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Do energy and geopolitical risks influence environmental quality? A quantile-based load capacity factor assessment for fragile countries

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ABSTRACT

Most countries have tried to decline fossil fuels dependency by supporting clean energy transition. In light of this, this study investigates the impact of energy security risk (ESR) and geopolitical risk (GPR) on the load capacity factor (LCF) in four fragile countries (Brazil-BRA; India-IND; South Africa-ZAF, Türkiye-TUR). The study applies quantile approaches for the period between 1985/m2 and 2018/m12, which represents the largest amount of accessible data. The results show that (i) at higher quantiles, ESR declines the LCF in IND and ZAF, while it has an increasing impact in BRA and a mixed impact in TUR; (ii) GPR increases the LCF in BRA, ZAF, and TUR at lower and middle quantiles, while GPR decreases ecological quality at higher quantiles in all countries; (iii) ESR and GPR have a causal effect on the LCF across various quantiles; (iv) ESR and GPR are strong predictors of the LCF, but their predictive power varies by quantile and becomes significantly weaker with increasing lags. With these fresh outcomes, the study underlines the significant influence of ESR and GPR in ensuring ecological sustainability across all quantiles and countries. The overall findings of the study emphasize that risks and uncertainties degrade the ecological quality of four fragile countries and that policymakers should turn to clean energy sources in case of an increase in geopolitical and energy risks.

1. Introduction

Environmental deterioration is a consequence of the use of various traditional energy sources, including fossil fuels. These energy sources cause air and water pollution, habitat destruction and climate change through their extraction, production and use. They also emit greenhouse gasses (GHG) and other toxic elements into the environment. The process of burning fossil fuels leads to various GHG emissions and thus contributes significantly to the phenomenon of climate-related critical problems [1,2]. Potential consequences include rising sea levels, severe weather events, and ecosystem disruption, which pose significant risks to both the environment and humans.

Carbon dioxide (CO_2) emissions from fossil fuels have increased significantly worldwide since the 1900s. Global CO_2 emissions have increased enormously at a rate of 60 % since 1990 [3]. In 2019, fossil fuels were found to account for 84 % of the world's primary energy consumption, with oil having the largest share at 33.1 %, followed by coal at 27 % and gas at 24.1 % [4]. International and country-specific initiatives have been introduced to decarbonize CO_2 emissions. Amidst this global discourse, governments have been exploring various ways to reduce CO_2 emissions.

CO_2 emissions only reflect one part of the environmental destruction. Wackernagel & Rees [5] have proposed an indicator called ecological footprint (EF), which can reflect environmental degradation and

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pollution of air, water and soil together. The ecological footprint reflects the human environmental impact in global hectares [6]. Biocapacity refers to the ability of natural resources to respond to human environmental pressures. Siche et al. [7] state that focusing solely on EF can lead to an incorrect environmental assessment and that it is more useful to analyze LCF in this context. Following Siche et al. [7], Pata [8] empirically investigated the drivers of LCF for the first time in the ecological economics. LCF is an ecological measure calculated as biocapacity/EF, and if the LCF value is greater than "1", ecological sustainability is given. LCF development contribute to achieving many of the Sustainable Development Goals (SDG) on a large scale. Increasing the LCF can support the reduction of carbon intensity (SDG-13), the provision of clean marine areas (SDG-14) and efficient land use (SDG-15). In this context, determining the factors that increase LCF and making provisions for factors that decrease LCF is an important research topic. In fact, Dogan and Pata [9] proposed a new hypothesis in the literature, called the load capacity curve (LCC), which takes into account the nonlinear relationship between LCF and economic progress, and subsequently many researchers have continued to analyze the determinants of LCF within the LCC framework. Although researchers have analyzed some determinants of LCF [10,11], the relationship between ESR and LCF has been neglected so far. Therefore, this research aims to uncover the newly developed relationship between ESR and LCF for the first time.

Risks can theoretically have a negative impact on economies. As Devereux and Smith [12] found, risk sharing can have a negative impact on human capital, capital accumulation and economic growth. Cui et al. [13] emphasized that risk leads to economic weakness and disruptions in global energy supply. In this context, it is theoretically possible that ESR and GPR have different impacts on countries' economies and environmental conditions. On this basis, the study examines the interaction of ESR, GPR and LCF using current quantile-based methods.

Energy security is highly related to clean energy transition. It is crucial to recognize that while fossil fuels have driven economic growth in the past, there is a growing recognition of the need to move to greener and more sustainable energy sources. The reasons for this shift are concerns about climate change, deteriorating air quality and the finite nature of fossil fuels. As a result, the global economy is increasingly focusing on greater energy efficiency and the use of renewable energy sources. The transition to cleaner and more sustainable energy sources prevents energy insecurity while reducing the negative impact of energy use on the environment [14]. Achieving energy security is therefore the most effective approach to allaying concerns about energy scarcity, promoting energy wellbeing and reducing the environmental impacts of resource use [15].

Energy security facilitates the identification of vulnerabilities and the formulation of approaches to ensure a consistent and cost-effective energy supply, thus boosting economic expansion [16]. In addition to ensuring a consistent supply, energy security also means promoting fair and equitable access to energy resources. Examining energy security facilitates the detection and resolution of inequalities in access to energy, thus guaranteeing reliable and affordable energy services for all sectors of society. Energy security combined with energy efficiency and decarbonization reduces the need for fossil fuels and lowers CO_2 emissions in the atmosphere. In particular, the reduction in CO_2 emissions is noticeable in the environmental impacts, which supports an improvement in environmental sustainability and is in line with carbon neutrality goals [17].

The concept of energy security, which is based on ensuring reliable, affordable, and sustainable access to energy resources [18–20], has recently gained importance, especially under the influence of the Russia-Ukraine conflict [21]. Consequently, empirical investigations have been applied to investigate the relationship between ESR and climate change [22–25]. These studies have shown that the main drivers of climate change are rapid industrial expansion and the use of fossil fuels, which lead to GHG emissions [17]. In addition, some studies (e.g., Ref. [15,26–28]) define that energy security curbs degradation in various countries.

Energy security and geopolitical stability are inextricably linked. Energy security plays a critical role in maintaining national security by reducing dependence on external energy sources and mitigating vulnerabilities associated with geopolitical events that may affect energy supplies. In recent decades, an increase in GPR has been observed, posing potential threats related to conflicts, and disputes both within and between nations. Noteworthy instances of GPR in the last years include events, such as the civil war in Syria, the Russian- Ukrainian conflict, and the Israeli-Palestinian conflict. Concurrently, GPR has been shown to have a negative impact on various economic activities. Numerous studies have delved into the repercussions of GPR on economies, examining its impact on technological progress, energy consumption, and overall economic growth [29]. Sweidan [30] emphasizes that GPR affects the ecological degradation of a country.

The influence of GPR on the environment can be viewed through two lenses. First, there is a mitigating impact, where GPR curbs ecological degradation by limiting energy consumption and thereby reducing CO_2 emissions. Few research papers, such as Anser et al. [31] and Jiao et al. [32], have reported that GPR reduces ecological degradation. Second, GPR diminishes research and development, innovation, and sustainable practices, thereby exacerbating ecological degradation. For example, Anser et al. [33], Bashir et al. [34], and Li [35] reveal that GPR exacerbates ecological degradation. Therefore, to guarantee stable and secure access to energy, countries can anticipate future disputes, seek diplomatic solutions, and promote international cooperation by exploring the geopolitical dynamics of energy resources.

Among countries, some countries (e.g., emerging markets) are much more vulnerable to external shocks resulting from either ESR or GPR compared to other countries. Therefore, any negative development in these areas can have a direct impact on the environment in these countries. Therefore, it is crucial to focus on emerging economies in case of high ESR and in times of increasing geopolitical tensions [35,36].

In light of the above, this study analyzes the impact of ESR and GPR on environmental sustainability in four fragile countries. The study focuses on these emerging countries because there are some key points. First, they are among the leading emerging countries. Second, most of these vulnerable countries are unsustainable in terms of the environment, considering the progress of the LCF over the years [57]. Third, they face high ESR and GPR, which threaten sustainability in various areas, including the environment. Due to these characteristics of the countries, focusing on these four fragile countries may be an appropriate approach to uncover the impact of ESR and GPR on the LCF.

By focusing on four fragile countries, the study seeks answers to the research questions: (i) how ESR and GPR affect environmental sustainability in these countries, (ii) how these impacts vary across quantiles, and (iii) whether the impacts become weaker or stronger over time (i.e., based on various lags)? To explore answers to these questions, the contribution of the study is to (i) use the LCF as the latest, novel indicator of ecological sustainability, rather than CO_2 emissions or the EF, which do not take into account the supply side of the environment; (ii) analyze environmental sustainability in the leading fragile emerging economies (i.e., BRA, IND, ZAF, & TUR) considering the role of ESR and GPR; (iii) uncover the impact of ESR and GPR on environmental sustainability across various levels (i.e., quantiles); (iv) apply quantile approaches for empirical investigations. Therefore, the researchers believe that the research provides a critical contribution to the literature.

The other sections are as follows: Section 2 reviews the literature; Section 3 details the methods used; Section 4 presents the results; and Section 5 concludes.

2. Literature review

Earlier studies were based on economic factors, while more recent studies have examined the impact of non-economic factors (e.g., energy security and geopolitical risks) on the environment. Doğan et al. [28] examine the impact of energy security on ecological degradation using data from 1990 to 2019 in emerging countries. They define that ESR has a positive impact on GHG emissions, which means that higher energy security reduces emissions. Shittu et al. [15] assess the influence of energy security on EF for 45 resource-rich Asian economies. They utilize a two-stage least square approach with data from 1996 to 2018. The results reveal that energy security lessens ecological degradation.

Subramaniam et al. [17] examine the impact of energy security on CO_2 emissions in 112 developing economies, employing the panel QR approach. They conclude that the impact of energy security on CO_2 emissions differs in the models that consider various perspectives of energy security. For instance, the availability of energy shows a significant negative influence on CO_2 emissions for both low and high quantiles. Conversely, the impacts of energy accessibility and acceptability on CO_2 emissions are positive, suggesting that they have not alleviated CO_2 emissions. He et al. [37] define that switching to sustainable energy options (e.g., wind energy) enhances energy security and diminishes CO_2 emissions.

Several studies have examined the relationship between GPR and CO_2 emissions. Zhao et al. [38] investigate the asymmetric impacts of GPR on CO_2 emissions in BRICS countries. The results verify that a reduction in GPR has a negative impact on CO_2 emissions in India, China, and South Africa, while it has a positive impact in Russia. Husnain et al. [36] analyze the impact of GPR on the environment in the E7 countries. The findings show that GPR leads to a reduction in CO_2 emissions and EF. Adams et al. [39] analyze the impact of GPR on CO_2 emissions using data from 1996 to 2017. The empirical findings reveal a negative and significant impact of GPR on CO_2 emissions. Jiao et al. [32] show that GPR causes a decrease in environmental degradation in China.

Recently, Pata et al. [21] investigate the influence of GPR on sector-specific CO_2 emissions. The findings indicate that GPR leads to a reduction in CO_2 emissions across some sectors (e.g., residential, commercial, industrial, and electricity). However, in the period from 2019/1 to 2022/10, encompassing the Russia-Ukraine conflict, GPR is related with a stimulate in CO_2 emissions, specifically within the transportation sector. Ulussever et al. [29] evaluate the impact of GPR on CO_2 emissions for the GCC countries. They discover that the impact of GPR on CO_2 emissions diminishes at the middle quantiles of GPR, but exerts a promotive influence at both the lower and higher quantiles of GPR across five GCC countries. Moreover, Syed et al. [40] conclude that GPR causes an increase in CO_2 emissions in the lower quantiles.

The positive impact of GPR on environmental degradation is defined in the case of different countries. Anser et al. [33] assess the impact of CO_2 emissions on GPR for the BRICS economies. The results indicate that a 1 % rise in GPR leads to a 13 % increase in CO_2 emissions. Hashmi et al. [41] investigate the influence of GPR on global CO_2 emissions. The results show that a 1 % increase in GPR leads to a 3.5 % decrease in global CO_2 emissions in the medium term. In the long term, however, a 1 % rise in the GPR is associated with a 13.24 % increase in CO_2 emissions. The long-term positive impact of the GPR on CO_2 emissions is also found by Ma et al. [42]. In addition, Riti et al. [43], Bashir et al. [34], and Du and Wang [44], Li [35] conclude that the GPR increases ecological degradation in the BRICS countries. In contrast to these studies, Pata and Ertuğrul (2023) find that GPR does not affect environmental degradation in India during 1988–2018. Nawaz et al. [45] investigate the relationship between GPR and CO_2 emissions in Italy using ARDL and wavelets coherence techniques and using data from 1997 to 2019. The results show a negative and insignificant impact of GPR on CO_2 emissions.

In the literature, various studies have used a variety of environmental indicators to examine the link between the factors and environmental sustainability. Most previous studies have mainly used CO_2 emissions as an indicator of ecological degradation. As the literature evolved, many later studies have considered EF as a proxy for ecological degradation. However, CO_2 emissions and EF have ignored the supply side of the environment in empirical research. After the theoretical study by Siche et al. [7] and the first empirical study by Pata [8], many research papers (e.g., Ref. [46]) have investigated the environment by focusing on the quality perspective instead of the pollution perspective by using LCF as the environmental indicator for the various country cases (e.g., Germany, Japan, USA, selected 8 countries, and USA). Therefore, using LCF instead of CO_2 emissions and LCF can further contribute to the literature by considering both the demand and supply sides simultaneously.

The review of the literature in terms of the dependent (i.e., LCF) and explanatory (i.e., ESR and GPR) variables reveals that the existing studies have not used both ESR and GPR in examining LCF in the leading fragile emerging countries by applying novel quantile approaches. Considering this lack of literature, the study uncovers the impact of ESR and GPR on LCF by focusing on the four leading fragile countries.

Although the countries are labeled “Fragile Countries”, there are still differences between countries as well as upon the impact of the ESR and GPR on the LCF across quantiles. Since there is sufficient data over a long period of time and panel data analysis approaches do not account for country-specific differences, the study applied quantile methods with time series to conduct a comprehensive empirical analysis.

3. Methods

3.1. Data

The study compiles data from three different sources. The data on LCF is collected from GFN [57], the data ESR is gathered from U.S. Chamber of Commerce’s Global Energy Institute [47] and the data on GPR is obtained from Caldara & Iacoviello [48]’s measurement. As the ESR data ends in 2018, the study collects data between 1985 and 2018.

The data from ESR and LCF are annual, while the data from GPR are monthly. In order to perform an analysis that includes these three variables, it is necessary to combine them with the same frequency. In this respect, there are two options: Either convert them to annual or convert them to a monthly frequency. By converting the data to an annual frequency, some information is lost in the dataset as the frequency is lower instead of higher (i.e. monthly) and the number of observations is much lower. This complicates the empirical analysis when considering country-specific differences, as this requires a long data set. Taking these points into account, the annual data are converted into monthly data using a quadratic sum approach. Thus, the study uses data between 1985/m2 and 2018/m12, which are the most recent available, overlapped data considering all included variables. Table 1 shows the variables’ details.

3.2. Empirical steps and methodology

For the empirical examination to uncover the impact of ESR and GPR on LCF in leading emerging countries, the study follows a comprehensive methodology, which is illustrated in Fig. 1.

At the beginning, the main statistics and correlations are considered. Then, the structure of the stationarity and the non-linear distribution of the variables are investigated by successively applying the Augmented Dickey-Fuller [ADF] [56], Phillips-Perron [PP] [49], and BDS [50] tests. Second, Quantile on Quantile Regression approach [QQ] [51] is used to analyze the impacts of ESR and GPR on LCF across quantiles. Third, the Granger causality in quantiles approach [GQ] [52] is applied to

Table 1
Variables.

Acronym	Indicator	Measurement	Data
LCF	Load Capacity Factor	Basis Points	GFN [57]
ESR	Energy Security Risk	Basis Points	USC [47]
GPR	Geopolitical Risk		Caldara & Iacoviello [48]

Fig. 1. Empirical Processes.

investigate the causal relationship of ESR and GPR with LCF across quantiles. Fourth, the cross-quantilogram (CQ) approach [53] is applied to analyze the impacts based on various lags, also considering the quantiles. Lastly, the quantile regression [QR] [54] approach is considered to check for the consistency.

The QR model minimizes weighted deviations and provides median-based estimates for each quantile. In other words, QR reflects the interactions between the variables on a quantile basis. The first stage of the QR method is shown in Eq. (1):

$$Q_{Y_t}(\tau|x_t) = f(x_t, \beta(\tau)) = x_t\beta(\tau), t = 1, 2, \ldots, n \tag{1}$$

where x_t includes explanatory variables, and $Q_{Y_t}(\tau|x_t)$ illustrates the τ-th quantile of the explained variable. The final stage of the QR approach is shown in Eq. (2):

$$\widehat{Q}_{Y_t}(\tau|x_t) = x_t\widehat{\beta}(\tau) \tag{2}$$

Eq. (2) can be used to statistically calculate the effect of x on y at a certain quantile. However, the effect of one variable at a particular quantile may affect the value of another variable at a different quantile. In this case, the relationships between the variables cannot be fully determined. To address this neglect, Sim & Zhou [51] proposed the QQ approach. The QQ approach represents the relationships between the variables by considering the interactions between the different quantiles. The first stage of the QQ approach can be expressed by Eq. (3):

$$Y_t = \beta^\theta(X_t) + z_t^\theta \tag{3}$$

where z_t^θ denotes the quantile error term and $\beta^\theta(.)$ represents the influence of the θ quantile of the explanatory variable. In the second stage of the QQ approach, β^θ is modified by first order Taylor expansion as in Eq. (4).

$$\beta^\theta(X_t) \approx \beta^\theta X^\tau + \beta^{\theta'}(X^\tau)(X_t - X^\tau) \tag{4}$$

$\beta^{\theta'}$ shows to the partial derivative of $\beta^\theta(X_t)$. In the third stage, the QQ method finally takes its form in Eq. (5).

$$Y_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X_t - X^\tau) + z_t^\theta \tag{5}$$

Eq. (5) can be employed, for example, to analyze and interpret the effect of x at the 0.10th quantile on y at the 0.20th quantile.

The GQ used in the study for the causality analysis is a kernel-based non-parametric approach. GQ enables a quantile-based causality investigation and the null hypothesis of τ-quantiles, that there is no causality from x to y, can be shown as in Eq. (6)

$$H_0 : Q_\tau^{Y,X}(Y_t I_t^Y) \quad 0 < \tau < 1 \tag{6}$$

where $(I_t^Y, I_t^X) \in R^d$ is the explanatory vector. In the final stage of the GQ approach, the null hypothesis $(Q_\tau^{Y,X}(Y_t I_t^Y))$ can be specified as in Eq. (7), defined by a parametric quantile model $(m(I_t^Y, \theta_0(\tau)))$.

$$E\{1[Y_t - m(I_t^Y, \theta_0(\tau))] - \tau I_t^Y, I_t^X\} = 0 \quad 0 < \tau < 1 \tag{7}$$

Troster [52] recommends calculating the ST value ($S_T = \frac{1}{Tn}\sum_{j=1}^{n}\left|\varphi'_{.j}\boldsymbol{W}_{\varphi.j}\right|$) for testing the null hypothesis, and if the calculated S_T statistic is greater than the critical value, it can be decided that x causes y.

The study analyzes the correlation between variables using the novel CQ approach. The CQ method by Han et al. [53] provides effective results by considering different lags for non-normally distributed data. The CQ approach can graphically depict periodic interactions between variables, and its first stage is shown in Eq. (8):

$$p_\alpha(k) = \frac{E[\varphi_{\alpha1}(x_{1,t-}q_1(\alpha_1))\varphi_{\alpha2}(x_{2,t-}q_2(\alpha_2))]}{\sqrt{E[\varphi_{\alpha1}^2(x_{1,t-}q_1(\alpha_1))]}\sqrt{E[\varphi_{\alpha2}^2(x_{2,t-}q_2(\alpha_2))]}} \tag{8}$$

In contrast to the QR and QQ methods, the CQ method shows the cross-quantile dependence between the series. In Eq. (8), $p_\alpha(k)$ denotes the estimator of the cross-correlation. The CQ approach captures the relationships between two variables such as x1,t (ESR) and x2,t (LCF) based on different quantiles and lags. In the CQ approach, the predictive power of one variable for another variable is analyzed using Eq. (9)

$$\widehat{Q}_\alpha^{(p)} = \frac{T(T+2)\sum_{k-1}^{p}(k)}{T-k} \tag{9}$$

where $\widehat{Q}_\alpha^{(p)}$ illustrates the portmanteau test for predictability from ESR to LCF based on lags (p) at different quantiles.

4. Results

4.1. Preliminary statistics

The first step of the empirical analysis is to examine the main statistics of the variables. Table 2 contains the main statistics.

As Table 2 presents, the ESR has the highest fluctuations in relation to GPR and LCF in all countries. ESR also has the highest values concerning the remaining variables. All variables, without exception, have a non-normal distribution. Table 3 demonstrates the correlation among the variables.

In BRA and ZAF, LCF is positively related to ESR, while there is a negative relationship with GPR. Differently, in IND, the LCF has a negative relationship with both ESR and GPR. Similar to the case of IND, in TUR, LCF has a positive relationship with ESR and GPR. Table 4 reports the unit root test results.

According to Table 4, all variables are stationary at the level based on the results of the ADF and PP tests. Therefore, the stationary series can be used for further empirical studies.

In addition, the study tests the non-linearity of the variables, which is shown in the Supplementary Annex 1. As shown, all variables have a non-linear structure. To summarize, the main statistics show that the ESR has a high variation, while all variables have a non-normal distribution and a non-linear structure. Accordingly, the use of non-linear approaches can be appropriate. Therefore, quantile methods are applied in the study to investigate the effects of ESR and GPR on the LCF across various quantiles.

4.2. QQ results

4.2.1. ESR impact on LCF

In a second step, the study applies the QQ approach to reveal the impacts of the variables on the LCF. Fig. 2 shows the influence of the ESR on the LCF in the countries.

In BRA, ESR declines the LCF at the lower quantiles (0.05). However, the impact becomes positive, and its power strengths as the quantile

Table 2
Main statistics.

Country	Variable	Mean	Max.	Min.	SD	Skewness	Kurtosis	JB	JB Prob.
BRA	LCF	0.31	0.42	0.24	0.05	0.37	2.05	24.49	0.0000
	ESR	79.46	92.79	59.49	7.98	−0.69	2.99	32.23	0.0000
	GPR	0.04	0.23	0.00	0.03	2.17	11.03	1411.10	0.0000
IND	LCF	0.04	0.05	0.03	0.01	−0.02	1.64	31.37	0.0000
	ESR	92.49	105.35	77.71	7.74	−0.46	2.32	22.00	0.0000
	GPR	0.21	1.13	0.04	0.14	3.08	16.09	3547.03	0.0000
ZAF	LCF	0.04	0.04	0.03	0.00	−0.07	1.47	40.01	0.0000
	ESR	87.12	102.48	73.75	8.50	0.09	1.67	30.32	0.0000
	GPR	0.09	0.62	0.00	0.09	3.19	16.67	3862.05	0.0000
TUR	LCF	0.05	0.08	0.04	0.01	0.33	1.91	27.73	0.0000
	ESR	90.72	105.82	73.95	7.74	0.22	2.20	14.07	0.0009
	GPR	0.19	1.20	0.02	0.17	2.24	9.79	1123.85	0.0000

Notes: JB and SD denote the Standard Deviation and Jarque-Bera, in order.

Table 3
Correlation Matrix.

Country	Variable	LCF	ESR	GPR
BRA	LCF	1.00		
	ESR	0.12	1.00	
	GPR	−0.06	0.02	1.00
IND	LCF	1.00		
	ESR	−0.11	1.00	
	GPR	−0.00	0.03	1.00
ZAF	LCF	1.00		
	ESR	0.18	1.00	
	GPR	−0.04	−0.05	1.00
TUR	LCF	1.00		
	ESR	0.04	1.00	
	GPR	0.04	−0.01	1.00

Table 4
Unit root test results.

Country	Variable	ADF		PP	
		I (0)	I (1)	I (0)	I (1)
BRA	LCF	0.0000		0.0000	
	ESR	0.0097		0.0000	
	GPR	0.0000		0.0001	
IND	LCF	0.0001		0.0000	
	ESR	0.0012		0.0000	
	GPR	0.0000		0.0001	
ZAF	LCF	0.0000		0.0000	
	ESR	0.0004		0.0000	
	GPR	0.0000		0.0001	
TUR	LCF	0.0000		0.0000	
	ESR	0.0003		0.0000	
	GPR	0.0000		0.0001	

Notes: Akaike information criteria and Bartlett Kernel are used in ADF and PP test, in order.

increases (0.10–0.95). In IND, the ESR declines the LCF across all quantiles (0.05–0.95). In ZAF, the ESR has an increasing impact on LCF at lower and middle quantiles (0.05–0.90), while it becomes negative at the highest quantile (0.95). In TUR, ESR decreases the LCF across all quantiles (0.05–0.85) except for the highest quantiles (0.90–0.95). In summary, ESR has a stimulatory impact on LCF at higher quantiles in BRA and TUR, while it has a decreasing effect in IND and ZAF. The effects of ESR on LCF are also varies in the different quantiles.

4.2.2. *GPR impact on LCF*

Fig. 3 presents the impact of GPR on LCF in the countries. In BRA, GPR increases the LCF across almost all quantiles (0.05–0.80) except for some higher ones (0.85–0.95). In ZAF, GPR increases the LCF across almost all quantiles (0.05–0.90), except the highest (0.95). In TUR, GPR stimulates the LCF across all quantiles except for some higher ones (0.90–0.95). In IND, however, the impact of GPR is only positive at a lower quantile (0.05), while the impact becomes a declining one across all remaining quantiles (0.10–0.95). Overall, it can be seen that the GPR has a decreasing impact on the LCF at higher quantiles in all countries, while its impact is an increasing one at lower and middle quantiles in BRA and ZAF.

4.3. *GQ results*

In the third step, the study applies the GQ approach to search the causal impacts of ESR and GPR on LCF across quantiles. The results of the GQ approach are shown in Table 5.

As Table 5 presents, ESR has a causal effect on the LCF in all countries across all quantiles, except for one middle (i.e., 0.50). GPR causes LCF in all countries across all quantiles except the 0.50th quantile. Thus, the GQ results show that both ESR and GPR have a significant causal effect on LCF in all countries and across almost all quantiles.

4.4. *CQ results*

4.4.1. *ESR impact on LCF*

In the fourth step, the study performs the CQ approach to reveal the impacts of the variables on the LCF over different time lags. In this regard, Fig. 4 presents the impacts of ESR on LCF across countries using 1, 3, 6, and 12 lags denoting 1, 3, 6, and 12 months (in that order).

In BRA, ESR has a significantly increasing impact (around 0.80) on LCF, when ESR is at 0.75th quantile and LCF is at 0.50th quantile as well as ESR is at 0.85th quantile and LCF is at both the 0.65th and 0.85th quantile, for 1-month lag. In lag of 3 months, the impact of ESR on LCF becomes slightly weaker (around 0.70), but it is still positive. The impact of ESR on LCF is negative (around −0.2) at 6 months lag when ESR is at 0.25th quantile and LCF is at 0.40th quantile. In addition, the negative impact of ESR on LCF becomes much stronger (around −0.3), when ESR is at 0.45th quantile and LCF is at 0.50th quantile at a lag of 12 months.

For IND, the ESR has an increasing impact (about 0.45) on the LCF when the ESR is at the 0.45th quantile and the LCF is at the 0.25th quantile. With a lag of 3 months, the impact of the ESR on the LCF is almost the same (about 0.45) when the ESR is at the 0.45th quantile and LCF is at 0.25th quantile, as well as ESR is at 0.35th quantile and LCF is at 0.75th quantile. However, with a lag of 6 months, the impact of the ESR on the LCF decreases (approx. −0.2) when the ESR is at the 0.25th quantile and the LCF at the 0.45th quantile, as well as when the ESR is at the 0.35th quantile, and LCF is at 0.85th quantile. Moreover, the negative impact of the ESR on the LCF becomes much stronger (approx. −0.3) when the ESR is at the 0.55th quantile and the LCF at the 0.65th quantile at 12 months lag.

In the ZAF, the ESR has an increasing influence (about 0.4) on the LCF, when the ESR is at the 0.15th quantile, the LCF is at the 0.05th quantile, as well as ESR is at 0.55th quantile and LCF is at 0.35th. With a lag of 3 months, the influence of the ESR on the LCF becomes somewhat

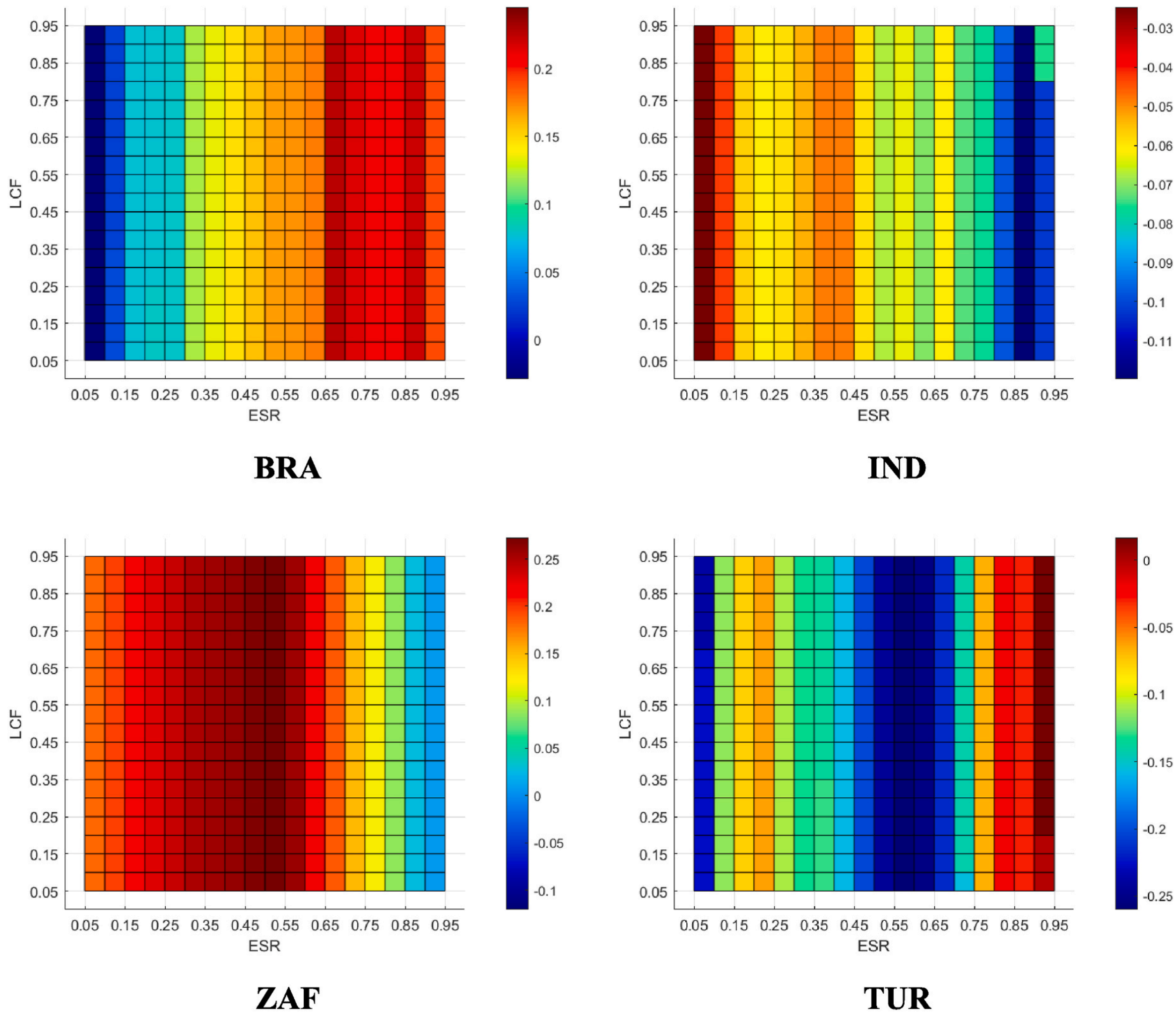

Fig. 2. Qq results for esr impact on LCF

weaker (around 0.30) when the ESR is at the 0.65th quantile and the LCF is at the 0.85th quantile, as well as ESR is at 0.35th quantile and LCF is at 0.65th quantile. The impact of the ESR on the LCF decreases (around −0.1) with a lag of 6 months when the ESR is at the 0.65th quantile and the LCF at the 0.85th quantile, as well as ESR is at 0.50th quantile and LCF is at 0.15th. The negative impact of the ESR on the LCF is much stronger (around −0.3) when the ESR is at the 0.35th quantile and the LCF at the 0.95th quantile, with a lag of 12 months.

In TUR, ESR has a stimulating impact (about 0.45) on LCF when ESR is at the 0.65th quantile and LCF at the 0.55th quantile for one month lag. With a lag of 3 months, the impact of ESR on LCF is almost the same (about 0.5) when ESR is at the 0.50th quantile and LCF at the 0.55th quantile. However, with a lag of 6 months, the impact of ESR on LCF becomes a dampening one (about −0.4) when ESR is at the 0.05th quantile and LCF is at the 0.55th quantile. The negative impact of ESR on LCF is relatively weaker (about −0.2) when ESR is at the 0.75th quantile and LCF is at the 0.95th quantile, with a lag of 12 months.

Overall, ESR has a significant and varied impact on LCF across various quantiles and different lags. Of all countries, ESR has the largest impact on LCF in BRA, followed by IND, TUR, and ZAF, in that order. ESR has a significantly increasing impact on LCF at much shorter lags, while the impact turns negative over time.

4.4.2. GPR impact on LCF

Fig. 5 presents the impact of the GPR on the LCF in the countries, considering 1, 3, 6, and 12 lags corresponding to 1, 3, 6, and 12 months, respectively.

In BRA, ESR has an amplifying impact (around 0.4) on LCF, when ESR is at the 0.50th quantile and LCF is at the 0.75th quantile, for a 1-month lag. With 3 months lag, the impact of ESR on LCF is almost the same (around 0.4), when ESR is at the 0.95th quantile and LCF is at the 0.95th quantile. The impact of the ESR on the LCF becomes a dampening effect (about −0.2) at a lag of 6 months when the ESR is at the 0.55th quantile and the LCF at the 0.65th quantile. The negative impact of the ESR on the LCF is much stronger (around −0.4), when the ESR is at the 0.15th quantile and the LCF at the 0.90th quantile, with a lag of 12 months.

In IND, the ESR has an increasing impact (about 0.40) on the LCF when the ESR is at the 0.85th quantile and the LCF at the 0.95th quantile. At a 3-month lag, the impact of the ESR on the LCF is almost the same (about 0.40) when the ESR is at the 0.45th quantile and the LCF at the 0.50th quantile. However, with a 6-month lag, the impact of the ESR on the LCF is negative (approx. −0.2) when ESR is at the 0.45th quantile and the LCF at the 0.50th quantile, as well as ESR is at the 0.65th quantile and the LCF at the 0.05th quantile. Furthermore, the negative impact of the ESR on the LCF becomes much stronger (about −0.3) when ESR is at the 0.45th quantile and the LCF at the 0.95th quantile, as well as ESR is at the 0.65th quantile and the LCF at the 0.15th quantile with a lag of 12 months.

In the ZAF, the ESR has a stimulating influence (approx. 0.40) on the LCF when ESR and the LCF are both in the 0.95th quantile with a lag of 1 month. With a lag of 3 months, the impact of the ESR on the LCF is

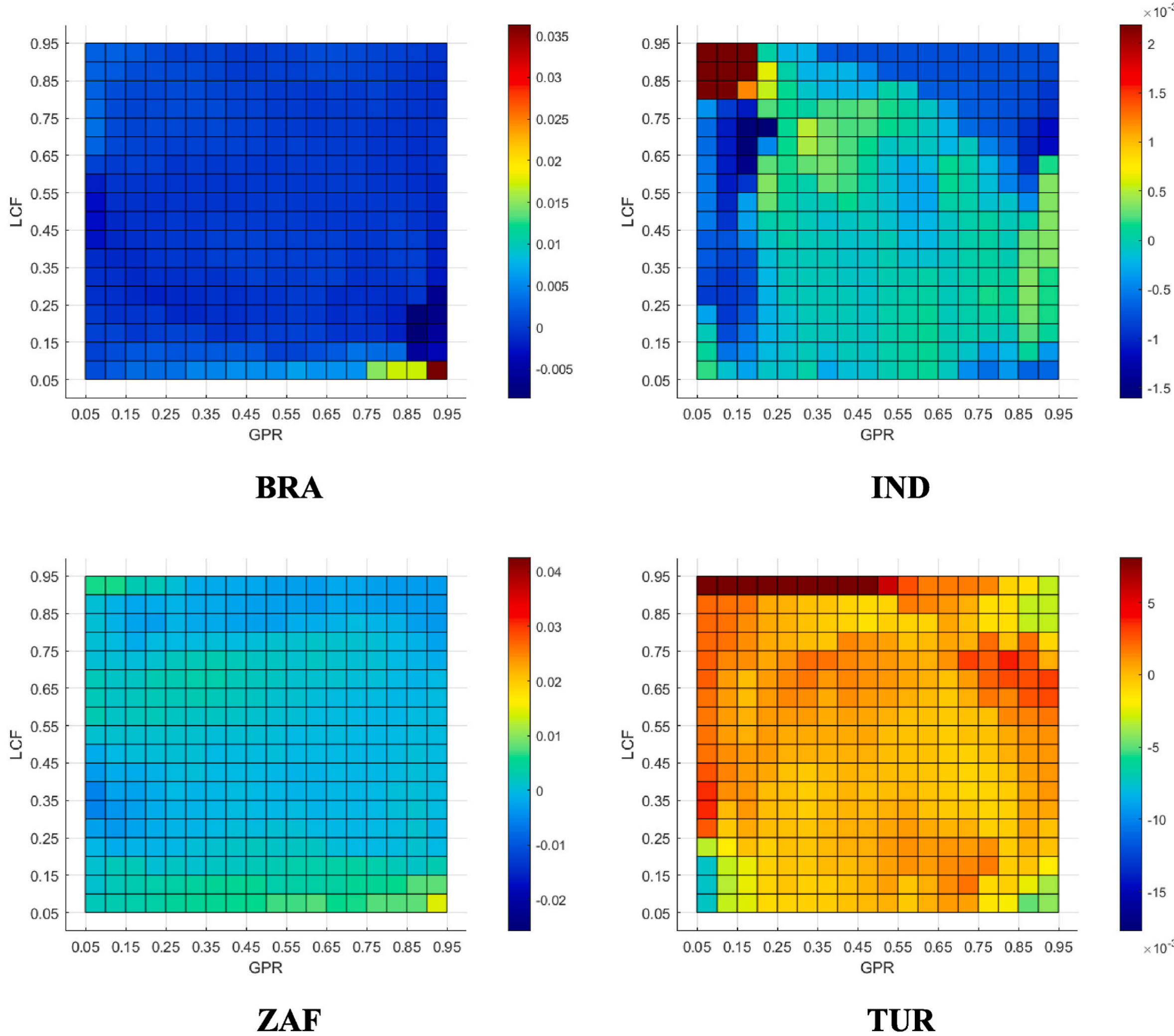

Fig. 3. Qq results for GPR impact on LCF

Table 5
GQ results.

Country	BRA		IND		ZAF		TUR	
Quantile	ESR⇨LCF	GPR⇨LCF	ESR⇨LCF	GPR⇨LCF	ESR⇨LCF	GPR⇨LCF	ESR⇨LCF	GPR⇨LCF
0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.45	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
0.50	0.14	0.13	0.47	0.52	0.14	0.10	0.61	0.59
0.55	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.00
0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.95	0.01	0.01	0.00	0.00	0.00	0.03	0.00	0.00

Note: Values indicate probability values.

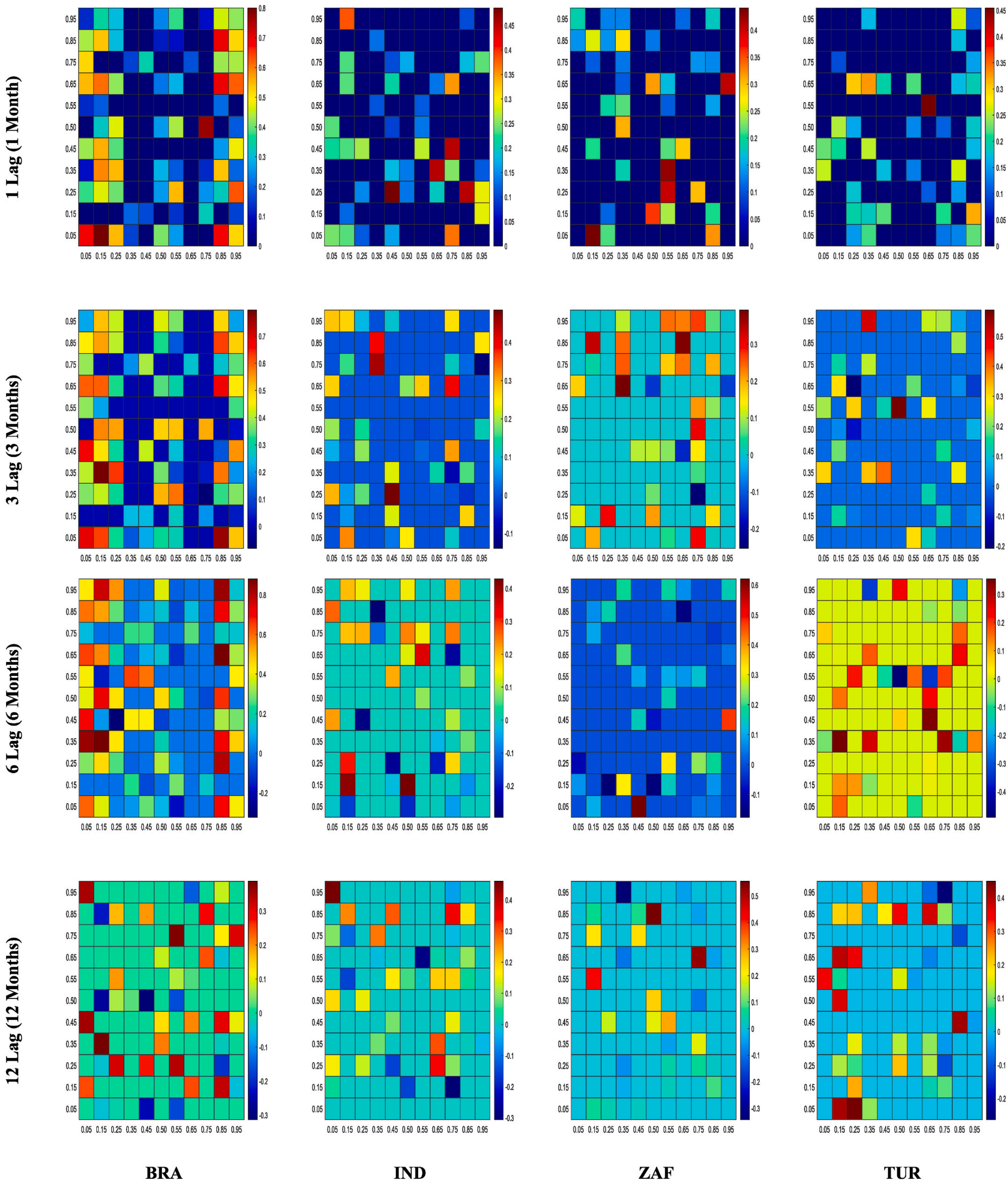

Fig. 4. CQ Results for ESR Impact on LCF
Note: y and x axes denote LCF and ESR, respectively.

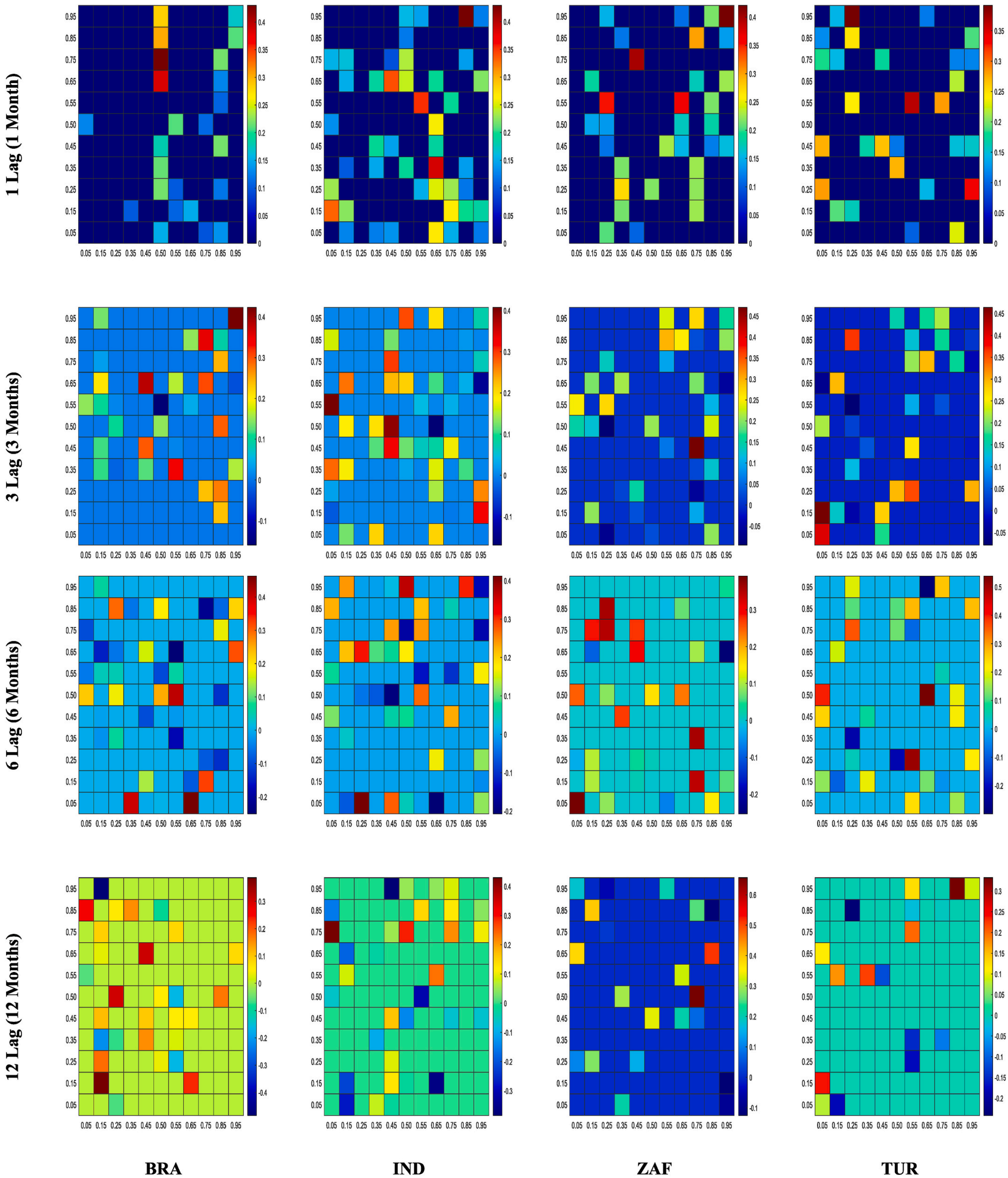

Fig. 5. CQ Results for GPR Impact on LCF
Note: y and x axes denote LCF and GPR, respectively.

slightly stronger (approx. 0.45) when ESR is at the 0.75th quantile and the LCF at the 0.45th quantile. However, with a lag of 6 months, the impact of the ESR on the LCF decreases (approximately −0.2), when the ESR is at the 0.95th quantile and the LCF at the 0.65th quantile. With at a lag of 12 months, the negative impact of the ESR on the LCF becomes slightly weaker (approximately −0.1) when both the ESR and the LCF are at the 0.85th quantile.

In TUR, the ESR has a stimulating impact (about 0.40) on the LCF when the ESR is at the 0.25th quantile and the LCF at the 0.95th quantile. With a lag of 3 months, the impact of the ESR on the LCF is slightly stronger (about 0.45) when the ESR is at the 0.05th quantile and the LCF at the 0.15th quantile. However, with a lag of 6 months, the impact of the ESR on the LCF decreases (approximately −0.3) when the ESR is at the 0.65th quantile and the LCF at the 0.95th quantile. With a lag of 12 months, the negative impact of the ESR on the LCF becomes slightly weaker (approximately −0.2) when the ESR is at the 0.25th quantile and the LCF at the 0.85th quantile.

To summarize, the GPR has a significant and changing influence on the LCF across different quantiles and various time lags. Of all countries, the GPR has the largest influence on the LCF in BRA, IND and ZAF, while its influence is somewhat weaker in TUR. The GPR has an important stimulating impact on LCF at shorter lags, while the impact becomes a curbing one over time.

4.5. Robustness

Finally, the study performs the QR approach to check the validity of the results. Fig. 6 presents the results of the comparison of the effects of ESR on LCF.

There is strong consistency between the QQ and QR approaches in estimating the impact of ESR on LCF in the countries. The results are therefore highly consistent with each other. Fig. 7 also demonstrates the results of the comparison of the impact of GPR on LCF.

As Fig. 7 shows, there are some differences between the QQ and QR approaches in estimating the impact of GPR on LCF in the countries. The quantile approaches have generally similar trends, indicating the robustness of the results. Considering the overall findings, it can be stated that the results of the empirical investigation can be used for discussing further policy recommendations.

5. Conclusion and policy recommendations

This study is the first to examine the impact of GPR and ESR on environmental quality in four fragile countries. The study uses several novel quantile methods. Although the relationship between GPR and LCF has already been partially analyzed, there is no study that examines the relationship between ESR and LCF. Problems that occur or could occur in energy security can have an impact on air, water and soil pollution. In this regard, increased energy security risk can support the development of ecological quality by stimulating the promotion of renewable sources from fossil fuels. However, when countries turn to cheaper and fossil resources at the risk of energy security, this leads to increased ecological destruction. This study discusses the environmental impacts of ESR and uncertainty in detail. The main findings of the study show that at high quantiles, GPR reduces LCF in all countries, while ESR reduces LCF in IND and ZAF. The environmental impact of ESR for BRA is positive. In addition, the CQ results show that as the lag length increases, the negative impact of uncertainty and increased risk on environmental degradation increases. These results indicate that it is important to take risks and uncertainties into account when designing environmental policy.

The findings of the study show that the increase in ESR in IND and ZAF causes a decrease in LCF. When there is a problem or shortage in energy supply, countries use the scarce energy resources to maintain economic growth, and this leads to energy inefficiency. In energy inefficiency, countries try to gain cost advantages instead of utilizing energy resources with eco-friendly technologies, which accelerates environmental destruction and leads to a decline in LCF. Energy security

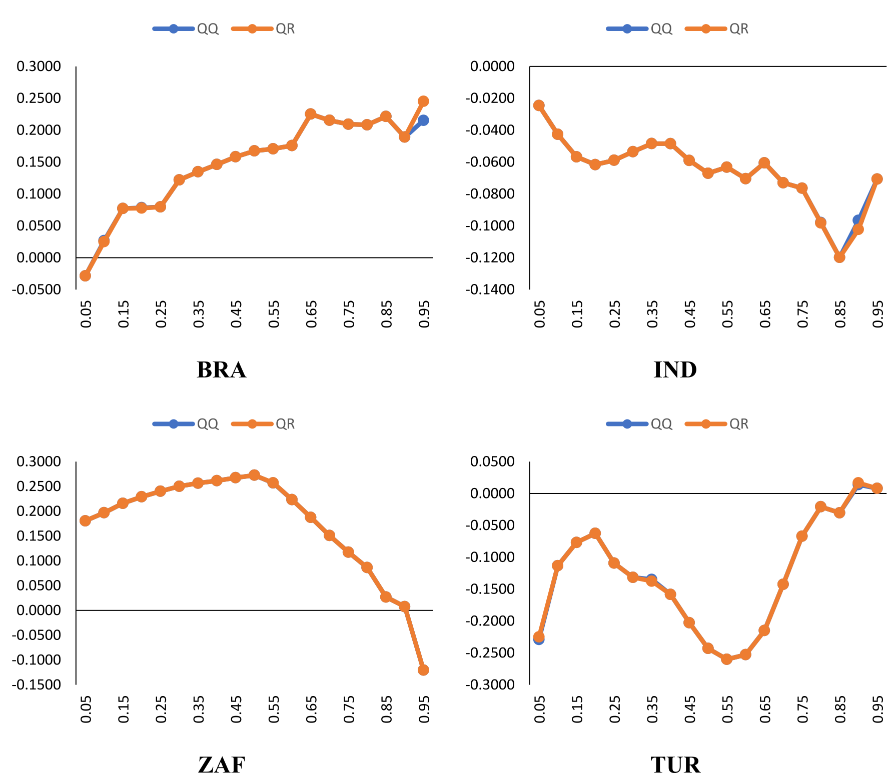

Fig. 6. Comparison of the QQ and QR results for esr impact on LCF

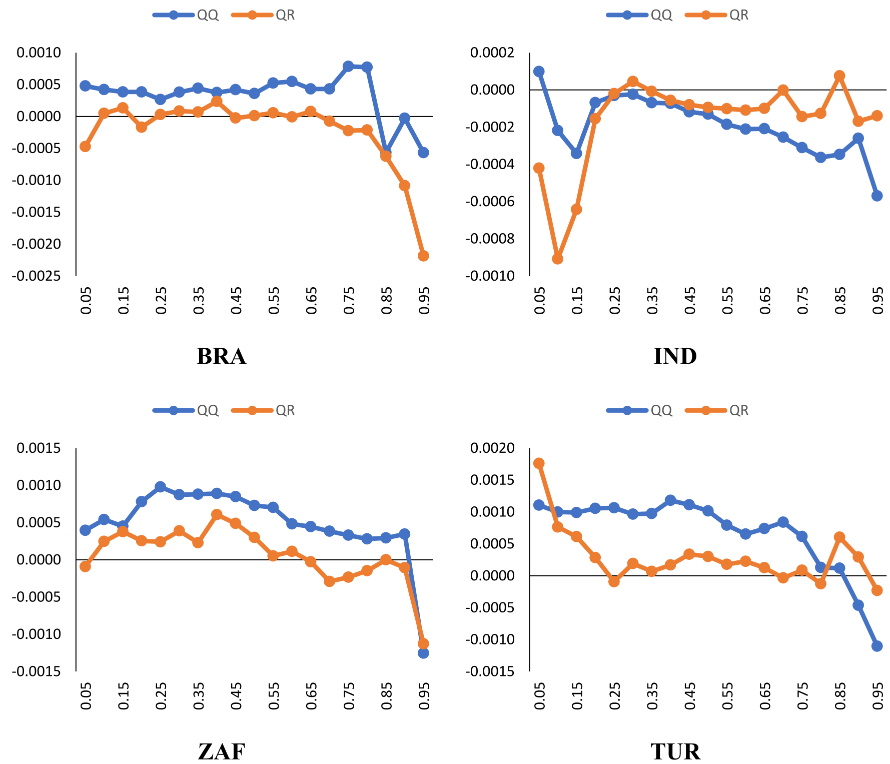

Fig. 7. Comparison of the QQ and QR for GPR impact on LCF

is a prerequisite for sustainable development [55]. Energy security issues force countries and policy makers to focus on their solutions and environmental concerns are not on the agenda. As the risk of energy security increases, the implementation of SDGs such as SDG 3, 7, 8 11, and 12 is at risk. If ensure energy security is not ensured, this can have a negative impact on economic growth, consumption efficiency, energy affordability and the sustainability of electricity generation in cities. In this context, policy makers of fragile countries should increase country diversity in energy imports to ensure energy security. Another policy suggestion in this context is the strategies of countries to reduce dependence on foreign countries by producing energy themselves. With these two strategies, fragile countries can more easily achieve both their economic and environmental goals.

The impact of the GPR on the LCF is negative for all countries. In other words, like the ESR, the increase in the GPR has a negative impact on ecological quality. When geopolitical risks increase, countries prioritize economic concerns. The rise in GPR also leads to disruptions in energy supply and a threat to energy security due to political tensions. The most recent example of this is the ongoing conflict between Russia and Ukraine and the resulting natural gas crisis, as well as the rise in ESR. Therefore, fragile countries need to promote renewable energy sources to protect themselves from the negative environmental impacts of GPR and ESR. As renewable energies are indigenous resources, they can help reduce energy imports and limit energy dependence in a region where GPR is increasing. Therefore, fragile countries can reduce the negative environmental impact of geopolitical and energy security-related risks by investing more in green technologies that promote renewable energies. Another policy recommendation is that policy-makers in fragile countries should emphasize improving institutional quality to minimize the negative impacts of GPR. With strong institutions, these countries can limit the impact of risks and uncertainties on the environment through good environmental planning. At this point, increasing the effectiveness of institutions to regulate and monitor the energy sector can be considered as an appropriate policy tool by the authorities.

The LCF values of the four fragile countries analyzed are below "1″, with the exception of Brazil, which indicates that measures need to be taken to develop environmental sustainability in South Africa (0.37), Turkey (0.44), and India (0.33) (GFN, 2023). Considering the LCF values in parentheses, these three fragile countries consume almost three times as much as their existing natural resources and cause ecological damage. In order to mitigate such huge environmental destruction, it is important to evaluate various risks and discuss their environmental impacts.

Fragile countries are economically dependent on the outside world and react highly sensitively to external shocks. In this context, global geopolitical tensions and increased energy security risks can have a negative impact on the fragile economies. Fragile countries should diversify their energy portfolio to eliminate the negative impact of ESR and GPR in the energy sector. Fragile countries are countries that are dependent on oil imports, and a disruption in oil supply could harm the economic activities of these countries. However, this may lead fragile countries to reduce their consumption of fossil fuels and improve their environmental quality. Fragile countries should increase their investment in clean energy and activate local energy resources as energy security and geopolitical risks increase, taking into account both environmental and economic balance. To this end, an incentive program should be launched on a country-by-country basis depending on the suitability for renewable energy sources. One fragile country may support the widespread use of wind turbines due to its geographical location, while another country may increase its investment and imports of solar panels. Fragile countries can therefore adjust their energy policies to turn the negative economic shocks caused by GPR and ESR into environmental opportunities. The environmental policies of fragile countries should include tax exemptions in the renewable energy sector and increased spending on renewable energy research and development. In addition, the governments of these countries can increase renewable energy deployment before the economic shocks that GPR and ESR can cause by imposing a provisional tax on the use of fossil fuels. Fragile countries can thus support the increase in LCF levels by having a stronger economic and ecological structure.

Although this is a pioneering study that analyze the impacts of ESR on LCF, it contains some limitations in nature. First, the study focuses on only fragile four countries. So, future studies can analyze larger groups of countries. Second, the study neglects structural breaks. Hence, researchers can obtain more detailed findings by using econometric methods that incorporate structural breaks in analyzing the impact of both ESR and GPR on the LCF. Third, the data used in the study ends in 2018 due to the limitations on the data of ESR. For this reason, new analysis can be made to include the most recent times when the ESR data is updated. Thus, an assessment of ESR on environmental quality can be made that takes into account the impact of the recent cases, such as Russia-Ukraine conflict. With the inclusion of these point in new research, the knowledge upon the impact of ESR and GPR on the LCF can be extended more.

Disclosure statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Ugur Korkut Pata: Conceptualization, Writing – original draft, Writing – review & editing. **Mustafa Tevfik Kartal:** Conceptualization, Formal analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Shahriyar Mukhtarov:** Writing – original draft. **Cosimo Magazzino:** Writing – review & editing.

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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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esr.2024.101430.

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