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Energy security risk and financial development nexus: Disaggregated level evidence from South Korea by cross-quantilogram approach

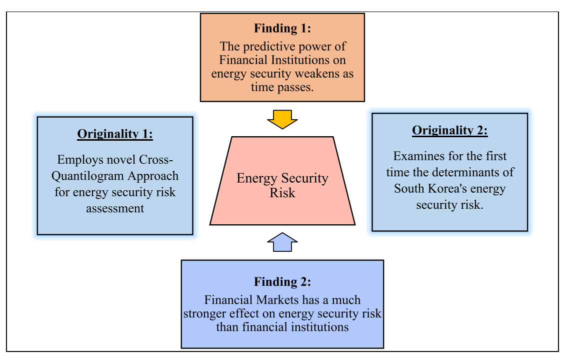
Mustafa Tevfik Kartal [a,b,*], Ugur Korkut Pata [b,c,d,e], Andrew Adewale Alola [f,g]

[a] Department of Finance and Banking, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Türkiye
[b] Clinic of Economics, Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan
[c] Department of Economics, Hatay Mustafa Kemal University, Hatay, Türkiye
[d] Adnan Kassar School of Business, Lebanese American University Beirut, Lebanon
[e] Advance Research Centre, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Türkiye
[f] Centre for Research on Digitalization and Sustainability, Inland Norway University of Applied Sciences, Elverum, Norway
[g] Nisantasi University Faculty of Economics, Administrative and Social Sciences, İstanbul, Türkiye

HIGHLIGHTS

- The study analyzes the effect of financial development on energy security risk.
- The study examines South Korea case for the period 1980/Q2–2018/Q2.
- The study applies the novel cross-quantilogram method.
- Financial markets have a powerful effect on energy security risk.
- Financial institutions have a relatively weaker effect on energy security risk.

GRAPHICAL ABSTRACT



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ABSTRACT

Countries have been aiming to reduce dependence on fossil fuel energy and increase the use of clean energy. In this context, energy security has become one of the most important issues for countries, especially in light of the recent energy crisis that threatens energy security. The financial structure of the countries can be also influential in ensuring energy security. By taking higher fossil fuel energy dependence resulting in higher energy security risk (ESR) and higher financial development (FD) into consideration, the study analyzes how FD affects energy security in South Korea, which is an important case and neglected in the current literature. To do so, the study considers the ESR index as the dependent variable, uses disaggregated level FD indicators as explanatory variables, conducts a novel cross-quantilogram method to account for the quantile dependence, and uses data between 1980/Q2 and 2018/Q4. The findings reveal that (i) disaggregated level FD indicators are powerful estimators of ESR; (ii) the financial markets component has a much stronger effect on ESR than the financial institutions component; (iii) the effect of FD sub-components on ESR varies across quantiles; (vi) the predictive power of the FD indicators on ESR weakens as time (lag) passes. The study emphasizes the critical role of FD on ESR, which implies that South Korean policymakers should consider the significant effect of FD and its sub-components as well as changing structure across quantiles and time-lags in shaping policy framework to

* Corresponding author at: Department of Finance and Banking, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Türkiye.

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ensure energy security. Based on the outcomes, South Korea can benefit from FD to mitigate ESR and ensure economic and environmental sustainability.

1. Introduction

Countries have been aiming to achieve green and sustainable economic growth to make their citizens have better living conditions [1,2]. In this context, providing an uninterrupted energy supply to society is highly critical. That is why a vast majority of home and office appliances have been working with energy (specifically, electricity). Hence, achieving energy security through a sustainable energy supply is highly critical for countries as well as economies, societies, and all people.

Ensuring the availability of energy resources at an affordable price and above all without disruption within the energy system vis-à-vis energy security is crucial for economic-wide development [3]. Maintaining a secure energy system is as big a challenge as enabling the global competitiveness of economies and development. Economic development and environmental imperatives are undermined by energy insecurity, which may arise across the short, medium, and long term due to various threats that can cause shortages in the energy supply chain.

Energy security can be considered in both the short term (i.e., about the elasticity of supply-demand balance concerning sudden changes in the energy system) and the long term (i.e., the aspect of energy supply investments according to economic and environmental demands) (International Energy Agency-[4]). In both cases, countries have been pursuing energy policies to avert disruptions in the energy market (both conventional and non-conventional energy sources) to avoid turmoil in the economic landscape resulting from energy shortages. Nevertheless, ensuring a balance between energy supply and demand and a disruption-free energy system remains highly unpredictable despite the efforts of countries. For instance, the vulnerability of the global oil market is still linked to natural disasters and geopolitical uncertainties, especially given the still high demand for fossil oil resulting from that it is the main energy component for the transportation sector. In addition, in the case of that countries are dependent on energy imports, there is a high potential for energy insecurity resulting from various negative factors, such as natural disasters and regional conflicts that cause geopolitical uncertainties [5,6,7].

ESR can be defined as "*an index that identifies the policies and other factors contributing either positively or negatively to the energy security of countries*" (U.S. Chamber of Commerce's Global Energy Institute-[8]). Hence, energy security implies the prioritization of the effectiveness of energy transfer and transmission mechanisms to ensure energy stability [9]. Energy security includes such critical dimensions as availability, acceptability, affordability, and accessibility [10]. Thus, energy security means availability and sustainability of energy supply as well as affordability and social acceptance of energy sources. Energy security has also been increasingly considered in other dimensions, such as energy, economic, environmental, and social areas [11]. Countries have to turn to domestic natural energy resources that reduce the dependence on fossil fuel imports to ensure energy security in the long term. Fossil fuel depletion, fires, earthquakes, floods, and other natural disasters threaten energy security [12].

In the literature, energy use and causes of higher ESR have been a hot topic in recent times. Accordingly, the researchers have been applying empirical analysis to uncover the potential causes of ESR by considering various factors, such as foreign direct investments [13], economic progress and population [14], foreign trade [15], diversification [16], technological advancement [17], economic complexity [18]. Hence, the nexus between ESR and such factors have been investigated in various countries, such as Pakistan, newly industrialized economies, top 23 energy exporters, and top 25 energy-using countries, by Kanwal et al. [12], Wang et al. [17] Chu et al. [19], Payne et al. [18], respectively.

Although the aforementioned factors are important in terms of ESR, recent studies have begun to consider the role of FD in ensuring ESR. That is why FD can increase energy demand by providing cheap financing [20] as well as it can be influential on ESR. The development of financial institutions (FI) and financial markets (FM) can provide a stronger market structure and the transfer of funds that are needed to invest in clean energy. FD through private and public financial instruments is key to mitigating energy insecurity. For example, to mobilize private sector financing into the energy sector, the IEA's report suggests ensuring effective capital markets and financial systems, amassing enormous quantities of concessional finance, and establishing green bonds, and voluntary carbon markets through green financing instruments and platforms among the necessary actions [21]. The IEA further reports that such instruments are important to achieve access to energy by ensuring annual energy investments. Hence, it can be expected that higher FD can reduce the ESR of countries. Considering this point, recent studies have begun to analyze the nexus between ESR and FD for various scopes, such as China, Chinese provinces, 66 countries, and 60 countries by Gholz et al. [22], Lee & Wang [23], Lee et al. [24], and Feng et al. [25], in order.

While the literature on ESR has been developing rapidly and the nexus between ESR and FD has begun to be uncovered recently, the scope of the studies has varied. Among all countries, South Korea has a unique place. That is why South Korea is a developed country that has a higher ESR with regard to its peers [8] as well as higher FD among the developed countries [26]. The ESR of South Korea cannot be decreased, instead, it has increased over recent years. Hence, it is beneficial to focus on the South Korean case in new research to investigate the nexus between ESR and FD.

In the South Korean case, energy security is a vital subject. It meets the demand for fossil fuels (i.e., liquefied natural gas and crude oil) mainly through tanker transportation because there are no international oil or natural gas pipelines. South Korea is a highly fossil energy-importing country and the fourth-largest crude oil importer in the world. According to the Energy Information Administration [27], South Korea obtained 98% of its fossil fuel energy imports from various countries, such as Saudi Arabia, the United States, Kuwait, Iraq, Mexico, and Russia, at least before the Russia-Ukraine conflict. Given the peculiarities of fossil fuel exporting countries to South Korea, especially from the Middle East and North Africa region, the vulnerability of South Korea's energy security to some transport-related issues (e.g., weather and geopolitical tensions) cannot be ignored. Energy security is also important for South Korea because it aims to be carbon-neutral by 2050. This commitment requires to decline ESR of the country and driving energy finance in the clean energy area. In line with its commitment as well as considering national contributions to reduce emissions at the rate of 40% until 2030, phasing out coal use, and becoming carbon neutral by 2050, South Korea has continued to prioritize green growth through "smart grid" financing and increased the share of clean energy in the country [28].

Although becoming carbon-neutral by ensuring energy security is important for South Korea, it is not clear whether the financial sources allocated to clean energy have been enough to achieve the goals of South Korea. That is why South Korea is a high fossil fuel import-dependent country, which increases ESR, which implies the increasing energy security problems. South Korea has been facing energy security problems based on the progress of the ESR over the years. In this context, analyzing the factors affecting South Korea's energy security is highly important. Hence, there is a new research need from this point of view that investigates the ESR and FD nexus for the South Korean case.

Based on this motivation, the nexus between ESR and FD is considered the main objective of this investigation. To achieve this objective, the study considers sub-components of FD (access and depth of FI and FM). The study tries to find answers to the following significant research questions; (i) how does FD affect ESR; (ii) how do the effects of sub-component of FD on ESR differ; (iii) is the effect of FD and its sub-components on ESR same across quantiles; (iv) is the effect of FD and its sub-components on ESR similar across time-lags. In searching for answers to these research questions, the study focuses on the South Korean case by considering the condition of this country from both ESR and FD perspectives. In doing so, the study applies a novel cross-quantilogram (CQ) approach and uses data between 1980/Q2 and 2018/Q4. Following this comprehensive approach, the research determines that FD has an important effect on ESR while the effect varies across quantiles; the financial markets component is stronger than financial institutions in terms of the effect on ESR; the effect of FD and its sub-components on ESR weakens as time passes.

By uncovering novel insights for both conceptual and empirical approaches, this investigation is expected to yield significant policy options for addressing ESR by benefitting from the South Korean case. In this way, the study achieves various novelties to the body of current knowledge. First, this study is the leading research for South Korean cases that uncover the nexus between ESR and FD. Although there are some studies (e.g., [25,22,23,24]) that examines this nexus for various scopes, based on the best knowledge, no study has analyzed this nexus for South Korea. This is the first study for South Korea from this point. Second, differentiating from most current studies, this study considers sub-components of FD in analyzing the nexus between ESR and FD. Third, this study applies a novel CQ approach to make a quantile-based empirical analysis to consider both tail dependence and nonlinearities of the data. This approach enables the researchers to analyze various time lags. Hence, the nexus between ESR and FD can be investigated across various time lags so that either the increasing or decreasing effect of FD on ESR across various periods can be defined.

After presenting the background of the study, Section 2 explains the theoretical framework and provides an overview of the empirical literature. In Section 3, the methods are described in detail, while the results of the investigation and discussion are presented in detail as well as relevant policy options are commented on in Section 4. Lastly, Section 5 concludes the study by also sharing future research directions.

2. Theoretical framework and literature review

2.1. Theoretical background

There can be a critical nexus between ESR and FD in the literature. This nexus can cause either a beneficial or a harmful way effect on energy security [25,7,29]. According to the scale effect, FD can help decline ESR in a way that increasing the financial system supports financial market efficiency and effective use of financial sources, in turn, this provides an increasing energy efficiency [30]. Based on the resource allocation effect, FD can decline ESR by affecting resource allocation between various sectors as well as energy investments by making capital allocation much more rational in declining financing costs [31,23]. In line with the policy effect, due to the improvement in financing capability and decreasing financing cost, a much better financial and energy system can be constructed by benefitting more cooperation across regional and international levels [32]. Hence, energy systems can be developed and much more resilient energy systems can be built. According to behavioral effects, FD can affect corporate image and consumer confidence [33]. By providing an increase in corporate image and consumer confidence, FD can provide a decline in the ESR of countries.

It is possible to mention that FD can, unfortunately, cause negative effects on ESR because there may be inefficient financial regulations and there is an inconsistency between the priorities of the financial sector and the energy sector [34]. In such a case, FD can cause an increase in ESR. In summary, according to theoretical background, FD can make either a decreasing or an increasing effect on ESR.

2.2. Empirical literature

In the contemporary literature, various studies have examined energy security as an important hot topic under the shadow of the most recent energy crisis. In these studies, energy security has been examined from different perspectives, such as technological advancement [17], economic complexity [19,18], tourism [35], and material footprint [36].

There is a growing literature on ESR. Various studies have defined that a decrease in energy use, increasing energy efficiency, and using much more domestic clean energy sources take place among the means that are beneficial in ensuring energy security [37,23,38]. FD takes place among the effective factors that affect energy security through various channels, such as affecting the cost of financing on energy consumption and energy investments and enhancing the ability of consumers to access energy.

From the perspective of the nexus between ESR and FD, the literature includes a few studies that focus directly on this point. Gholz et al. [22] examine the Chinese case qualitatively and the study reveals that such multi-billion dollar investments are made in the form of loans by China's state development banks to oil-producing countries in return for securing oil imports in the form of "loan-for-oil" agreements. However, it defines that such an approach (i.e., loan-for-oil arrangements) is not a profit-oriented investment and is unlikely to fully relieve China from energy insecurity that is caused by a shock in the global energy market. Lee and Wang [23] examine 30 Chinese provinces from 2000 to 2018 and show that FD has an improving effect on ESR. The positive role of FD can be harnessed by deploying technological innovation. Importantly, given the regional differences in the penetration of technological innovations, there is evidence of a non-linear threshold effect in the interlinkage between ESR and FD. Lee et al. [24] examine selected 66 countries from 1996 to 2019 to search for the effect of information and communication technology (ICT) on energy security and define that the effect is only determined through the mediation of FD. Feng et al. [25] analyze the selected 60 countries for the period 1995–2019 and determine that the effect of FD on ESR is not a certain way. In other words, FD contributes to energy security between 2010 and 2015, whereas it prevents energy security from 2013 to 2017. The dynamic effect of FD on energy security varies by income level and region, such that the effect is significantly more pronounced in America, Europe, and Asia-Pacific, but smaller in the Middle East and North Africa.

Apart from the theoretical documentation of the role of institutions and markets in energy security by Goldthau and Witte [39] and Prontera [40], there are a few empirical studies to support this view.

Jarrett et al. [41] investigate the role of FD in energy security by examining 11 oil-rich countries over the period from 2006/Q1 to 2016/Q4 by questioning the uncertainty/volatility of FI that naturally affects the predictability of energy security. The research defines that improving FI is critical to reducing oil production volatility and improving energy security. Qin et al. [42] examine the role of FI in the transition to green energy for 214 countries between 1960 and 2017. FI as well as the components of FI (i.e., financial depth and financial access) are found to have a strong causal nexus with the transition to green energy globally. However, the effect of FI and its components (i.e., financial depth, access, efficiency, and stability) on the transition to green energy varies across regions and income levels. Zhao and Duan [43] investigate the effectiveness of green bonds on the energy security aspect (energy dependence or energy efficiency transition) in Asian countries from 2017 to 2022 and find that financial systems are supportive of the energy transition. With this observation, indicating an improvement in energy security, Zhao and Duan [43] attribute the positive effect of the financial market on energy reliance to the increase in green financing.

2.3. Evaluation of the literature

In the literature, there is a rich set of studies on clean energy use. However, the literature on ESR and the nexus of ESR with FD has been quite shallow. When the present studies are evaluated altogether, it can be summarized that various scopes (e.g., China, Chinese cities, energy-exporting countries, highly energy-using countries) are examined by using a variety of econometric approaches (e.g., panel quantile regression), but there are still a limited number of studies that empirically examines the nexus between ESR and FD.

However, the present literature fails to consider a crucial perspective that reflects the aim of this investigation. In the present literature, although there are some studies on the ESR and FD nexus, the question of whether sub-components (i.e., the access and depth) of FI and FM influence energy security has remained an unexplored issue. In addition, the nexus between ESR and FD across quantiles by considering also various time lags cannot be explored for any country. Hence, there is an apparent literature gap, which is that this research aims to fill in this gap and expand the body of knowledge on the ESR and FD nexus by focusing on South Korea and applying a novel CQ approach. In this way, the study examines the South Korean case by using the CQ approach by making a quantile-based examination as well as considering various time-lags so that the effect of FD and its sub-components on ESR can be investigated across quantiles and time-lags to find answers for the research questions.

3. Methods

3.1. Data

The study uses disaggregated level FD data to explore comprehensively the nexus between FD and ESR. The data for FD are obtained from the International Monetary Fund [26]. The data for the ESR are collected from USC [8]. After the collection of the raw dataset, it is converted to quarterly data by applying the quadratic-sum-method as well as return series by following up the recent studies in the literature (e.g., [44]). Hence, the study uses a logarithmic difference (return) series for the variables between 1980/Q2 and 2018/Q4.

Table 1 demonstrates the summarized details of the variables.

3.2. Empirical methodology

In the empirical analysis, to examine the effect of disaggregated level FD on ESR in South Korea, the study applies a total of five steps as presented in Fig. 1.

In the first two steps, the study analyzes descriptive statistics and examines correlations. Thirdly, the study examines the stationarity structure of the variables by conducting the Augmented Dickey-Fuller (ADF) test [45] and Phillips-Perron (PP) test [46]. Fourthly, the study analyzes whether the variables have a nonlinear structure [47]. Finally, the study applies the CQ approach [48] to investigate the quantile-varying effect of disaggregated level FD on ESR in South Korea across various time lags.

The CQ approach provides effective results by accounting for various lags to reveal asymmetric information in non-normally distributed data. In contrast to quantile regression, where the results are based on the conditional distribution of the dependent variable, the CQ approach reveals the cross-quantile dependence between two-time series [49]. The CQ approach helps to avoid model misspecification by choosing different lag lengths at various quantiles [50]. The CQ approach can be estimated using Eq. (1):

$$p_\alpha(k) = \frac{E\left[\varphi_{\alpha1}\left(x_{1,t-}q_1(\alpha_1)\right)\varphi_{\alpha2}\left(x_{2,t-}q_2(\alpha_2)\right)\right]}{\sqrt{E\left[\varphi_{\alpha1}^2\left(x_{1,t-}q_1(\alpha_1)\right)\right]}\sqrt{E\left[\varphi_{\alpha2}^2\left(x_{2,t-}q_2(\alpha_2)\right)\right]}} \quad (1)$$

where $p_\alpha(k)$ shows the quantile-based cross-correlation estimator. The CQ approach takes into account two series such as x1,t = energy security risk, and x2,t = disaggregated FD indicators (i.e., FI, FIA, FID, FM, FMA, & FMD). The quantiles of two-dimensional series can be stated as {q1(α1) q2(α2)}T, for α ≡ (α1, α2)T, where T demonstrates a transpose function. The CQ approach captures the nexus between x1,t and x2,t within a range of quantiles. Han et al. [48] use Eq. (2) to test the predictive power of one variable over the other as H_0: ρα(k) = 0, for all k, 1 ≤ k ≤ p.

$$\widehat{Q}_\alpha^{(p)} = \frac{T(T+2)\sum_{k-1}^{p}(k)}{T-k} \quad (2)$$

where $\widehat{Q}_\alpha^{(p)}$ denotes the portmanteau test for predictability from one variable (i.e., FD) to another variable (i.e., ESR) depending on lags (p) at various quantiles. The bootstrap technique is used to determine confidence intervals [48]. In the CQ approach, the null hypothesis represents no directional predictability, and CQ plots are shown as a red box (much warmer) for the relevant quantiles and lag when the null hypothesis is rejected for a strong positive nexus. As Chishti et al. [51] report, CQ calculates all lags simultaneously and is a non-parametric method that removes specification errors thanks to the quantile hits. Similarly, Islam et al. [52] note the CQ method is suitable for non-parametric distributions with curvy tails and can therefore be referred to as a non-parametric approach. Due to these advantages, the study applies the non-parametric CQ approach.

Table 1
Variables.

Symbol	Definition	Unit	Data Source
ESR	Energy Security Risk	Index	USC [8]
FI	Financial Institutions		
FIA	Financial Institutions-Access		
FID	Financial Institutions-Depth		
FM	Financial Markets		
FMA	Financial Markets-Access		
FMD	Financial Markets-Depth	Index	IMF [26]

4. Results

4.1. Descriptive statistics

As the first step of the empirical analysis, the descriptive statistics of the variables are examined, which take place in Table 2.

According to Table 2, ESR has the highest values, whereas FI, FM, and their sub-components have much lower values. Among all variables, ESR has the highest deviations implying higher volatility. Moreover, based on JB values, all variables have a nonnormal distribution. In the absence of a normal distribution, linear econometric approaches are not able to capture non-parametric information in the variables. The fact that the variables are not normally distributed implies that effective results can be obtained with quantile methods [53]. Quantile approaches can provide robust information about the interactions between series that do not have a normal distribution by accounting for nonlinearity and asymmetric interactions, and therefore quantile-based nonparametric methods are used in the study.

4.2. Correlation results

As the second step, Table 3 demonstrates the correlations between variables. These correlations show the interaction between the variables. Correlation values close to 1 indicate a completely positive interaction, while correlation values close to −1 indicate a completely negative relationship. The statistical significance of these relationships is indicated by the probability values in brackets.

Based on Table 3, ESR has a mainly positive relationship with FI, FM, and their sub-components, whereas there are some negative links as

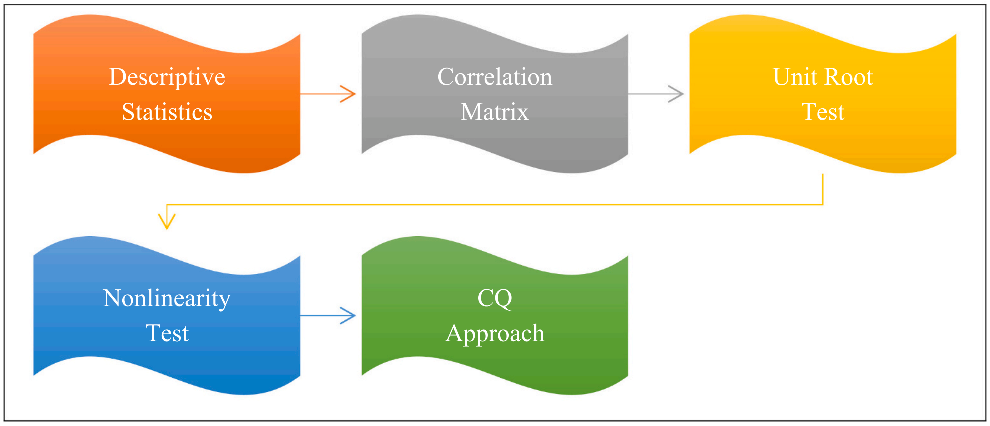

Fig. 1. Empirical Process.

Table 2
Descriptive Statistics.

Variable	Mean	Max.	Min.	SD	Skewness	Kurtosis	JB	JB Prob.
ESR	335.15	392.36	279.80	36.95	−0.04	1.43	16.03	0.0003
FI	0.18	0.21	0.15	0.02	0.14	1.32	18.79	0.0001
FIA	0.17	0.18	0.15	0.01	−0.24	1.45	16.93	0.0002
FID	0.14	0.20	0.10	0.03	0.37	1.51	17.91	0.0001
FM	0.15	0.22	0.05	0.05	−0.35	1.64	15.08	0.0005
FMA	0.12	0.24	0.03	0.07	0.09	1.31	18.73	0.0001
FMD	0.11	0.21	0.01	0.07	−0.10	1.65	11.99	0.0025

Notes: Min: Minimum; Max: Maximum; SD: Standard Deviation; JB: Jarque-Bera. The units for all sectoral greenhouse gas emissions are million tons.

Table 3
Correlation Matrix.

Variable	ESR	FI	FIA	FID	FM	FMA	FMD
ESR	1.00						
	0.07						
FI	(0.37)	1.00					
	0.14	0.57					
FIA	(0.07)	(0.00)	1.00				
	−0.10	0.70	0.31				
FID	(0.20)	(0.00)	(0.00)	1.00			
	0.12	−0.19	−0.21	−0.09			
FM	(0.13)	(0.02)	(0.01)	(0.27)	1.00		
	0.22	−0.08	0.00	−0.16	0.54		
FMA	(0.00)	(0.31)	(0.99)	(0.05)	(0.00)	1.00	
	−0.16	−0.16	−0.28	0.06	0.63	0.11	
FMD	(0.05)	(0.05)	(0.00)	(0.48)	(0.00)	(0.16)	1.00

Note: Values denote coefficients. () denotes p-values.

Table 4
Unit Root Test Results.

Variable	ADF	PP
	Level	Level
ESR	0.0189	0.0000
FI	0.0000	0.0000
FIA	0.0001	0.0000
FID	0.0000	0.0000
FM	0.0000	0.0000
FMA	0.0002	0.0000
FMD	0.0001	0.0000

Notes: Akaike information criteria is used in the ADF Test. Bartlett Kernel is used in the PP test. Because all variables are stationary at the level based on ADF and PP tests, first differences of the variables do not need to be checked for the stationarity.

well. In detail, ESR is positively correlated with all variables, except for FID and FMD, which are negatively correlated. Among all variables, ESR has the highest correlation with FMA followed by FMD, FIA, FM, FID, and FI, in order. Because the correlations between ESR and the variables are not so high, it is essential to make any estimation based on such a lowly correlated series.

4.3. Stationarity test results

As the third step, Table 4 demonstrates reports the results of unit root tests.

As Table 4 presents, all variables including both dependent variables and independent variables are stationary at the level based on the ADF test. The results of the PP test demonstrate that all variables are stationary at I(0), which is consistent with the ADF results. The fact that the variables are I(0) means that the external shocks to which they will be exposed over time will not change their long-run equilibrium values. For this reason, the relationships between level-stationary variables can be analyzed using regression approaches. Since the variables are not normally distributed and are all I(0), it is appropriate to apply the CQ approach, and the study applies the BDS test as a precursor to applying the CQ approach in the next step.

4.4. Nonlinearity test results

As the fourth step, Table 5 shows the results of the nonlinearity test. Table 5 shows the BDS results. The null hypothesis of the BDS test implies that the series are linearly dependent, while the alternative hypothesis implies that the series is not linearly dependent. The results show that all variables have a non-linear structure across different dimensions. In other words: *p*-values of 0.0000 for all series and dimensions except FI and FIA in dimension 4 mean that the null hypothesis is rejected and thus the series have a nonlinear and nonparametric structure. In the case of the overall evaluation of the preliminary statistics of the variables, it can be summarized that variables have higher

Table 5
Nonlinearity Test Results.

Variable	D2	D3	D4	D5	D6	Result
ESR	0.0000	0.0000	0.0000	0.0000	0.0000	NL
FI	0.0000	0.0000	0.0002	0.0000	0.0000	NL
FIA	0.0000	0.0000	0.0008	0.0000	0.0000	NL
FID	0.0000	0.0000	0.0000	0.0000	0.0000	NL
FM	0.0000	0.0000	0.0000	0.0000	0.0000	NL
FMA	0.0000	0.0000	0.0000	0.0000	0.0000	NL
FMD	0.0000	0.0000	0.0000	0.0000	0.0000	NL

Notes: Values indicate probability values. D and NL denote the dimension and nonlinear, in order.

variations, their distributions are nonnormal, there are low correlations between variables, they are stationary at the level, and their structures are nonlinear. Considering these points, using a nonlinear method for further empirical examination can be the most appropriate option [54]. Accordingly, the study applies the novel CQ approach.

4.5. CQ results

4.5.1. Effect of financial institutions on energy security risk

After checking the preliminary statistics as well as the preliminary test, the study applies the CQ approach. The study presents CQ diagrams in Fig. 2 and Fig. 3. In these graphs, red and dark brown boxes indicate a strong positive relationship between the variables based on the quantiles. In contrast, dark blue colors indicate that there is no correlation between the variables or, if the vertical axis takes negative values, the analyzed variables show a negative interaction.

The study first analyzes the effects of FI and its sub-components on ESR, which are shown in Fig. 2.

The effects of FI on ESR are presented in Fig. 2a. In detail, it can be seen that there are significant effects of FI on ESR across various quantiles. For 1 lag (3 months), the FI effect on ESR is highly powerful when FI is at 0.25th quantile and ESR is at 0.65th quantile, which has a 0.69 correlation. Another significant effect occurs when FI is at 0.95th quantile and ESR is at 0.35th quantile, which has a 0.53 correlation. There are significant positive effects of FI on ESR across some other quantiles, whereas there is no significant effect across the remaining quantiles. For 2 lags (6 months), the effect of FI on ESR becomes a bit weaker concerning 1 lag (i.e., 3 months), but there are still positive effects of FI on ESR. Differently from 1 and 2 lags, in 3 and 4 lags (12 and 24 months, in order), the effect of FI on ESR has become mixed. In other words, the effect of FI on ESR is positive at some quantiles, whereas it becomes a negative one at some quantiles, when FI is at 0.75th quantile and ESR is at 0.15th quantile that has −0.46 correlation, at 3 lags; when FI is at 0.15th quantile and ESR is at 0.55th quantile that has −0.11 correlation, at 4 lags. An increase in FI can provide a decrease in ESR when the time passes. However, the declining effect of FI weakens also as time goes on.

The effects of FIA on ESR are demonstrated in Fig. 2b. There are important effects of FIA on ESR across various quantiles. For 1 lag, the FIA effect on ESR is highly powerful when FIA is at 0.15th quantile and ESR is at 0.65th quantile, which has a 0.66 correlation. Another significant effect occurs when FIA is at 0.05th quantile and ESR is at 0.25th quantile, which has a 0.66 correlation. There are significant positive effects of FIA on ESR across some other quantiles, whereas there is no significant effect across the remaining quantiles. For 2 lags, the effect of FIA on ESR becomes a bit weaker concerning 1 lag, but there are still mainly positive effects of FIA on ESR, except for only 2 quantiles. Differently, in 3 and 4 lags, the effect of FIA on ESR has become mixed. In other words, the effect of FIA on ESR is positive at some quantiles, whereas it becomes a negative one at some quantiles when FID is at 0.95th quantile and ESR is at 0.25th quantile that has −0.27 correlation, at 3 lags; when FID is at 0.65th quantile and ESR is at 0.15th quantile that has −0.33 correlation, at 4 lags. Thus, FIA results show that an increase in FIA can decrease ESR as time passes and the declining effect of FIA gets stronger as time progresses.

Moreover, the effects of FID on ESR are shown in Fig. 2c. There are significant effects of FID on ESR across various quantiles. For 1 lag, the FID effect on ESR is highly powerful when FID is at 0.45th quantile and ESR is at 0.65th quantile, which has a 0.52 correlation. Another significant effect occurs when FID is at 0.05th quantile and ESR is at 0.05th quantile, which has a 0.53 correlation. There are significant positive effects of FID on ESR across some other quantiles, whereas there is no significant effect across the remaining quantiles. For 2 lags, the effect of FID on ESR becomes a bit weaker concerning 1 lag, however, there are still mainly positive effects of FID on ESR. On the other hand, in 3 and 4 lags, the effect of FID on ESR has a mixed structure. In other words, the effect of FID on ESR is positive at some quantiles, whereas it becomes a negative one at some quantiles when FID is at 0.35th quantile and ESR is at 0.65th quantile that has −0.14 correlation, at 3 lags; when FID is at 0.35th quantile and ESR is at 0.35th quantile that has −0.41 correlation, at 4 lags. FID findings reveal that an increase in FID provides a decline in ESR when time passes, while the decreasing effect of FID gets stronger as time progresses.

4.5.2. Effect of financial markets on energy security risk

Fig. 3 demonstrates also the effects of FM and its sub-components on ESR.

The effects of FM on ESR are presented in Fig. 3a. There are significant effects of FM on ESR across various quantiles. For 1 lag, the FM effect on ESR is highly powerful when FM is at 0.85–0.95th quantile and ESR is at 0.15th quantile, which has 0.61 and 0.57 correlations. Another significant effect occurs when FM is at 0.45th quantile and ESR is at 0.35th quantile, which has a 0.60 correlation. There are significant positive effects of FM on ESR across some other quantiles, whereas there is no significant effect across the remaining quantiles. For 2 lags, the effect of FM on ESR is almost the same concerning 1 lag and still positive. Differently in 3 and 4 lags the effect of FM on ESR has become mixed. In other words, the effect of FM on ESR becomes a negative one at some quantiles, when FM is at 0.85th quantile and ESR is at 0.50th quantile, which has a − 0.13 correlation, at 3 lags; when FM is at 0.95th quantile and ESR is at 0.65th quantile that has −0.17 correlation, at 4 lags. Thus, an increase in FM makes ESR decrease the time passes and the declining effect of FM gets stronger as time goes on.

The effects of FMA on ESR are demonstrated in Fig. 3b. There are important effects of FMA on ESR across various quantiles. For 1 lag, the FMA effect on ESR is highly powerful when FMA is at 0.45th quantile and ESR is at 0.75th quantile, which has a 0.67 correlation. Another significant effect occurs when FMA is at 0.05th quantile and ESR is at 0.15th quantile, which has a 0.66 correlation. There are significant positive effects of FMA on ESR across some other quantiles, whereas there is no significant effect across the remaining quantiles. For 2 lags, the effect of FMA on ESR becomes a bit weaker concerning 1 lag, but there are still mainly positive effects of FMA on ESR, except for only 2 quantiles. Differently, in 3 and 4 lags, the effect of FMA on ESR has become mixed. In other words, the effect of FMA on ESR is positive at some quantiles, whereas it becomes a negative one at some quantiles when FMA is at 0.15th quantile and ESR is at 0.75th quantile that has −0.38 correlation, at 3 lags; when FMA is at 0.95th quantile and ESR is at 0.35th quantile that has −0.32 correlation, at 4 lags. Thus, FMA results show that an increase in FMA can have a declining effect on ESR as time passes and the declining effect of FIA a bit weaker as time progresses.

Moreover, the effects of FMD on ESR are shown in Fig. 3c. There are significant effects of FMD on ESR across various quantiles. For 1 lag, the FMD effect on ESR is highly powerful when FMD is at 0.95th quantile and ESR is at 0.25th quantile that has a 0.65 correlation. Another significant effect occurs when FMD is at 0.95th quantile and ESR is at 0.95th quantile, which has a 0.51 correlation. There are significant positive effects of FMD on ESR across some other quantiles, whereas

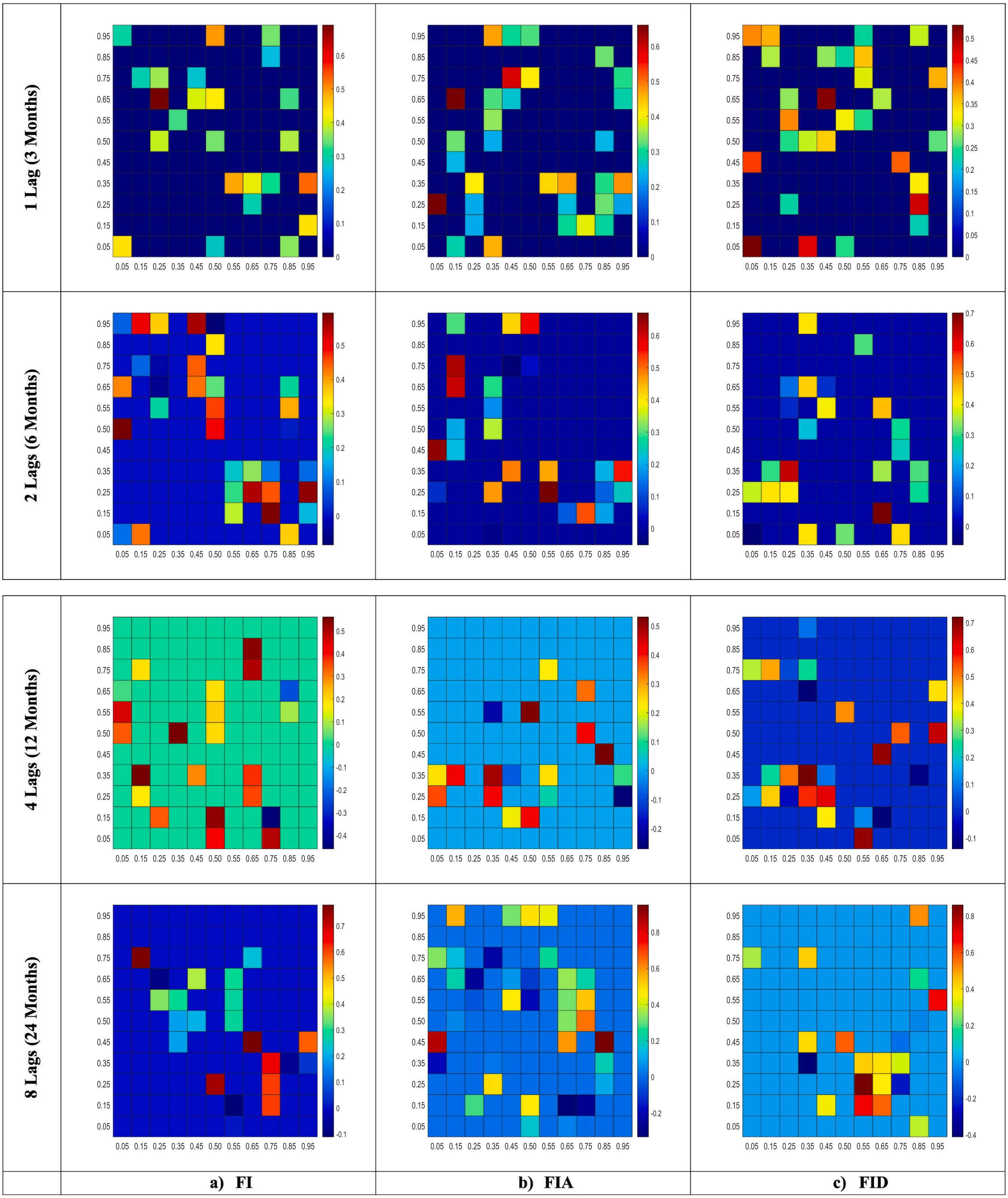

Fig. 2. CQ Results for the Effect of Financial Institutions on ESR.
Note: The y and x axes denote ESR and respective FI components (i.e., FI, FIA, and FID).

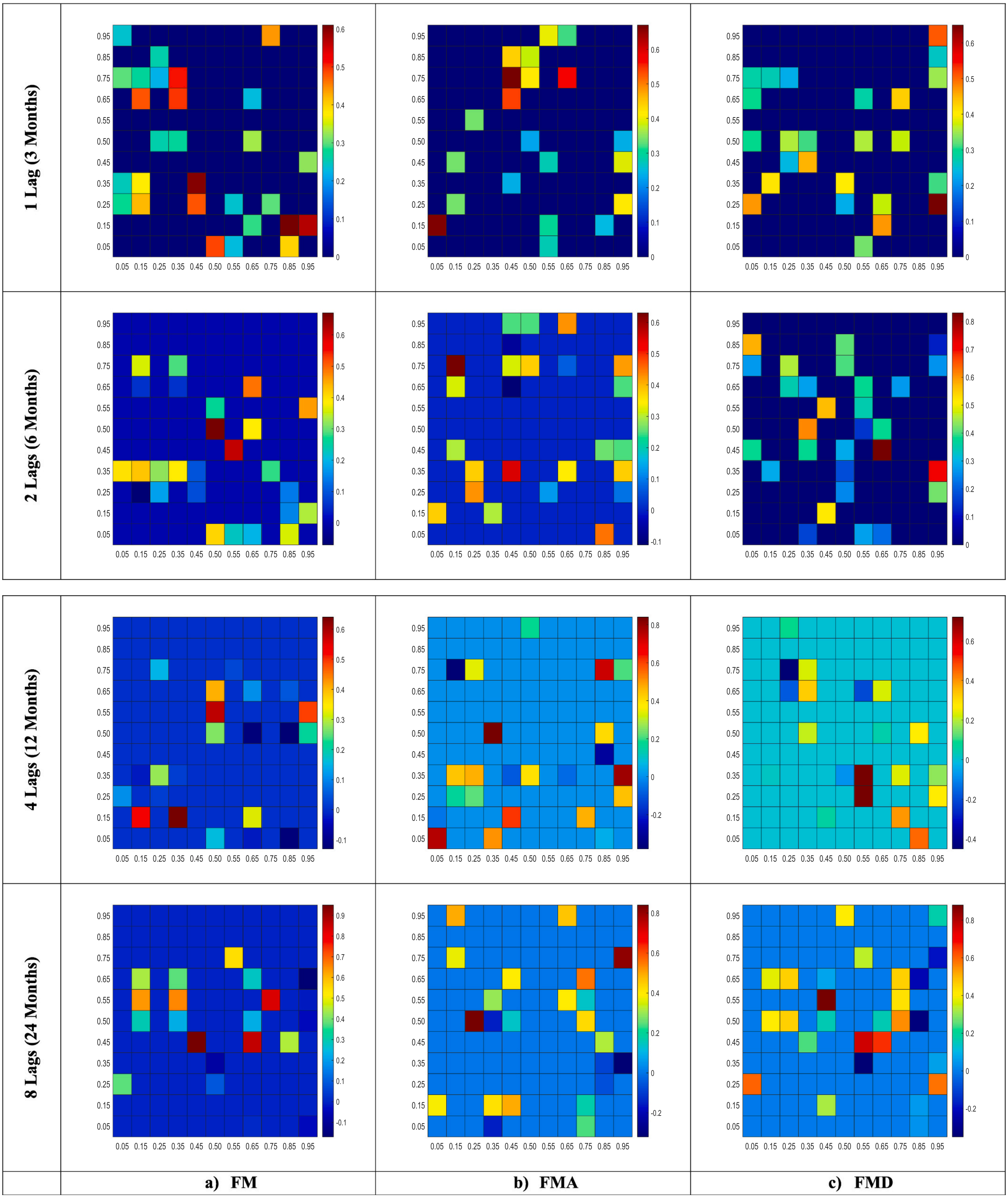

Fig. 3. CQ Results for the Effect of Financial Markets on ESR.
*Note: The y and x axes denote ESR and respective FM components (*i.e., *FM, FMA, and FMD).*

there is no significant effect across the remaining quantiles. For 2 lags, the effect of FMD on ESR gets a bit stronger concerning 1 lag, however, there are still mainly positive effects of FMD on ESR. On the other hand, in 3 and 4 lags, the effect of FMD on ESR has a mixed structure. In other words, the effect of FMD on ESR is positive at some quantiles, whereas it becomes a negative one at some quantiles, where FMD is at 0.25th quantile and ESR is at 0.75th quantile that has −0.45 correlation, at 3 lags; when FMD is at 0.55th quantile and ESR is at 0.35th quantile that has −0.35 correlation, at 4 lags. Therefore, results reveal that an increase in FMD declines ESR as time passes, whereas the decline of FMD gets a bit weaker as time progresses. The overall findings of the study are summarized in Table 6.

Table 6 shows that the FD indicators for 1 and 2 lags show a positive interaction with the ESR. With increasing lag length and over time, the financial development partially reduces the ESR in some quantiles and the predictive power decreases. This situation shows that the predictive power of financial institutions and financial markets for ESR decreases in the future, but has a reducing effect on energy security risk and that the positive impact of financial progress on energy security for South Korea takes time.

4.6. Discussion and policy options

In the investigation of ESR in South Korean case, this study focuses on the effect of FD. In doing so, the study uses the FD index proposed by IMF [26] as well as consider not only FD but also sub-components of the FD (i.e., institutions, markets, access, & depth). Hence, the study has a much richer content from these points as well as differs from the current studies in this respect. Thus, the makes a comprehensive analysis of the South Korean case, which is a country that has higher ESR and FD.

As a result of the application of a novel CQ approach to the South Korean data set, the study suggests that disaggregated level FD indicators are powerful estimators of ESR based on the strong correlation reaching 95% between ESR and FD over some quantiles. Hence, it can be stated that FD can play a key role in reducing ESR if it can be canalized in the right way to eliminate the issues that create energy insecurity as well as stimulate clean energy generation from the domestic sources of the country.

The study reveals that the FM component has a stronger effect on ESR than the FI component. This determination requires South Korean policymakers to take this fact into account in formulating FD-related policies to benefit from FD in a better way in combating ESR. In this context, it is important for South Korea that policymakers should focus on the FM side of FD. They should regulate FM to make it much more efficient as well as eco-friendly so that FM can be a strategic tool to support the domestic clean energy generation from domestic sources much further. Some other precautions, such as the removal of some entrance barriers to South Korean financial markets, and providing some incentives for new market player to move their know-how to South Korean financial markets by taking place in this area, can be evaluated by policymakers. Hence, FM can play a more effective role in reducing ESR than FI and the FM component can support much more the decline of ESR by benefitting from the FD perspective.

Table 6
Summary of the Findings.

	1 Lag	2 Lags	4 Lags	8 Lags
FI	Positive correlated	Positive correlated	Positive correlated	Positive correlated
FIA	Positive correlated	Positive correlated	Partially negative correlated	Partially negative correlated
FID	Positive correlated	Positive correlated	Partially negative correlated	Partially negative correlated
FM	Positive correlated	Positive correlated	Partially negative correlated	Partially negative correlated
FMA	Positive correlated	Positive correlated	Partially negative correlated	Partially negative correlated
FMD	Positive correlated	Positive correlated	Partially negative correlated	Partially negative correlated

In addition to the aforementioned measures, policymakers should ensure that domestic savings and foreign portfolio investments into the country are effectively utilized and transferred to green energy investments as well as foreign direct investments can be canalized also into the clean energy generation areas from the domestic clean energy sources. A more developed financial market structure can make it easier for South Korea to support clean energy. Clean energy deployment is a good way to increase energy security and reduce dependence on weak energy systems [55]. It is known that the use of clean (renewable) energy has a reducing effect on ESR by reducing the dependence of countries on energy imports [56]. In this regard, policymakers can support companies that generate clean energy, and increase their investments by providing various subsidies, such as low-interest loans and tax exemptions. In addition, South Korean policymakers can enable domestic and international companies, which have been generating energy, to turn to further use of domestic clean energy sources to reduce ESR by introducing green bonds as a financing source for new energy-related projects.

Energy utilization, investment in energy storage, and many other things have depended on energy financing. Therefore, ensuring energy security should have been closely related to FD. Therefore, South Korean policymakers can take measures to support green finance to turn the FD structure and its components into an eco-friendly manner. Policymakers can create incentives to mitigate the investment risks of companies that manufacture solar panels and wind turbines. In addition, South Korea needs to expand its legal regulations on environmental, social, and governance (ESG). Although South Korea has promised to expand the ESG system for many companies by 2030, this process can be postponed until 2026 as announced in October 2023 (ISS [57]). More recently, it has been argued that ESG must include fossil fuels due to the Russia-Ukraine crisis, and even Saudi Aramco has stated that ESG threatens energy security [58]. However, ESG, which is an important component of well-functioning in FM, has been helping to reduce ESR by providing a shift from fossil sources to clean energy resources. As part of FM development, South Korea needs to create a strong ESG structure that supports energy security by enabling energy transition at both levels of generation and use.

Although the study determines that the FM component has a stronger effect on ESR than the FI component, it does not mean that the FI side of FD can be ignored in combating ESR. Instead, this determination implies that South Korean policymakers should focus on the FM side of FD as much more important than the FI side. Following taking necessary measures to make FM decline ESR, South Korea should deal with the FI side of FD to benefit also from this sub-component of FD. Working on these sub-components step by step is not a required approach. South Korean policymakers should deal with both perspectives simultaneously, but it is highly recommended to give much more attention to the FM side first.

The study reveals that the effect of FD and its sub-components on ESR is not linear. In other words, although there is a strong theoretical background between ESR and FD ([23,24]; & [25]), this link can be valid for South Korea only across some quantiles. Therefore, this determination requires South Korean policymakers to continuously monitor the effect of their measures and policies implemented on ESR. Hence, they can have the capability to take immediate additional measures when the effect of measures taken in the FD area becomes either harmful or inefficient in combating ESR. Hence, they can move quickly without causing any delay and can take new measures on time.

The study determines that the effect of FD and its sub-components (i.e., the predictive power of the explanatory indicators) on ESR weakens as time (lag) passes. In other words, there is a much higher correlation between ESR and FD at the beginning, however, the strength of the effect decreases over time. This finding also requires South Korean policymakers to apply close monitoring of the policy framework that they implement to decrease ESR by benefitting from FD. That is why there will probably be a new need to take additional measures or revise the policy framework as the effect of measures will decrease.

In summary, the study defines the mixed effect of FD on ESR. While FD has an increasing effect on ESR across some quantiles, the effect becomes reversed. The findings of the study are mainly consistent with the result of the Lee & Wang [23], Lee et al. [24], and Feng et al. [25]. However, this empirical investigation extends the current knowledge on the nexus between ESR and FD by providing new insights about quantile-based as well as time-lag-based examination, which reveals a critical role of FD on ESR and empirical investigation over quantiles and various time-lags. Hence, the study finds comprehensive answers to the research questions that it aims for.

By considering the above-mentioned policy options as well as other possible policies, which can be developed by South Korean policymakers through using much more information they have and considering their own conditions, South Korea can benefit from FD further to mitigate ESR, which is highly critical under the presence of ongoing energy crisis, and, in turn, ensure economic and environmental sustainability.

5. Conclusion

ESR, which implies energy insecurity, has become an important issue for countries recently due to the fact that there has been a recent energy crisis. In this context, ensuring energy supply is highly critical for countries. Energy security is not only important for countries' economic growth path but also significant for the sustainability of environmental conditions as well. For this reason, achieving a decline in ESR takes place among the key elements for a sustainable economy and environment.

While previous studies have been focused on clean energy use, the most recent studies have begun to consider some new factors, such as financial progress. It is known that some studies analyze the effect of financial progress on clean energy, however, the effect of financialization on declining ESR has become still an untouched area. By considering the gap in the literature, this study examines the effect of financial progress on ESR for South Korea for the first time by focusing on sub-components of FD (i.e., institutions, markets, access, & depth) by using a novel CQ approach.

By following up such an approach, the study indicates some new insights that there is a strong nexus between ESR and FD; the FM sub-component has a greater effect on ESR than the FI sub-component; the effect of FD and its sub-components on ESR varies across quantiles and their predictive power declines as time passes. Overall, the findings of the study are generally in line with the studies of Lee & Wang [23], Lee et al. [24], and Feng et al. [25]. However, the different point of this research from those studies is that this investigation extends the current knowledge on the nexus between ESR and FD by providing new insights from quantile-based as well as time-lag-based empirical analysis. Thus, the study obtains robust results but extends the current knowledge as well. Based on the results obtained from a novel CQ approach, the study discusses various policy options to ensure energy security, such as consideration of sub-components of FD in policy framework restructuring, focusing on financial market sub-components firstly due to its more dominant and stronger effect, and increasing financing capabilities to the companies to stimulate green energy projects that use more domestic clean energy sources, for South Korean case.

In searching answers for to the research questions, the study tries to follow up a comprehensive theoretical and econometric approach. Hence, in the belief of the researchers, this study presents new insights. Despite best efforts, it cannot be argued that this research is free from any limitations.

First, because the study examines the ESR and FD nexus for only South Korea, future studies can examine this nexus in other developed countries. New studies can consider other countries that have high ESR, such as Singapore, and Middle East and North African countries. Even, new studies can focus on European countries because they have been affected highly by the ongoing energy crisis. Further, a comparative analysis of the effect of FD on ESR can be prepared in a comparative way for the countries that have higher and lower ESRs.

Second, the study uses a novel CQ approach for empirical investigation. Although the CQ approach provides its predictive power across quantiles and different lags, this method neglects structural breaks and frequency domain properties of variables. Therefore, new studies can investigate ESR by using various methods, such as wavelet and Fourier transform-based econometric approaches. Hence, the aforementioned types of variables can be considered in empirical analysis.

Third, the study uses quarterly data in empirical analysis that is relatively low-frequency. Therefore, new studies can use much higher-frequency data in empirical analysis to consider the time and frequency domain in the new analyses.

Fourth, the study uses only disaggregated level FD indicators as explanatory variables. However, energy security may be related to other factors, such as globalization, geopolitical risk, economic policy uncertainty, foreign trade and direct investments, economic progress and population, technological advancement, economic complexity, economic policy uncertainty, technological innovation, environmental policy stringency, use of sub-types of clean energy sources, and fiscal decentralization [59–61]. Hence, the social and macro-financial sides of ESR can be included in new empirical investigations. In this way, the effects of such factors on ESR should be considered in future studies.

Lastly, although the study considers FM, it does not directly examine the effect of ESG on ESR. Therefore, future studies can analyze the effect of ESG on ESR for various country cases. In this way, researchers can present a broader discussion on ESR mitigation and provide more policy options to decline ESR by benefitting from ESG.

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Authors' contributions

The authors have contributed equally to this work. All authors read and approved the final manuscript.

CRediT authorship contribution statement

Mustafa Tevfik Kartal: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ugur Korkut Pata**: Conceptualization, Writing – original draft, Writing – review & editing. **Andrew Adewale Alola**: Writing – original draft.

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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