Politická ekonomie 2026

Volume 74 (3)
https://doi.org/10.18267/j.polek.1505
Open Access

VŠE / PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Impact of Geopolitical Risk and Economic Globalization on Turkey's Environmental Sustainability: Novel Quantile-on-quantile KRLS Method

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Abstract

This study investigates the impact of economic globalization, geopolitical risk and natural resources on carbon emissions (CO_2) in Turkey, while controlling for economic development and renewable energy. The study uses annual data from 1970 to 2019 and employs a quantile-on-quantile-based regularized least squares (QQKRLS) approach. The findings confirm a weak positive association between economic globalization and CO_2 emissions at low and high quantiles,

Citation: Awan, A., Jahanger, A., Emran Hossain, M., et al: Impact of Geopolitical Risk and Economic Globalization on Turkey's Environmental Sustainability: Novel Quantile-on-quantile KRLS Method. *Politická ekonomie,* 2026, 74(3), 490–514. https://doi.org/10.18267/j.polek.1505

while this association becomes strong at quantiles from 0.40 to 0.65 of both variables. The study also confirms an overall positive association between geopolitical risk and CO_2 emissions; however, this correlation becomes stronger at quantiles from 0.40 to 0.80 for both variables. In addition, the study also finds an overall inverse relationship between natural resource rents and CO_2 emissions, except for extremely low quantiles of both variables, where the correlation becomes positive. To strengthen the reliability of our results, the study utilizes a non-parametric bivariate quantile-on-quantile regression (QQR) method for a robustness check. Based on the findings, it is recommended that policymakers encourage green trade practices and promote climate change action initiatives by starting joint clean projects to make this world cleaner for current and future generations.

Keywords: Geopolitical risk, economic globalization, quantile-on-quantile kernel-based regularized least squares, natural resources, green energy

JEL Classification: Q56, F60, C21, P48, Q32

1. Introduction

Climate change has been recognized as the most challenging environmental issue since the mid-20th century (Saadaoui *et al*., 2024) with global warming being its primary cause (Kartal, 2022; Ulussever *et al*., 2023; Kartal *et al*., 2024). Global warming is caused by the release of greenhouse gases (GHGs), primarily carbon dioxide (CO_2), which is linked to the use of polluting energy sources (Nordhaus, 2019). In this regard, it is vital to analyse the factors that influence CO_2 emissions in emerging and advanced countries because each country has unique economic structures and political settings that affect its climate change policies. Thus, it is crucial to inquire "*What factors determine the levels of CO_2 emissions worldwide?*" The potential answers differ among countries and cannot be generalized. Thus, this research aims to address this query for Turkey by examining key country-specific factors, including geopolitical risk, economic globalization, renewable energy, natural resources and economic expansion.

Turkey, as a member of the Group of Twenty (G-20), has set a challenging goal of achieving net zero emissions by 2053. However, Turkey witnessed a substantial increase of about 180% in CO_2 emissions from 1990 to 2022. Turkey accounted for around 1.1% of the global CO_2 emissions in 2022, the energy sector being the primary contributor to the CO_2 emissions (TurkStat, 2021). To attain its ambitious objectives of net zero emissions and conserving the environment, the Turkish government ought to establish effective techniques for mitigating emissions. Conversely, geopolitical risks have an impact on energy markets, which in turn affect the environment through two pathways. Firstly, geopolitical risks catalyse en-

ergy conversion and lead to a decrease in oil prices, mostly driven by the substitution of fuels (Rasoulinezhad *et al*., 2020). Secondly, disputes exert a detrimental impact on investor outlook, further influencing crude oil prices (Ji *et al*., 2019). Accordingly, these channels have an impact on crude oil prices, which in turn affects the transition towards renewable energy and leads to varying amounts of CO_2 emissions. Thus, it is crucial to assess the environmental influence of Turkey's geopolitical risk in this study.

Economic globalization is an important phenomenon that involves the movement of commodities, capital, services and information among countries over large distances (Gygli *et al*., 2019). This has led to a rise in trade and investment activities, which in turn has had an impact on the environment and resulted in increased CO_2 emissions (Dumrul *et al*., 2023). Despite criticism, if economic globalization is guided by deliberate policies and interstate contacts and collaborations, it has the potential to facilitate green growth and enhance the environment by facilitating the transfer of technology (Li and Haneklaus, 2022). Nevertheless, the influence of economic globalization on Turkish pollution remains uncertain and requires additional research. Therefore, we incorporated this aspect into our model.

Sweidan and Elbargathi (2022) emphasized the crucial role of natural resources in the discourse on sustainability, as they can either facilitate or impede progress towards achieving environmental sustainability. It is crucial for Turkey to conduct a thorough assessment of its abundant mineral resources. This evaluation will enable policymakers to implement effective policies that can bring about changes in energy and environmental regulations (Gozgor *et al*., 2018).

Based on our current understanding, some studies have examined the ecological circumstances of Turkey (*e.g.*, Agboola *et al*., 2022; Dumrul *et al*., 2023; Saadaoui *et al*., 2024). Among them, Saadaoui *et al*. (2024) examined the environmental impacts of hydroelectric power, FDI and geopolitical risk. Dumrul *et al*. (2023) incorporated economic globalization and renewable energy into the existing body of environmental literature. Nevertheless, all the existing studies have relied on standard mean-based approaches. Therefore, a more extensive investigation is required to assess the environmental conditions in Turkey. Based on this research gap, we developed the following research questions:

i. Does geopolitical risk asymmetrically affect Turkey's carbon emissions?

ii. Does Turkey's economic globalization affect its carbon emissions asymmetrically?

iii. What are the asymmetric effects of natural resources, economic development and renewable energy on Turkey's carbon emissions?

This research contributes to the literature in three specific areas. Firstly, this study examines the impacts of geopolitical risk, economic globalization and clean energy on CO_2 levels in Turkey. The incorporation of these variables together is crucial since devising suitable and efficient strategies for safeguarding environmental quality necessitates the examination of all potential elements and quantifying their influence, which has been disregarded in prior research. Secondly, the study incorporates other significant variables, such as natural resources and economic expansion, which contribute to a more comprehensive analysis of the factors influencing carbon emissions. Thirdly, unlike previous research, which used customary econometrics instruments, this empirical study utilizes advanced and forward-thinking econometric methods, such as quantile-on-quantile kernel-based regularized least squares (QQKRLS) introduced by Adebayo *et al.* (2024a) and quantile-on-quantile regression (QQR). This study is the first empirical investigation conducted in Turkey to evaluate the environmental concern utilizing the novel QQKRLS approach. The QQKRLS can incorporate non-linear relationships between outcome and explanatory factors, allowing the detection of complex structures and patterns that traditional linear models may not be able to detect. The regularization strategy implemented in QQKRLS mitigates overfitting by redressing superfluous coefficients, improving the ability of the model to adapt to new data Adebayo *et al.* (2024b). This unique strategy enhances the understanding of the relationships being examined by providing more detailed insights across various quantiles and providing reliable findings for policy ramifications.

The remainder of the paper is organized as follows: Section 2 examines the pertinent literature, followed by the data description and methods in Section 3. Section 4 presents empirical findings to fulfil the study objectives, while Section 5 concludes the study with policy implications and recommendations for further research.

2. Literature Review

Some research has been undertaken on the relationship between globalization and environmental quality (Saint Akadiri *et al*., 2020). For example, Saint Akadiri *et al*. (2019) investigated the influence of globalization on Turkey's ability to achieve environmental sustainability goals. Their findings indicate that globalization has a negligible negative effect on CO_2 emissions in Turkey. Similarly, Saint Akadiri *et al*. (2020) discovered comparable findings, stating that there is no significant evidence to suggest that globalization has an impact on carbon emissions in Turkey. Adeleye *et al*. (2023) conducted a study on the influence of globalization on CO_2 emissions in South Asia. They employed quantile regression to analyse panel

data and discovered a U-shaped correlation between globalization and CO_2 emissions specifically at the 50^{th} and 75^{th} quantiles.

These results have highlighted the economic and environmental consequences that arise because of such vulnerabilities (Chen *et al*., 2024). Due to their substantial influence on economic activity and environmental performance, managing geopolitical risk has become one of the foremost concerns in many countries. Existing literature, however scarce, has examined the impacts of geopolitical risk on carbon emissions. Geopolitical risk can incentivize the shift towards cleaner and renewable energy sources (Rasoulinezhad *et al*., 2020), resulting in a reduction in carbon emissions. The aforementioned moderating impact has been documented by Anser *et al*. (2021) and Husnain *et al*. (2022). Additionally, geopolitical risk associated with conflict or political instability has the potential to impair energy infrastructure, including renewable sources. This disruption can lead to an increase in the disparity of CO_2 emissions (Shahbaz *et al*., 2023). In contrast, Chen *et al*. (2023a) discovered that geopolitical risks lead to an increase in carbon emissions in emerging economies.

Recent studies have argued that the impact of resource rents extends beyond the realm of economics, particularly in relation to economic growth and other indices of well-being. Lewis (2019) proposed the treadmill theory of production, which posits that the utilization of natural resources in the creation of economic output is directly accountable for environmental damage. Danish *et al*. (2023) analysed the rental prices of natural resources and the levels of CO_2 emissions in the USA between 1985 and 2020. They discovered that the presence of natural resources had a beneficial impact on the level of environmental contamination. Aladejare (2022) and Lei *et al*. (2022) have established that natural resource usage in Africa and Asia has made a substantial contribution to environmental pollution. Chen *et al*. (2023b) utilized the cross-sectional autoregressive distributed lag (CS-ARDL) method to demonstrate that natural resource rents resulted in environmental deformation in 27 European countries.

In the field of energy and environmental economics, it is widely recognized that the only way to overcome the problems caused by using fossil fuels is to increase and enhance the use of renewable energy (REN) sources. Recent research has examined the optimal level of consumption of renewable resources, specifically to reduce environmental harm using REN. Kartal *et al*. (2022) examined the influence of energy usage on environmental deterioration at both aggregated and disaggregated levels in the USA. The empirical results emphasize the importance of renewable energy utilization in enhancing environmental quality by reducing CO_2 emissions at both aggregated and disaggregated levels. Shan *et al*.

(2021) examined the impact of REN on CO_2 emissions and determined that REN was effective in enhancing environmental quality in Turkey. Onifade *et al*. (2021) investigated the impact of REN usage on CO_2 emissions. The findings indicated that the consumption of REN had a detrimental impact on the levels of CO_2 in both Turkey and the Caspian countries. Karaaslan and Çamkaya (2022) employed the ARDL methodology to examine the impact of REN on CO_2 emissions. Their findings indicate that REN consumption led to a reduction in CO_2 emissions. In a similar vein, Rahian and Tuspekova (2022) discovered that the utilization of REN has a diminishing effect on the release of CO_2 into the atmosphere. Similarly, Dam and Sarkodie (2023) stated that the usage of renewable energy had a positive effect on the quality of the environment. Multiple studies have been carried out on the subject of economics that highlight economic expansion as a crucial factor influencing the environment. Adebayo *et al*. (2023)demonstrated a positive correlation. In contrast, Ayhan *et al*. (2023) and Sreenu (2022) discovered a negative correlation between GDP and CO_2 emissions.

2.1 Research gap

Based on the analysed literature, the following deficiencies were identified: (i) There is a lack of literature on the relationship between economic globalization and CO_2 emissions in Turkey. (ii) There is a lack of research on the relationship between geopolitical risk and CO_2 emissions in the specific context of Turkey, despite Turkey's favourable geographical position which makes it a significant participant in geopolitical matters. (iii) Furthermore, the relationship between GDP and CO_2 emissions in the Turkish economy has not been definitively established. (iv) In contrast to prior studies that used linear methods, this research utilizes the unique non-linear quantile-on-quantile kernel-based regularized least squares (QQKRLS) and Quantile-on-quantile regression (QQR) approaches.

3. Methods

3.1 Data

This study investigates the impact of economic globalization (*EGI*), geopolitical risk (*GPRI*) and natural resources (*NRR*) on carbon emissions (CO_2) in Turkey, while controlling for economic development (*GDPPC*) and renewable energy (*REN*) using annual data from 1970 to 2019. The study employs annual data on CO_2, *GDPPC*, *REN* and *NRR* from the World Bank (WB, 2024), *EGI* from the KOF index (KOF, 2024) and *GPRI* from GPRH (GPRH, 2024). Table 1 shows the abbreviations, measurement units of variables and sources of the data. The annual frequency data were converted to quarterly frequency employing the quadratic

match-sum approach to mitigate the bias caused by the small number of observations. This method is extensively employed when converting data from lower to higher frequencies, as seen by its extensive use in previous studies (Balcilar *et al*., 2024). Additionally, the quarterly series of carbon emissions was converted into a natural logarithmic series to reduce heteroscedasticity and ensure that other variables are unaffected by this issue.

Table 1: Variables, sources, measurement units and abbreviations

Abbreviation	Variable	Measurement unit	Source
CO_2	Carbon emissions	Tonnes per capita	WB (2024)
EGI	economic globalization index	(0–100)	KOF (2024)
GPRI	Geopolitical risk	Geopolitical risk historical index	GPRH (2024)
NRR	Total natural resource rent	(% of GDP)	WB (2024)
GDPPC	Economic growth	GDP per capita (current US$)	WB (2024)
REN	Renewable energy	% of total final energy consumption	WB (2024)

Source: Authors' own elaboration

3.2 Methodology

Before investigating the relationship between economic globalization, economic growth, geopolitical risk, renewable energy, natural resources and carbon emissions, we initially performed a preliminary examination of the fundamental properties of the sample series. This included analysing descriptive statistics, performing a BDS test initially proposed by Brock *et al*. (1996) to detect nonlinear relationships in time series data and evaluating parameter stability using the Exp-F, Ave-F and Max-F tests developed by Miao *et al*. (2022) and Andrews (1993). Subsequently, we employed the quantile-on-quantile kernel-based regularised least squares (QQKRLS) method, which is a non-parametric approach.

Numerous studies demonstrate that economic factors exhibit a fascinating, non-linear pattern in response to the ongoing global energy crisis and the significant impact of the COVID-19 pandemic on the global economy. Considering nonlinearities between the suggested variables, we employed the QQKRLS method suggested by Adebayo *et al.* (2024b) to analyse the dynamic relationships among the variables. The KRLS is a machine-learning technique developed by Hainmueller and Hazlett (2014) which is utilized for regression analysis.

Meanwhile, the QQKRLS approach has predefined limitations and assumptions that ensure a reliable estimation. The QQKRLS regression is subject to specific limitations and assumptions, which include the following: (i) The QQKRLS regression implies that the observations are mutually independent. (ii) Similarly, the QQKRLS regression requires that the variability of the error terms remains consistent across all quantiles. Indeed, the selection of the kernel function in QQKRLS regression can significantly influence the performance of the model. Various kernel functions exhibit distinct smoothing characteristics, and selecting a suitable kernel is essential for attaining optimal outcomes. (iii) QQKRLS regression involves the selection of the bandwidth parameter, which defines the width of the kernel function. Quantile regression, especially QQKRLS regression, is typically more robust to outliers than mean regression.

The KRLS algorithm effectively uses the Gaussian kernel to determine and understand the ideal fitting function accurately, reducing the impact of misspecification bias. Using the KRLS methodology, the influence of an independent variable on each of the data points comprising a dependent variable is considered. Furthermore, the KRLS gives information about the size and statistical significance of the impact of the independent variable on the dependent variable by calculating the average pointwise marginal effects (Hainmueller and Hazlett, 2014; Ferwerda *et al*., 2017; Özkan *et al*., 2023). The KRLS method draws on Equation (1), which estimates the average pointwise marginal effect, to analyse the impact of the independent variable *X* on the dependent variable *Y*.

$$A_N\left[\frac{\widehat{\beta Y}}{\beta X_k}\right] = \frac{-2}{\sigma^2 N}\sum_k \sum_i j_i e^{\frac{\|X_i - X_k\|^2}{\sigma^2}}(X_i - X_k) \tag{1}$$

The equation indicates the average pointwise marginal effect of *X* on *Y*, where $A_N\left[\frac{\widehat{\beta Y}}{\beta X_k}\right]$ is the variable used to denote this effect. Furthermore, the variable *k* denotes a singular observation, while *N* denotes the size of the sample.

The nonlinearity of the impact can be perceived at all points in the dependent variable data. Statistical significance is indicated by a single value representing the average pointwise marginal effect. To overcome these challenges, Adebayo *et al*. (2024a) integrated the KRLS technique, originally developed by Hainmueller and Hazlett (2014), with the QQR method introduced by Sim and Zhou (2015), resulting in the formulation of QQKRLS. QQKRLS can consider all possible distributions of the explained and predictor variables and determine statistically significant non-linear effects across all distributions of the explained and predictor variables.

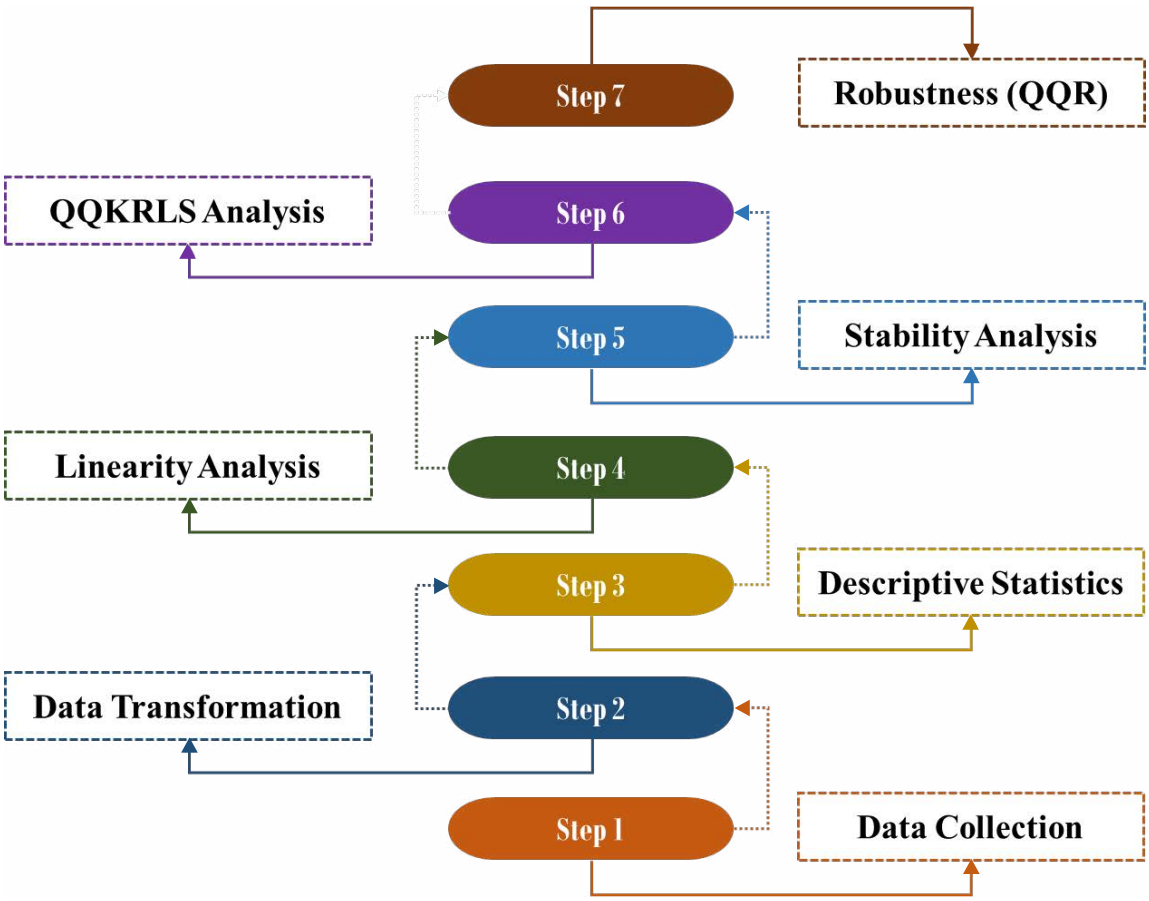
In addition, QQKRLS performs better than KRLS in other parameters, including its ability to capture subtle and non-linear associations between variables that traditional linear models such as KRLS may fail to detect. The regularisation method in QQKRLS is employed to mitigate overfitting, promote generalization to novel data and improve prediction accuracy. This is particularly beneficial for situations that involve non-linear associations or data distributions that are not normal. QQKRLS demonstrates versatility in handling several data types and domains, such as finance, economics and machine learning. Calculating different quantiles provides a comprehensive understanding of data variability and conditional quantiles, which KRLS may not offer.

The QQKRLS examines the effects of an independent variable *X* on a dependent variable *Y* using the modified average pointwise marginal effect equation.

$$A_N\left[\frac{\widehat{\beta QY_\tau}}{\beta QX_{\delta k}}\right] = \frac{-2}{\sigma^2 N}\sum_k \sum_i j_i e^{\frac{\|X_{\delta i}-X_{\delta k}\|^2}{\sigma^2}}(X_{\delta i} - X_{\delta k}) \tag{2}$$

Here, $A_N\left[\frac{\widehat{\beta QY_\tau}}{\beta QX_{\delta k}}\right]$ represents the average pointwise marginal effect of the δ-th conditional quantile of the independent variable *X* on the τ-th conditional quantile of the dependent variable *Y*. Furthermore, QY_τ and QX_δ represent the conditional quantile series of the dependent variable *Y* and the independent variable *X*, respectively, where QY_τ denotes the τ-th quantile and QX_δ denotes the δ-th quantile. Lastly, regarding the effectiveness of the recently established QQKLRS, we also employed the QQR method developed by Sim and Zhou (2015) for the robustness of the model. Figure 1 provides a concise overview of our analysis; the first step is data collection, followed by data transformation by taking the series. In the next step, linearity of the series is checked using the BDS test of Brock *et al*. (1996). We further assessed parameter stability using the Max-F, Exp-F and Ave-F tests developed by Andrews (1993). In the next step, we applied the QQKRLS approach and finally, we applied the QQR approach to check the robustness of the findings.

Figure 1: Step chart of empirical analysis



Source: Authors' own elaboration

4. Results and Discussion

4.1 Fundamental analysis

Prior to investigating the relationships between economic globalization, economic growth, geopolitical risk, renewable energy, natural resources and carbon emissions, we conducted an initial exploration of the fundamental properties of the sample series. Table 2 summarizes the findings of descriptive statistics. Notably, GDP per capita (*GDPPC*) exhibits the highest mean value (2.012425), followed by log-transformed CO_2 emissions (log CO_2; 1.247891) and economic globalization (*EGI*; 0.942668). Normality testing was performed using the Jarque–Bera test (Jarque and Bera, 1980). The results, presented in Table 2, indicate that all the sample variables reject the null hypothesis of normality. Based on this finding and in accordance

with Adebayo *et al*. (2024b) who recommend non-parametric methods for non-normal data, we employed the QQKRLS approach to analyse the relationships between the variables.

Table 2: Descriptive statistics of parameters

	EGI	*GDPPC*	*GPRI*	log CO_2	*NRR*	*REN*
Mean	0.942668	2.012425	0.045732	1.247891	0.138612	0.010156
Median	0.977054	2.000546	0.035275	1.257236	0.117882	0.000601
Maximum	1.015663	2.361934	0.146379	1.499122	0.340488	0.112202
Minimum	0.829191	1.526307	0.003445	0.907021	0.031521	−5.08E-05
Std. dev.	0.063252	0.237553	0.031809	0.161370	0.078549	0.024083
Skewness	−0.636268	−0.103451	1.150000	−0.255547	0.829957	2.838715
Kurtosis	1.823870	1.992347	3.626704	1.969903	2.878332	10.33146
Jarque–Bera	25.02191	8.818097	47.35635	11.01930	23.08430	716.5290
Probability	0.000004	0.012167	0.000000	0.004048	0.000010	0.000000

Source: Authors' own calculations

Having verified the non-normality of the sample series, we further enriched the analysis by employing the BDS test for nonlinearity, introduced by Brock *et al*. (1996). This approach aligns with recent studies by Adebayo *et al*. (2024a) and Jie *et al*. (2024), which highlighted the repercussions of nonlinearities in economic data. The rationale for examining non-linear properties stems from the significant disruptions caused by recent global events. The ongoing COVID-19 pandemic, geopolitical tensions (*e.g.*, China-US and Russia-Ukraine conflicts) and the global energy crisis have fundamentally reshaped the social and economic landscape. Traditional econometric approaches may yield inaccurate inferences in the presence of such nonlinearities. Our findings, presented in Table 3, reveal that the series deviates from the assumption of independent and identically distributed (IID) behaviour across all dimensions. This confirms the presence of nonlinear dynamics within the time series.

Table 3: BDS test results

	EGI	*GDPPC*	*GPRI*	log CO_2	*NRR*	*REN*
D[2]	59.5***	298	34.4***	404*	99.4***	16.4***
***p*-value**	0.000	0.110	0.000	0.000	0.000	0.000
D[3]	96.3***	584	46.2***	830*	172.2**	17.1***
***p*-value**	0.000	0.110	0.000	0.000	0.000	0.000
D[4]	166.8***	1,259	65.3***	1,888*	324.1**	18.1***
***p*-value**	0.000	0.110	0.000	0.000	0.000	0.000
D[5]	309.4***	2,966	99.2***	4714*	658.2**	19.5***
***p*-value**	0.000	0.110	0.000	0.000	0.000	0.000
D[6]	601.3***	7,506	157.1***	12,621*	1,439.1**	21.5***
***p*-value**	0.000	0.110	0.000	0.000	0.000	0.000

Note: ***, **, * denote statistical significance at the 1%, 5% and 10% levels, respectively. D means dimension.
Source: Authors' own calculations

Following Meo *et al*. (2024) and Shahbaz *et al*. (2024), we further assessed parameter stability using the Max-F, Exp-F and Ave-F tests developed by Andrews (1993) and Miao *et al*. (2022). Table 4 presents the results, which confirm the instability of the parameters within the series. In summary, the preliminary normality tests indicated non-normality, the BDS test confirmed the presence of nonlinearities and the parameter stability tests revealed instability. Collectively, these findings suggest that traditional parametric approaches for examining the relationship between the proposed variables may not be suitable. Therefore, considering the fundamental characteristics of the sample series, we opted for a non-parametric approach known as the QQKRLS method.

Table 4: Parameter stability test

	EGI	*GDPPC*	*GPRI*	log CO_2	*NRR*	*REN*
Max-f	1,107*	512*	317*	560*	380*	585*
***p*-value**	0.000	0.000	0.000	0.000	0.000	0.000
EXP-F	549*	252*	154*	276*	186*	287*
***p*-value**	0.000	0.000	0.000	0.000	0.000	0.000
AVE	417*	321*	73*	354*	147*	90*
***p*-value**	0.000	0.000	0.000	0.000	0.000	0.000

Note: * denotes statistical significance at the 1% level.
Source: Authors' own calculations

4.2 Quantile-on-quantile kernel-based regularized least squares (QQKRLS) results

The findings from the QQKRLS analysis are presented in Figure 2(a–e). Each panel in the figure includes a colour bar representing the strength of the correlation between the examined variables.

Figure 2a depicts the QQKRLS results for *EGI* and CO_2. The analysis reveals a weak positive correlation between the variables at low quantiles (0.05 to 0.35). This correlation strengthens at mid-range quantiles (0.40 to 0.65) but weakens again at extremely high quantiles (0.90 to 0.95). These findings align with the observations of Kalaycı and Hayaloğlu (2019), Khan *et al*. (2019) and Muhammad and Khan (2021), who have also reported a significant positive association between economic globalization and CO_2 emissions. This connection is likely driven by several key factors. Firstly, Turkey's rapid industrial growth, fuelled by its integration into the global market, often relies on traditional energy sources such as coal and natural gas. This dependence on fossil fuels directly translates into increased carbon emissions. Secondly, globalization can incentivize foreign companies to relocate production to countries such as Turkey, potentially bypassing stricter environmental regulations in their home countries. Finally, the transportation boom associated with increased global trade necessitates significant movement of goods by land, air and sea.

Figure 2b depicts the QQKRLS association between *GDPPC* and CO_2. The results reveal a strong positive correlation overall but with variations across quantiles. A weak positive correlation is observed at both low quantiles of CO_2 and low to high quantiles (0.05 to 0.95) of *GDPPC*. However, a strong positive correlation is observed at low to high quantiles (0.05 to 0.80) of CO_2 and medium to high quantiles (0.40 to 0.80) of *GDPPC*. These findings align with previous studies by Mitić *et al*. (2017), Aye and Edoja (2017), Mikayilov *et al*. (2018) and Sikder *et al*. (2022), who also reported a positive association between economic growth and CO_2 emissions. There are various reasons for the positive association between economic growth and CO_2 emissions. Firstly, economic expansion often spurs growth in industrial activity. Secondly, rising economic output translates into growing demand for energy across all sectors. Finally, economic growth often leads to increased transportation needs.

Figure 2c explores the QQKRLS association between *GPRI* and CO_2. The analysis reveals an overall positive correlation but with variations in strength across quantiles. At low quantiles (0.05 to 0.35) of CO_2 and low to high quantiles (0.05 to 0.95) of *GPRI*, a weak positive correlation is observed. This correlation strengthens at mid-to-high quantiles (0.40 to 0.80) for both variables but weakens again at extremely high quantiles (0.80 to 0.95). These findings can be explained from various perspectives. Firstly, geopolitical tensions can

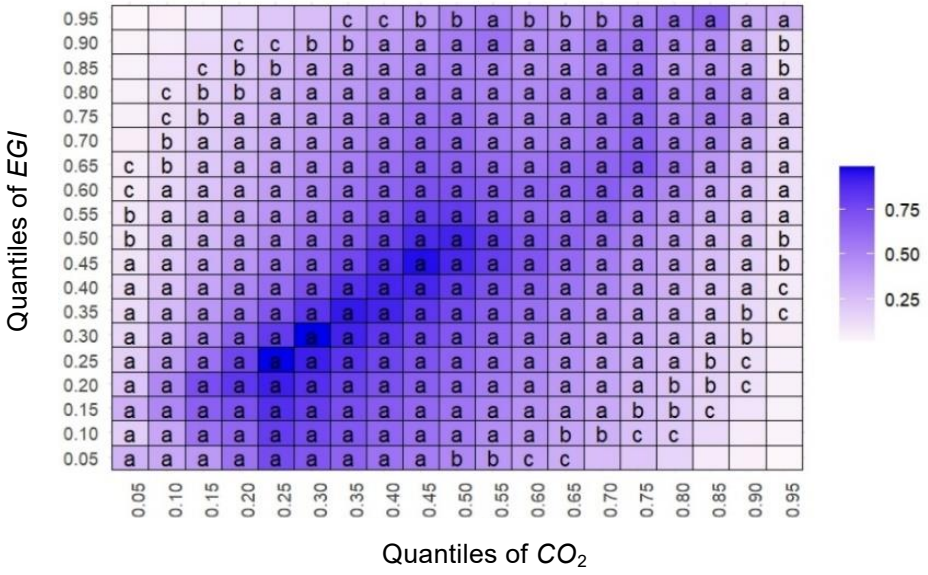
push countries towards prioritizing energy security over environmental concerns. Secondly, geopolitical instability can disrupt international cooperation and investment in clean energy technologies. Additionally, governments facing geopolitical tensions might prioritize short-term economic stability, leading to policies that encourage increased fossil fuel use to stimulate economic activity, even at the cost of higher CO_2 emissions.

Figure 2d depicts the QQKRLS association between *NRR* (natural resources) and CO_2. The results reveal an overall negative correlation, indicating that an abundance of natural resources is associated with lower CO_2 emissions. However, this correlation is not uniform across quantiles. At extremely low quantiles (0.05 to 0.25) of both variables, a positive correlation is observed. Interestingly, a strong negative correlation emerges between low-to-high quantiles of *NRR* (0.05 to 0.90) and low-to-medium quantiles (0.30 to 0.60) of CO_2. This aligns with the findings of Balsalobre-Lorente *et al*. (2018) and Baloch *et al*. (2019), who have suggested that natural resources can contribute to environmental sustainability. The findings can be justified in various ways. Turkey possesses a unique set of natural resources that offer significant potential for reducing CO_2 emissions. Forests, for example, act as vital carbon sinks, absorbing and storing atmospheric CO_2 through photosynthesis.

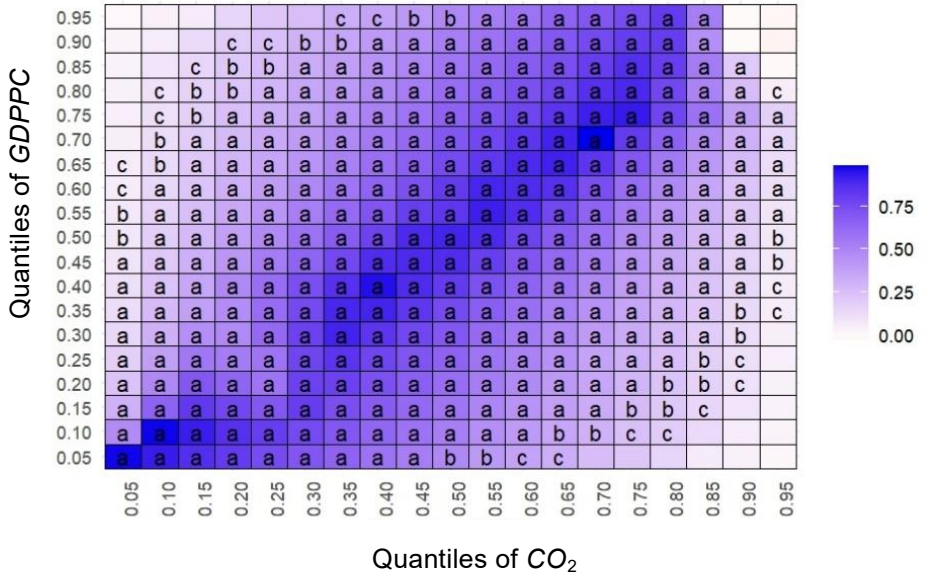
Figure 2e presents the QQKRLS association between *REN* (renewable energy) and CO_2. The analysis reveals a complex relationship, with the strength of the negative correlation varying across quantiles. At low quantiles of CO_2, a strong negative correlation is observed with increasing levels of renewable energy. This suggests that promoting renewable energy can be particularly effective in reducing emissions at lower pollution levels. However, the correlation weakens at mid-range CO_2 quantiles and even becomes positive in some cases. This might indicate diminishing returns or limitations of renewable energy in significantly reducing emissions at higher pollution levels. Finally, a strong negative correlation re-emerges at high CO_2 quantiles. These findings align with previous studies by Adams and Acheampong (2019), Sharif *et al*. (2021), Chang *et al*. (2022) and Adebayo *et al*. (2024), who have also reported a negative association between renewable energy and CO_2 emissions. Turkey's abundant sunshine, wind and geothermal resources offer a clean alternative to coal, a major source of the country's CO_2 emissions. Replacing fossil fuels with renewables directly reduces greenhouse gas releases, helping Turkey achieve its climate goals.

Figure 2: Quantile-on-quantile kernel-based regularized least squares (QQKRLS) estimate

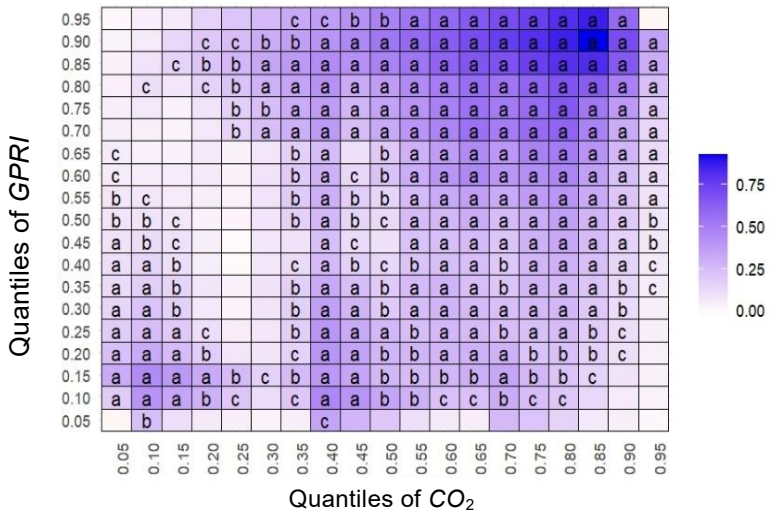
a) QQKRLS between *EGI* and CO_2



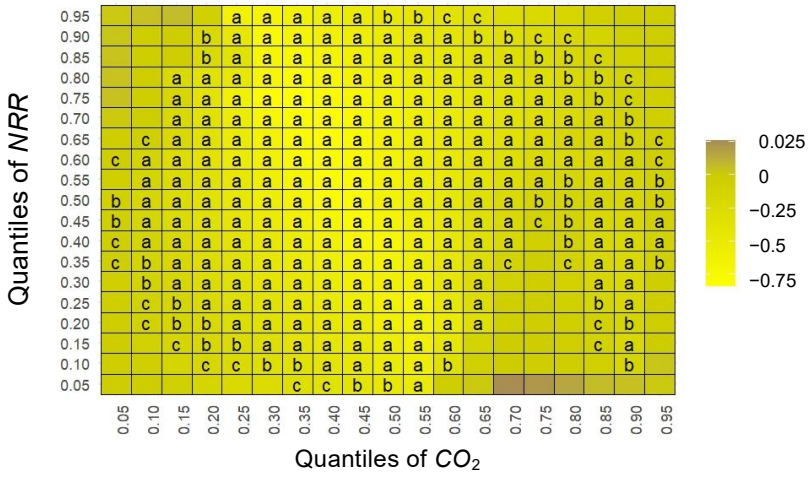
b) QQKRLS between *GDPPC* and CO_2



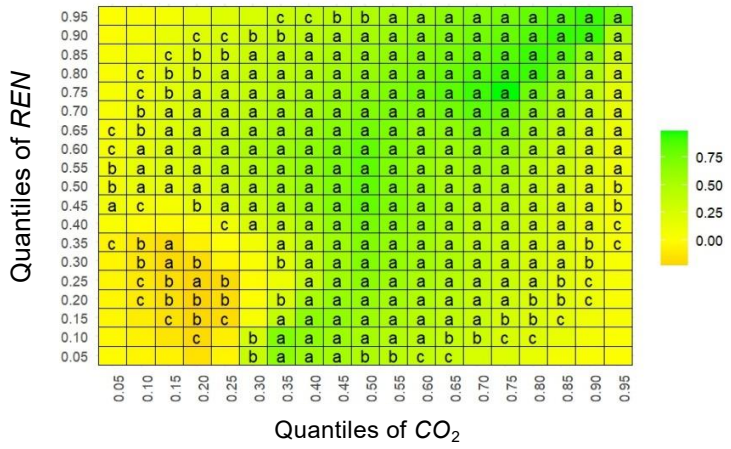
c) QQKRLS between *GPRI* and CO_2



d) QQKRLS between *NRR* and CO_2



e) QQKRLS between *REN* and CO_2



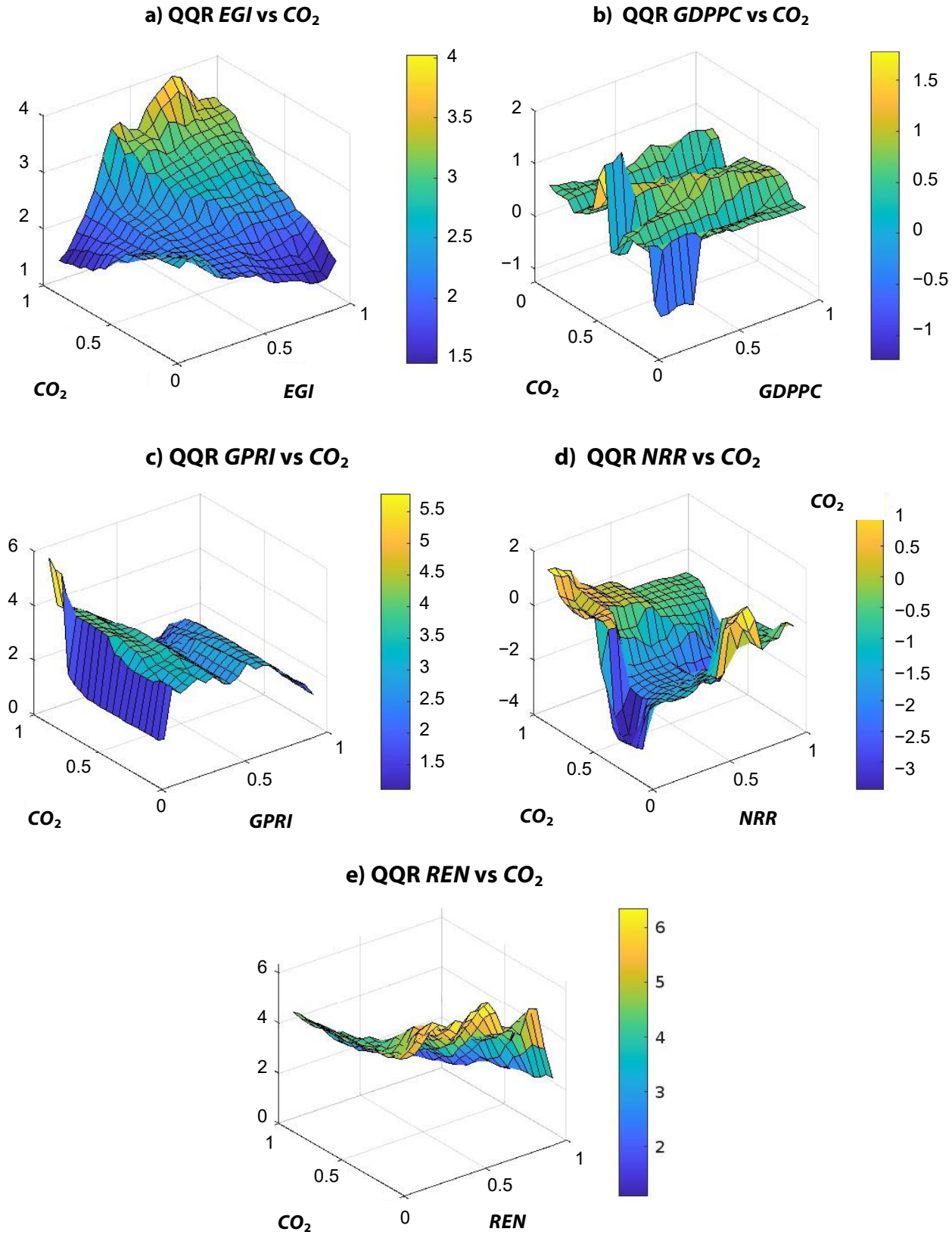
Source: Authors' own elaboration

4.3 Robustness check based on quantile-on-quantile regression

To further solidify the robustness of our findings from the QQKRLS approach, we employed a complementary non-parametric method: bivariate quantile-on-quantile regression (QQR). This method facilitates the comprehension of correlations between factors beyond the mean/average of the data, rendering it advantageous for analysing outcomes that are non-normally distributed and exhibit nonlinear associations with predictor variables (Ozcan *et al*., 2024; Kartal *et al*., 2024). For this reason, this method is employed for checking the robustness of the QQKRLS technique, which is applicable to non-linear relationships.

The results of the QQR analysis are presented in Figure 3(a–e). Figure 3a depicts the QQR findings for *EGI* and CO_2. The results confirm that *EGI* has a positive and statistically significant effect on CO_2 emissions. However, the strength of this correlation varies across quantiles, with a stronger positive correlation observed at higher quantiles of both variables. Figure 3b presents the QQR output for *GDPPC* and CO_2. The findings reveal an overall positive correlation, although it varies across quantiles. At extremely low quantiles, both variables exhibit a negligible correlation. However, a positive correlation emerges at all other quantile levels. Figure 3c displays the QQR findings for *GPRI* and CO_2. The results confirm an overall positive correlation between the variables, but with varying strengths across quantiles. Furthermore, Figure 3d showcases the QQR outcomes for *NRR* and CO_2. The analysis reveals that *NRR* generally has a negative correlation with CO_2 emissions. However, both variables have an exceptionally negative correlation at extremely low quantiles. Interestingly, a positive correlation is observed between extremely high quantiles of CO_2 emissions and low quantiles of *NRR*. Finally, Figure 3e reveals a somewhat comparable outcome with the QQKRLS estimation.

Figure 3: Results of QQR estimation



Source: Authors' own elaboration

5. Conclusion and Policy Recommendations

This study examined the effects of various factors on carbon emissions in Turkey in the period from 1970 to 2019 employing the quantile-on-quantile kernel-based regularized least squares (QQKRLS) approach. These factors include the economic globalization index, economic growth, geopolitical risk, renewable energy and natural resources. We also employed the quantile-on-quantile regression (QQR) method to ensure the robustness of the QQKRLS approach.

The QQKRLS findings reveal a weak positive correlation between economic globalization and carbon emissions at lower quantiles. This correlation becomes more pronounced in the middle-range quantiles but becomes less significant again at the highest quantiles. Similarly, there is a strong and consistent positive correlation between economic growth and carbon emissions, although this correlation varies among different quantiles. A slight positive correlation has been found between low quantiles of carbon emissions and low to high quantiles of economic growth. However, a substantial positive correlation is shown between carbon emissions at low to high quantiles and economic growth at medium to high levels. Furthermore, the analysis demonstrates an overall positive correlation between geopolitical risk and carbon emissions, while the intensity of this relationship varies across different quantiles. A slight positive correlation is found when carbon emissions are at low quantiles and geopolitical risk fluctuates between low and high quantiles. This correlation becomes more robust at quantiles that range from mid to high for both variables but decreases again at extremely high quantiles. Conversely, the QQKRLS findings suggest an overall negative correlation between natural resources and carbon emissions, suggesting that higher availability of natural resources corresponds to reduced carbon emissions. Nevertheless, this correlation does not exhibit a consistent pattern across quantiles. A strong negative correlation is observed between the lower to higher quantiles of natural resources and the lower to middle quantiles of carbon emissions. Additionally, the analysis indicates a complex relationship between renewable energy and carbon emissions, with the intensity of the negative correlation varying among quantiles. At lower quantiles of carbon emissions, there is a strong negative correlation with higher levels of renewable energy.

Based on these findings, we suggest the following policy revision: (i) The results indicate that economic globalization has a detrimental effect on the environment; therefore, policymakers should prioritize enforcement of strict environmental regulations and encourage sustainable practices for resource extraction as well as within industries, especially in terms of collaborating with other countries for trade and investment. Turkey should exclusively engage in trade in items and services that are both ecologically benign and free from pollution. Moreover, in international trade agreements, environmental sustainability clauses must be included. In addition, governments should impose penalties on high-carbon-emission imports and pro-

vide incentives for low-carbon imports. (ii) The study discovered a direct correlation between geopolitical risk and CO_2 emissions. Therefore, it is crucial to enhance the quality of institutions in Turkey in order to successfully implement and reap the advantages of global efforts that aim to promote environmental sustainability. Policymakers should prioritize promotion of international cooperation, enhancing institutional capacity and accelerating integration of global knowledge and technology to achieve sustainable development. Moreover, it is recommended that Turkey's government promote cooperation with international countries for climate change actions and initiate joint projects, such as clean energy projects. (iii) Enhancing the proportion of *REN* sources in Turkey's energy composition is important. This can be accomplished by conducting research and development in *REN* sources and establishing public-private collaborations to enhance innovation and competitiveness. Renewable energy use can also be stimulated by subsidies and advantageous tax regimes. (iv) While a positive GDP shock does increase CO_2 emissions, the solution lies not in reducing the production of goods and services, but rather in embracing environmentally sustainable technologies.

This study does possess several limitations. Firstly, the analysis focused exclusively on Turkey. Subsequent inquiries could include a wider array of countries (either through time series or panel analysis), thereby bolstering the formulation of more robust policies. Furthermore, it is possible to perform an investigation of the impact of disaggregated globalization and disaggregated energy sources on the environment. Furthermore, the current study utilized the bivariate QQR approach; however, future research studies can use the multivariate QQR approach so that the effects of other control variables can be considered for more robust policies.

List of acronyms

CAT	Climate Action Tracker
CO_2	Carbon dioxide
QQKRLS	Quantile-on-quantile-based regularized least squares
QQR	Quantile-on-quantile regression
GHGs	Greenhouse gases
COP	Conferences of Parties
EGI	Economic Globalization Index
GPRI	Geopolitical risk
NRR	Total natural resource rent
GDPPC	Economic growth
REN	Renewable energy

Acknowledgement

Funding: There was no funding, either externally or internally, towards this study.

Conflicts of interest: The authors hereby declare that this article was neither submitted nor published elsewhere.

AI usage statement: The authors confirm that no artificial intelligence (AI) or AI-assisted tools were used in the creation of this manuscript.

References

Adams, S., Acheampong, A. O. (2019). Reducing carbon emissions: the role of renewable energy and democracy. *Journal of Cleaner Production*, 240, 118245. https://doi.org/10.1016/j.jclepro.2019.118245

Adebayo, T. S., Kartal, M. T., Ullah, S. (2023). Role of hydroelectricity and natural gas consumption on environmental sustainability in the United States: evidence from novel time-frequency approaches. *Journal of Environmental Management*, 328, 116987. https://doi.org/10.1016/j.jenvman.2022.116987

Adebayo, T. S., Meo, M. S., Eweade, B. S., et al. (2024a). Analyzing the effects of solar energy innovations, digitalization, and economic globalization on environmental quality in the United States. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-02831-0

Adebayo, T. S., Meo, M. S., Eweade, B. S., et al. (2024b). Examining the effects of solar energy Innovations, information and communication technology and financial globalization on environmental quality in the United States via Quantile-On-Quantile KRLS analysis. *Solar Energy*, 272, 112450. https://doi.org/10.1016/j.solener.2024.112450

Adeleye, B. N., Akam, D., Inuwa, N., et al. (2023). Does globalization and energy usage influence carbon emissions in South Asia? An empirical revisit of the debate. *Environmental Science and Pollution Research*, 30(13), 36190–36207. https://doi.org/10.1007/s11356-022-24457-9

Agboola, P. O., Hossain, M. E., Gyamfi, B. A., et al. (2022). Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey. *Environmental Science and Pollution Research*, 29(35), 53584-53597. https://doi.org/10.1007/s11356-022-19656-3

Aladejare, S. A. (2022). Natural resource rents, globalisation and environmental degradation: new insight from 5 richest African economies. *Resources Policy*, 78, 102909. https://doi.org/10.1016/j.resourpol.2022.102909

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

Aye, G. C., Edoja, P. E. (2017). Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance*, 5(1), 1379239. https://doi.org/10.1080/23322039.2017.1379239

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

Balcilar, M., Usman, O., Özkan, O. (2024). Tourism development and US energy security risks: a KRLS machine learning approach. *Current Issues in Tourism*, 27(1), 37–44. https://doi.org/10.1080/13683500.2023.2245109

Baloch, M. A., Mahmood, N., Zhang, J. W. (2019). Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries. *Science of the Total Environment*, 678, 632–638. https://doi.org/10.1016/j.scitotenv.2019.05.028

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., et al. (2018). How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? *Energy policy*, 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Bekun, F. V., Ozturk, I. (2024). Economic globalization and ecological impact in emerging economies in the post-COP21 agreement: A panel econometrics approach. *Natural Resources Forum*, 49(1), 637–655. https://doi.org/10.1111/1477-8947.12408

Bosah, C. P., Li, S., Ampofo, G. K. M., et al. (2023). A continental and global assessment of the role of energy consumption, total natural resource rent, and economic growth as determinants of carbon emissions. *Science of the Total Environment*, 892, 164592. https://doi.org/10.1016/j.scitotenv.2023.164592

Brock, W. A., Dechert, D., Scheikman, H., et al. (1996) A Test for Independence Based on the Correlation Dimension. *Econometric Reviews*, 15(3), 197–235. https://doi.org/10.1080/07474939608800353

Bulut, U., Atay-Polat, M., Bulut, A. S. (2024). Environmental deterioration, renewable energy, natural resource rents, and schooling in Türkiye: Does the degree of energy transition matter for environmental quality? *Journal of Environmental Management*, 365, 121639. https://doi.org/10.1016/j.jenvman.2024.121639

Chang, L., Saydaliev, H. B., Meo, M. S., et al. (2022). How renewable energy matter for environmental sustainability: Evidence from top-10 wind energy consumer countries of European Union. *Sustainable Energy, Grids and Networks*, 31, 100716. https://doi.org/10.1016/j.segan.2022.100716

Chen, L., Gozgor, G., Mahalik, M. K., et al. (2023a). How does geopolitical risk affect CO_2 emissions? The role of natural resource rents. *Resources Policy*, 87, 104321. https://doi.org/10.1016/j.resourpol.2023.104321

Chen, J., Huang, S., Kamran, H. W. (2023b). Empowering sustainability practices through energy transition for sustainable development goal 7: the role of energy patents and natural resources among European Union economies through advanced panel. *Energy Policy*, 176, 113499. https://doi.org/10.1016/j.enpol.2023.113499

Chen, L., Gozgor, G., Lau, C. K. M., et al. (2024). The impact of geopolitical risk on CO_2 emissions inequality: Evidence from 38 developed and developing economies. *Journal of Environmental Management*, 349, 119345. https://doi.org/10.1016/j.jenvman.2023.119345

Dam, M. M., Sarkodie, S. A. (2023). Renewable energy consumption, real income, trade openness, and inverted load capacity factor nexus in Türkiye: Revisiting the EKC hypothesis with environmental sustainability. *Sustainable Horizons*, 8, 100063. https://doi.org/10.1016/j.horiz.2023.100063

Danish, Ulucak, R., Baloch, M. A. (2023). An empirical approach to the nexus between natural resources and environmental pollution: do economic policy and environmental-related technologies make any difference? *Resources Policy*, 81, 103361. https://doi.org/10.1016/j.resourpol.2023.103361

Dumrul, Y., Bilgili, F., Dumrul, C., et al. (2023). The impacts of renewable energy production, economic growth, and economic globalization on CO_2 emissions: evidence from Fourier ADL co-integration and Fourier-Granger causality test for Turkey. *Environmental Science and Pollution Research*, 30(41), 94138–94153. https://doi.org/10.1007/s11356-023-28800-6

Emir, F., Karlilar, S. (2023). Application of RALS cointegration test assessing the role of natural resources and hydropower energy on ecological footprint in emerging economy. *Energy & Environment*, 34(4), 764–779. https://doi.org/10.1177/0958305X211073807

Ferwerda, J., Hainmueller, J., Hazlett, C. J. (2017). Kernel-based regularized least squares in R (KRLS) and Stata (krls). *Journal of Statistical Software*, 79(3), 1–26. https://doi.org/10.18637/jss.v079.i03

Gozgor, G., Lau, C. K. M., Lu, Z. (2018). Energy consumption and economic growth: New evidence from the OECD countries. *Energy*, 153, 27–34. https://doi.org/10.1016/j.energy.2018.03.158

GPRH. (2024). Geopolitical risk historical index. [Retrieved 2024-09-28]. Available at: https://www.policyuncertainty.com/gpr.html

Gygli, S., Haelg, F., Potrafke, N., et al. (2019). The KOF globalisation index–revisited. *The Review of International Organizations*, 14, 543–574. https://doi.org/10.1007/s11558-019-09344-2

Hainmueller, J., Hazlett, C. (2014). Kernel regularized least squares: Reducing misspecification bias with a flexible and interpretable machine learning approach. *Political Analysis*, 22(2), 143–168. https://doi.org/10.1093/pan/mpt019

Ji, Q., Zhang, D. (2019). How much does financial development contribute to renewable energy growth and upgrading of energy structure in China? *Energy Policy*, 128, 114–124. https://doi.org/10.1016/j.enpol.2018.12.047

Ji, Q., Li, J., Sun, X. (2019). Measuring the interdependence between investor sentiment and crude oil returns: New evidence from the CFTC's disaggregated reports. *Finance Research Letters*, 30, 420–425. https://doi.org/10.1016/j.frl.2019.02.005

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., Kılıç Depren, S., Ayhan, F., et al. (2022). Impact of renewable and fossil fuel energy consumption on environmental degradation: evidence from USA by nonlinear approaches. *International Journal of Sustainable Development & World Ecology*, 29(8), 738–755. https://doi.org/10.1080/13504509.2022.2087115

Kartal, M. T., Kılıç Depren, S., Ayhan, F., et al. (2024). Quantile-based heterogeneous effects of nuclear energy and political stability on the environment in highly nuclear energy-consuming and politically stable countries. *Applied Energy*, 365, 123237. https://doi.org/10.1016/j.apenergy.2024.123237

KOF (2024). KOF Globalisation Index. KOF Swiss Economic Institute, ETH Zurich. [Retrieved 2024-09-28]. Available at: https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html

Lei, X., Alharthi, M., Ahmad, I., et al. (2022). Importance of international relations for the promotion of renewable energy, preservation of natural resources and environment: Empirics from SEA nations. *Renewable Energy*, 196, 1250–1257. https://doi.org/10.1016/j.renene.2022.07.083

Lewis, T. L. (2019). Globalizing the treadmill of production: a solutions-oriented application to Ecuador. *Environmental Sociology*, 5(3), 219–231. https://doi.org/10.1080/23251042.2018.1514942

Li, B., Haneklaus, N. (2022). Reducing CO_2 emissions in G7 countries: The role of clean energy consumption, trade openness and urbanization. *Energy Reports*, 8, 704–713. https://doi.org/10.1016/j.egyr.2022.01.238

Mansour-Ichrakieh, L., Zeaiter, H. (2019). The role of geopolitical risks on the Turkish economy opportunity or threat. *The North American Journal of Economics and Finance*, 50, 101000. https://doi.org/10.1016/j.najef.2019.101000

Meo, M. S., Erum, N., Ayad, H. (2024). Understanding how climate preferences, environmental policy stringency, and energy policy uncertainty shape renewable energy investments in Germany. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-02876-1

Mikayilov, J. I., Galeotti, M., Hasanov, F. J. (2018). The impact of economic growth on CO_2 emissions in Azerbaijan. *Journal of Cleaner Production*, 197, 1558–1572. https://doi.org/10.1016/j.jclepro.2018.06.269

Mitić, P., Ivanović, O. M., Zdravković, A. (2017). A cointegration analysis of real GDP and CO_2 emissions in transitional countries. *Sustainability*, 9(4), 568. https://doi.org/10.3390/su9040568

Muhammad, B., Khan, S. (2021). Understanding the relationship between natural resources, renewable energy consumption, economic factors, globalization and CO_2 emissions in developed and developing countries. *Natural Resources Forum*, 45(2), 138–156. https://doi.org/10.1111/1477-8947.12220

Nordhaus, W. (2019). Climate change: The ultimate challenge for economics. *American Economic Review*, 109(6), 1991–2014. https://doi.org/10.1257/aer.109.6.1991

Ozcan, B., Kılıç Depren, S., Kartal, M. T. (2024). Impact of nuclear energy and hydro electricity consumption in achieving environmental quality: evidence from load capacity factor by quantile based non-linear approaches. *Gondwana Research*, 129, 412–424. https://doi.org/10.1016/j.gr.2023.05.014

Ozkan, O., Haruna, R. A., Alola, A. A., et al. (2023). Investigating the nexus between economic complexity and energy-related environmental risks in the USA: empirical evidence from a novel multivariate quantile-on-quantile regression. *Structural Change and Economic Dynamics*, 65, 382–392. https://doi.org/10.1016/j.strueco.2023.03.010

Raihan, A., Tuspekova, A. (2022). Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, tourism, agriculture, and forests on carbon emissions in Turkey. *Carbon Research*, 1(1), 20. https://doi.org/10.1007/s44246-023-00052-6

Rasoulinezhad, E., Taghizadeh-Hesary, F., Sung, J., et al. (2020). Geopolitical risk and energy transition in Russia: evidence from ARDL bounds testing method. *Sustainability*, 12(7), 2689. https://doi.org/10.3390/su12072689

Saint Akadiri, S., Alola, A. A., Akadiri, A. C. (2019). The role of globalization, real income, tourism in environmental sustainability target. Evidence from Turkey. *Science of the Total Environment*, 687, 423–432. https://doi.org/10.1016/j.scitotenv.2019.06.139

Saint Akadiri, S., Alola, A. A., Olasehinde-Williams, G., et al. (2020). The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. *Science of the Total Environment*, 708, 134653. https://doi.org/10.1016/j.scitotenv.2019.134653

Shahbaz, M., Saeed Meo, M., Kamran, H. W., et al. (2024). Financial regulations and sustainability: The role of energy price and climate policy uncertainty. *Journal of Environmental Management*, 359, 121037. https://doi.org/10.1016/j.jenvman.2024.121037

Shan, S., Genç, S. Y., Kamran, H. W., et al. (2021). Role of green technology innovation and renewable energy in carbon neutrality: A sustainable investigation from Turkey. *Journal of Environmental Management*, 294, 113004. https://doi.org/10.1016/j.jenvman.2021.113004

Shang, Y., Sang, S., Tiwari, A. K., et al. (2024). Impacts of renewable energy on climate risk: A global perspective for energy transition in a climate adaptation framework. *Applied Energy*, 362, 122994. https://doi.org/10.1016/j.apenergy.2024.122994

TurkStat (2021). *Sera Gazi Emisyon İstatistikleri, 1990–2019*. [Retrieved 2024-09-28]. Available at: https://data.tuik.gov.tr/Bulten/Index?p=Greenhouse-Gas-Emissions-Statistics-1990-2019-37196

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

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