have become an important driving force behind the recent rise in international commodity prices. For example, the Russia's invasion of Ukraine has led to increased volatility in the commodity market and pushed up commodity prices further. According to Staff (2022) data, Russia contributed 35% and 21% of the total global crude oil and natural gas exports, and 45% of the EU's gas imports in 2021. Moreover, due to the limited capacity of some OPEC (the Organisation of the Petroleum Exporting Countries) countries to increase production, Russia has become the main force behind the recent OPEC production increase. According to the 2021 U.S. Geological Survey, Russia's global nickel, tin, and palladium reserves account for 8%, 4%, and 6%, respectively. According to USDA (2021) data, Ukraine's wheat and corn exports account for 12% and 16% of global exports in 2021, respectively. On the other hand, the continued conflict between Russia and Ukraine will increase risk aversion in the market, and commodities will once again become the main safe-haven investments for institutions.

Additionally, the prices of some non-ferrous metals (e.g., copper and nickel) may break new highs, mainly due to the green transition has generated a large number of new demands for related metals, and the superimposed inventory are still at a historically low level (Zhang et al.,2021b; Liu et al., 2020).

3. Data

To uncover the time-varying causal relationship between green finance and geopolitical risk, we select a variety of green finance instruments that focus on both the global context and the European region. Our particular interest in the European region arises from the pioneering role of Europe in green finance, especially the first green bond was issued by the European Investment Bank in 2007. Specifically, the S&P Green Bond Index, S&P Global Clean Energy Index, and NASDAQ OMX Renewable Energy Generation Index track the global green finance market while the NASDAQ OMX Clean Energy Focused Europe Index tracks the green finance market in Europe. The S&P Green Bond Index tracks the development of the global green bond market, the proceeds of which are used to fund environmentally friendly projects. The S&P Global Clean Energy Index tracks the development of businesses associated with clean energy globally. The NASDAQ OMX Clean Energy Focused Europe Index measures the performance of sectors that advance the generation of non-fossil energy in Europe. The NASDAQ OMX Renewable Energy Generation Index measures the development of businesses in renewable energy sector that produce hydro, solar, wind, biomass, geothermal, wave and tide power. Overall, the green finance data included in this study are recognised as prominent instruments to represent green finance by the literature (Khalfaoui et al., 2022; Madaleno et al., 2022; Lee et al., 2021).

Moreover, we use the geopolitical risk (GPR) index[4] (Caldara and Iacoviello, 2022) to measure geopolitical tensions at a global scale, which is constructed from the automated text-search results of ten newspapers: Chicago Tribune, the Daily Telegraph, Financial Times, The Globe and Mail, The Guardian, the Los Angeles Times, The New York Times, USA Today, The Wall Street Journal, and The Washington Post. We also include the S&P 500 index, S&P GSCI Precious Metals Index and S&P Global Oil Index in the LA-VAR model to control for the conditions of the stock market, precious metals commodity market and crude oil market, respectively. The sample consists of daily data for the period from 1 March 2012 to 16 February 2022. The sample period is determined by the data availability. The data source of the NASDAQ OMX Renewable Energy Generation Index and NASDAQ OMX Clean Energy Focused Europe Index is Investing.com. The remaining data is collected from the official

[4] https://www.matteoiacoviello.com/gpr.htm.

website of S&P Global.

4. Research methodology

We employ the test following Nasir et al., (2021) and Shi et al. (2020) to examine the causal relationship running from geopolitical risk to return and volatility of green finance instruments, including the S&P Global Clean Energy Index, S&P Green Bond Index, NASDAQ OMX Clean Energy Focused Europe Index and NASDAQ OMX Renewable Energy Generation Index. We consider the model as follows,

$$f_t = c_0 + \sum_{i=1}^{k} A_i f_{t-i} + \sum_{j=k+1}^{k+d} A_j f_{t-j} + \varepsilon_t , \qquad t = 1,2,\ldots,T \qquad (1)$$

where k denotes the order of lag in the vector autoregressive (VAR) model, ε_t denotes the error term, d denotes the maximum integrated order in variable f_t. T denotes the sample size. Then, the regression can be written as the following form,

$$f_t = c_t + \Phi g_t + \Psi h_t + \varepsilon_t \qquad (2)$$

where $g_t = (f'_{t-1},\ldots,f'_{t-k})'_{nk\times 1}$, $h_t = (f'_{t-k-1},\ldots,f'_{t-k-d})'_{nd\times 1}$, $\Phi = (A_1,\ldots,A_k)_{n\times nk}$, $\Psi = (A_{k+1},\ldots,A_{k+d})_{n\times nd}$. To test for the null hypothesis of Granger non-causality, we impose the following restrictions,

$$H_0 : R\theta = 0 \qquad (3)$$

where θ=vec(Φ) and R is a $m \times n^2k$ matrix. Then, we extend equation (1) to a more compact form,

$$F = c + G\Phi' + H\Psi' + \varepsilon \qquad (4)$$

where $F = (f_1, f_2,\ldots,f_T)'_{T\times n}$, $c = (c_1,\ldots,c_T)'_{T\times 1}$, $G = (g_1,\ldots,g_T)'_{T\times nk}$, $H = (h_1,\ldots,h_T)'_{T\times nd}$, $\varepsilon = (\varepsilon_1,\ldots,\varepsilon_T)'_{T\times n}$. According to the OLS estimator,

$$\hat{\Phi} = F'QG(G'QG)^{-1} \qquad (5)$$

The hypothesis H_0 is tested by employing the standard Wald statistic W in the form of,

$$W = (\mathcal{V}\hat{\theta})'[\mathcal{V}\{\hat{\Sigma}_\varepsilon \otimes (G'QG)^{-1}\}\mathcal{V}']^{-1}\mathcal{V}\hat{\theta} \qquad (6)$$

where $\hat{\theta}$=vec($\hat{\Phi}$), $\hat{\Sigma}_\varepsilon = \frac{1}{T}\hat{\varepsilon}'\hat{\varepsilon}$, $\otimes$ represents the Kronecker product.

Shi et al. (2020) present three recursive strategies which are combined with Granger causality test, i.e., forward expanding window, rolling window and recursive evolving window method. We first determine the starting point S_1 and ending points S_2 of the regression sample, and the window size S_w can be expressed as $S_w = S_2 - S_1$. The starting and ending point differs in the three methods. In particular, the starting point is fixed at the first observation and the ending point shifts from S_w to T in the forward expanding window approach. The starting and ending point both shifts at distance S_w in the rolling-window approach. The starting point moves from 1 to $S_2 - S_w + 1$ and the ending point S_2 changes within $[S_W, T]$. Along with these strategies, one can obtain a series of Wald statistics $\{W_{S_1,S_2}\}_{S_2 \geq S_w}^{S_1 \in [1, S_2 - S_w + 1]}$. To test for the non-Granger causality hypothesis, Shi et al. (2020) propose a super-Wald statistic when recursive rolling window technique is utilized,

$$Sup - W_{S_w} = \sup_{S_1 \in [1, S_2 - S_w + 1], S_2 \geq S_w} \{W_{S_1,S_2}\} \quad (7)$$

Alternatively, Shi et al. (2020) construct a sub-sample Wald test statistic with heteroskedastic errors,

$$W^* = T_w(\mathcal{V}\hat{\theta})'[\mathcal{V}\{\hat{V}^{-1}\hat{\Sigma}\hat{V}^{-1}\}\mathcal{V}']^{-1}\mathcal{V}\hat{\theta} \quad (8)$$

where $\hat{\theta} = \mathrm{vec}(\hat{\Phi})$ and $\hat{\Phi}$ is the OLS estimate for the sub-sample in the range of S_1 to S_2. Besides, $\hat{V} = I_n \otimes \hat{Q}$ with $\hat{Q} = \frac{1}{T_w}\sum g_t g_t'$ and $\hat{\Sigma} = \frac{1}{T_w}\sum \hat{\xi}_t \hat{\xi}_t'$ with $\hat{\xi}_t = \hat{\varepsilon}_t \otimes g_t$. Therefore, the heteroskedasticity-consistent sub-sample Wald statistic is in the form of,

$$Sup - W_{S_w}^* = \sup_{S_1 \in [1, S_2 - S_w + 1], S_2 \geq S_w} \{W_{S_1, S_2}^*\} \quad (9)$$

5. Empirical results and discussions

5.1 Unit root tests

According to Shi et al. (2020), the LA-VAR based Granger causality test does not impose the restrictions of detrending or differencing the series. However, we should pre-test the maximum order of integration. As such, we implement augmented Dickey-Fuller (ADF) unit root test (Dickey and Fuller, 1979) and KPSS unit root test (Kwiatkowski et al., 1992) for all-time series by considering a constant as well as a linear time trend in the testing regression, respectively. Table 1 points out that the ADF and KPSS test disagrees the stationarity of green bond volatility, European clean energy volatility, renewable energy volatility, GPR and metals when we test level variables. After taking the first difference, both ADF and KPSS test suggests that the time series are stationary. Hence, we can conclude that the maximum integration order of variables is I (1).

Table 1 Unit Root Tests

	Level				1st difference			
	ADF		KPSS		ADF		KPSS	
	c	c,t	c	c,t	c	c,t	c	c,t
Green bond return	-33.731***	-33.724***	0.100	0.086	-19.208***	-19.208***	0.083	0.069
Green bond volatility	-13.546***	-13.613***	0.403*	0.138*	-27.895***	-27.893***	0.052	0.041
Clean energy return	-17.423***	-17.445***	0.165	0.002	-23.597***	-23.592***	0.029	0.026
Clean energy volatility	-9.261***	-9.517***	0.003	0.003	-21.888***	-21.884***	0.003	0.003
European clean energy return	-48.826***	-48.821***	0.0753	0.044	-21.075***	-21.082***	0.086	0.040
European clean energy volatility	-9.659***	-9.676***	0.214	0.169**	-18.645***	-18.640***	0.025	0.011
Renewable energy return	-16.897***	-16.903***	0.080	0.052	-21.986***	-21.986***	0.139	0.038
Renewable energy volatility	-9.243***	-9.328***	0.365*	0.121*	-9.243***	-9.328***	0.025	0.011
Geopolitical risk	-13.468***	-13.470***	0.418*	0.420**	-20.847***	-20.844***	0.097	0.076
Oil return	-53.331***	-53.365***	0.220	0.051	-18.895***	-18.892***	0.042	0.026
S&P return	-16.305***	-16.305***	0.037	0.029	-23.834***	-23.829***	0.018	0.017
Metals return	-53.343***	-53.398***	0.390*	0.034	-25.334***	-25.329***	0.159	0.105

Note: ***, ** and * denote 1%, 5% and 10% significance levels. The ADF test has the null hypothesis of unit root process and the KPSS test has the stationary null hypothesis.

5.2 Pairwise Granger causality tests

Table 2 reports the findings from the pairwise Granger causality tests. It is shown that significant Granger causality is detected from GPR to clean energy volatility whilst the null hypothesis of no causality is rejected from GPR to other green financial products. However, traditional Granger causality tests do not account for unknown change points in the causality whereas the causal linkages between geopolitical risk and green finance may vary over time, which can result in unreliable test results from the traditional Granger causality approach. Therefore, a methodology that allows for time heterogeneity in the causal relationships is needed to detect any potential change points in the causal relations between green finance and geopolitical risk.

Table 2 Pairwise Granger Causality tests

Null Hypothesis:	**F-Statistic**	**Prob.**
GPR does not Granger Cause Green bond return	0.376	0.540
GPR does not Granger Cause Green bond volatility	0.594	0.441
GPR does not Granger Cause Clean energy return	1.075	0.300
GPR does not Granger Cause Clean energy volatility	5.965	0.015
GPR does not Granger Cause European Clean energy return	0.020	0.887
GPR does not Granger Cause European Clean energy volatility	2.352	0.125
GPR does not Granger Cause Renewable energy return	0.071	0.790
GPR does not Granger Cause Renewable energy volatility	1.903	0.168

Note: The pairwise Granger causality test is performed by using Eviews 10. The lags are determined as 1 by using BIC based on the typical VAR model.

5.3 Time-varying Granger causality analysis

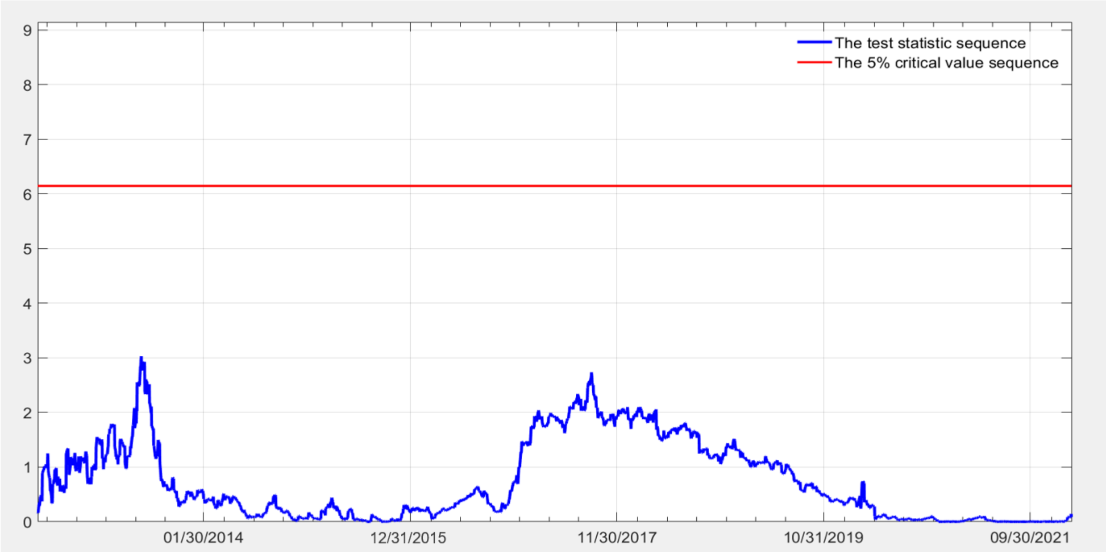
We discuss the empirical results that uncover the time-varying causal relationship between geopolitical risk and green finance in this section.

Figure 1 presents the time-varying Granger causality from geopolitical risk to the return of green bond. Since a significant causality can be identified in the LA-VAR specification if the Wald statistic exceeds the corresponding critical value, panel (a) of Figure 1 shows that no causality is detected during the sample period by using the forward expanding procedure. However, the rolling-window and recursive-evolving algorithm demonstrate distinct test results in comparison with the forward expanding method. As shown in panel (b) of Figure 1, two periods of causal switch-on from geopolitical risk to the return of green bond is found with the first period being 21 February- 22 March 2017 and the second period being 25 February- 8 April 2021. The beginning of 2017 was featured by the UK's official two-year countdown to formally leave the European Union with the Prime Minister of the UK triggering Article 50. The significant causal relationship between geopolitical risk and green bond return during this period signifies that the environmental impact of Brexit can be profound, which led the green bond market to respond accordingly. Furthermore, the first half of 2021 witnessed geopolitical instability arising from the inequitable economic recovery between emerging and developed economies following the outbreak of Covid-19 pandemic. Thus, it can be seen that geopolitical risk has significant ability in explaining green bond return during periods with heightened geopolitical tensions.

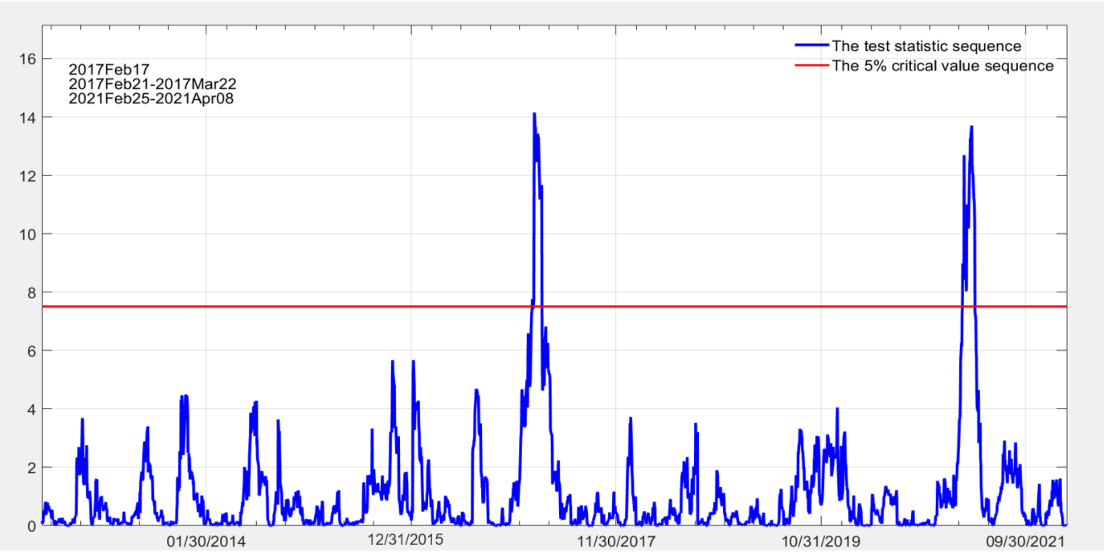
Moreover, recursive-evolving method in panel (c) reports a slightly different story as more periods with significant Granger causality is detected from geopolitical risk to green bond return. Apart from the significant periods detected in panel (b), it is found that geopolitical risk has a significant impact on green bond returns during June-September 2017. This period accords with the time when the Trump administration declared the intention to withdraw from the Paris Agreement on climate change and the intention to cease participation in the Joint Comprehensive Plan of Action, which imposed significant uncertainty to climate change legislation and environmental policy in the US. Consequently, changes in geopolitical stress can result in fluctuations in the return of green bond market.

Figure 1 Time-varying Granger causality from GPR to green bond return

Panel (a) Forward expanding



Panel (b) Rolling-window



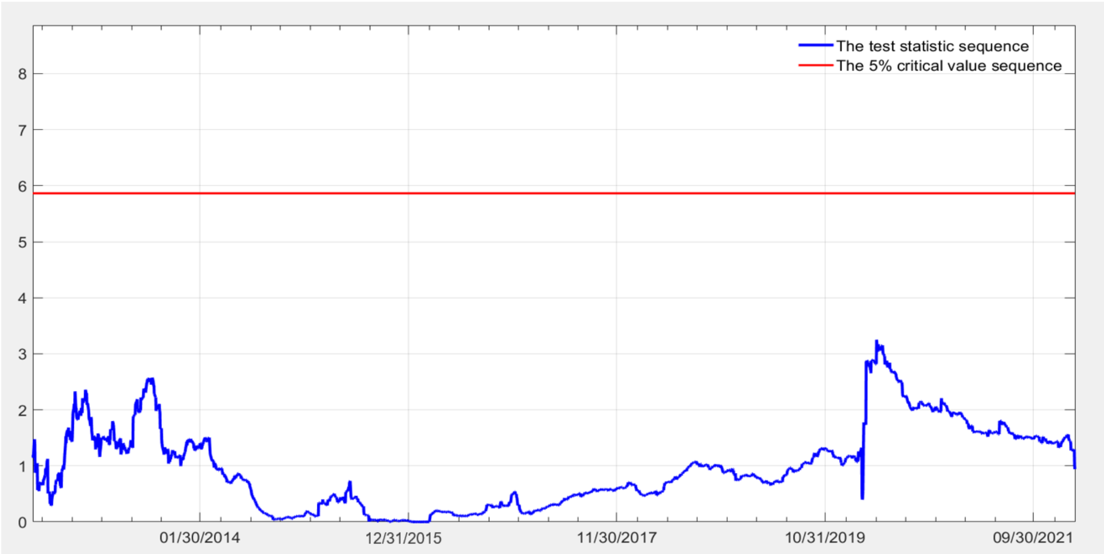
Panel (c) Recursive-evolving

Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

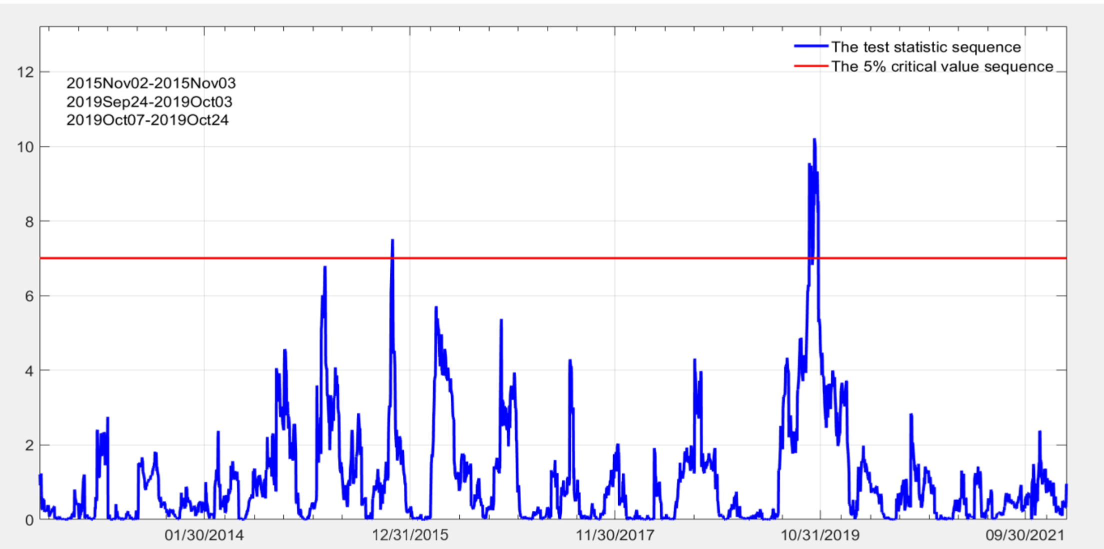
We explore the time-varying Granger causality from geopolitical risk to the volatility of green bond in Figure 2. Both the rolling window and recursive-evolving methods find that variations in geopolitical risk result in fluctuations of green bond volatility on 3 November 2015 and 24 September- 24 October 2019. The latter period coincides with the escalation of trade conflicts between the two largest economies in the world, the US and China, with tariffs hiked on Chinese imports imposed by the Trump administration. The green bond market responded to the associated geopolitical tensions with a greater amount of volatility. It is worth noting that panel (c) of Figure 2 also detects a significant Granger causality from geopolitical risk to green bond volatility for the period of 17 March- 17 July 2020, which is in accordance with the first wave of Covid-19 crisis and the introduction of lockdowns and restrictions to contain the spread of virus. The unprecedented challenges brought by Covid-19 led to a more uncertain geopolitical landscape, which in turn influenced the volatility of green bond market significantly. Moreover, our findings are consistent with the previous work regarding the causal relation between geopolitical risk and green bond (Lee et al., 2021), which show that there exists a unidirectional causality from geopolitical risk to green bond at lower quantiles. The consistency between our findings and the previous work may in part due to the fact that geopolitical risk plays a key role in influencing the prices of green bond.

Figure 2 Time-varying Granger causality from GPR to green bond volatility

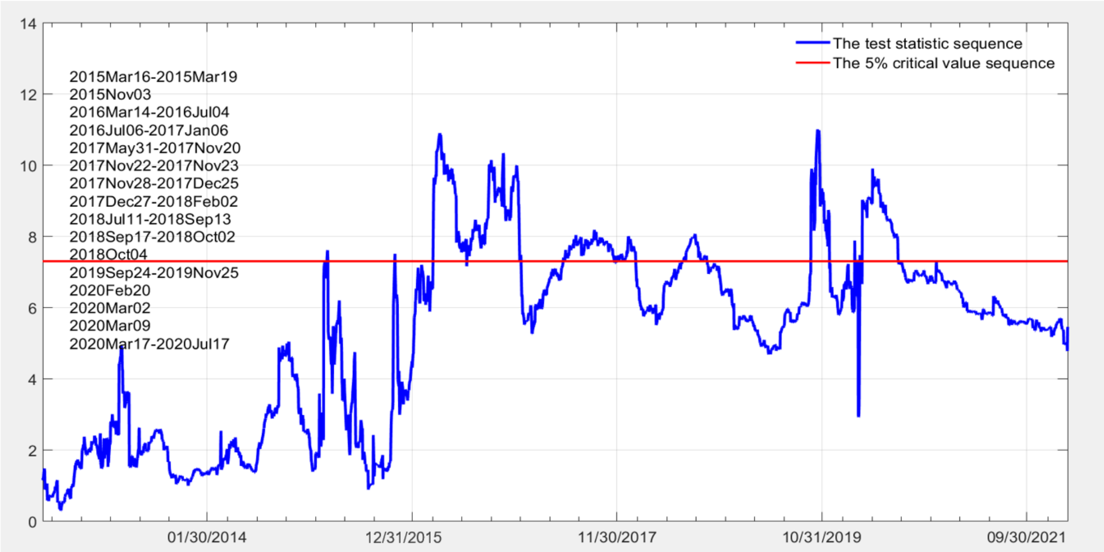
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving

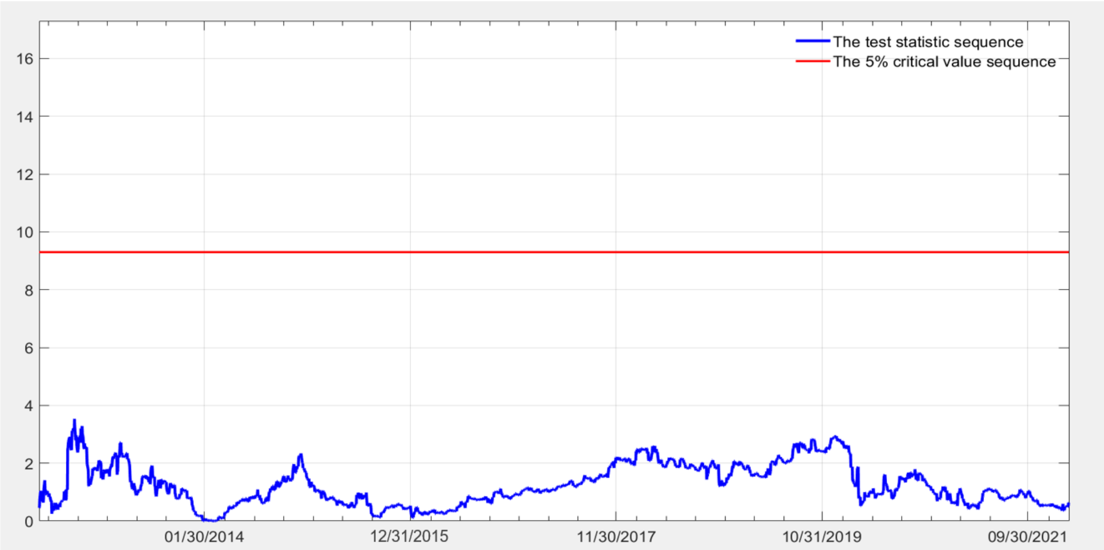


Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

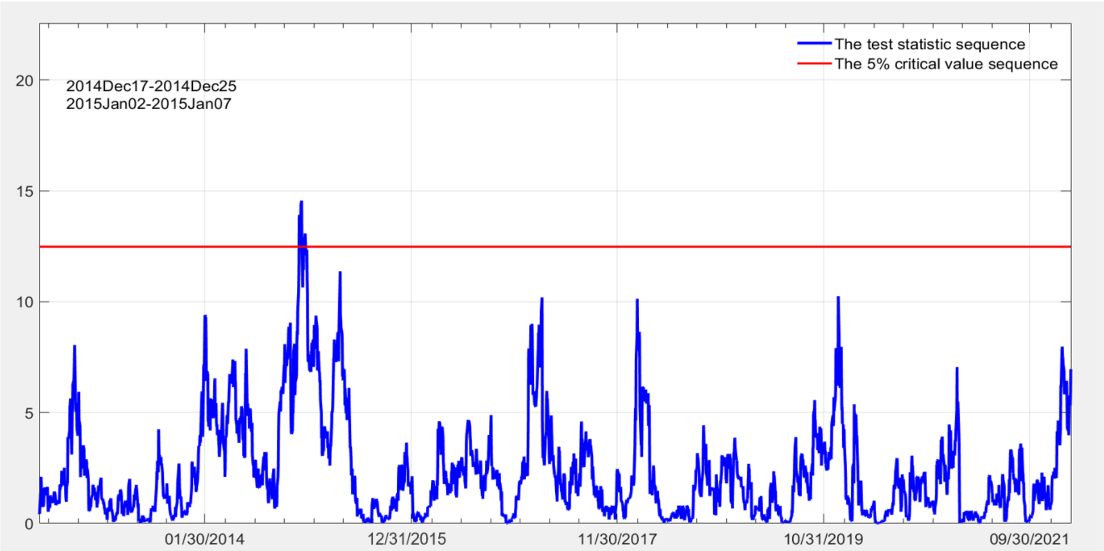
Figure 3 and 4 examines the time-varying causal relationship from geopolitical risk to the return and volatility of clean energy, respectively. As we can see from panel (b) and (c) of Figure 3, a significant causality from geopolitical risk to clean energy return was found between December 2014 and January 2015. Following the Russian invasion of Ukraine over Crimea in February 2014, international sanctions and restrictive measures were imposed against Russia subsequently. By the end of 2014, the European Union suspended the oil and gas exploration in Russian Black Sea and the US banned the exports to Russian-occupied Crimea. Moreover, Figure 4 demonstrates that geopolitical risk has significant explanatory power for the volatility of clean energy in December 2014 and December 2017, the profound geopolitical repercussions of the sanctions against Russia played a part in triggering the Russian financial crisis over 2014-2016 and the collapse of crude oil price. Overall, we find that geopolitical risk appears to have more significant causal relations with the return rather than the volatility of clean energy. In comparison with the relevant literature, Qin et al. (2020) use a quantile regression approach to examine the asymmetric effects of geopolitical risk on the return and volatility of non-renewable energy including crude oil, gas and heating oil. In particular, they find that geopolitical risk poses heterogeneous effects on energy returns and volatility under different market conditions. This is in line with our results on the time-varying causality between geopolitical risk and clean energy return and volatility. Since the time-varying nature is closely linked with the changing market conditions, it can be seen that the effects of geopolitical risk on clean energy varies with the rapidly changing geopolitical environment.

Figure 3 Time-varying Granger causality from GPR to clean energy return

Panel (a) Forward expanding



Panel (b) Rolling-window

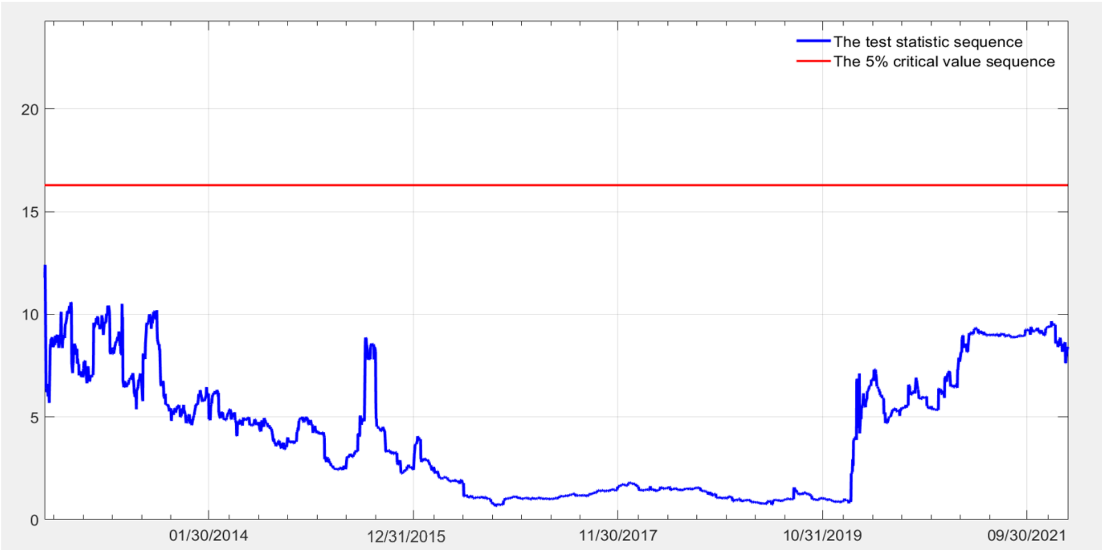


Panel (c) Recursive-evolving

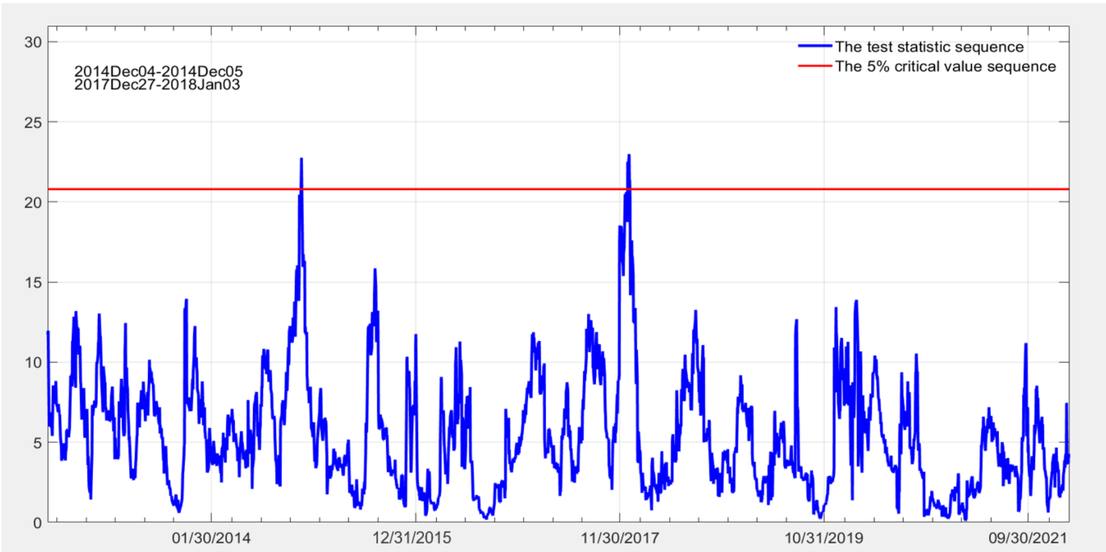
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 4 Time-varying Granger causality from GPR to clean energy volatility

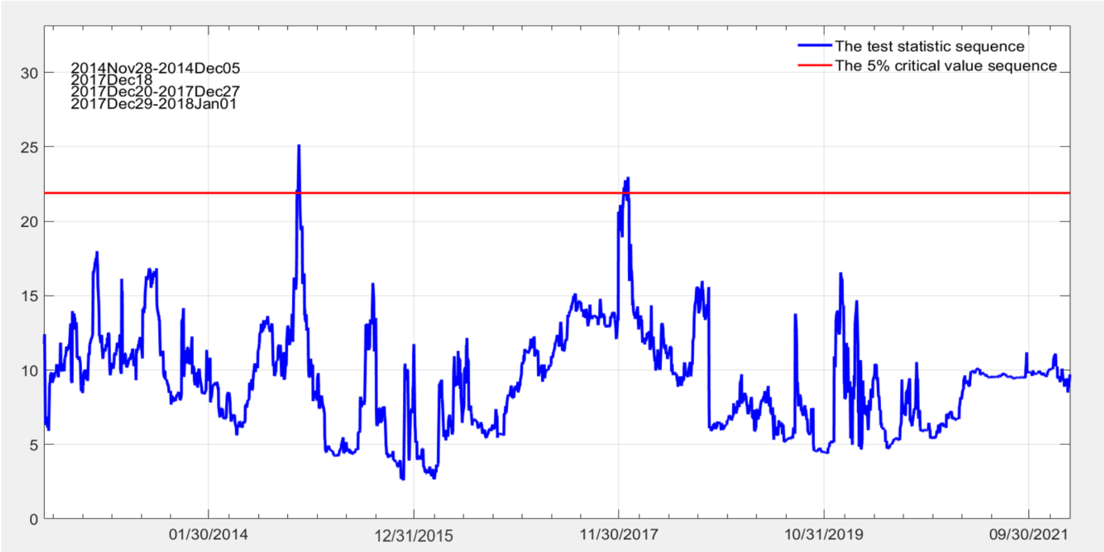
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving

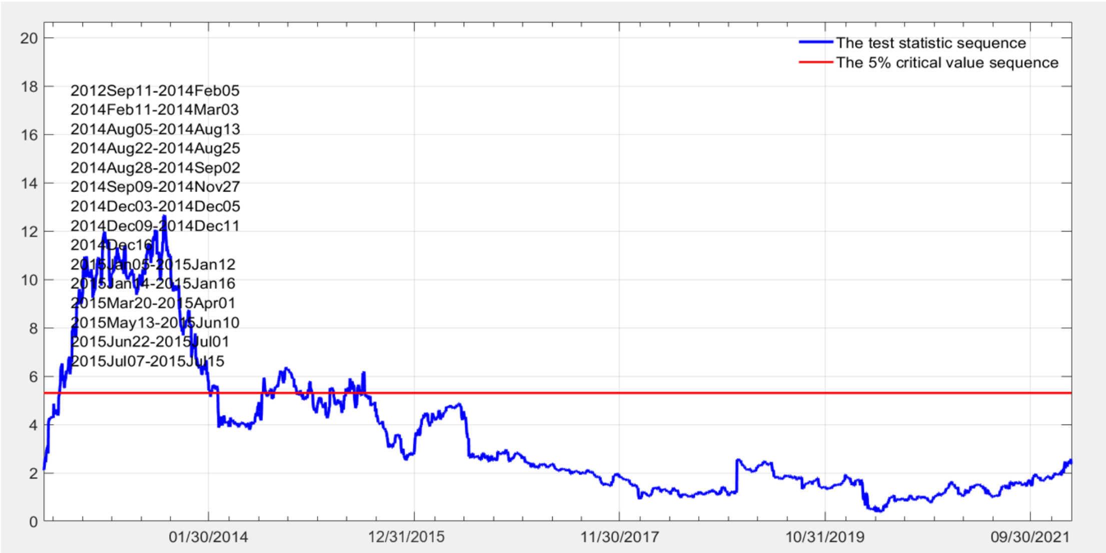


Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

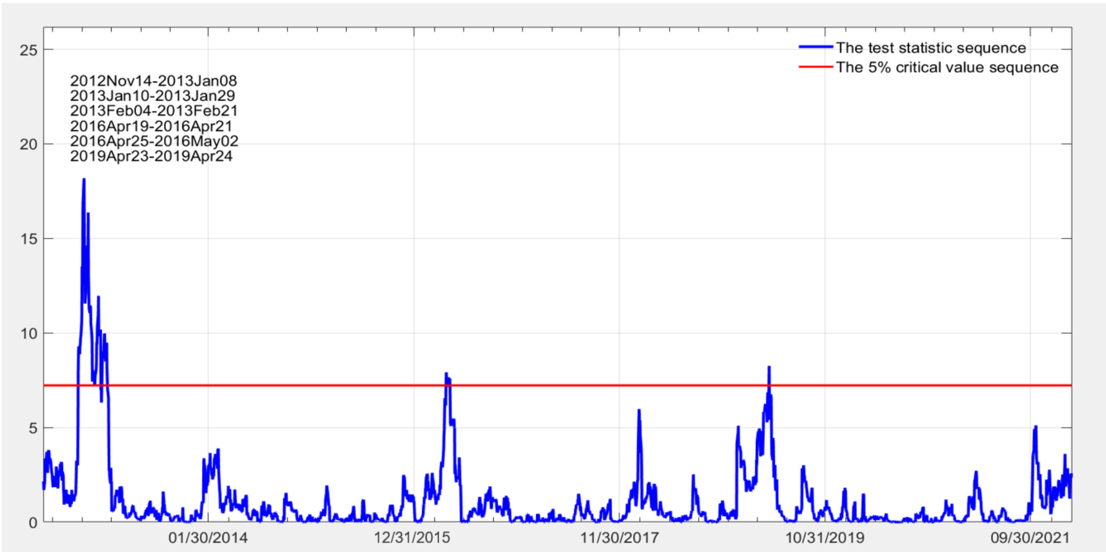
As we can see from Figure 5, the forward expanding method in panel (a) detects a prolonged period of causality from geopolitical risk to the return of Europe focused clean energy index from 11 September 2012 to 15 July 2015. An overlap of significant causality from geopolitical risk to the return of European clean energy is found by rolling window and recursive evolving algorithm in panel (b) and (c) over 14 November 2012- 21 February 2013. This period is in accordance with the 2012–2013 escalation of the Syrian Civil War and Syria being the major crude oil producing country in the Eastern Mediterranean region. In addition, we suspect that the significant causal relation from geopolitical risk to European clean energy return in 2016 is associated with the prosperity of the US shale revolution as well as the collapse of global oil prices, which is generally considered as one of the largest oil price plunges since World War II. Figure 6 shows that no causal relationship is found between geopolitical risk and the volatility of European clean energy index in the sample period except that a burst of causality over 22 June- 17 July 2015 was detected. This might be attributed to the European Union has been promoting green financing in the recent decade to accelerate sustainable green transition, which include the introduction of the European Green Deal in 2019. Accordingly, clean energy sector in Europe is shielded from volatile fluctuations due to geopolitical risk.

Figure 5 Time-varying Granger causality from GPR to European clean energy return

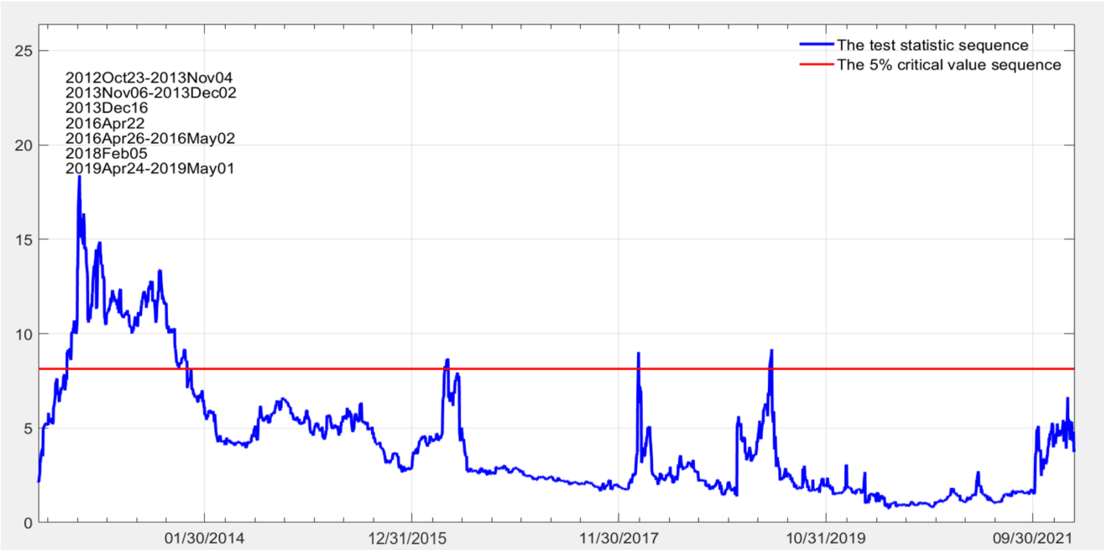
Panel (a) Forward expanding



Panel (b) Rolling-window



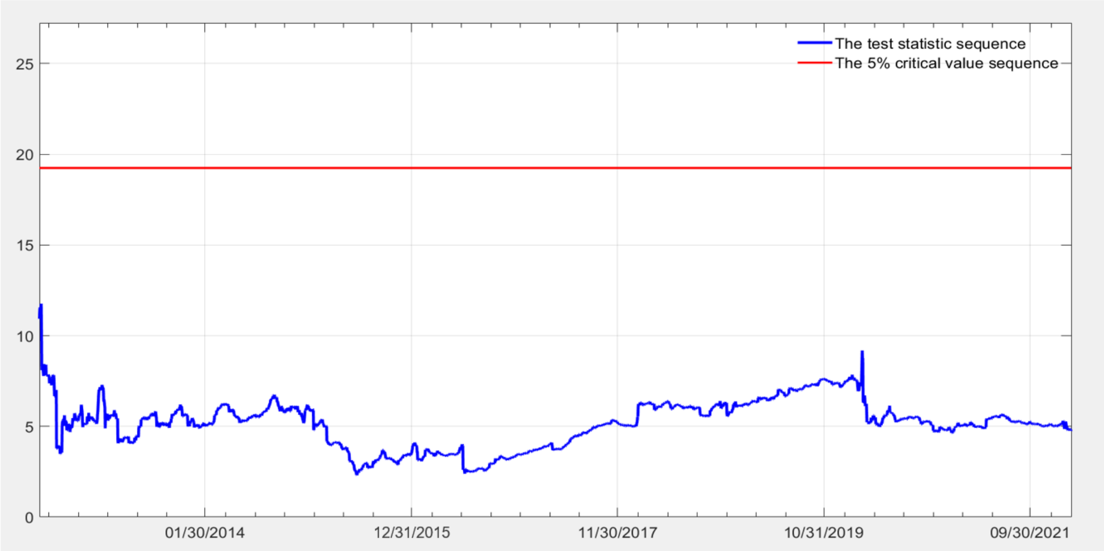
Panel (c) Recursive-evolving



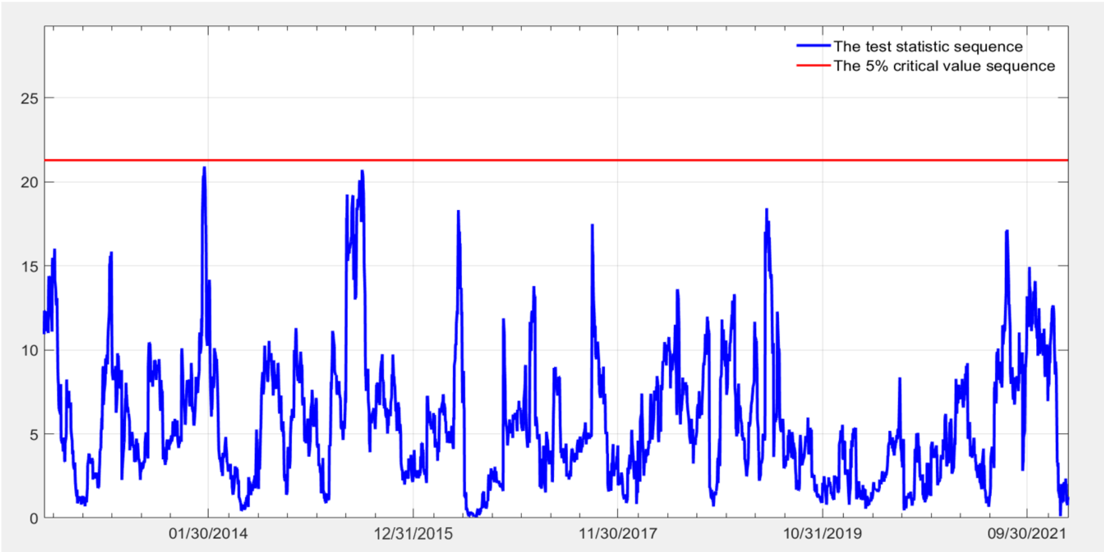
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

*Figure 6 Time-varying Granger causality from GPR to **European** clean energy volatility*

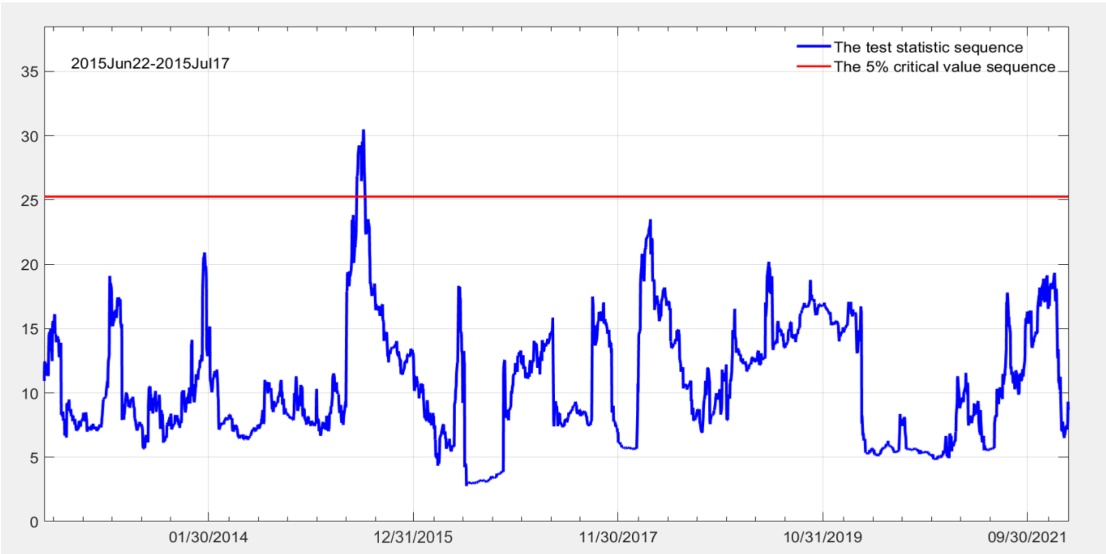
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving

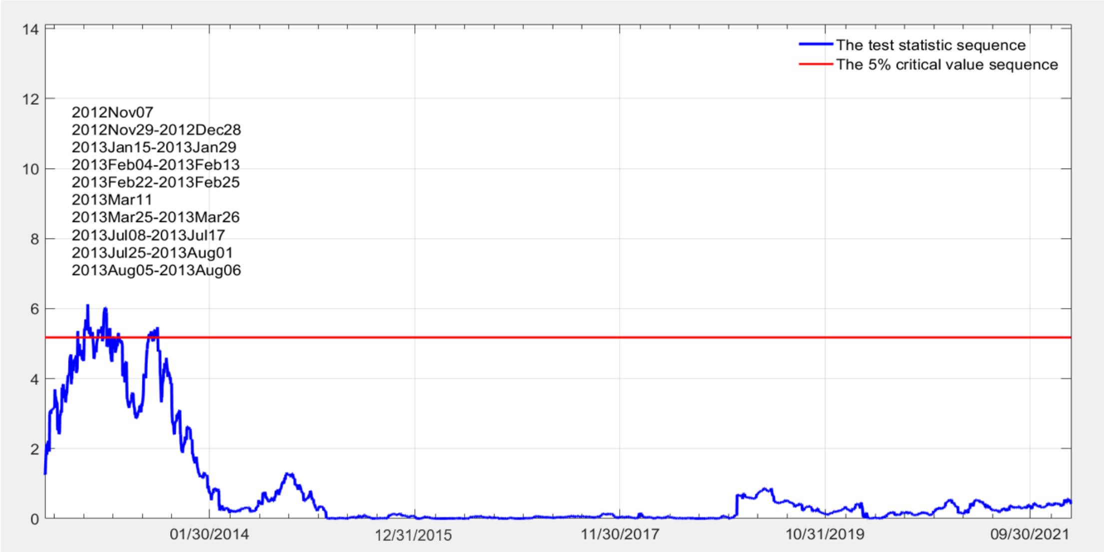


Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

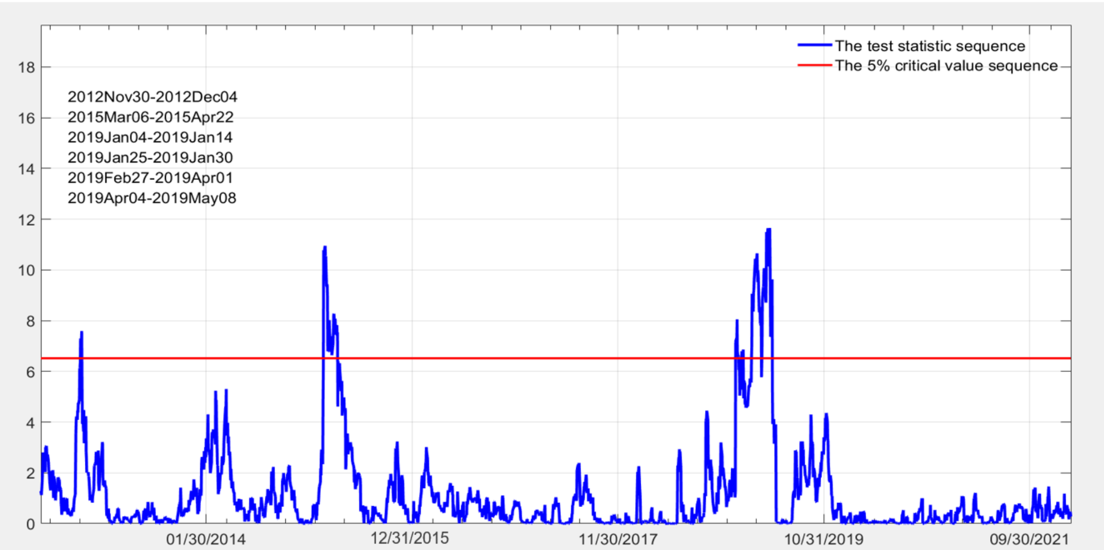
The time-varying Granger causality from geopolitical risk to the return and volatility of renewable energy is investigated in Figure 7 and 8, respectively. Forward expanding procedure in panel (a) of Figure 7 suggests that changes in geopolitical risk can result in significant variations of renewable energy return over 29 November 2012-6 August 2013, which accords with the geopolitical shocks caused by the unanticipated escalation of Syrian crisis. As shown in panel (b) and (c) of Figure 7, rolling window and recursive evolving method both detected that geopolitical risk has a statistically significant explanatory power for renewable energy return in 2012, 2015 and 2019. Moreover, panel (b) and (c) of Figure 8 shows that there is a significant causality running from geopolitical risk to the volatility of renewable energy in 2014, 2018, 2019 and 2021. In particular, the detected dates of significant causality in 2021 coincide with the world's slow economic recovery from pandemic, and the rapid rise of inflation due to the global supply chain disruptions as well as expansionary monetary and fiscal policy. In this regard, the adverse impacts of Covid-19 on the stability of economic system and financial market resulted in exacerbated geopolitical risk, which is found to significantly affect the volatility of renewable energy. Prior study on the relationship between geopolitical risk and renewable energy (Su et al., 2021) suggests that there is a bidirectional causality between global geopolitics risk and renewable energy. Our analysis adds to the current literature by further investigating the time-varying causality between geopolitical risk and both the return and volatility of renewable energy, which allows us to uncover the geopolitical risk-green finance nexus at a granular level and highlight the critical role of geopolitical risk in affecting the development of renewable energy through green financing.

Figure 7 Time-varying Granger causality from GPR to renewable energy return

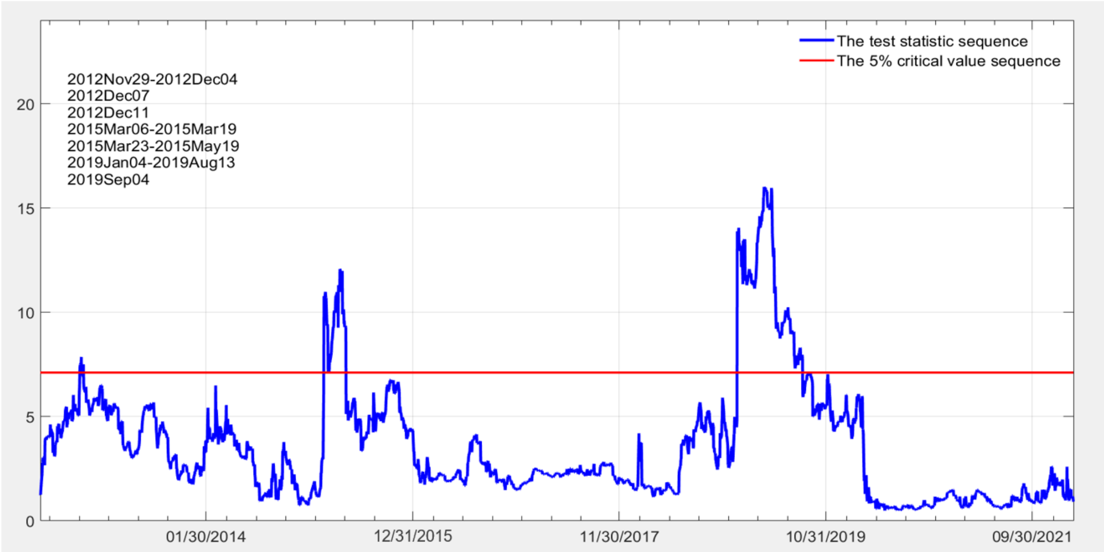
Panel (a) Forward expanding



Panel (b) Rolling-window



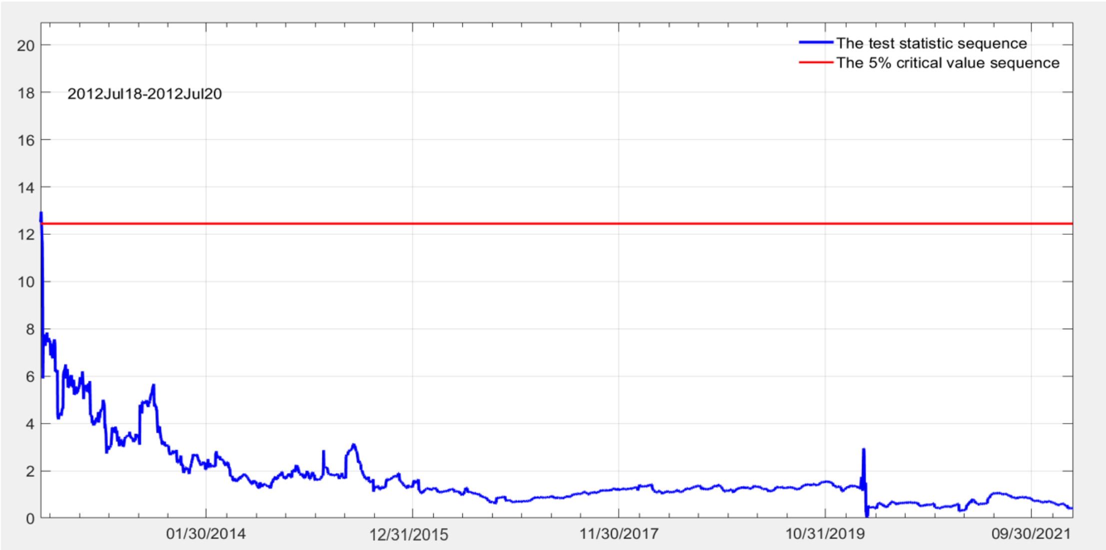
Panel (c) Recursive-evolving



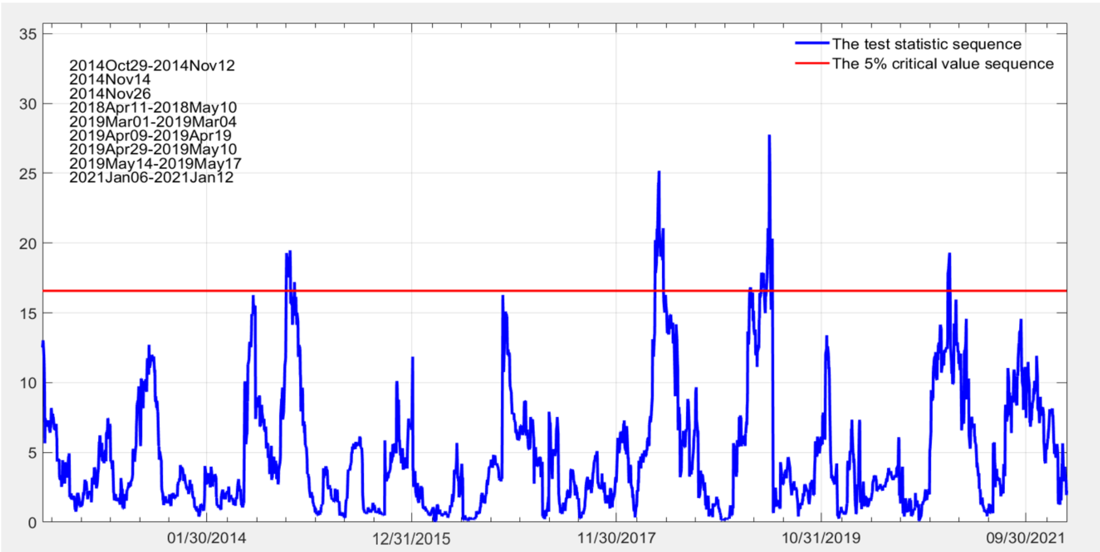
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 8 Time-varying Granger causality from GPR to renewable energy volatility

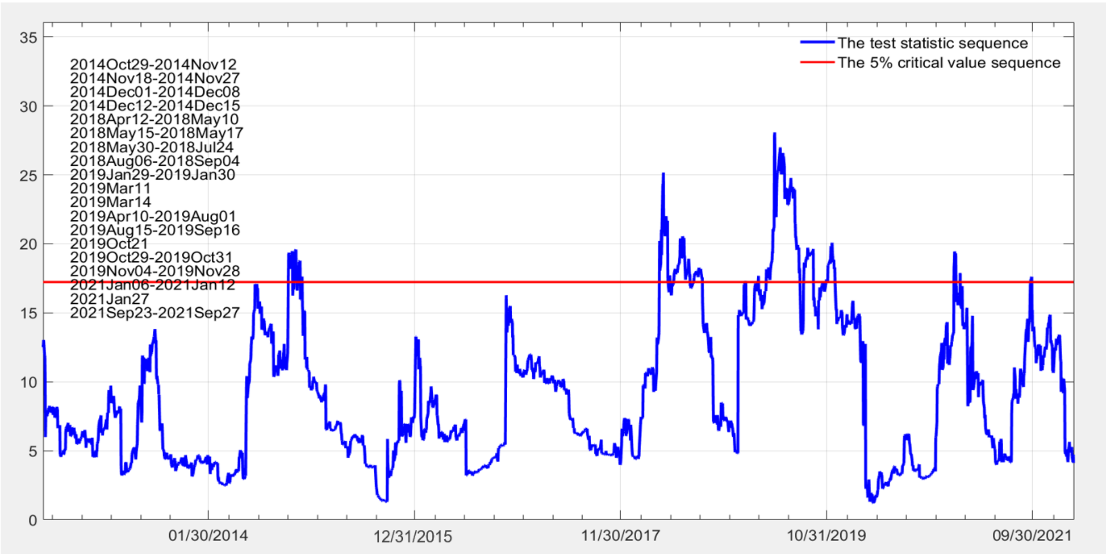
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving



Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of homoscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

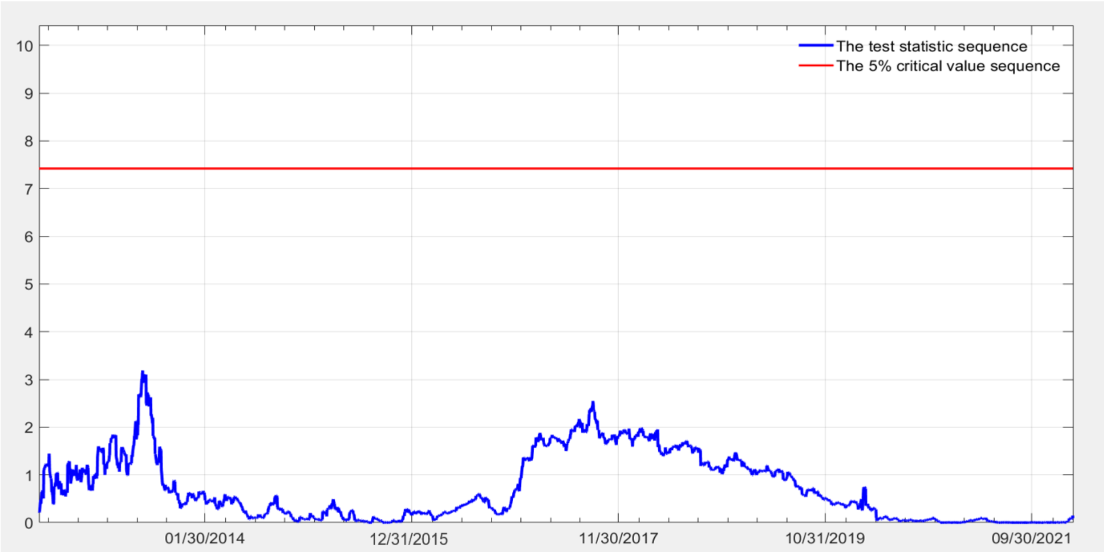
5.4 Robustness check

The robustness of our results is examined by employing the assumption of heteroskedasticity in this section. The test results and corresponding 5% critical values are reported in Figure 9-16, from which we can see that the majority of the heteroskedastic-consistent results are highly similar to the findings obtained assuming homoscedasticity, while there are minor differences the general trends under the assumption of homoscedasticity and heteroskedasticity follow very closely to the same pattern. This confirms that the validity of our findings is not sensitive to the assumptions on the property of the variance in the LA-VAR testing framework.

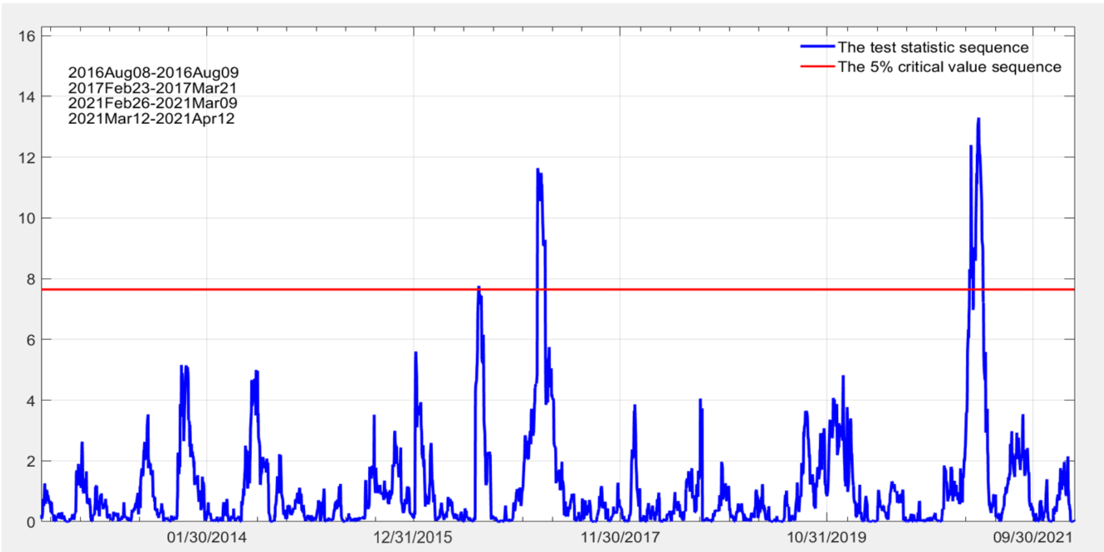
Nonetheless, a few minor differences between the results assuming homoscedasticity and heteroskedasticity do emerge. It is noteworthy that the assumption of heteroscedasticity tends to result in a more significant and prolonged causality running from geopolitical risk to the volatility of clean energy index in relative to the results assuming homoscedasticity. As shown in Figure 12, forward expanding method in panel (a) suggests that a significant causality is detected from geopolitical risk to clean energy volatility between 18-20 July 2012. Rolling-window and recursive-evolving method reported in panel (b) and (c) also shows additional significant periods of causality, respectively. Moreover, Figure 14 shows that the forward expanding and rolling-window techniques detect no causal relationship from geopolitical risk to the volatility of European clean energy by assuming heterogenous variance, which is in line with the main results shown in Figure 6. Panel (c) of Figure 14 shows that the volatility of European clean energy index is not affected by global geopolitical risk, indicating that European clean energy equity index is a safe haven asset for hedging against geopolitical risk during uncertain times.

Figure 9 Time-varying Granger causality from GPR to green bond return

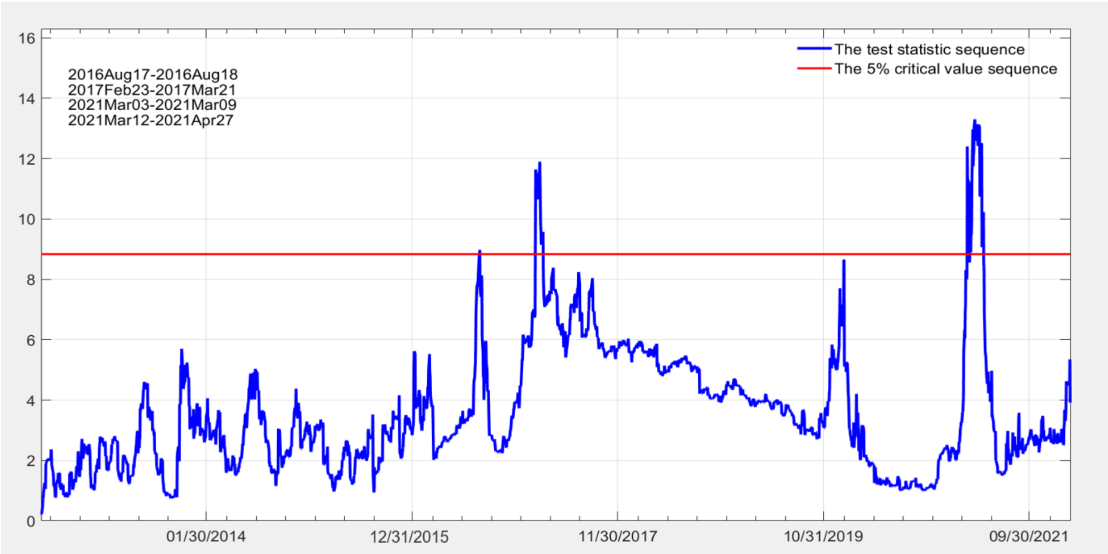
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving

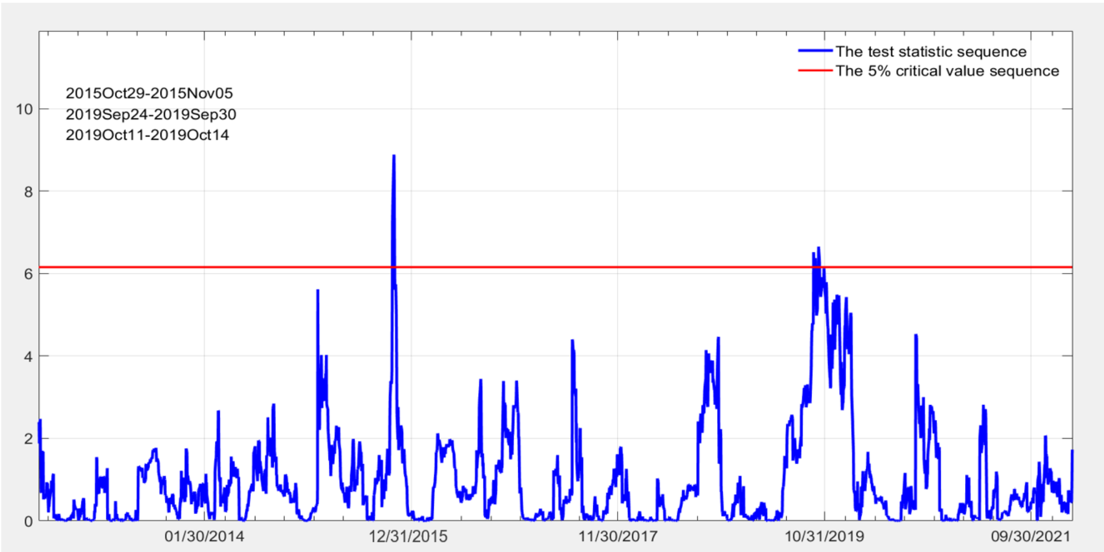


Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

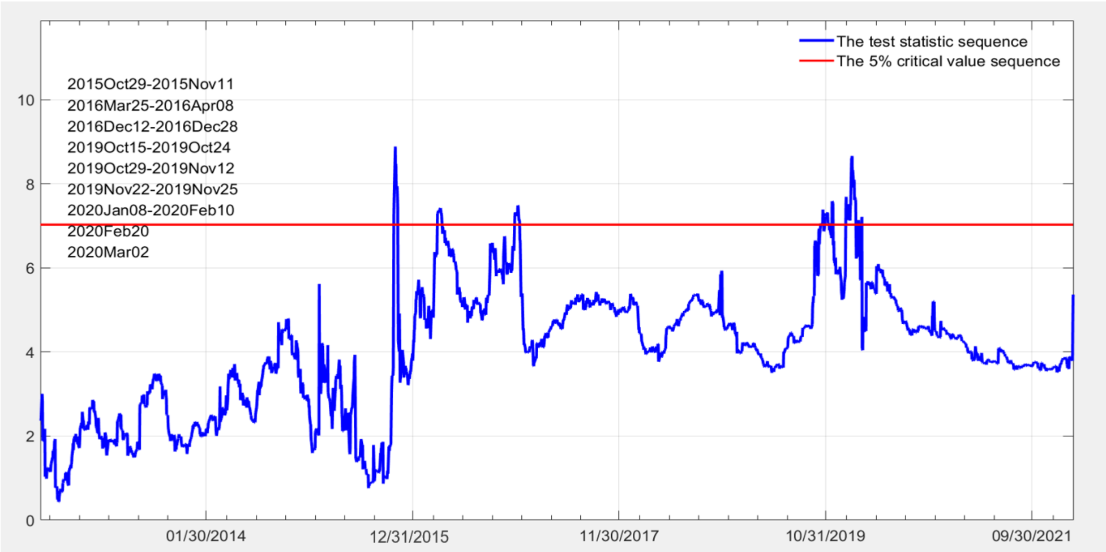
Figure 10 Time-varying Granger causality from GPR to green bond volatility

Panel (a) Forward expanding

Panel (b) Rolling-window



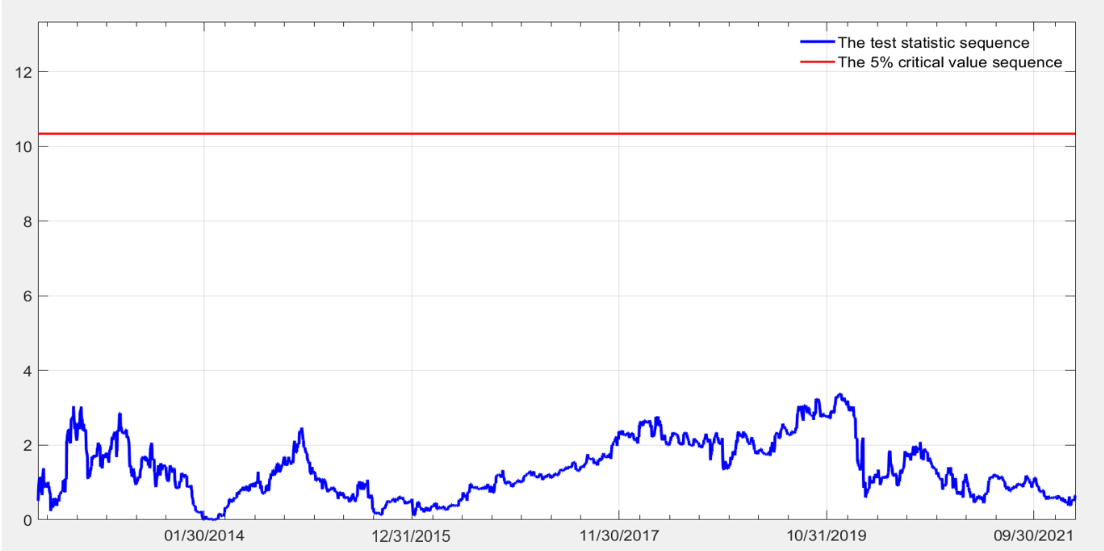
Panel (c) Recursive-evolving



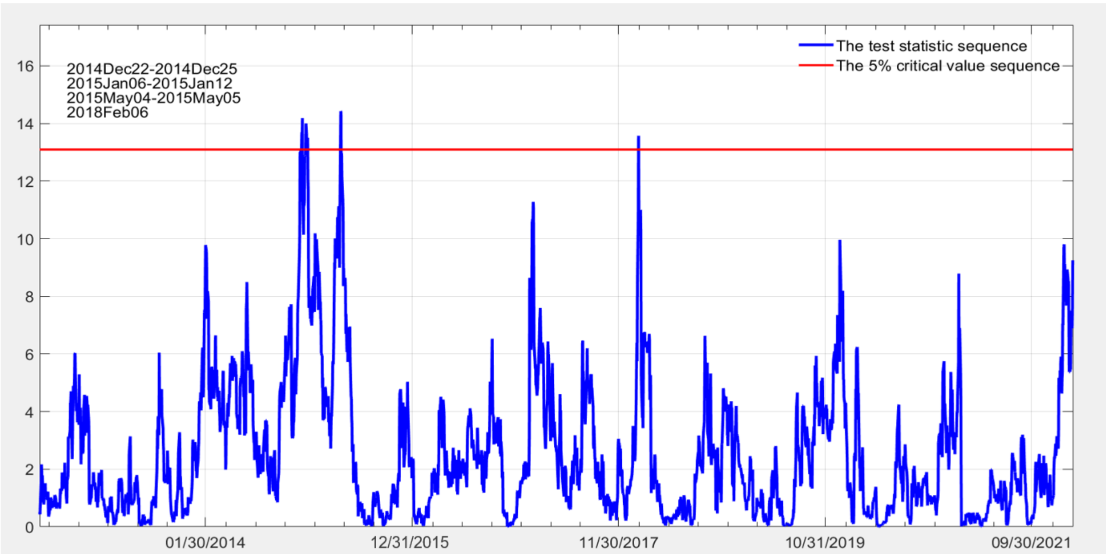
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 11 Time-varying Granger causality from GPR to clean energy return

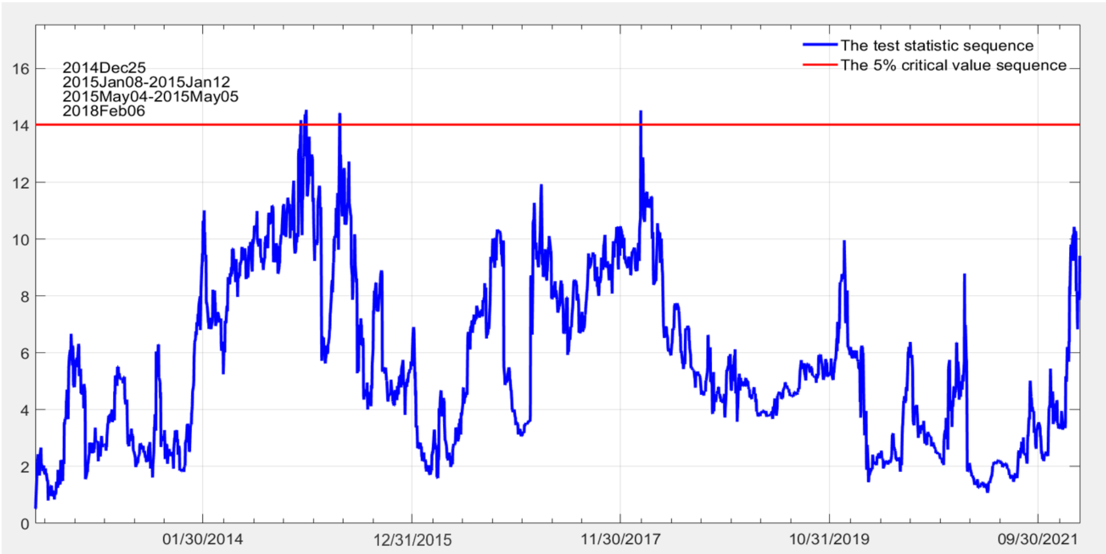
Panel (a) Forward expanding



Panel (b) Rolling-window



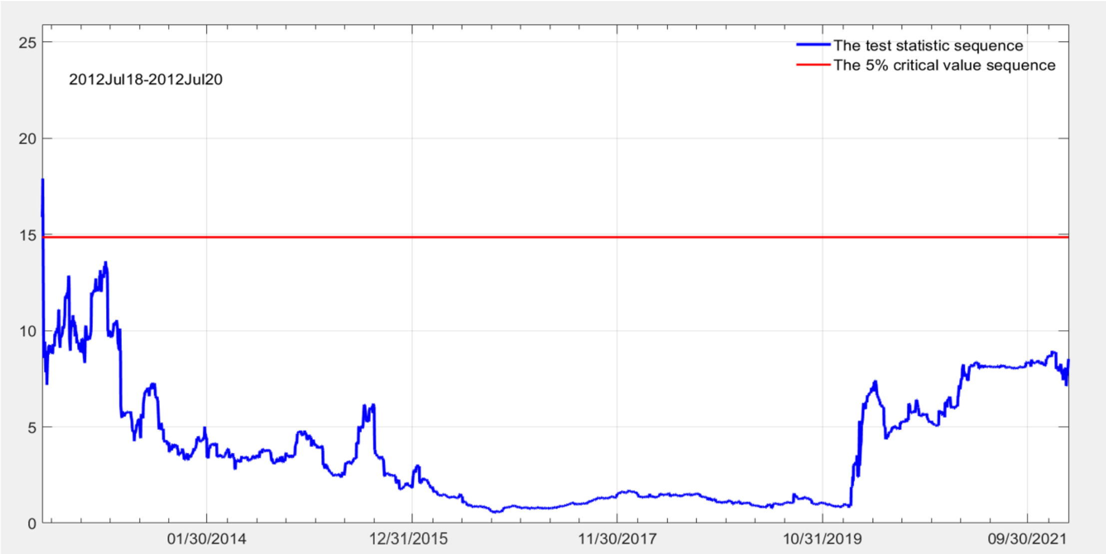
Panel (c) Recursive-evolving



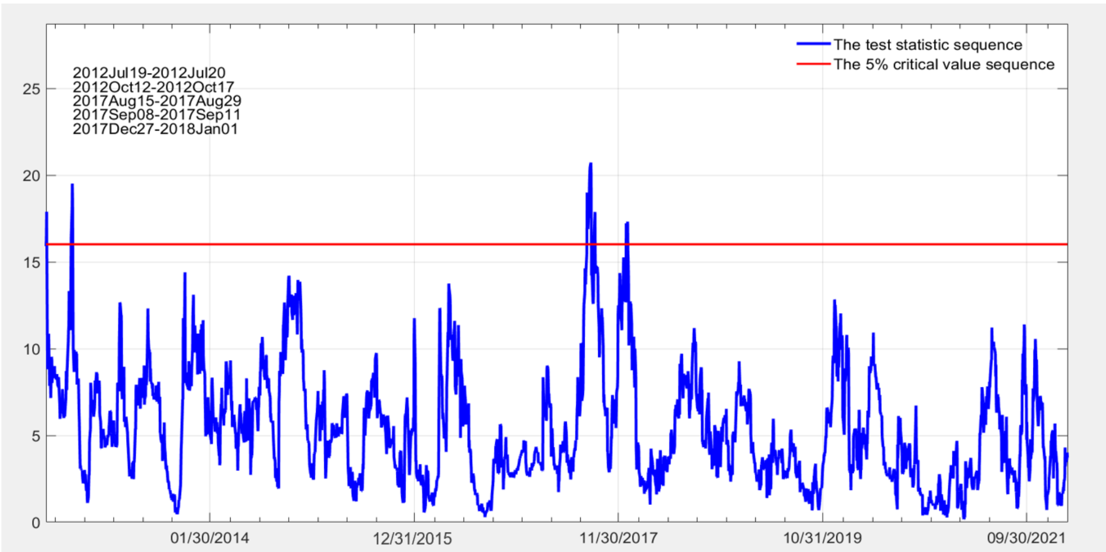
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 12 Time-varying Granger causality from GPR to clean energy volatility

Panel (a) Forward expanding



Panel (b) Rolling-window

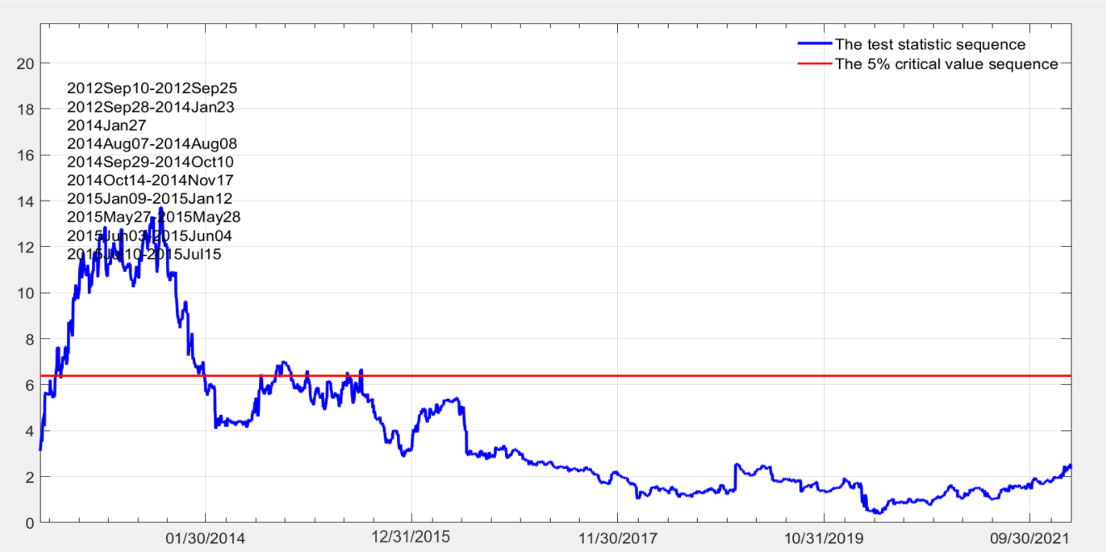


Panel (c) Recursive-evolving

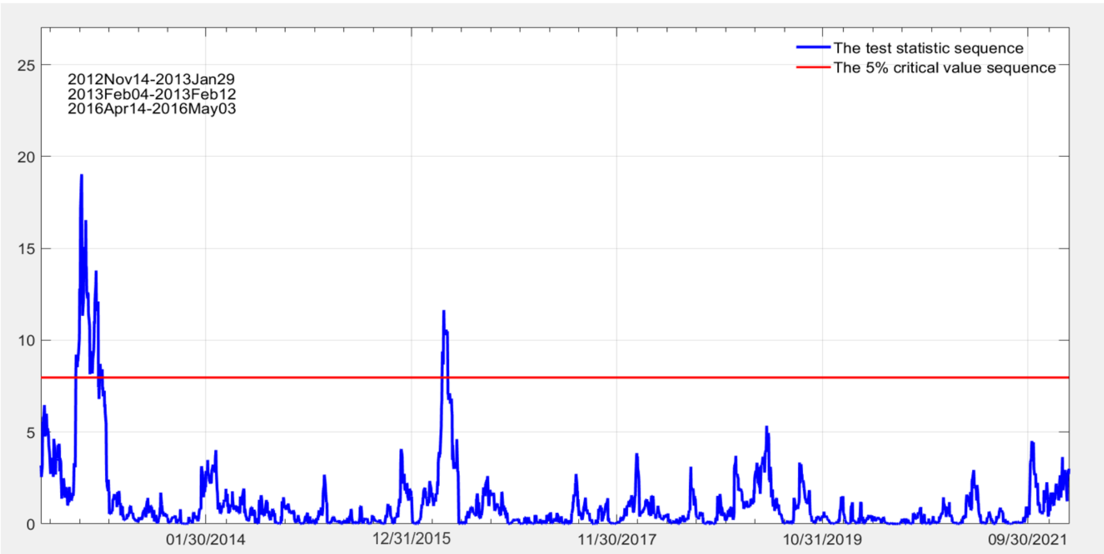
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC)

Figure 13 Time-varying Granger causality from GPR to ***European*** *clean energy return*

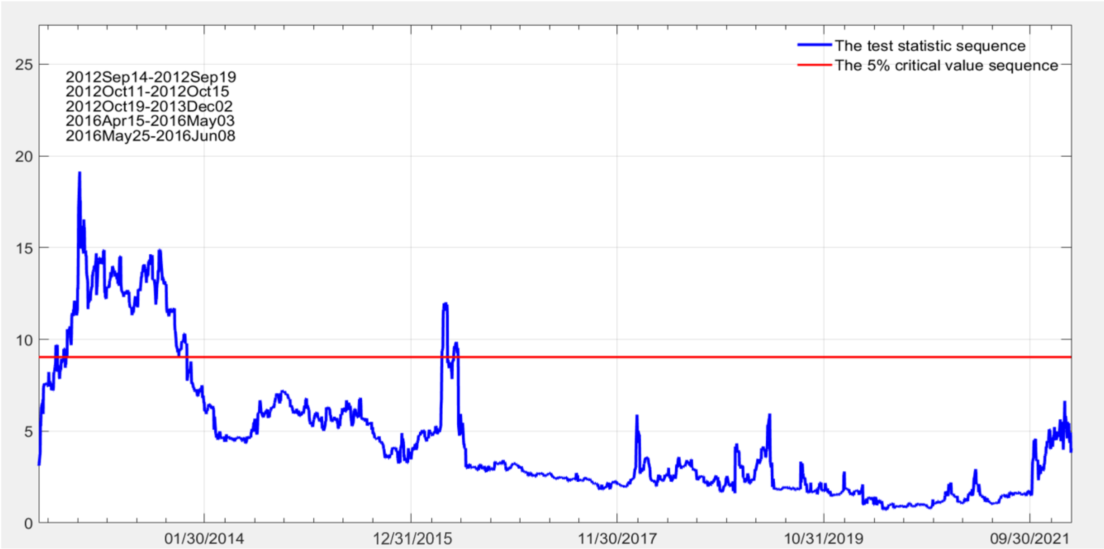
Panel (a) Forward expanding



Panel (b) Rolling-window



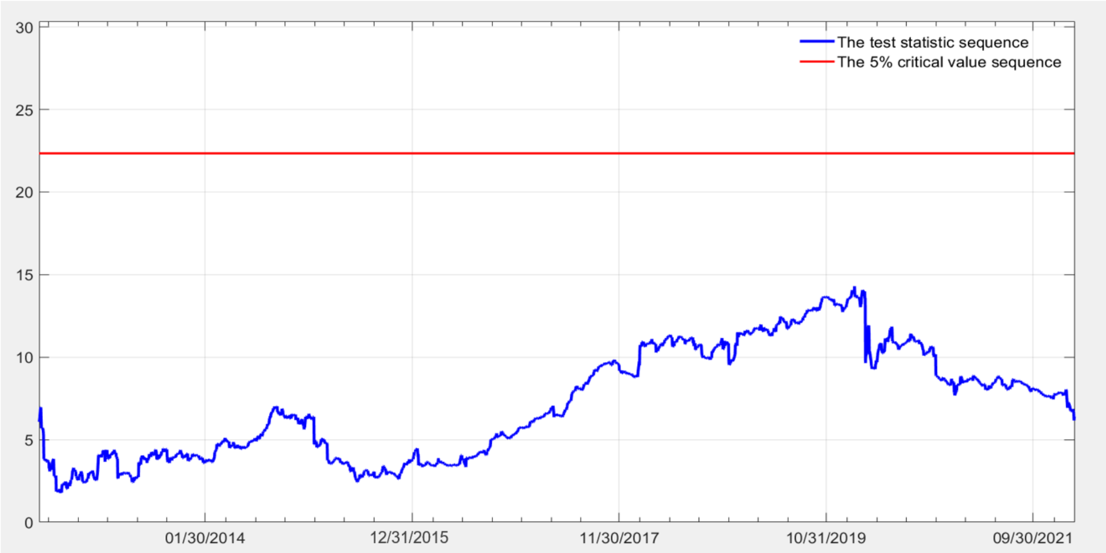
Panel (c) Recursive-evolving



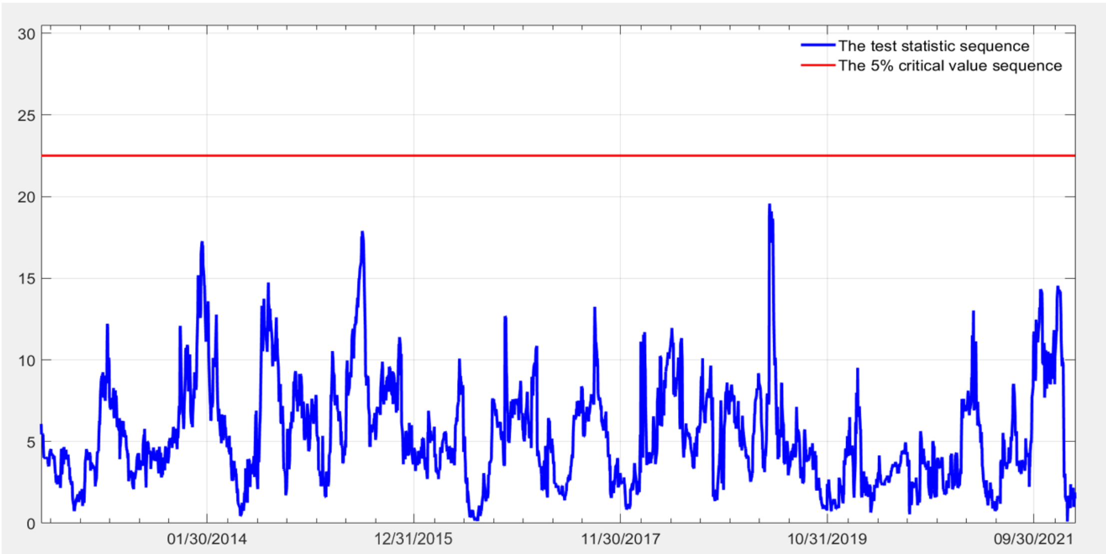
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

*Figure 14 Time-varying Granger causality from GPR to **European** clean energy volatility*

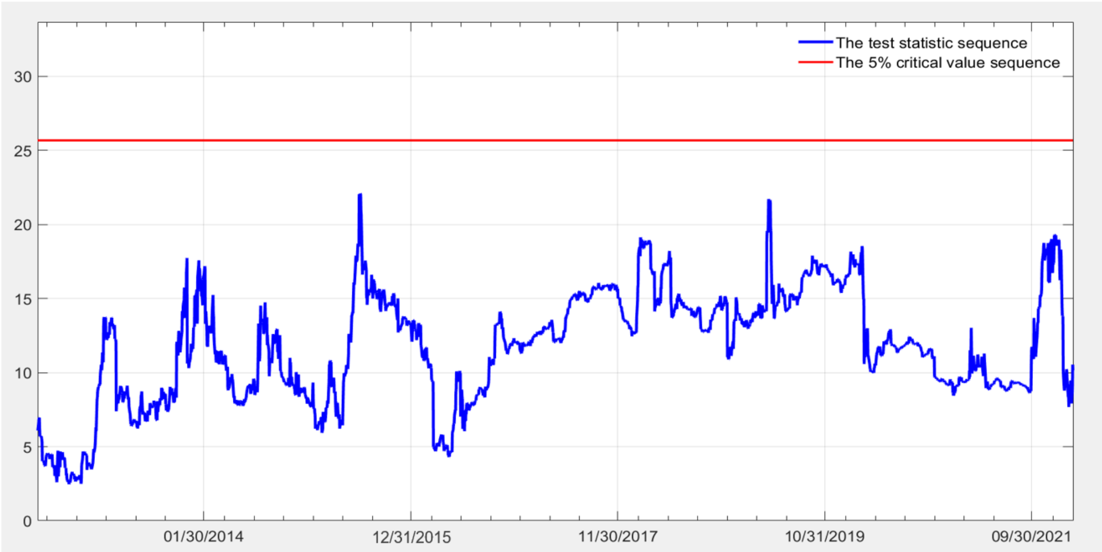
Panel (a) Forward expanding



Panel (b) Rolling-window



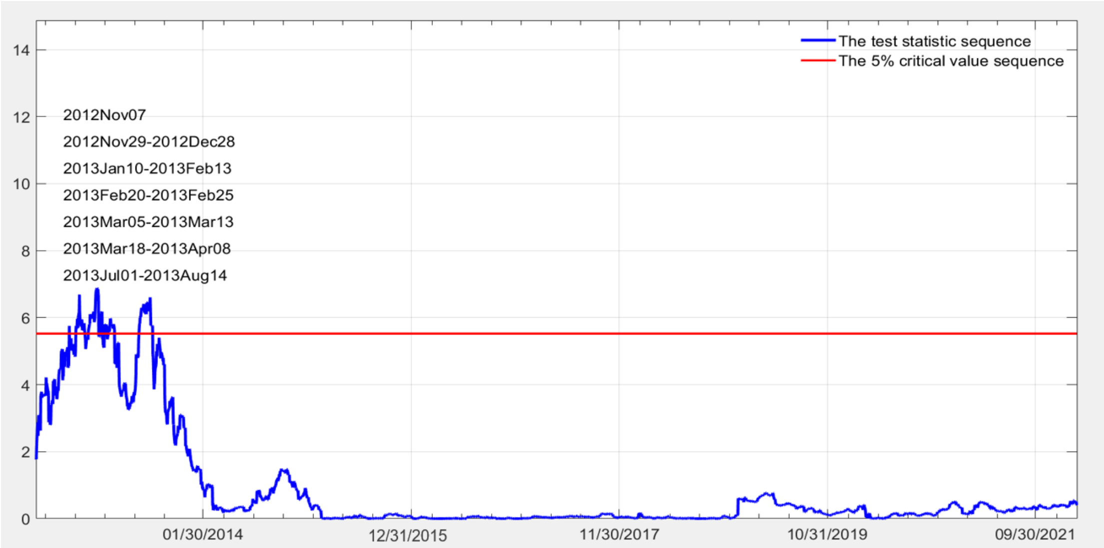
Panel (c) Recursive-evolving



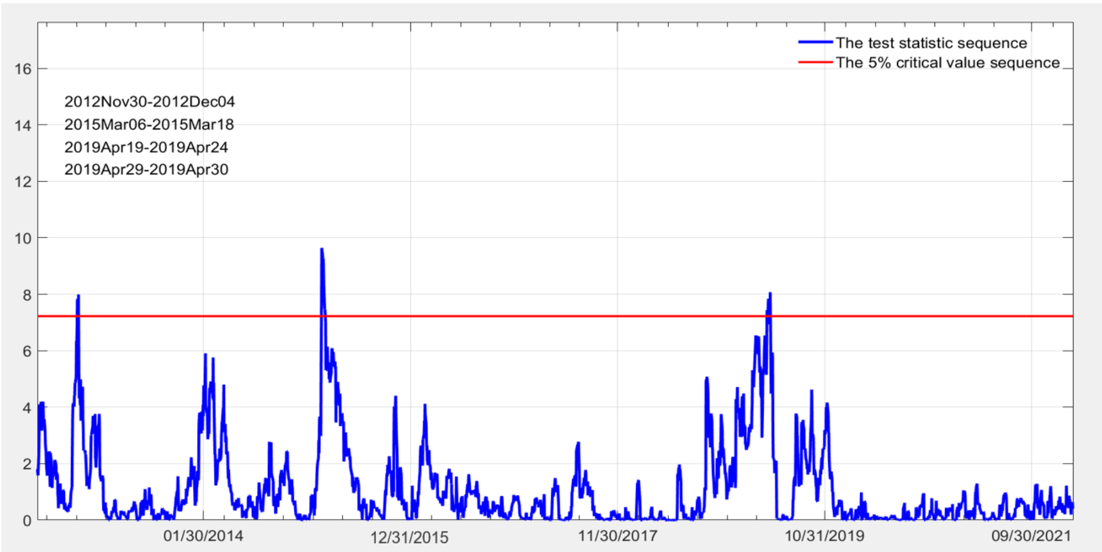
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 15 Time-varying Granger causality from GPR to renewable energy return

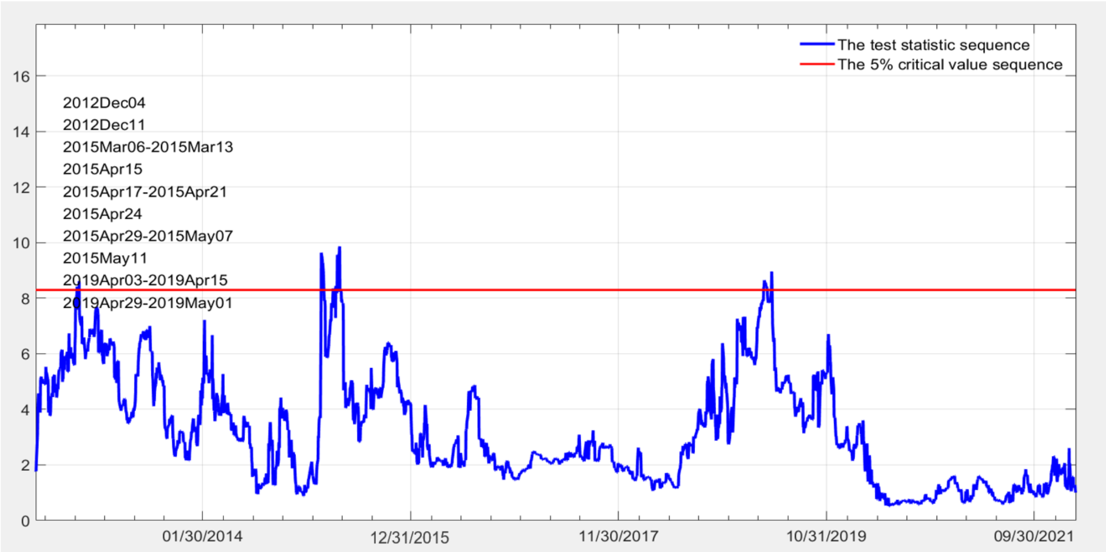
Panel (a) Forward expanding



Panel (b) Rolling-window



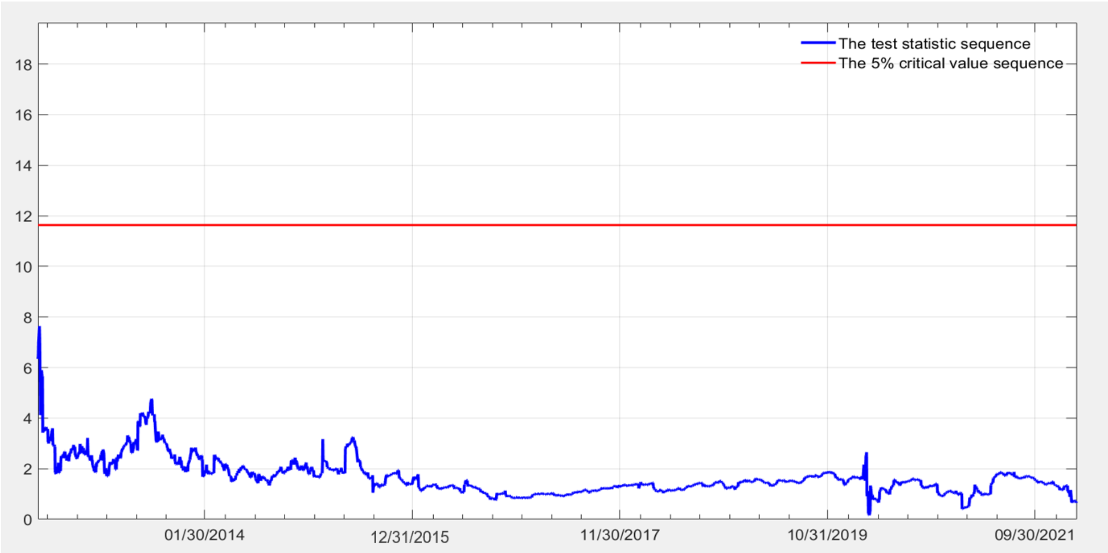
Panel (c) Recursive-evolving



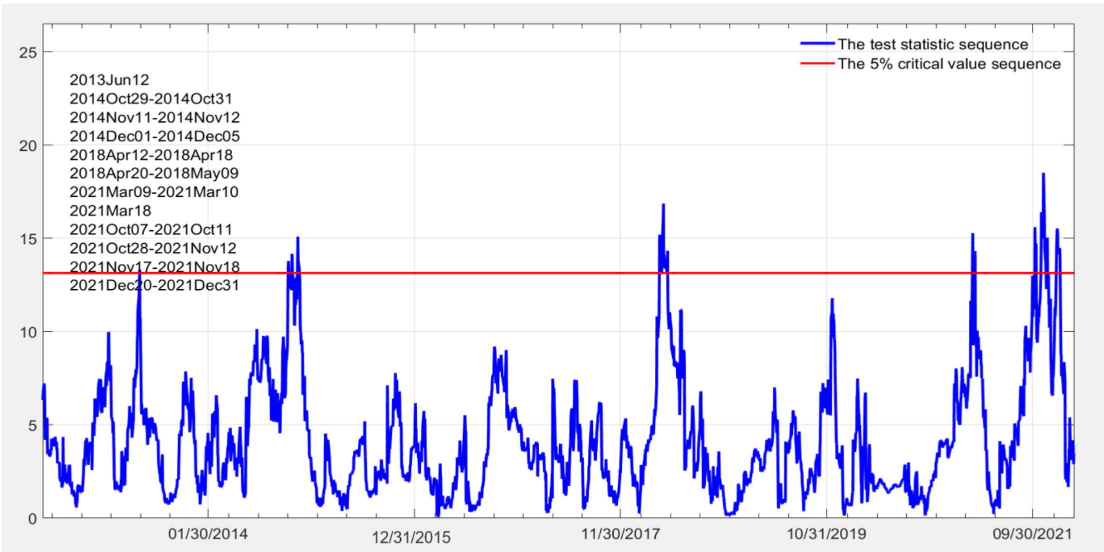
Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

Figure 16 Time-varying Granger causality from GPR to renewable energy volatility

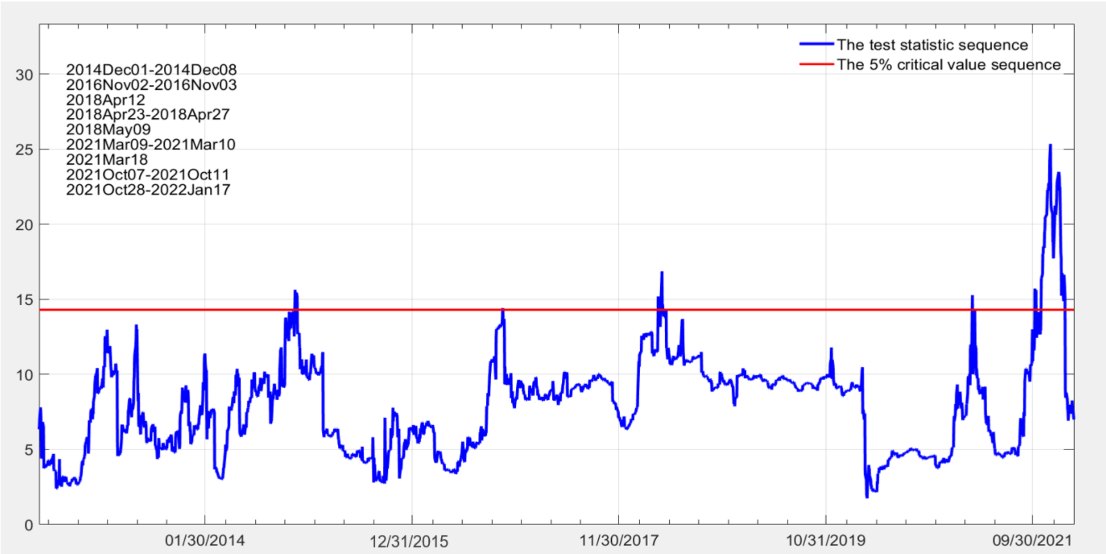
Panel (a) Forward expanding



Panel (b) Rolling-window



Panel (c) Recursive-evolving



Notes: Panel (a)- (c) reports the results from the forward expanding, rolling-window and recursive-evolving algorithm under the assumption of heteroscedastic errors, respectively. The VAR model is specified as $f_t = [GB_t, GPR_t, SP_t, Oil_t, Metals_t]$. The optimal order of lags in the VAR model is selected as 1 based on the Bayesian Information Criteria (BIC).

5.5 Discussions

We find that geopolitical risk imposes heterogenous impacts on the return and volatility of different green financial products whilst time heterogeneity does exist in the causal relations between geopolitical risk and green finance. This offers important implications to improve environmental management and enhance environmental sustainability. Green finance serves as an intermediary in channelling capital toward projects that contribute to the sustainable environmental management and the green economy transition to mitigate climate change (Yousaf et al., 2021; Li et al., 2022). In particular, the green financing system plays an important role in promoting the advancement of green energy technologies and widespread utilisation of clean energy and renewable energy. Drawing on our findings, the environmental benefits of green finance may be hindered by geopolitical risk. In light of this, effective environmental management practices should ensure the green financing mechanism is resilient to geopolitical risk. Capital investments in climate transition to prevent environmental degradation may in turn alleviate the financial bottlenecks of environmental management reforms.

Moreover, our results document a significant Granger causality from geopolitical risk to the volatility and return of green bond in the period after the Covid-19 outbreak. Through aligning the financial capital from the public and private sector with environmentally sustainable initiatives, green bond enables innovative environmental management and protection applications to achieve climate-resilient growth (Madaleno et al., 2022). This is accomplished by allocating the green bond proceeds to projects that promote the utilisation of green energy and awareness of environmental sustainability. Nevertheless, our findings imply that the green financing path of green bond is susceptible to geopolitical risk in times of turbulence. This indicates that it is essential for environmental management policymakers to incorporate perceptions of geopolitical risk in the green bond market to reduce the geopolitical externalities.

Based on the time-varying causal relations between geopolitical risk and the NASDAQ OMX Clean Energy Focused Europe Index, clean energy sector in Europe is shown to be resilient against geopolitical uncertainty. This highlights the necessity to stimulate clean energy transition in Europe to decrease energy dependency on fossil fuels and accelerate the progress of energy independence in the context of escalated Russia-Ukraine conflict. Furthermore, clean energy transformation is aligned with the UN 2030 Agenda for Sustainable Development (United Nations, 2015). Mobilising public and private investments into green energy projects with sustainability objectives facilitates the delivery of the UN's Sustainable Development Goals. In this regard, green finance plays a key role in directing financial flows to support clean energy transition and achieve effective environmental management. Our results are in line with the view that green finance is an essential component in enhancing environmental quality and regulation in the pursuit of carbon neutrality (Su et al., 2022).

In addition, our empirical evidence suggest that geopolitical risk has a more sustained impact on the return and volatility of renewable energy than clean energy. This might be due to the distinct nature between clean energy and renewable energy, albeit both clean and renewable energy generate less greenhouse gas emissions than fossil fuels. Specifically, the generation of clean energy such as solar, wind, geothermal and hydro power brings about zero greenhouse gas emissions but is generally restricted by geographic locations and weather conditions. Renewable energy can be constantly replenished from natural resources but involves a low carbon footprint. The stronger influence of geopolitical risk on renewable energy relative to clean energy has important implications for constructing a sustainable environmental management framework, which should prioritise investments in developing clean technologies and building geopolitical risk resilient green economy. This is in agreement with the perception that green finance is an effective mechanism in mitigating environmental pollution through promoting environmentally friendly technologies (Li et al., 2022). Despite the differences in environmental impacts and resources availability, clean and renewable energy are both an integral part of green transition to combat climate change.

6. Conclusion and policy implications

6.1 Conclusion

Green financial products and instruments redirect credit and investment toward environmentally sustainable development. Meanwhile, geopolitical episodes such as the Russia-Ukraine war, Gulf tensions, US-China trade war and climate policy gridlock have intensified the competition among world powers and the fragmentation of efforts to achieve environmental sustainability. Transition towards green finance can fulfil the collective commitment to climate action in a world with elevated geopolitical risk by mobilising financial flows to environmentally friendly projects, thereby fostering resilient environmental management (Zhang et al., 2021).

Against the aforementioned backdrop, this study examines the time-varying causal relationship between geopolitical risk and green finance from the period of 1 March 2012 to 16 February 2022. Our findings shed light on the nexus between geopolitical risk and green finance in informing environmental management decisions. We find that there exists significant time-varying Granger causality (Shi et al., 2020) from geopolitical risk to green finance. Specifically, this study shows that geopolitical risk has a more prolonged impact on the volatility of green bond and renewable energy than return. Yet, geopolitical risk tends to influence the return of clean energy more persistently than volatility. Furthermore, our findings document a significant causal relationship between geopolitical risk and green bond since the World Health Organization (WHO) declared the outbreak of Covid-19 as a worldwide pandemic in March 2020.

We also observe that geopolitical risk has a more sustained impact on the return and volatility of renewable energy than clean energy. This might be due to the distinct nature between the production of clean energy and renewable energy and provides implications for effective environmental management. Moreover, this paper demonstrates that the impact of geopolitical risk on the return of European clean energy has diminished since the onset of 2015. More importantly, the volatility of European clean energy is not affected by global geopolitical risk, indicating that European clean energy equity index is a safe haven asset for hedging against geopolitical risk during uncertain times. This also highlights the need to further develop the clean energy sector in Europe in an attempt to reduce the reliance on fossil fuels and enhance energy independence.

Moreover, our findings demonstrate that the heterogenous impacts of geopolitical risk on the return and volatility of green finance can be used to improve financial and environmental risk management, which enhances energy independence and green transformation (Alkathery et al., 2022). In light of the significant causal relationships between geopolitical risk and green finance tend to occur during periods of geopolitical crises and financial market turmoil, investors and businesses can use our findings to optimise portfolio diversification. Given that geopolitical risk contains the predictive content for the return and volatility of green finance products, it is prominent for policymakers to strengthen the green finance regulatory environment in ensuring the stabilisation of the green financial market, especially during turmoil times. In addition, this paper also provides practical implications on how the development of green finance can pave the way for sustainable environmental management.

6.2 Policy implications

This study provides profound implications for investors, enterprises, and regulators in improving financial and environmental risk management. It is of prominence for policymakers to strengthen the policy framework supporting the development of green finance so as to ensure the channel of green financing towards environmentally friendly projects is resilient against geopolitical risk, thereby maintaining the stability of green finance market (Nasir et al., 2021). Since geopolitical risk may undermine the progress to prevent environmental degradation, a comprehensive green finance roadmap would be crucial to promote effective environmental management.

Furthermore, enhancing regulatory transparency in green finance market can play a key part in aligning public and private sector capital with the environmental dimensions outlined in the Sustainable Development Goals (United Nations, 2015). This is because transparent green finance agenda allows investors to gauge the financing requirement details of projects that contribute to environmental sustainability, ranging from sustainable management applications of natural resources to technological innovations in green energy. Lastly, green finance policies should prioritise investments in clean energy to diversify the energy resources and improve the affordability in an attempt to accelerate energy transformation and enhance energy security.

6.3 Limitations and recommendations for future study

In this section, we present an overview of possible limitations of this study and offer recommendations for future research accordingly. First, the selection of green financial instruments in this paper is limited to four types of equity indices. The fast development of green financing has allowed for the emergence of new green financial products such as carbon emissions trading, green investment funds, weather derivatives and sustainability-linked derivatives (Nguyen et al., 2021; Shahbaz et al., 2018). As different green financial instruments may respond to geopolitical risk in a different way, extending the category of green financial instruments would be a promising area of future research. Second, this study is limited in the sense that we only consider the geopolitical risk index at global scale. Future research could disentangle the geopolitical risk by using country-level geopolitical risk index or geopolitical risk subindex, including the geopolitical threats (GPRT) index and the geopolitical acts (GPRA) index. Third, the causal relation between geopolitical risk and green finance is not analysed at different time horizons in this paper. We recommend employing the parametric modelling approach (Dufour and Renault, 1998; Dufour and Taamouti, 2010) to disentangle the influences of geopolitical risk on green finance in the short run and long run for future research.

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