Politická ekonomie
2024, Volume 72 (2), Special Issue:
Achieving Energy Transition and Sustainable Development:
The Roles of Political Risk and Energy Technology Investments

PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Effect of Political Stability, Geopolitical Risk and R&D Investments on Environmental Sustainability: Evidence from European Countries by Novel Quantile Models*

Serpil Kılıç Depren, Sinan Erdogan, Mustafa Tevfik Kartal, Ugur Korkut Pata

Serpil Kılıç Depren (e-mail: serkilic@yildiz.edu.tr): Yildiz Technical University Department of Statistics, Istanbul, Turkey

Sinan Erdogan (e-mail: phderdogan@gmail.com): Hatay Mustafa Kemal University Department of Economics, Hatay, Turkey; Azerbaijan State University of Economics (UNEC) Clinic of Economics, Baku, Azerbaijan

Mustafa Tevfik Kartal (e-mail: mustafatevfikkartal@gmail.com): Borsa Istanbul Strategic Planning, Financial Reporting, and Investor Relations Directorate, Istanbul, Turkey; Lebanese American University Adnan Kassar School of Business, Beirut/Lebanon; Azerbaijan State University of Economics (UNEC) Clinic of Economics, Baku, Azerbaijan

Ugur Korkut Pata (*corresponding author*, e-mail: ugur.pata@lau.edu.lb): Osmaniye Korkut Ata University Department of Economics, 80 000 Merkez, Osmaniye, Turkey; Lebanese American University Adnan Kassar School of Business, Beirut, Lebanon; Azerbaijan State University of Economics (UNEC) Clinic of Economics, Baku, Azerbaijan

Abstract

This research investigates the effect of political stability and geopolitical risk on environmental sustainability (ES) by considering R&D investments in nuclear and renewable energy. Considering the high political stability and recent energy crisis and increasing geopolitical risk, the study focuses on three leading European countries. We use the load capacity factor, include data between 1985/1 and 2020/12, and apply quantile on quantile regression (QQ), Granger causality in quantiles (GQ), and quantile regression (QR) models. The study finds that in higher quantiles (i) increasing political stability stimulates the ES in Sweden and the United Kingdom; (ii) increasing geopolitical risk supports the ES in France; (iii) R&D investments increase the ES in all the countries; (iv) there are generally causal effects from the explanatory variables to the ES except some quantiles (0.45–0.50) in all the countries; (v) the power effects of the variables differ according to countries, quantiles and variables.

Keywords: Load capacity factor, political stability, geopolitical risk, European countries, environmental sustainability

JEL Classification: C32, N55, O13

* Data will be made available on request.

Citation: Depren, S. K., Erdogan, S., Kartal, M. T., Pata, U. K.: Effect of Political Stability, Geopolitical Risk and R&D Investments on Environmental Sustainability: Evidence from European Countries by Novel Quantile Models. *Politická ekonomie,* 2024, 72 (2), Special Issue, 151–180, https://doi.org/10.18267/j.polek.1413

Acronyms	
AARDL	Augmented ARDL
AMG	Augmented mean group
ARDL	Autoregressive distributed lag
BDS	Brock, Scheinkman, Dechert and LeBaron
BPS	Basis points
CCE	Common correlated effects
CSARDL	Cross-sectional ARDL
DOLS	Dynamic ordinary least squares
EKC	Environmental Kuznets curve
ES	Environmental sustainability
EU	European Union
FMOLS	Fully modified ordinary least squares
GFN	Global Footprint Network
GHA	Global hectares
GMM	Generalized method of moments
GQ	Granger causality in quantiles
IEA	International Energy Agency
NARDL	Non-linear ARDL
PRS	Political risk service
PS	Political stability
QQ	Quantile-on-quantile regression
QR	Quantile regression
R&D	Research and development
SDGs	Sustainable Development Goals
UN	United Nations
USD	United States dollar
WC	Wavelet coherence
Dependent variable	
LCF	Load capacity factor
Independent variables	
PRI	Political risk index
GPR	Geopolitical risk index
NRD	Nuclear energy R&D investments
RRD	Renewable energy R&D investments
Sample countries	
FRA	France
GBR	United Kingdom
SWE	Sweden

1. Introduction

Addressing negative externalities of economic development on the environment and ensuring ES is of great importance for policymakers in the modern era. Several steps have been taken since the UN Conference on the Human Environment in 1972 to limit anthropogenic effects on nature and harmonize increasing economic welfare and environmental pollution reduction targets. Therefore, the sustainability concept has been at the centre of economic and environmental goals, and increasing productivity and efficiency of resources have gained significance alongside limiting resource use and environmental pollution. In this context, R&D activities have become crucial. Indeed, SDGs pay specific attention to R&D efforts, of which three sub-goals of SDG-8 (specifically, 8.2, 8.3, and 8.4) are related to R&D (UN, 2023).

Eco-innovation is the traditional strategy to increase ES and economic performance (Lee and Min, 2015). Promotion of R&D activities is a need for firms and governments because of bringing a win-win opportunity. Thus, He (2006) outlined that increasing R&D efforts can increase the productivity level by boosting technical efficiency, which may help strengthen the technique effect of economic development as envisaged in the EKC hypothesis. Also, Jin *et al*. (2023) stated that increasing R&D and innovation investments particularly in the energy sector can help the development of eco-friendly technologies to curb excessive resource use and environmental deterioration. So, increasing eco-friendly technology research investments can help reallocate resources that revise production structures, increase productivity and reduce energy use and greenhouse gas emissions. Moreover, increasing R&D investments promotes invention of technologies enabling production of fewer pollutants and less waste. In this way, R&D investments can be an effective tool for achieving environmental targets (Mushafiq and Prusak, 2023; Pata, Caglar, *et al*., 2023).

However, some researchers have asserted that R&D investments in environmental technologies are expenditures without economic benefits. Walley and Whitehead (1994) emphasized that environmental initiatives may not always increase economic performance because of the high costs of environmental challenges. So, R&D investments may not produce envisaged results in environmental performance. Palmer *et al*. (1995) suggested that R&D activities have an inherent ambiguity. Thus, R&D investments in environmental technologies may not pay off. Ambec and Lanoie (2008) stated that the environmental market mechanism can successfully allocate scarce resources. Thus, intervention in market mechanisms (*e.g.*, boosting or cutting R&D expenditures) may not help in addressing environmental problems. Therefore, how R&D investments affect environmental performance is an ambiguous research topic.

Moreover, Al-Mulali and Öztürk (2015) unveiled that both internal and international political circumstances can affect environmental performance as much as economic factors. In this regard, environmental regulations may not be successfully implemented during times of political instability and the use of production technologies and materials against environmental standards can easily spread, which causes an increase in environmental pollution. Abid (2016) asserted that poor political conjuncture can be associated with weaker environmental implementations. Simionescu *et al*. (2023) reported that political instability can increase environmental damage and hinders the positive effects of incentives. Besides, historical evidence has shown that environmental harm of violence and turmoil increase when political instability rises. For instance, burning oil wells during Iraq–Kuwait and Iraq – United States wars caused extra greenhouse gas emissions. So, decreasing political stability can hinder investments and economic development. Thus, resource use, consumption and production can weaken and environmental pollution may not increase.

Furthermore, Riti *et al*. (2022) stated that rising GPR because of international conflicts can reduce the effectiveness of environmental initiatives. In this regard, GPR can change the behaviour of economic agents and policymakers. Increasing GPR can hinder investment in ecological technologies by entrepreneurs and incentives provided by governments. Du and Wang (2023) reported that GPR can hurdle financing eco-friendly investments. For example, some European countries have reverted to coal use for powering economic activities (IEA, 2023a) because of high GPR due to the Russia-Ukraine conflict and sanctions applied against Russia (Kartal, Pata *et al*., 2023). Increasing GPR can change the composition of public spending, scarce resources can be withdrawn from productive areas, and environmental budgets can be allocated to unproductive areas. Also, rising GPR can lead to conventional wars, which have serious environmental consequences. For instance, the recent Nova Kakhovka dam incident in Ukraine, because of the continuing war, has caused a huge flood and natural disaster. Thus, increasing GPR can have adverse effects on every economic aspect including R&D efforts (Anser, Syed, Apergis, 2021; Anser, Syed, Lean, *et al*., 2021b). So, economic performance can decline during high GPR times, resource use decreases, anthropogenic effect on nature may weaken and the trend of environmental pollution can revert.

By considering the above discussion, the answer to the question "*How do PS, GPR and R&D investments affect environmental pollution?*" is not clear. So, the main objective of this study is to investigate the effect of PS, GPR and R&D investments on the environmental performance of leading European countries for the period between 1985/1 and 2020/12 by performing quantile methods. In this way, the study makes the following unique contributions. Firstly, understanding the effects of PS and GPR on environmental quality can provide evidence for policymakers to shape domestic and international policies for internalizing the externalities of PS and GPR on the environment. Secondly, understanding how R&D investments drive environmental performance can provide key evidence for policymakers regarding the ecological efficiency of R&D activities. This can help shape R&D policies and reallocate resources. Thirdly, using quantile methods allows researchers to understand the nature of the interactions between mentioned variables in different quantiles. This enables researchers to make inferences about the changes in the interactions in different quantiles. Moreover, the use of quantile-based methods can serve better in capturing non-linearities and provide robust results.

The introduction is followed by a literature review, methods, results, and a conclusion section, in said order.

2. Literature Review

Understanding the environmental effects of economic activities is one of the current debate topics for researchers since the prominent papers of Grossman and Krueger (1991). Early studies focused on unveiling the effect of traditional economic indicators (*e.g.*, investments, trade openness, foreign direct investment, urbanization) on the environment (Nurgazina *et al*., 2022). The second wave of the research has investigated the effect of input-based variables (*e.g.*, electricity, renewable energy consumption and non-renewable energy consumption) on environmental performance (Pata and Çağlar, 2021; Ulussever *et al*., 2023; Adebayo *et al*., 2023; Akhayere *et al*., 2023; Kartal, 2023; Pata, Erdoğan, Ozkan, 2023; Ullah *et al*., 2023; Wang, Chandavuth, *et al*., 2023). Besides, most of the empirical research has adopted the EKC hypothesis (Shahbaz and Sinha, 2019; Pata and Kartal, 2023). Another wave of empirical papers has focused on the type of economic activities, such as disaggregated infrastructure investments (Erdogan *et al*., 2020), industry share in GDP (Pata, 2018; Apergis and Öztürk, 2015), agricultural value added (Agboola and Bekun, 2019; Pata, 2021), tourism (Okumus and Erdogan, 2021), disaggregated transport demand (Erdogan *et al*., 2022) and economic growth (Ahmad, Ahmed, Khan, *et al*., 2023; Ahmad, Ahmed, Riaz, *et al*., 2023; Dai *et al*., 2023) in terms of their effect on environmental performance.

Moreover, recent investigations have been focusing on the effect of institutions that determine the general framework of interactions among economic agents through various factors, such as democracy, corruption, rule of law, accountability, PS, GPR and R&D efforts. Some of the prominent recent studies about the effects of PS, GPR and R&D on the environment are presented in Table 1 with a summarized approach.

Table 1: Literature on effect of PS, GPR and R&D on environmental degradation

Authors	Sample countries	Period	Methodology	Results
Panel A: PS				
Al-Mulali and Öztürk (2015)	MENA	1996–2012	FMOLS	PS (–)
Abid (2016)	25 Sub-Saharan African	1996–2010	GMM	PS (–)
Adebayo (2022)	Canada	1990–2018	ARDL	PS (–)
Bildirici (2022)	MENA and Sub-Saharan African	1996–2018	FMOLS, DOLS	Political governance (+)
Kartal *et al*. (2022)	Finland	1990/Q1–2019/Q4	NARDL	PS (–)
Kirikkaleli *et al*. (2022)	China	1990/Q1–2018/Q4	FMOLS, DOLS	PS (–)
Sohail *et al*. (2022)	Pakistan	1990–2019	ARDL, NARDL	Political instability (M)
Awosusi *et al*. (2023)	Turkey	1970–2018	NARDL	PS (–)
Ayhan *et al*. (2023)	G-7	1997–2021	QQ	PS (M)
Farooq *et al*. (2023)	BRICS	2000–2019	FMOLS, DOLS	PS (–)
Kartal, Kılıç Depren *et al*. (2023)	United Kingdom	1995/Q1–2018/Q4	NARDL	Political instability (M)
Kılıç Depren *et al*. (2023)	Iceland	1995/Q1–2019/Q4	NARDL	PS (–)
Simionescu *et al*. (2023)	11 CEE	2007–2021	DOLS, FMOLS, CCE	PS (+)
Panel B: GPR				
Anser, Syed, Apergis (2021)	BRICS	1985–2015	AMG	GPR (+)
Anser, Syed, Lean, *et al*. (2021)	Emerging economies	1995–2015	AMG, FMOLS, DOLS	GPR (–)
Zhao *et al*. (2021)	BRICS	1985–2019	NARDL	GPR (M)
Hashmi *et al*. (2022)	Global level	1970–2015	Bootstrap ARDL	GPR (–)
Ul Husnain *et al*. (2022)	E7	1990–2015	AMG	GPR (–)
Riti *et al*. (2022)	BRICS	1985–2020	Panel ARDL	GPR (M)
Syed *et al*. (2022)	BRICST	1990–2015	CCE, AMG	GPR (M)
Du & Wang (2023)	China	1995–2020	Quantile ARDL	GPR (+)
Li *et al*. (2023)	BRICS	2000/1–2021/1	CSARDL	GPR (–)
Nawaz *et al*. (2023)	Italy	1997–2019	ARDL, WC	GPR (–)
Pata & Ertuğrul (2023)	India	1988–2018	ARDL	GPR (*)
Sweidan (2023)	Selected 18	1992–2018	Two-way fixed Prais-Winsten regression	GPR (M)
Wang, Niu, *et al*. (2023)	China	1988–2021	QR	GPR (+)
Panel C: R&D				
Lee & Min (2015)	Japanese firms	2001–2010	Panel regression	Green R&D (–)
Liu & Lin (2019)	China	2000–2015	Spatial methods	R&D investments (–)
Bilgili *et al*. (2021)	13 developed	2003–2018	Panel QR	Energy R&D (M)
Chen *et al*. (2021)	China	2000–2016	FMOLS	R&D investments (–)
Jiang *et al*. (2022)	G7	1990–2020	CSARDL	Environmental R&D (–)
Baba Ali *et al* (2023)	EU	1996–2018	Panel QR	R&D expenditures (–)
Mushafiq & Prusak (2023)	EU	2000–2020	ARDL, NARDL	R&D expenditures (+)
Jin *et al*. (2023)	Germany	1974–2018	AARDL, DOLS	Energy R&D (M)
Pata, Kartal, Erdoğan (2023)	Germany	1974–2018	Fourier ADL	Energy R&D (M)

Note: +: positive effect; –: negative effect; M: mixed results; *: statistically insignificant effect.
Source: Authors’ own elaboration

As can be seen from Table 1, the apparent characteristics of the former literature are as follows. On the methodological aspect, firstly, a great part of the former studies has investigated the effects of PS, GPR and R&D on environmental performance on multi-country samples. Secondly, first-generation panel data methods have been used widely and the possibility of cross-sectional dependence has frequently emerged in estimations, which may lead authors to estimate and infer in a biased way (Acaravci and Erdogan, 2017). Thirdly, the studies adopting time-series analyses have widely utilized linear estimation methods.

On the policy aspects, firstly, it can be inferred that exploring the environmental effects of PS, GPR and R&D is an immature research topic compared to studies investigating the role of traditional variables on environmental performance. Secondly, there is no consensus among studies on how PS, GPR and R&D drive environmental pollution. Thirdly, a few studies have investigated the environmental effects of PS by using different proxy indicators (*e.g.*, political governance, political instability, PRI). Fourthly, there has not been a consensus on which R&D indicators should be used in the estimation of the environmental effects of R&D investments. So, the studies have used either total R&D investments or energy-related R&D investments.

Unlike the previous studies, the present research seeks to answer how PS, GPR and R&D investments affect environmental pollution in leading European countries by employing monthly data and adopting several quantile estimation methods. Employing monthly data allows researchers to consider detailed characteristics of the data while utilizing quantile methods provides an opportunity to obtain information on how regressors affect environmental performance in different quantiles and consider possible non-linearities in the data. Thus, the study makes unique contributions to the literature on the mentioned aspects.

3. Methods

This study provides a comprehensive overview of the variables used, the data sources and the units of measurement as well as detailed explanations of these variables. Furthermore, it outlines the methodological steps employed throughout the research process.

3.1 Data

The availability of data for the variables taken into consideration determines the sample period, which extends from 1985 to 2020. As the dependent variables, this study uses the LCF, which is the most comprehensive ES indicator, and the GFN (2023) is the data source for the LCF. Also, the PRS Group (2023) provided the data for the PRI, and the GPR data are sourced from Iacoviello (2023). Moreover, data for the NRD and RRD are gathered from the IEA (2023b). Detailed information about the variables can be found in Table 2.

Table 2: Variables

Variable	Explanation	Unit	Source
LCF	Load capacity factor*	GHA	GFN (2023)
PRI	Country political risk index	BPS	PRS Group (2023)
GPR	Country geopolitical risk index	BPS	Iacoviello (2023)
NRD	Nuclear energy R&D investments	Million USD	IEA (2023b)
RRD	Renewable energy R&D investments	Million USD	IEA (2023b)

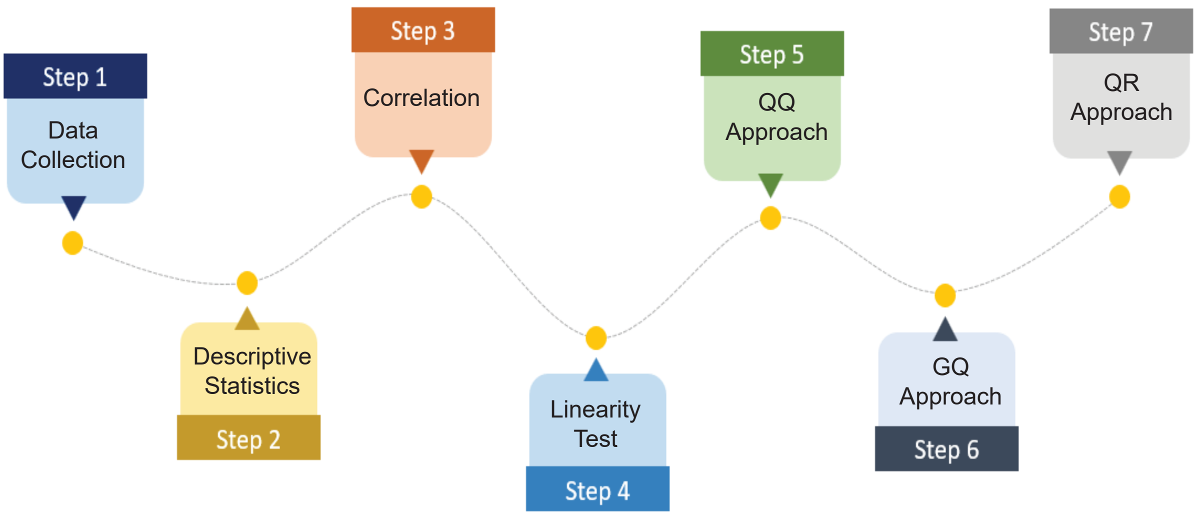
Note: * denotes the dependent variable.
Source: Authors' own elaboration

Taking into account that the PRI and GPR data are published monthly, while the data for the LCF, NRD and RRD are issued yearly, this study applies the quadratic-sum method, as suggested by Balcılar *et al*. (2016), Ali *et al*. (2021) and Shahbaz *et al*. (2023), to convert the LCF, NRD and RRD data into monthly frequencies. The entire dataset undergoes a logarithmic difference transformation. The study utilizes monthly data spanning from 1985/1 to 2020/12 for three leading European countries (namely, FRA, SWE and GBR).

3.2. Empirical methodology

Figure 1 illustrates the framework utilized in the empirical analysis. The methodology proposed in this study consists of seven essential steps, all designed to further the exploration of the research objectives and enable the investigation of causal relationships between variables.

Figure 1: Empirical methodology process



Source: Authors' own elaboration

The methodology begins with the crucial initial phase of data collection, encompassing the compilation of pertinent data from four distinct sources.

Subsequently, the second and third steps involve conducting a preliminary analysis, which serves as a foundational step in comprehending the data and variables under scrutiny. This analysis entails the calculation of descriptive statistics, providing a concise summary of key characteristics and distributional properties of the variables. Furthermore, a correlation analysis is executed to explore relationships among the variables. Additionally, a normality test is conducted to evaluate the assumption of normal distribution, which holds significance for numerous statistical analyses.

As the methodology progresses, the fourth step focuses on testing fundamental assumptions underlying the dataset, thereby ensuring the validity of subsequent analyses. An assessment of linearity (BDS test) is conducted to evaluate the non-linear characteristics of the variables, thus determining the suitability of non-linear models for subsequent analyses (Broock *et al*., 1996).

In the fifth and sixth steps, QQ and GQ approaches are conducted to measure the quantile-based relationship and causality, respectively. In contrast to conventional approaches that primarily concentrate on mean-based relationships, the QQ approach offers a deeper exploration of the connections at distinct quantiles or specific points within the distribution (Sim & Zhou, 2015). Through an examination of the associations specific to each quantile, this approach yields a more comprehensive comprehension of how variables interrelate across diverse segments of the distribution. Furthermore, the study utilizes the GQ approach to investigate quantile-based causality. Unlike traditional causality measures such as correlation or regression that primarily focus on mean effects, the GQ approach expands the analysis to encompass causal relationships at different quantiles of the distribution (Troster, 2018).

Lastly, the study incorporates the QR method to conduct for robustness. The inclusion of the QR analysis serves as an additional verification measure to ensure the consistency of the findings obtained through the QQ approach (Koenker, 2005).

4. Results

The findings begin by undertaking the calculation of preliminary statistics, which involves computing key summary measures and descriptive statistics to gain initial insights into the data. Additionally, correlations between variables are examined to assess the strength and direction of their relationships. This correlation analysis aids in identifying potential associations and dependencies among the variables under investigation. Furthermore, a test of linearity is conducted to evaluate the non-linear characteristics of the variables, assessing the appropriateness of non-linear models for subsequent analyses.

The study employs advanced quantitative methods to explore the data further. The QQ approach investigates quantile-specific relationships, providing a comprehensive understanding of variable associations across different quantiles. The GQ approach explores quantile-based causality relationships. Also, the study includes the QR approach as a robustness check, evaluating relationships in various quantiles. These methods enhance the analysis and ensure reliable findings.

4.1. Preliminary statistics

Table 3 provides an overview of the measures of central tendency and variation statistics, accompanied by the outcomes of the normality test.

Table 3: Descriptive statistics

Country	Variable	Mean	Min.	Max.	Std. dev.	Jarque–Bera	Prob.
FRA	LCF	0.04	0.04	0.05	0.00	79.24	0.0000
	PRI	77.09	67.50	85.00	3.67	30.88	0.0000
	GPR	0.52	0.14	2.80	0.31	4,046.61	0.0000
	NRD	63.11	41.77	95.59	8.52	33.03	0.0000
	RRD	9.09	0.26	25.14	8.93	54.56	0.0000
SWE	LCF	0.14	0.10	0.17	0.01	8.80	0.0123
	PRI	86.74	78.00	93.50	3.29	36.76	0.0000
	GPR	0.04	0.00	0.28	0.03	2,391.97	0.0000
	NRD	0.81	0.03	2.03	0.61	51.81	0.0000
	RRD	3.03	0.80	7.40	1.51	45.20	0.0000
GBR	LCF	0.02	0.02	0.02	0.00	50.99	0.0000
	PRI	82.04	73.00	92.50	4.20	19.72	0.0001
	GPR	0.93	0.23	5.99	0.61	16,594.11	0.0000
	NRD	14.23	2.38	68.20	14.54	174.99	0.0000
	RRD	6.09	0.55	23.42	5.21	98.68	0.0000

Source: Authors' own calculations

In FRA, the LCF variable exhibits a relatively stable pattern, with a mean of 0.04 and a small standard deviation of 0.01. The PRI variable stands out with a higher mean of 77.09, suggesting a comparatively lower level. The GPR variable shows moderate variability, as indicated by a mean of 0.52 and a standard deviation of 0.31. The NRD variable displays a wide range of values, with a mean of 63.11 and a standard deviation of 8.52. Similarly, the RRD variable demonstrates considerable variability, with a mean of 9.09 and a standard deviation of 8.93.

Moving to SWE, the LCF variable shows a higher mean value of 0.14, indicating a relatively higher level compared to FRA. The PRI variable stands out with the highest mean value among the three countries, indicating a relatively higher level. On the other hand, the GPR variable exhibits a low mean of 0.04, suggesting a lower level compared to FRA and GBR.

The LCF variable for GBR has the lowest mean value of 0.02 among the three countries, indicating a relatively lower level. The PRI variable exhibits a mean of 82.04, suggesting a moderate level. The GPR variable shows high variability, with a mean of 0.93 and a relatively large standard deviation of 0.61. The NRD variable demonstrates a wide range of values, with a mean of 14.23 and a standard deviation of 14.54. Moreover, the Jarque–Bera test statistics reveal that the variables examined in each country do not satisfy the underlying assumption of normality.

In Table 4, the correlation matrix provides insights into the relationships between variables across the different countries.

Table 4: Correlation matrix

Country		LCF	PRI	GPR	NRD	RRD
FRA	LCF	1.00				
	PRI	0.05	1.00			
	GPR	−0.01	−0.04	1.00		
	NRD	0.50	0.02	−0.03	1.00	
	RRD	0.31	0.07	−0.01	0.47	1.00
SWE	LCF	1.00				
	PRI	0.01	1.00			
	GPR	−0.04	−0.06	1.00		
	NRD	0.08	−0.02	0.04	1.00	
	RRD	0.43	0.05	0.03	0.29	1.00
GBR	LCF	1.00				
	PRI	0.01	1.00			
	GPR	−0.05	−0.07	1.00		
	NRD	0.24	0.03	−0.01	1.00	
	RRD	−0.20	−0.06	0.03	0.27	1.00

Source: Authors' own calculations

In FRA, the variables LCF and PRI exhibit a weak positive correlation (*r* = 0.05), while LCF and NRD show a moderate positive correlation (*r* = 0.50). Additionally, LCF and RRD demonstrate a moderate positive correlation (*r* = 0.31). However, the variables GPR and all other variables have negligible correlations. The correlations between variables considered in this study are generally weak, with the highest correlation observed between LCF and RRD (*r* = 0.43) in SWE. Similarly, the correlations are predominantly weak, with a negative correlation observed between RRD and LCF (*r* = −0.20) in GBR. Overall, the correlation matrix highlights the varying degrees of association between the variables in different countries, indicating the presence of both positive and negative relationships.

Table 5 presents the linearity test results.

Table 5: Linearity test results

Country	Variables	Dimensions					Results
		2	3	4	5	6	
FRA	LCF	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	PRI	0.0088	0.0031	0.0008	0.0014	0.0023	N-L
	GPR	0.0015	0.0000	0.0000	0.0000	0.0000	N-L
	NRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	RRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
SWE	LCF	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	PRI	0.1858	0.620	0.0137	0.0009	0.0000	N-L
	GPR	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	NRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	RRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
GBR	LCF	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	PRI	0.0002	0.0000	0.0000	0.0000	0.0000	N-L
	GPR	0.0030	0.0000	0.0000	0.0000	0.0000	N-L
	NRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L
	RRD	0.0000	0.0000	0.0000	0.0000	0.0000	N-L

Note: Values indicate *p*-values. N-L implies non-linear.

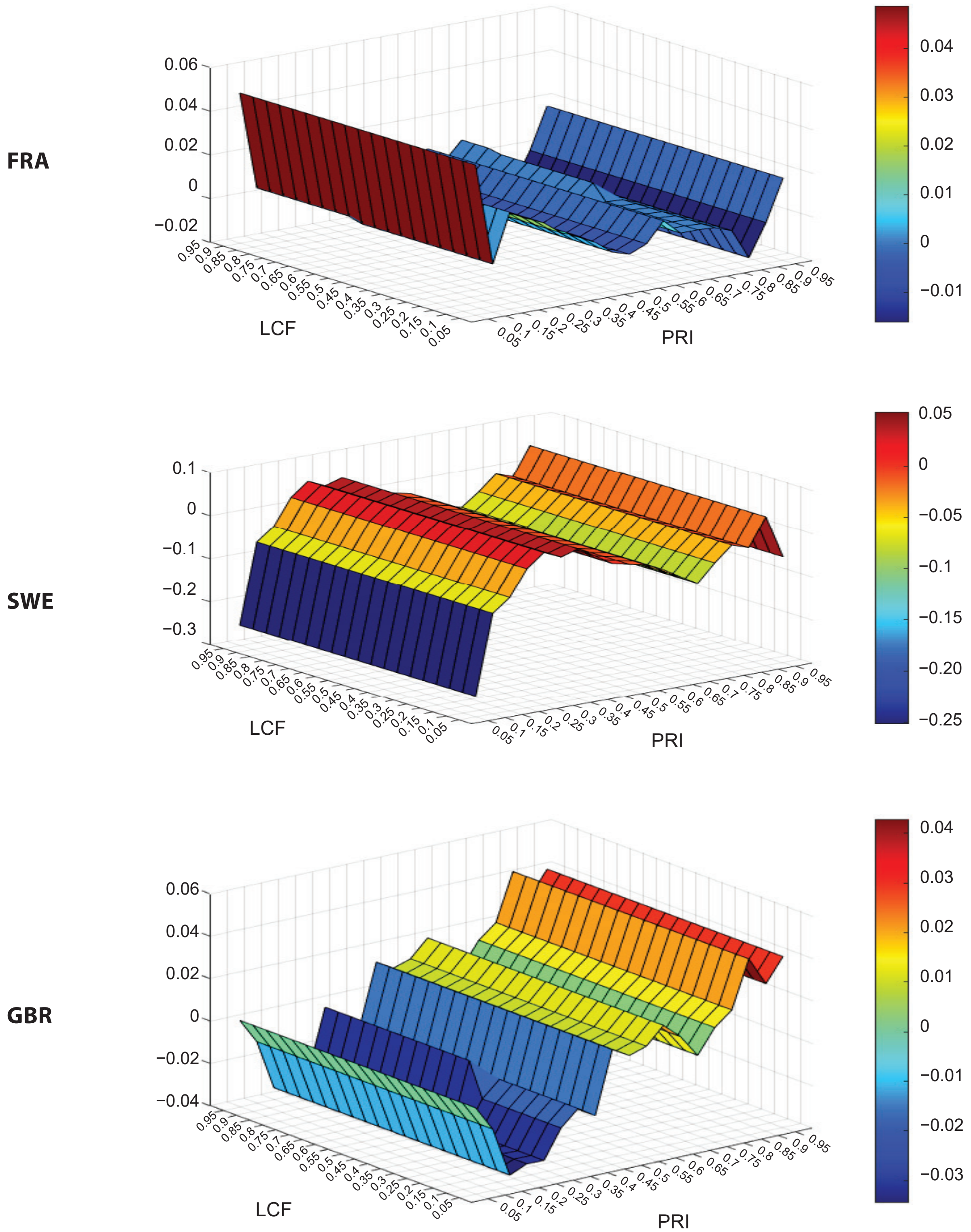
Source: Authors' own calculations

Table 5 shows the results of the linearity tests conducted for each variable in different countries. The dimensions of linearity, ranging from 2 to 6, are assessed, and the results are reported. In FRA, all the variables (LCF, PRI, GPR, NRD, RRD) exhibit a lack of linearity, as indicated by the N-L designation across all the dimensions tested. Similarly, in SWE and GBR, all the variables show a lack of linearity across the dimensions tested, with the results consistently indicating N-L with *p*-values of 0.0000. Notably, for SWE, there is a slight deviation in the linearity results for PRI in dimension 2, with a *p*-value of 0.1858, but it remains statistically significant. Overall, the linearity results suggest that the relationships between the variables in each country are non-linear, emphasizing the importance of considering non-linear modelling techniques in subsequent analyses.

4.2. QQ results

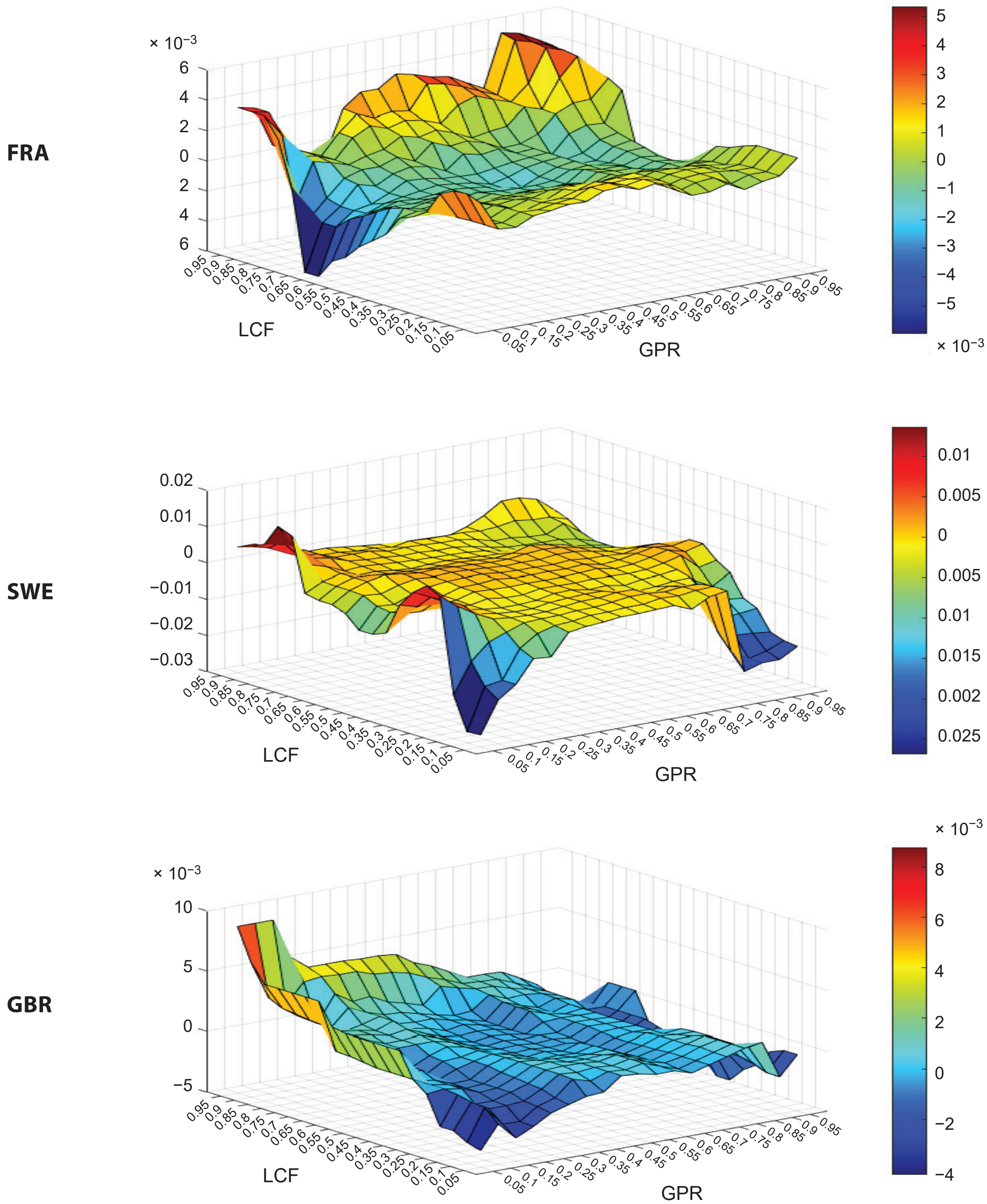
The QQ approach is a comprehensive methodology that investigates quantile-based effects, offering insights into how variations in one variable affect the distribution of another across various quantiles. The QQ approach is performed and the findings for each country are displayed in Figure 2.

Figure 2: PRI effect on LCF



Source: Authors' own elaboration

Figure 3: GPR effect on LCF



Source: Authors' own elaboration

It can be seen that the effect of PRI on LCF for FRA is relatively weak for each quantile as indicated from −0.01 to 0.04. However, this effect is relatively strong and negative in SWE, especially in the lower quantiles of PRI. Also, this effect varies from −0.05 to 0.05 in the quantiles higher than 0.20 of PRI. In GBR, the effect of PRI on LCF has different characteristics than in FRA and SWE. Moreover, the sign turns from negative to positive in the area where the quantile of PRI is higher than 0.50. The relationship between PRI and LCF demonstrates an interesting pattern. With the upper quantiles of 0.5, as the quantiles of PRI increase, a negative effect is found on LCF. However, in the area where PRI quantiles exceed 0.5, the effect on LCF increases with the lower to upper quantiles of PRI.

Figure 3 illustrates the relationship between GPR and LCF in each country.

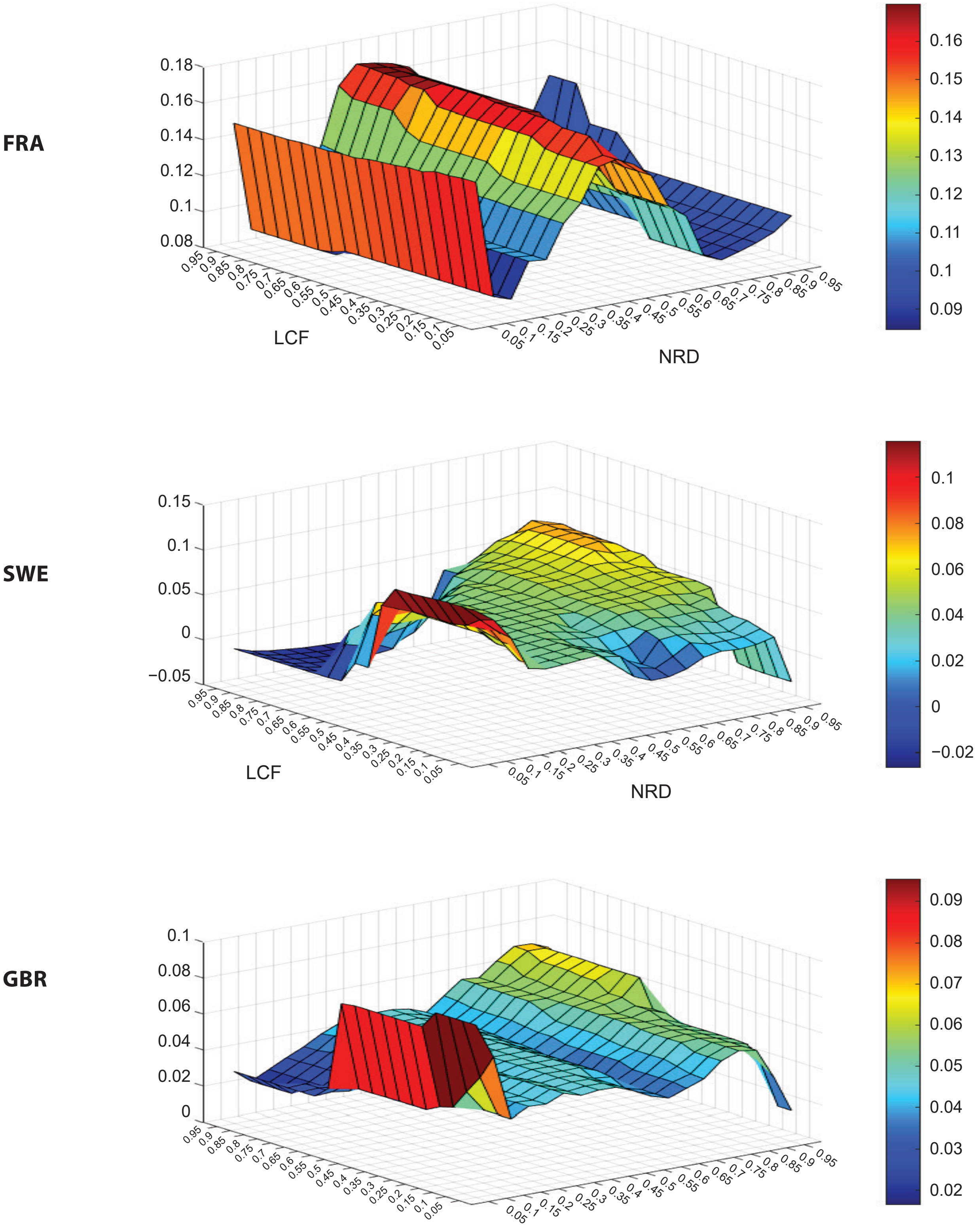
The effect of GPR on LCF exhibits a more complicated structure within each country. In FRA, a relatively low effect is observed in the area that combines the middle quantiles of the LCF (0.40–0.70) with the lower quantiles of the GPR (0.05–0.20). Conversely, the effect of GPR on LCF is relatively high in the area that combines the lower quantiles (0.20) with the upper quantiles of the LCF (0.80). For SWE, the effect of GPR on LCF remains close to 0 across most areas, except at the points along the diagonal of the figure. In fact, the effect becomes relatively significant at these specific points. The results indicate that the effect of GPR on LCF in GBR is predominantly negative across various quantile combinations. However, there is one exceptional area, where the quantiles of LCF exceed 0.75 and the quantiles of GPR fall below 0.35. In this particular region, the effect is noticeably positive.

Figure 4 depicts the relationship between NRD and LCF in each country.

In the case of FRA, a significant relationship is observed in the NRD quantiles ranging from 0.30 to 0.55. However, the effect is characterized as positive yet comparatively weak in other areas. In contrast to FRA, the relationship between NRD and LCF in SWE and GBR exhibits distinct characteristics. Specifically, within the range where the LCF quantiles exceed 0.50 and NRD quantiles fall below 0.50, a weaker relationship is observed regarding the influence of NRD on LCF in both countries. Conversely, in the region where LCF quantiles are below 0.50 and NRD quantiles are below 0.25, the effect of NRD on LCF is noticeably strong. Across other areas, most of the effect ranges from 0.02 to 0.06.

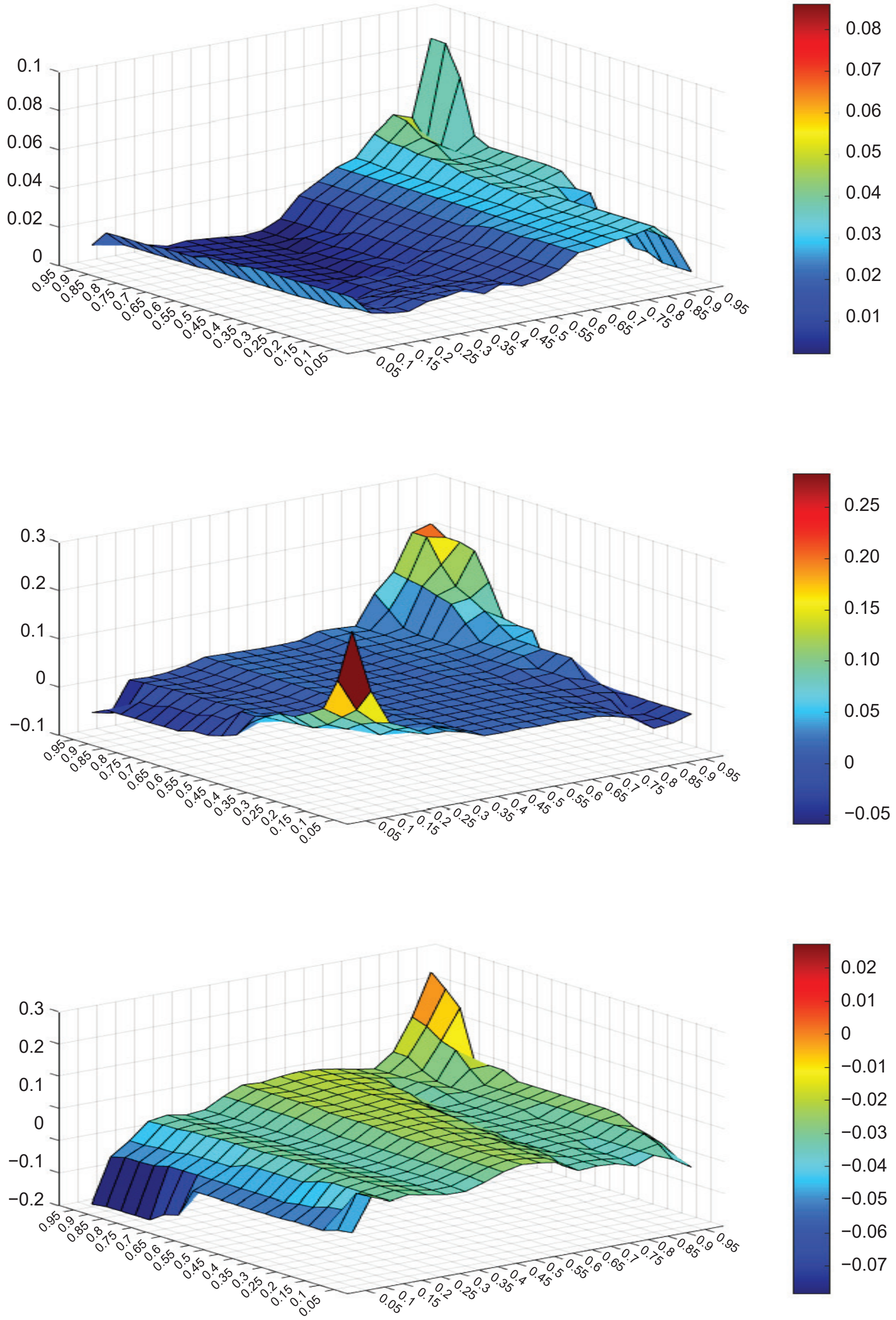
Figure 5 demonstrates the relationship between RRD and LCF in each country.

Figure 4: NRD effect on LCF



Source: Authors' own elaboration

Figure 5: RRD effect on LCF



Source: Authors' own elaboration

The influence of RRD on LCF falls within the range from −0.03 to 0.03 for nearly all the combinations of quantiles in the three countries, except in certain instances characterized by diagonal combinations of quantiles. These exceptional areas can be identified as follows: Firstly, they correspond to the combinations of the highest quantiles of both RRD and LCF in FRA. Secondly, in SWE, they encompass the combinations of the highest quantiles of both RRD and LCF, as well as the combinations of the lowest quantiles of both RRD and LCF. Lastly, they involve the combinations of the highest quantiles of both RRD and LCF in GBR, as well as the region formed by the highest quantiles of LCF and the lowest quantiles of RRD.

4.3 GQ results

The GQ approach is applied to uncover the causal relationships between variables in each country, and the findings are reported in Table 6. It displays the path of causality and the corresponding tau values for various levels (*i.e.*, quantiles) ranging from 0.05 to 0.95.

Table 6: GQ results

Country	Causality	Tau																		
		0.05	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**
FRA	PRI → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.43	0.51	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	GPR → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.41	0.54	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.43	0.51	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	RRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.43	0.51	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWE	PRI → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	GPR → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	RRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GBR	PRI → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.50	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	GPR → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.51	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.50	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	RRD → LCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.50	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Numbers represent *p*-values.

Source: Authors' own claculations

In FRA, the *p*-values associated with the causality paths PRI → LCF, GPR → LCF, NRD → LCF and RRD → LCF are all 0.00 for all the significance levels tested, except the 0.45 and 0.50 quantiles. These *p*-values indicate strong evidence to reject the null hypothesis, which suggests a significant causal relationship between the variables. In both SWE and GBR, the *p*-values for all the causal paths (PRI → LCF, GPR → LCF, NRD → LCF, and RRD → LCF) in almost all quantiles except 0.50 are consistently 0.00 for all the significance levels. This implies strong statistical evidence to support the presence of a significant causal relationship between the variables except for the middle quantile. It is important to note that the p-values represent the likelihood of observing the test results under the assumption of no causal relationship. Therefore, the extremely low *p*-values obtained in this analysis suggest strong evidence in favour of the alternative hypothesis, implying the presence of a causal relationship. Overall, the GQ results provide substantial statistical support for the presence of significant causal relationships between the variables in FRA, SWE and GBR.

4.4 Robustness test by QR approach

Table 7 demonstrates the results of the robustness test, specifically examining the correlation percentages between the QQ and QR approaches for different variables in each country.

Table 7: Comparison of QQ and QR approaches

Country	Variable	Correlation (%)
FRA	PRI & LCF	99.77
	GPR & LCF	70.39
	NRD & LCF	99.26
	GPR & LCF	98.28
SWE	PRI & LCF	99.99
	GPR & LCF	91.61
	NRD & LCF	38.30
	GPR & LCF	16.82
GBR	PRI & LCF	99.83
	GPR & LCF	90.72
	NRD & LCF	86.08
	GPR & LCF	97.04

Source: Authors' own calculations

In both FRA and GBR, the observed correlations between variables exceed the threshold of 70%, suggesting a robust and significant positive association. In SWE, the correlations between PRI and LCF as well as GPR and LCF exhibit remarkable strength, exceeding the 90% mark, thus underscoring a highly pronounced positive correlation. Only the relationship between NRD versus LCF as well as GPR versus LCF in SWE is weak. These correlation percentages demonstrate the strength and direction of the relationships between the variables under investigation. The high correlation values observed in several cases indicate a strong positive relationship, whereas lower values indicate weaker positive relationships.

Bearing these results in mind, the analysis presents a high level of compatibility between the findings derived from two distinct approaches. This is due, in part, to the fact that the results obtained through both approaches align closely, indicating consistency and coherence in the observed outcomes. This convergence of findings lends additional credibility to the robustness and reliability of the research outcomes.

5. Conclusion and Policy Options

5.1 Conclusion

ES has been attributed importance for countries, societies and people. Accordingly, policymakers and scholars have been dealing with ES much more frequently in recent times. Also, the tension between Russia and Ukraine has resulted in increasing geopolitical risk and a recent energy crisis that hit European countries severely. Thus, European countries have had to make a hard decision for the trade-off between ensuring ES, supplying necessary energy and sustaining economic growth. Some European countries have postponed the phase-out of nuclear power and extended the lifetime of current nuclear power plants, whereas some others have relied more on fossil fuel sources. However, such decisions are of a short-term nature. Instead of these, European countries should focus on long-term solutions to get rid of the trade-off between the environment, energy and economy.

By considering the critical energy decisions that EU countries have faced, the study examines ES by including the effect of PS, GPR and R&D investments in nuclear and renewable energy. In this context, three leading European countries have been investigated for the period between 1985/1 and 2020/12 by applying novel quantile models. In summary, the study revealed that (i) increasing PS stimulates the ES in Sweden and the United Kingdom; (ii) increasing GPR develops the ES in France; (iii) R&D investments increase the ES in all the countries; (iv) there are generally causal effects from the explanatory variables to the ES except some quantiles (0.45–0.50) in all the countries; (v) the power effects of the variables differentiate according to countries, quantiles and variables; (vi) the alternative approach validates the robustness.

The results of the study are fundamentally consistent with the current studies, for instance, Awosusi *et al*. (2023), Farooq *et al*. (2023) and Kılıç Depren *et al*. (2023) for the developing effect of PRI on ES; Ul Husnain *et al*. (2022), Li *et al*. (2023) and Nawaz *et al*. (2023) for the stimulating effect of GPR on ES; and Chen *et al*. (2021), Chen *et al*. (2021) and Baba Ali *et al*. (2023) for the increasing effect of RD on ES.

The results gathered in the study can be generalized for such countries that are similar to France, the United Kingdom and Sweden. In other words, this study presents generalizable results for highly politically stable countries that have also faced high geopolitical risk and have a significant amount of R&D investments in nuclear and renewable energy. Furthermore, the study provides further findings by enriching the current literature by presenting novel outcomes.

5.2 Policy options

By following a comprehensive approach and applying novel quantile models, the study reveals that increasing political stability stimulates ES in Sweden and the United Kingdom in higher quantiles. Also, an increase in geopolitical risk develops ES in France. Besides, both nuclear and renewable R&D investments have an increasing effect on ES in all the countries. Moreover, there is a causal effect from the explanatory variables to ES except for some middle quantiles (*e.g.*, 0.45–0.50) in all the countries. Furthermore, the results demonstrate that the power effects of the variables differentiate according to variables, quantiles and countries. Accordingly, various policy options are discussed.

Firstly, countries should consider the effect of political stability on the environment. To recall, political stability has an increasing effect on ES in both Sweden and the United Kingdom, whereas it has a curbing effect in France. So, it is clear that political stability works in a better way in Sweden and the United Kingdom, whereas France cannot benefit from political stability for ensuring ES. Based on this determination, it can be proposed that Sweden and the United Kingdom should continue to sustain their political stability (because it is beneficial for the environment), and France should work on transforming its decision-making process by considering the negative effects of political stability on the environment to benefit from political stability. In this context, France can work on sub-components of political stability (*e.g.*, investment profile, internal and external conflict, corruption, bureaucracy quality) and transform its political stability into an eco-friendly structure.

Secondly, in contrast to the political stability case, geopolitical risk is beneficial for France, whereas it is harmful to ES in both Sweden and the United Kingdom. Accordingly, it can be suggested that Sweden and the United Kingdom should consider times of geopolitical tension to transform their economy and energy structure to an eco-friendly structure, especially focusing on a much cleaner energy transition. Thus, they can use times of geopolitical risk as leverage and benefit from it highly to sustain ES.

Thirdly, it is clear that nuclear and renewable R&D investments are highly beneficial for countries. Remember that they have a supporting effect on ES in all the countries. So, it can be easily proposed that the countries should continue to rely on R&D investments in both nuclear and renewable energy to curb environmental degradation and increase ES. While doing this, the countries should channel public R&D investments to appropriate and beneficial areas, such as energy efficiency. Thus, countries can have the opportunity to decrease energy dependency on foreign countries, improve ES and support economic growth.

Finally, it is seen from the empirical results that political stability, geopolitical risk and R&D investments in nuclear and renewable energy have a quantile-varying effect on ES according to countries. So, countries should think that there is a non-linear relationship between the variables and ES. Thus, while making any decision about the variables, countries should continuously follow up on the effects of ES and take necessary measures on time.

5.3 Future research

The study presents various insights for ES in leading European countries, but it still has some limitations. Since the study focuses on three countries, new studies can either include more European countries that experience energy crises or consider many more countries diversified over the world from different perspectives, such as consuming high amounts of energy and having low environmental quality, *etc*. Also, future studies can apply some other novel techniques to make detailed empirical examinations from various perspectives, such as time and frequency-varying. Moreover, new analyses can include much newer data as soon as they are published. Thus, the literature can be developed more.

Acknowledgement

Funding: There was no funding, either externally or internally, towards this study.
Conflicts of interest: The authors hereby declare that this article was not submitted nor published elsewhere.

References

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO_2 emissions: Evidence from sub-Saharan Africa economies. *Utilities Policy*, 41, 85–94, https://doi.org/10.1016/j.jup.2016.06.009

Acaravci, A., Erdogan, S. (2017). The Relationship between institutional structure and economic growth: A comparative analysis for selected countries. *International Journal of Economics and Financial Issues*, 7(6), 141.

Adebayo, T. S. (2022). Renewable energy consumption and environmental sustainability in Canada: Does political stability make a difference? *Environmental Science and Pollution Research*, 29(21), 61307–61322, https://doi.org/10.1007/s11356-022-20008-4

Adebayo, T. S., Ağa, M., Kartal, M. T. (2023). Analyzing the co-movement between CO_2 emissions and disaggregated nonrenewable and renewable energy consumption in BRICS: Evidence through the lens of wavelet coherence. *Environmental Science and Pollution Research*, 30(13), 38921–38938, https://doi.org/10.1007/s11356-022-24707-w

Ahmad, M., Ahmed, Z., Khan, S. A., et al. (2023). Towards environmental sustainability in E-7 countries: Assessing the roles of natural resources, economic growth, country risk, and energy transition. *Resources Policy*, 82, 103486, https://doi.org/10.1016/j.resourpol.2023.103486

Ahmad, M., Ahmed, Z., Riaz, M., et al. (2023). Modeling the linkage between climate-tech, energy transition, and CO_2 emissions: Do environmental regulations matter? *Gondwana Research*, https://doi.org/10.1016/j.gr.2023.04.003

Agboola, M. O., Bekun, F. V. (2019). Does agricultural value added induce environmental degradation? Empirical evidence from an agrarian country. *Environmental Science and Pollution Research*, 26(27), 27660–27676, https://doi.org/10.1007/s11356-019-05943-z

Akhayere, E., Kartal, M. T., Adebayo, T. S., et al. (2023). Role of energy consumption and trade openness towards environmental sustainability in Turkey. *Environmental Science and Pollution Research*, 30(8), 21156–21168, https://doi.org/10.1007/s11356-022-23639-9

Ali, U., Li, Y., Wang, J. J., et al. (2021). Dynamics of outward FDI and productivity spillovers in logistics services industry: Evidence from China. *Transportation Research Part E: Logistics and Transportation Review*, 148, 102258, https://doi.org/10.1016/j.tre.2021.102258

Al-Mulali, U., Öztürk, İ. (2015). The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. *Energy*, 84, 382–389, https://doi.org/10.1016/j.energy.2015.03.004

Anser, M. K., Syed, Q. R., Apergis, N. (2021). Does geopolitical risk escalate CO_2 emissions? Evidence from the BRICS countries. *Environmental Science and Pollution Research*, 28(35), 48011–48021, https://doi.org/10.1007/s11356-021-14032-z

Anser, M. K., Syed, Q. R., Lean, H. H., et al. (2021). Do economic policy uncertainty and geopolitical risk lead to environmental degradation? Evidence from emerging economies. *Sustainability*, 13(11), 5866, https://doi.org/10.3390/su13115866

Ambec, S., Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, 22(4), 45–62.

Apergis, N., Öztürk, İ. (2015). Testing environmental Kuznets curve hypothesis in Asian countries. *Ecological Indicators*, 52, 16–22, https://doi.org/10.1016/j.ecolind.2014.11.026

Awosusi, A. A., Akadiri, S. S., Olanrewaju, V. O., et al. (2023). The role of energy, political stability, and real income on achieving carbon neutrality: Asymmetric evidence. *Environmental Science and Pollution Research*, 30, 83302–83318, https://doi.org/10.1007/s11356-023-28136-1

Ayhan, F., Kartal, M. T., Kılıç Depren, S., et al. (2023). Asymmetric effect of economic policy uncertainty, political stability, energy consumption, and economic growth on CO_2 emissions: Evidence from G-7 countries. *Environmental Science and Pollution Research*, 30(16), 47422–47437, https://doi.org/10.1007/s11356-023-25665-7

Baba Ali, E., Radmehr, R., Shayanmehr, S., et al. (2023). The role of technology innovation, R&D, and quality governance in pollution mitigation for EU economies: Fresh evidence from method of moment quantile regression. *International Journal of Sustainable Development & World Ecology*, 30(3), 244–261, https://doi.org/10.1080/13504509.2022.2134939

Balcılar, M., Gupta, R., Pierdzioch, C. (2016). Does uncertainty move the gold price? New evidence from a nonparametric causality-in-quantiles test. *Resources Policy*, 49, 74–80, https://doi.org/10.1016/j.resourpol.2016.04.004

Bildirici, M. (2022). The impacts of governance on environmental pollution in some countries of Middle East and sub-Saharan Africa: The evidence from panel quantile regression and causality. *Environmental Science and Pollution Research*, 29(12), 17382–17393, https://doi.org/10.1007/s11356-021-15716-2

Bilgili, F., Nathaniel, S. P., Kuşkaya, S., et al. (2021). Environmental pollution and energy research and development: An Environmental Kuznets Curve model through quantile simulation approach. *Environmental Science and Pollution Research*, 28(38), 53712–53727, https://doi.org/10.1007/s11356-021-14506-0

Broock, W. A., Scheinkman, J. A., Dechert, W. D., et al. (1996). A test for independence based on the correlation dimension. *Econometric Reviews*, 15(3), 197–235, https://doi.org/10.1080/07474939608800353

Chen, L., Li, K., Chen, S., et al. (2021). Industrial activity, energy structure, and environmental pollution in China. *Energy Economics*, 104, 105633, https://doi.org/10.1016/j.eneco.2021.105633

Dai, J., Ahmed, Z., Pata, U. K., et al. (2023). Achieving SDG-13 in the era of conflicts: The roles of economic growth and government stability. *Evaluation Review*, https://doi.org/10.1177/0193841X231160626

Du, Y., Wang, W. (2023). The role of green financing, agriculture development, geopolitical risk, and natural resource on environmental pollution in China. *Resources Policy*, 82, 103440, https://doi.org/10.1016/j.resourpol.2023.103440

Erdogan, S., Adedoyin, F. F., Bekun, F. V., et al. (2020). Testing the transport-induced environmental Kuznets curve hypothesis: The role of air and railway transport. *Journal of Air Transport Management*, 89, 101935, https://doi.org/10.1016/j.jairtraman.2020.101935

Erdogan, S., Sarkodie, S. A., Adedoyin, F. F., et al. (2022). Analyzing transport demand and environmental degradation: The case of G-7 countries. *Environment, Development and Sustainability*, https://doi.org/10.1007/s10668-022-02729-1

Farooq, U., Gillani, S., Subhani, B. H., et al. (2023). Economic policy uncertainty and environmental degradation: The moderating role of political stability. *Environmental Science and Pollution Research*, 30(7), 18785–18797, https://doi.org/10.1007/s11356-022-23479-7

GFN (2023). *Country trends*. [Retrieved on 2023-06-16] Available at: https://data.footprintnetwork.org/?_ga=2.213014356.193975080.1607636931-1228825067.1607467693#/countryTrends?type=BCtot,EFCtot&cn=68

Grossman, G. M., Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement*. NBER Working Paper No. 3914, https://doi.org/10.3386/w3914

Hashmi, S. M., Bhowmik, R., Inglesi-Lotz, R., et al. (2022). Investigating the Environmental Kuznets Curve hypothesis amidst geopolitical risk: Global evidence using bootstrap ARDL approach. *Environmental Science and Pollution Research*, 29(16), 24049–24062, https://doi.org/10.1007/s11356-021-17488-1

He, J. (2006). Pollution haven hypothesis and environmental impacts of foreign direct investment: The case of industrial emission of sulfur dioxide (SO_2) in Chinese provinces. *Ecological Economics*, 60(1), 228–245.

Iacoviello, M. (2023). *Geopolitical Risk Index*. [Retrieved 2023-07-13] Available at: www.matteoiacoviello.com/gpr.htm

IEA (2023a). *Coal*. [Retrieved on 2023-06-13] Available at: https://www.iea.org/energy-system/fossil-fuels/coal

IEA (2023b). *Energy Technology RD&D Budgets*. [Retrieved on 2023-06-16] Available at: https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2

Jiang, S., Chishti, M. Z., Rjoub, H., et al. (2022). Environmental R&D and trade-adjusted carbon emissions: Evaluating the role of international trade. *Environmental Science and Pollution Research*, 29(42), 63155–63170, https://doi.org/10.1007/s11356-022-20003-9

Jin, X., Ahmed, Z., Pata, U. K., et al. (2023). Do investments in green energy, energy efficiency, and nuclear energy R&D improve the load capacity factor? An augmented ARDL approach. *Geoscience Frontiers*, 101646, https://doi.org/10.1016/j.gsf.2023.101646

Kartal, M. T. (2022). The role of consumption of energy, fossil sources, nuclear energy, and renewable energy on environmental degradation in top-five carbon producing countries. *Renewable Energy*, 184, 871–880, https://doi.org/10.1016/j.renene.2021.12.022

Kartal, M. T. (2023). Production-based disaggregated analysis of energy consumption and CO_2 emission nexus: Evidence from the USA by novel dynamic ARDL simulation approach. *Environmental Science and Pollution Research*, 30(3), 6864–6874, https://doi.org/10.1007/s11356-022-22714-5

Kartal, M. T., Kılıç Depren, S., Kirikkaleli, D., et al. (2022). Asymmetric and long-run impact of political stability on consumption-based carbon dioxide emissions in Finland: Evidence from nonlinear and Fourier-based approaches. *Journal of Environmental Management*, 321, 116043, https://doi.org/10.1016/j.jenvman.2022.116043

Kartal, M. T., Pata, U. K., Kılıç Depren, S., et al. (2023). Effects of possible changes in natural gas, nuclear, and coal energy consumption on CO_2 emissions: Evidence from France under Russia's gas supply cuts by dynamic ARDL simulations approach. *Applied Energy*, 339, 120983, https://doi.org/10.1016/j.apenergy.2023.120983

Kartal, M. T., Kılıç Depren, S., Kirikkaleli, D. (2023). Asymmetric effect of political stability on production-based CO_2 emissions in the UK: Long-run evidence from nonlinear ARDL and frequency domain causality. *Environmental Science and Pollution Research*, 30(12), 33886–33897, https://doi.org/10.1007/s11356-022-24550-z

Kirikkaleli, D., Shah, M. I., Adebayo, T. S., et al. (2022). Does political risk spur environmental issues in China? *Environmental Science and Pollution Research*, 29(41), 62637–62647, https://doi.org/10.1007/s11356-022-19951-z

Kılıç Depren, S., Kartal, M. T., Kirikkaleli, D., et al. (2023). Effect of political stability on environmental quality: Long-run and asymmetric evidence from Iceland by non-linear approaches. *Air Quality, Atmosphere & Health*, 16, 1407–1417, https://doi.org/10.1007/s11869-023-01351-y

Koenker, R. (2005). *Quantile Regression*. Cambridge: Cambridge University Press. ISBN 9780511754098.

Lee, K.-H., Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *Journal of Cleaner Production*, 108, 534–542, https://doi.org/10.1016/j.jclepro.2015.05.114

Li, H., Ali, M. S. E., Ayub, B., et al. (2023). Analysing the impact of geopolitical risk and economic policy uncertainty on the environmental sustainability: Evidence from BRICS countries. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-023-26553-w

Liu, K., Lin, B. (2019). Research on influencing factors of environmental pollution in China: A spatial econometric analysis. *Journal of Cleaner Production*, 206, 356–364, https://doi.org/10.1016/j.jclepro.2018.09.194

Mushafiq, M., Prusak, B. (2023). Nexus between stock markets, economic strength, R&D and environmental deterioration: New evidence from EU-27 using PNARDL approach. *Environmental Science and Pollution Research*, 30(12), 32965–32984, https://doi.org/10.1007/s11356-022-24458-8

Nawaz, M. Z., Guo, J., Nawaz, S., et al. (2023). Sustainable development goals perspective: Nexus between Christians' religious tourism, geopolitical risk, and CO_2 pollution in Italy. *Environmental Science and Pollution Research*, 30(22), 62341–62354, https://doi.org/10.1007/s11356-023-26463-x

Nurgazina, Z., Guo, Q., Ali, U., et al. (2022). Retesting the influences on CO_2 emissions in China: Evidence from dynamic ARDL approach. *Frontiers in Environmental Science*, 10, 868740, https://doi.org/10.3389/fenvs.2022.868740

Okumus, I., Erdogan, S. (2021). Analyzing the tourism development and ecological footprint nexus: Evidence from the countries with fastest-growing rate of tourism GDP. In: Balsalobre-Lorente, D., Driha, O. M., Shahbaz, M. *Strategies in Sustainable Tourism, Economic Growth and Clean Energy*, 141–154, https://doi.org/10.1007/978-3-030-59675-0_8

Palmer, K., Oates, W. E., Portney, P. R. (1995). Tightening environmental standards: The benefit-cost or the no-cost paradigm? *Journal of Economic Perspectives*, 9(4), 119–132, https://doi.org/10.1257/jep.9.4.119

Pata, U. K. (2018). The influence of coal and noncarbohydrate energy consumption on CO_2 emissions: revisiting the environmental Kuznets curve hypothesis for Turkey. *Energy*, 160, 1115–1123, https://doi.org/10.1016/j.energy.2018.07.095

Pata, U. K. (2021). Linking renewable energy, globalization, agriculture, CO_2 emissions and ecological footprint in BRIC countries: A sustainability perspective. *Renewable Energy*, 173, 197–208, https://doi.org/10.1016/j.renene.2021.03.125

Pata, U. K., Çağlar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: Evidence from augmented ARDL approach with a structural break. *Energy*, 216, 119220, https://doi.org/10.1016/j.energy.2020.119220

Pata, U. K., Ertuğrul, H. M. (2023). Do the Kyoto Protocol, geopolitical risks, human capital and natural resources affect the sustainability limit? A new environmental approach based on the LCC hypothesis. *Resources Policy*, 81, 103352, https://doi.org/10.1016/j.resourpol.2023.103352

Pata, U. K., Kartal, M. T. (2023). Impact of nuclear and renewable energy sources on environment quality: Testing the EKC and LCC hypotheses for South Korea. *Nuclear Engineering and Technology*, 55(2), 587–594, https://doi.org/10.1016/j.net.2022.10.027

Pata, U. K., Caglar, A. E., Kartal, M. T., et al. (2023). Evaluation of the role of clean energy technologies, human capital, urbanization, and income on the environmental quality in the United States. *Journal of Cleaner Production*, 402, 136802, https://doi.org/10.1016/j.jclepro.2023.136802

Pata, U. K., Erdoğan, S., Ozkan, O. (2023). Is reducing fossil fuel intensity important for environmental management and ensuring ecological efficiency in China? *Journal of Environmental Management*, 329, 117080, https://doi.org/10.1016/j.jenvman.2022.117080

Pata, U. K., Kartal, M. T., Erdoğan, S., et al. (2023). The role of renewable and nuclear energy R&D expenditures and income on environmental quality in Germany: Scrutinizing the EKC and LCC hypotheses with smooth structural changes. *Applied Energy*, 342, 121138, https://doi.org/10.1016/j.apenergy.2023.121138

PRS Group (2023). *Country Risk Data*. Mount Pleasant: PRS Group. Obtained by email on 16 June 2023.

Rehman, M. A., Fareed, Z., Salem, S., et al. (2021). Do diversified export, agriculture, and cleaner energy consumption induce atmospheric pollution in Asia? application of method of moments quantile regression. *Frontiers in Environmental Science*, 9, 781097, https://doi.org/10.3389/fenvs.2021.781097

Riti, J. S., Shu, Y., Riti, M. K. J. (2022). Geopolitical risk and environmental degradation in BRICS: Aggregation bias and policy inference. *Energy Policy*, 166, 113010, https://doi.org/10.1016/j.enpol.2022.113010

Shahbaz, M., Balcılar, M., Mahalik, M. K., et al. (2023). Is causality between globalization and energy consumption bidirectional or unidirectional in top and bottom globalized economies? *International Journal of Finance & Economics*, 28(2), 1939–1964, https://doi.org/10.1002/ijfe.2519

Shahbaz, M., Sinha, A. (2019). Environmental Kuznets curve for CO_2 emissions: A literature survey. *Journal of Economic Studies*, 46(1), 106–168, https://doi.org/10.1108/JES-09-2017-0249

Sim, N., Zhou, H. (2015). Oil prices, US stock return, and the dependence between their quantiles. *Journal of Banking & Finance*, 55, 1–8, https://doi.org/10.1016/j.jbankfin.2015.01.013

Simionescu, M., Radulescu, M., Balsalobre-Lorente, D., et al. (2023). Pollution, political instabilities and electricity price in the cee countries during the war time. *Journal of Environmental Management*, 343, 118206, https://doi.org/10.1016/j.jenvman.2023.118206

Sohail, M. T., Majeed, M. T., Shaikh, P. A., et al. (2022). Environmental costs of political instability in Pakistan: Policy options for clean energy consumption and environment. *Environmental Science and Pollution Research*, 29(17), 25184–25193, https://doi.org/10.1007/s11356-021-17646-5

Sweidan, O. D. (2023). The effect of geopolitical risk on environmental stress: Evidence from a panel analysis. *Environmental Science and Pollution Research*, 30(10), 25712–25727, https://doi.org/10.1007/s11356-022-23909-6

Syed, Q. R., Bhowmik, R., Adedoyin, F. F., et al. (2022). Do economic policy uncertainty and geopolitical risk surge CO_2 emissions? New insights from panel quantile regression approach. *Environmental Science and Pollution Research*, 29(19), 27845–27861, https://doi.org/10.1007/s11356-021-17707-9

Troster, V. (2018). Testing for Granger-causality in quantiles. *Econometric Reviews*, 37(8), 850–866, https://doi.org/10.1080/07474938.2016.1172400

Ul Husnain, M. I. U., Syed, Q. R., Bashir, A., et al. (2022). Do geopolitical risk and energy consumption contribute to environmental degradation? Evidence from E7 countries. *Environmental Science and Pollution Research*, 29(27), 41640–41652, https://doi.org/10.1007/s11356-021-17606-z

Ullah, S., Luo, R., Adebayo, T. S., et al. (2023). Paving the ways toward sustainable development: The asymmetric effect of economic complexity, renewable electricity, and foreign direct investment on the environmental sustainability in BRICS-T. *Environment, Development and Sustainability*, https://doi.org/10.1007/s10668-023-03085-4

Ulussever, T., Kılıç Depren, S., Kartal, M. T., et al. (2023). Estimation performance comparison of machine learning approaches and time series econometric models: Evidence from the effect of sector-based energy consumption on CO_2 emissions in the USA. *Environmental Science and Pollution Research*, 30(18), 52576–52592, https://doi.org/10.1007/s11356-023-26050-0

UN (2023). *Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all*. [Retrieved 2023-07-12] Available at: https://sdgs.un.org/goals/goal8

Wang, Z., Chandavuth, Y., Zhang, B., et al. (2023). Environmental degradation, renewable energy, and economic growth nexus: Assessing the role of financial and political risks? *Journal of Environmental Management*, 325, 116678, https://doi.org/10.1016/j.jenvman.2022.116678

Wang, W., Niu, Y., Gapich, A., et al. (2023). Natural resources extractions and carbon neutrality: The role of geopolitical risk. *Resources Policy*, 83, https://doi.org/10.1016/j.resourpol.2023.103577

Walley, N., Whitehead, B. (1994). *It's not easy being green*. [Retrieved 2023-07-13] Available at: https://hbr.org/1994/05/its-not-easy-being-green

Zhao, W., Zhong, R., Sohail, S, et al. (2021). Geopolitical risks, energy consumption, and CO_2 emissions in BRICS: An asymmetric analysis. *Environmental Science and Pollution Research*, 28(29), 39668–39679, https://doi.org/10.1007/s11356-021-13505-5