sustainability

Article

Analysis of Factors Affecting CO_2 Emissions in Türkiye Using Quantile Regression

Serpil Türkyılmaz and Kadriye Nurdanay Öztürk *

Department of Statistics and Computer Sciences, Faculty of Science, Bilecik Şeyh Edebali University, 11100 Bilecik, Türkiye; serpil.turkyilmaz@bilecik.edu.tr
* Correspondence: kadriye.ozturk@bilecik.edu.tr

Abstract: This study aims to show how the impact of factors on carbon dioxide (CO_2) emissions differs at the quantile level and to demonstrate the superiority of the quantile regression method over the OLS method by using quantile regression and ordinary least squares (OLS) methods in order to examine the factors affecting CO_2 emissions in Türkiye in depth. Covering the period 1990–2021, this study evaluates the relationship between CO_2 emissions and GDP per capita growth, population growth, and renewable energy consumption. One of the important findings of the study is that the increase in the population ratio, which is insignificant according to the OLS method, positively affects CO_2 emissions at the 0.25 quantile point. According to both OLS and quantile regression methods, GDP growth does not affect CO_2 emissions, while renewable energy consumption has a significant and negative effect according to both models. These results demonstrate that economic growth has no discernible impact on CO_2 emissions in Türkiye, while investments in renewable energy can significantly lower emissions and open the door for quantile regression to be used more widely in related research. Unlike traditional methods that focus only on the conditional mean, the quantile regression method provides a comprehensive framework for Türkiye's sustainable development policies by exploring factor effects at different emission levels.

Keywords: CO_2 emissions; quantile regression; OLS; Türkiye

Citation: Türkyılmaz, S.; Öztürk, K.N. Analysis of Factors Affecting CO_2 Emissions in Türkiye Using Quantile Regression. *Sustainability* **2024**, *16*, 9634. https://doi.org/10.3390/su16229634

Academic Editor: Joana Ferreira

Received: 10 October 2024
Revised: 28 October 2024
Accepted: 31 October 2024
Published: 5 November 2024

1. Introduction

Environmental deterioration and climate change have an impact on emerging nations' main objectives of economic growth and sustainability. In order to mitigate the risks associated with climate change that can give rise to economic difficulties that may have an adverse effect on people's lives and well-being, society needs to make collective decisions, put strategic plans into action, and forecast future climate changes while accounting for greenhouse gas emissions and patterns of socioeconomic development [1]. Researchers and policy makers are becoming more interested in learning how energy use and carbon emissions are related as a result of growing concerns about finite energy resources and the ensuing emphasis on the green economy. Environmental pollution has surged in tandem with the world's energy demand, contributing to both the energy crisis and global warming [2].

In recent years, the rapid increase in the world population, the increase in income, the effective use of technological tools and equipment in human life, and the great developments in the field of industry have led to a rapid increase in energy consumption. When energy is evaluated in social and economic terms, it is one of the most important factors in terms of living standards and the development of countries. Energy consumption rises by an average of 4–5% per year as a result of energy being a basic input in many industries, including electronic gadgets utilized in households, workplaces, workshops, lights, railroad transportation, and heating [3].

Renewable energy has a very important place in terms of ensuring sustainable energy use and diversity in order to reduce the external dependency of countries and to minimize the damage to the environment through energy consumption [3]. According to the Renewable Energy Working Group of the International Energy Agency (IEA), renewable energy is defined as energy obtained from continuously renewed natural processes. A renewable energy source is defined as "an energy source that can be present the next day in the same way within nature's own evolution". By lowering carbon dioxide emissions, renewable energy sources contribute to environmental protection, which is one of its most significant characteristics, and since they are domestic resources, they help increase employment and lessen reliance on outside energy sources. [4]. In other words, they have all the features of easy accessibility, availability, and acceptability. For this reason, the issue of energy diversification has become one of the important elements of countries' energy policies.

Energy production and consumption based on fossil resources have direct and/or indirect negative impacts on natural resources and the environment on a local, regional, and worldwide scale. The increase in environmental awareness in the 1990s has led to a renewed interest in environmentally friendly, clean, renewable energy sources that do not emit emissions that would cause pollution to the atmosphere [5]. Today, approximately 20 percent of the energy consumed worldwide is obtained from renewable energy sources. Although the dependence on fossil fuels is high, the use of environmentally friendly renewable energy sources has been increasing over the years [6]. Carbon dioxide is one of the most important greenhouse gases, accounting for 58% of global energy consumption. CO_2 is a major greenhouse gas released into the atmosphere through natural processes and human activities, such as deforestation and fossil fuel combustion, as well as volcanic eruptions and respiration. The amount of CO_2 emissions is an important indicator of a country's level of development and its approach to the environment.

A country's level of industrialization and economic growth are also closely related to this. Overproduction of the greenhouse gas carbon dioxide makes the greatest contribution to the global greenhouse effect. Carbon dioxide induces atmospheric radiation, resulting in a global warming impact. The volume of carbon dioxide emissions has also increased significantly due to the Industrial Revolution. The expansion of carbon dioxide volume is attributed to the use of fossil-based energy sources such as oil, coal, and gas, which changes the structure of the atmosphere and causes temperatures to increase. If no precautions are taken, there is a strong possibility that the increase in average surface temperature will exceed 1.5 degrees in the coming years, the amount required by the Paris Agreement. Similarly, if the rate of increase in greenhouse gases continues, it is estimated that global temperatures will increase by an average of 5 to 6 degrees towards the end of this century [7].

Environmental pollution and environmental protection are among the global issues that are of international priority. The Kyoto Protocol was adopted in 1997 as the first step towards clarifying the steps to be taken in combating climate change and entered into force in 2005. The Kyoto Protocol stands out from other international environmental agreements primarily because of its flexibility mechanisms, which were established to meet the reduction target specified in the convention and the fines that will be enforced in the event of non-compliance. The Kyoto Protocol is the first global agreement to set a measurable goal for reducing emissions. The protocol's comprehensive implementation guidelines were approved during the 7th Conference of the Parties, which took place in Marrakech in 2001 [8]. Since greenhouse gas emissions in particular cause global warming and climate change, it has become inevitable for countries to develop technologies and pursue policies to reduce their emission volumes. A large portion of the carbon dioxide emissions that cause the greenhouse effect are caused by the use of fossil fuels in energy production and consumption. Therefore, a tax policy that encourages the adoption of environmentally friendly renewable energy sources in place of fossil fuels will help to reduce environmental externalities [9].

According to Figure 1, per capita CO_2 emission values as of 2022 are seen as the world (4.7 t), USA (14.9 t), Russia (11.4 t), Japan (8.5 t), China (8 t), Türkiye (5.1 t), United Kingdom (4.7 t), and India (2 t). According to 2022 greenhouse gas statistics, the energy sector ranked first in terms of emission amounts by sector. In total greenhouse gas emissions, the largest share in 2022 in terms of CO_2 equivalent was energy-related emissions with 71.8%, followed by agriculture with 12.8%, industrial processes and product use with 12.5%, and the waste sector with 2.9%. Energy sector emissions in 2022 were calculated as 400.6 Mt CO_2 equivalent, increasing by 179.8% compared to 1990 but decreasing by 1.4% compared to the previous year. Industrial process and product use emissions increased by 208.1% compared to 1990 but decreased by 6.4% compared to the previous year and were calculated as 69.9 Mt CO_2 equivalent. Agricultural sector emissions were calculated as 71.5 Mt CO_2 equivalent in 2022, increasing by 37.9% compared to 1990 but decreasing by 5.1% compared to the previous year. Waste sector emissions increased by 57.7% compared to 1990 and by 5.5% compared to the previous year, amounting to 16.3 Mt CO_2 equivalent. The largest share in CO_2 emissions is energy-related emissions. In 2022, 86.6% of total CO_2 emissions will come from the energy sector, 32.6% from electricity and heat production, 13.1% from industrial processes and product use, and 0.3% from the agriculture and waste sectors [10].

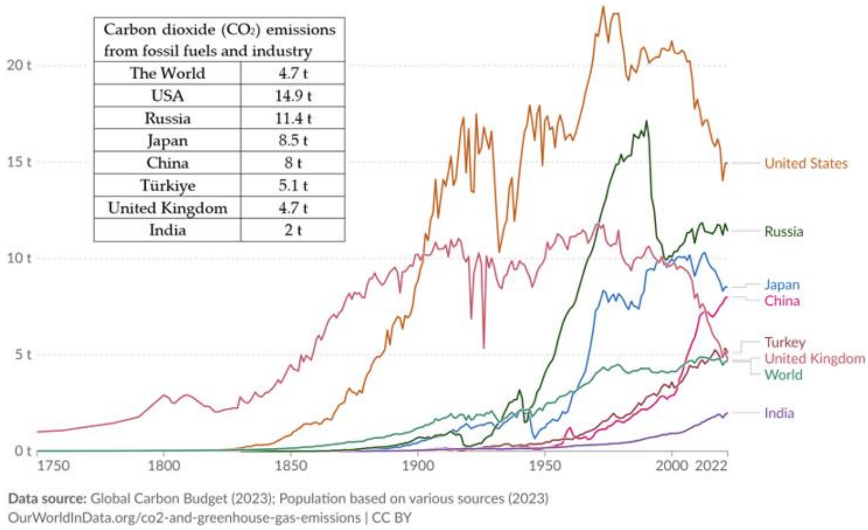

Figure 1. Per capita CO_2 emissions [11].

Among the significant topics covered in the literature are the effects of climatic disasters and global warming, two of the world's most pressing challenges, on carbon emissions and whether or not they are related to economic growth. The increasing trend of environmental degradation and depletion of global resources have motivated academics and policy makers to identify the factors that cause environmental degradation. Numerous studies have assessed the extent of environmental pollution by considering various issues. A summary of the literature is presented in Table 1.

Table 1. Literature review.

Author	Variable	Country	Period	Methodology	Findings
[12]	CO_2: CO_2 emissions, GDP: GDP per capita, UR: use of renewable energy per capita, EFC: total consumption of fossil energy per capita, ETC: trade openness	G20 Countries	2001–2010	Panel Data Analysis	According to the Environmental Kuznet's Curve (EKC) hypothesis, GDP per capita has a positive influence. CO_2 emissions per capita can rise in response to factors such as trade openness, urban population growth, and per capita fossil fuel energy consumption. As fossil energy prices rise and the amount of renewable energy used per person increases, CO_2 emissions per person decrease. Additionally, using renewable energy sources like wind has a general positive impact on lowering CO_2 emissions per person.

Table 1. *Cont.*

Author	Variable	Country	Period	Methodology	Findings
[13]	CO_2: CO_2 emissions, KGDP: real GDP per capita, SO: share of the population living in the city in the total population, EC: energy consumption (oil equivalent per capita kg)	Türkiye	1960–2011	ARDL Bounds Test	Growth and urbanization rates have a beneficial long-term influence on CO_2, but they have no short-term effect on the CO_2.
[14]	GDP, CO_2: carbon emissions, INF: CPI inflation, INV: gross domestic investment, EMP: employment, TOT: terms of trade	South African	1970–2014	Quantile Regression	Empirical findings suggest that the greatest benefits for economic growth come from extremely low carbon emissions. The results should motivate governments to keep launching energy efficiency initiatives that particularly aim to reduce carbon emissions.
[15]	CO_2: carbon emissions, GDP: GDP per capita	China	1975–2015	Fractional Integration Cointegration Methods	The cointegration tests (using both conventional and fractional procedures) suggest that the two variables (CO_2, GDP) in first differences have a long-run equilibrium relationship, meaning that, over time, their growth rates are connected.
[16]	EC: energy consumption, CO_2: carbon dioxide emissions, GCF: gross capital formation, L: labor force, GE: government expenditures	The European and Asian regions (22 countries), Latin American and Caribbean regions (15 countries), and Middle Eastern and African regions (20 countries)	1990–2018	Panel Quantile Regression	According to the results, energy consumption (at medium and high levels) and carbon emissions (at all levels) have a negative effect on economic growth, indicating that these countries are unable to attain sustainable economic growth.
[17]	CO_2: carbon emissions, energy use, GDP: GDP squared, industrial sector, finance, trade, urbanization	45 countries comprising 12 Sub-Saharan African countries, 10 American countries, 10 Asian countries, 5 European countries, and 8 MENA member countries	1980–2011	Quantile Regression	The consequences of energy consumption and financial development, which raise CO_2 emissions, are more pronounced in nations with lower pollution levels. Industrialization increases pollution especially in countries with greater degree of pollution. In low-pollution countries, trade openness and urbanization have a negative correlation with emissions.
[18]	CO_2: carbon dioxide emissions (metric tons per capita), RE: renewable energy consumption (% of total final energy), FDPVT: financial development proxied by domestic credit to private sector, FDI: foreign direct investment (net inflows as a percent of GDP), POP: urban population, TO: trade openness (% of GDP), FBF: labor force, MT: merchandise trade (% of GDP)	192 countries	1980–2018	Panel Quantile Regression	Consumption of renewable energy has a negative impact on carbon emissions, while the influence of financial development on carbon emissions is growing. While financial development has a beneficial impact on the consumption of renewable energy, carbon emissions reduce the use of renewable energy. It has also been discovered that the use of renewable energy sources and carbon emissions have a growing impact on financial development.
[19]	CO: carbon emissions, IPNT: environmental innovation ENT: energy consumption, GDP: economic growth	OECD countries (18 countries)	2005–2018	Panel (GMM) models	The results show that CO_2 emissions are reduced by 0.02% for every 1% increase in patent applications aimed at preventing climate change. Conversely, a 1% rise in energy demand results in a 0.56% rise in CO_2 emissions. Lastly, there is a 0.001% rise in CO_2 emissions for every 1% increase in the GDP growth rate.

Table 1. *Cont.*

Author	Variable	Country	Period	Methodology	Findings
[20]	CO_2: carbon dioxide (CO_2) emissions, GDP: GDP per capita, FC: fossil fuel consumption, URB: urbanization, TR: trade openness, PD: population density, LPI, HDI: socioeconomic indicators	G20 Countries	2000–2019	Quantile Regression	A reduction in CO_2 emissions was accompanied by inclusive socioeconomic growth. At quantiles ranging from 0.2 to 1, the LPI and HDI showed a negative marginal association with CO_2 emissions. Second, over the study period, the EKC hypothesis held true for the G20 countries, with an inflection point located around quantile 0.15. Third, during the study period, there was a negative correlation between trade openness and urbanization, while there was a strong positive correlation between CO_2 emissions and the usage of fossil fuels. Lastly, the study provides empirical evidence for the possibility of reducing CO_2 emissions without sacrificing inclusive growth through the implementation of efficient policies and coordinated policies across a wide range of social, economic, and living domains.
[21]	EPE: environmental protection expenditure (percent of GDP), CO_2: carbon dioxide emissions measured in million tons per capita, EXP is employed as a proxy for health status.	20 European Countries	1995–2019	Panel Quantile Regression	The findings indicate that whereas GDP, education, and spending on environmental preservation all contribute to improving health, CO_2 emissions actually worsen it.
[22]	REC: renewable energy consumption NREC: natural gas power utilization, GDP: per capita as a proxy of economic growth, FC: an index that is calculated using four sub-indices, CO_2: carbon dioxide emissions per capita	BRICS nations	2002–2019	The Method of Moments Quantile Regression (Panel)	The results of the panel quantile estimations demonstrated that the coefficients for financial inclusion and the use of renewable energy are negative for CO_2 emissions across all quantiles, from the first to the ninth. This implies that financial inclusion and renewable energy lower CO_2 emission levels.
[23]	YE: Renewable energy, FG: financial development, DYY: foreign direct investments	Asia-Pacific and Latin America	2000–2020	Simultaneous Panel Quantile Regression	The frameworks utilized for the analyses in this paper were simultaneous panel quantile regression analysis and the Dumitrescu–Hurlin panel causality test. A strong empirical argument has been established for the role that FG and DYY play in the development of YE based on the evidence gathered. Consequently, YE is greatly and favorably impacted by FG and DYY.
[24]	CN: per capita CO_2, REC: renewable energy consumption GDP: per capita real gross domestic product, FD: financial development	Five sub-Saharan African nations	2000–2020	Panel Data Analysis	The study's variables show a strong long-term link with one another, but no substantial short-term relationship. Financial development and CO_2 emissions are positively correlated, although there is a negative correlation between CO_2 emissions and renewable energy usage and financial development.
[25]	CO_2: CO_2 emissions, GDP: GDP per capita, REC: renewable energy consumption and URB: urban population	EU Member States	1996–2018	Fully Modified Ordinary Least Square (FMOLS) Model	The variables exhibit cointegration, according to the results. The calculated FMOLS model demonstrates that while consumption of renewable energy reduces CO_2 emissions, GDP and population increase CO_2 consumption. The utilization of renewable energy reduces CO_2 emissions according to the results.
[26]	CO_2, primary energy consumption (PEC, exajoule)	Türkiye	2000–2020	Linear Regression Analysis, Quantile Regression	Results of quantile regression: Using the RMSE and MAE criteria, the model based on the dependent variable's 0.50 quantile value is the best appropriate model. This model predicts that a unit increase in energy consumption will result in an approximate rise of 54.3 million tons in CO_2 emissions.

Table 1. *Cont.*

Author	Variable	Country	Period	Methodology	Findings
[7]	CO_2: carbon emissions, GDP: GDP per capita	G7 Countries	1991–2021	(1) Cross-section dependence, (2) CIPS panel unit root test, (3) Durbin-Hausman panel cointegration test and (4) Adjusted Least Squares (FMOLS) and Dynamic Least Squares Method (DOLS) estimators. In testing cross-sectional dependence, Breusch and Pagan used CDLM1, Pesaran CDLM2, Pesaran CD and Pesaran et al. tests	The results show that there is a negative association between the factors. Stated differently, the G7 countries' economic expansion results in a decrease in carbon emissions. This finding implies that the environmental Kuznets hypothesis's claim, that development and expansion will not have a negative impact on pollution but will instead reduce it, is only partially true beyond a specific stage of economic growth and development.
[27]	CO_2: carbon emissions (metric tons) Energy consumption: energy use (kg of oil equivalent per capita) Economic growth: GDP per capita (USD)	ASEAN-5 (Indonesia, Malaysia, Philippines, Singapore and Thailand) Countries	1990–2021	Causality Analysis	The relationship between economic growth and CO_2 emissions in Singapore was found to be bilateral; in the Philippines, the relationship between economic growth and CO_2 emissions was found to be unilateral; and in Indonesia and Malaysia, the relationship between CO_2 emissions and economic growth was found to be unilateral. Furthermore, in Singapore, there exists a bidirectional causal relationship between economic growth and energy consumption, whereas in Indonesia and the Philippines, there is a unilateral causal relationship between economic growth and energy consumption.
[28]	CO_2_BUILD: CO_2 from the building, GDP: GDP per capita (current US$), URB: urban population growth (annual %) ENR_BUILD: energy consumption for residential and commercial and public services includes coal, oil, bio-fuels, electricity and natural gas (kiloton of oil equivalent), FD: domestic credit to the private sector	Pakistan	1990–2020	The Quantile Autoregressive Distributed Lag Error Correction Model (QARDL-ECM).	The results of this study support the hypothesis that the variables under study have a long-term, asymmetric, and nonlinear connection.
[29]	CO_2: carbon dioxide emissions metric tons per capita, AGING: the aging population(65 years and above), GDP: gross domestic product per capita (constant at 2015 USD), TRDO: trade openness (% of GDP), RE: renewable energy (% of final energy consumption)	Bangladesh, India, Nepal, Pakistan, and Sri Lanka	1996–2020	Panel Data Analysis	Trade openness, population aging, and economic expansion all contribute to rising carbon emissions, but renewable energy sources and unemployment lower them. Additionally, an inverted U-shaped relationship between South Asian income and carbon emissions is confirmed by this study.
[30]	CO_2: carbon emissions per capita, GDP: GDP per capita, URB: total urbanization	BRICS (Brazil, Russia, India, China, South Africa)	1988–2018	Panel Data Analysis, Westerlund Panel Cointegration Test with Multiple Structural Breaks Panel Causality	The empirical study led to the conclusion that, for the relevant nations and time period, urbanization had a greater influence on CO_2 emissions than economic growth. The country-based study yielded inconsistent results, but at a significance level of 1%, the bidirectional causal link between urbanization, economic growth, and CO_2 emissions was established.

As can be seen from Table 1, there is no common consensus about the relationship among CO_2 emissions and other influencing factors.

In reducing environmental pollution, along with climate change, it is important to implement policies such as the carbon cap policy, carbon tax policy, carbon cap and trade policy, and carbon balancing policy for carbon regulation. There are also studies in the literature using different optimization methods that offer solutions for different scenarios regarding the policies in question. In such studies, it is examined how changing the carbon ceiling, tax value, sales and purchase price of carbon, and balancing price affects the solution value of each proposed scenario. For this purpose, different methods such as fuzzy control model and simulation for the supply chain system and closed-loop supply chain based on fuzzy robust control approach have been used [31–34].

It is important to examine the determinants of CO_2 emissions as the most important indicator of environmental pollution that causes climate change and to determine the affecting factors. The motivation of the study was the analysis of factors that have an important impact on reducing CO_2 emissions for Türkiye.

In this paper, we focus the attention on the influence of renewable energy consumption, economic growth, and population growth on CO_2 emissions in Türkiye. This study seeks answers to the following research questions:

- Do changes in economic growth in Türkiye affect CO_2 emissions?
- Is the effect of population growth on CO_2 emissions in Türkiye statistically significant?
- Is the trend towards renewable energy sources effective in reducing CO_2 emissions in Türkiye?

The effects of economic growth, population growth, and renewable energy consumption on CO_2 emissions in Türkiye have not been examined with the quantile regression model approach. In order to fill this research gap, in this study, the relationships between the variables in question for the 1990–2021 period in Türkiye were estimated with the quantile regression approach.

This study contributes to the literature as follows:

(i) This study is an additional study that contributes to the literature by examining the relationship among renewable energy consumption, economic growth, population growth, and CO_2 emissions in Türkiye. (ii) This study compares linear regression and quantile regression prediction performances.

This is how the rest of the study is structured. The materials and procedures are presented in Section 2, the results are presented in Section 3, and the policy implications and findings are discussed in Section 4.

2. Materials and Methods

Quantile regression, proposed by [35] Koenker and Bassett in 1978, is seen as an alternative approach to classical linear regression models. The quantile regression model estimates a particular quantile of the dependent variable, whereas classical linear regression just estimates the conditional mean. It also takes into account unobservable heterogeneity and heterogeneous covariate effects in panel data [36] (p. 5). It has been frequently preferred in recent years to overcome the situations where the least squares method is limited—such as the mean of the error terms being zero, constant variance, no autocorrelation, no linear relationship between explanatory variables [37] (p. 67). Being resistant to extreme values and not requiring the assumption of normality makes the quantile regression method more advantageous compared to the least squares method. While the least squares method produces biased estimates under the influence of extreme values and in cases where the assumption of normality is not provided, quantile regression is not affected by these limitations. It offers a complementary method to reveal data features that the least squares method ignores, and the increased diversity of data and a better understanding of the importance of heterogeneity make this method even more important [38] (p. 23). Quantile regression describes the distribution in more detail when independent variables show different effects at different points of the distribution of the dependent variable. In this way, it increases the reliability of the results by providing a more comprehensive analysis [39] (p. 5105). Among the models developed for various quantile points, it enables researchers to analyze the complete conditional distribution and select the best model.

The general representation of the quantile regression model is as in Equation (1):

$$y_i = x_i \, \beta_\theta + u_\theta. \tag{1}$$

In the expression given in Equation (1), y_i represents the dependent variable to be estimated in the quantile regression model. x_i is the independent variables included in the model to explain the dependent variable. θ represents quantile values and takes values between 0 and 1. β_θ is the parameter vector estimated for each quantile value. u_θ is the error term.

The dependent variable y_i is estimated using the conditional quantiles of the independent variables x_i. The conditional quantile of the dependent variable y_i is:

$$Q_\theta(y_i \mid x_i) = x_i\beta_\theta. \tag{2}$$

The β_θ estimator of the θth quantile of the conditional distribution is obtained by solving the formula given in Equation (3):

$$\hat{\beta}(\theta) = argmin_{\beta \in \boldsymbol{R}^p} \sum_{i=1}^{n} \rho_\theta\left(y_i - x_i'\beta\right), \tag{3}$$

The ρ_θ in the equation is the control function and its main objective is to minimize each error term using different weights depending on the direction of deviations. ρ_θ is defined as follows:

$$\rho_\theta(u) = u(\theta - I(u < 0)), \tag{4}$$

Here, $I(u < 0)$ is the indicator function and is defined as in Equation (5):

$$I(u < 0) = \begin{cases} 1, & u < 0 \\ 0, & u \geq 0. \end{cases} \tag{5}$$

The indicator function weights deviations differently depending on whether they are positive or negative. Positive deviations are weighted by θ and negative deviations are weighted by $1 - \theta$.

The objective function is obtained by minimizing the sum of the weighted absolute deviations:

$$\min_\beta \frac{1}{n}\left\{ \sum_{i:y_i \geq x_i\beta} \theta|y_i - x_i\beta| + \sum_{i:y_i < x_i\beta} (1-\theta)|y_i - x_i\beta| \right\}, \tag{6}$$

$$\min \frac{1}{n}\left\{ \sum_{i=1}^{n} \rho_\theta(y_i - x_i\beta) \right\}. \tag{7}$$

The objective function used to optimize the quantile regression model to give the best predictions at various quantile levels is optimized with different weights according to whether the deviations are positive or negative.

As can be clearly seen from the equations, quantile regression has the ability to model different quantiles. This allows for more detailed analysis of the data from a broad perspective.

3. Results

3.1. Dataset and Structure

This study was conducted to comprehensively analyze the relationship between CO_2 emissions and GDP per capita growth, population growth, and renewable energy consumption. The study sample consists of annual data for Türkiye for the period 1990–2021. Since the renewable energy consumption variable ended in 2021, the scope of the study was limited to 2021. Therefore, the data used in the analyses cover the period 1990–2021. The variables used in the study were selected in line with the information obtained from the literature. Data on independent variables were taken from the World Bank database, while data on CO_2 emissions came from the Turkish Statistical Institute.

Figure 2 shows the graph showing the trend in annual CO_2 emissions in Türkiye between 1990 and 2021.

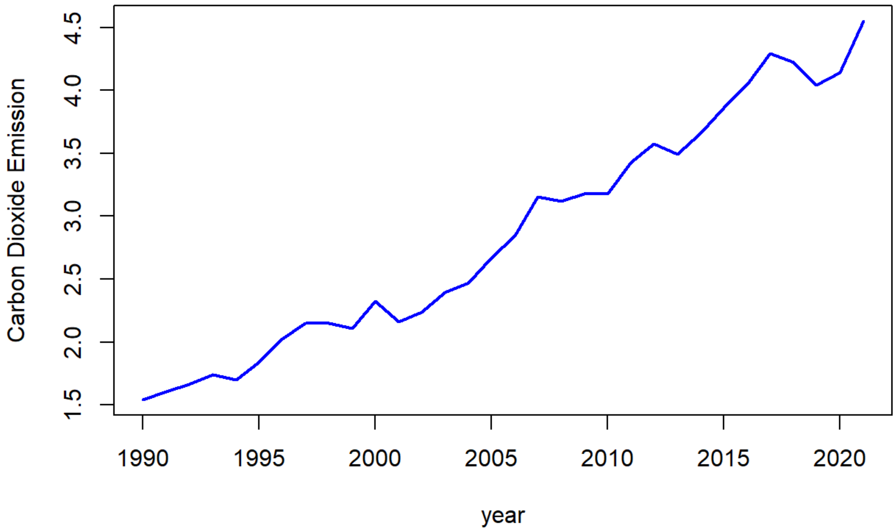

Figure 2. CO_2 emission trend graph for the period 1990–2021.

When the CO_2 emission graph presented in Figure 2 is examined, it is seen that although the general trend of CO_2 emissions in the 1990–2021 period is in the direction of increase, it is at different levels in each year and there are slight decreases in some years. The reason for these decreases may be economic recession or temporary decreases in energy demand. While 2021 stands out as the year when CO_2 emissions reached the highest level in Türkiye, the lowest amount of emissions was recorded in 1990.

The definitions and units of measurement for the variables used in the investigation are listed in Table 2.

Table 2. Description of variables.

Variable	Source	Measurement	Definition
CO_2 Emissions	Turkish Statistical Institute (TURKSTAT)	Metric Tons	CO_2 emissions refer to carbon dioxide released into the atmosphere as a result of burning fossil fuels, deforestation and various industrial processes.
GDP Per Capita Growth	World Bank Indicator	Annual Percentage	GDP per capita is an indicator that measures the pace of economic growth, obtained by dividing gross domestic product by the mid-year population.
Population Growth	World Bank Indicator	Annual Percentage	The exponential growth rate of the mid-year population, which includes all people living in a nation regardless of their citizenship or legal status, expressed as a percentage over the years $t-1$ to t, is the population growth rate for year t.
Renewable Energy Consumption	World Bank Indicator	Percentage of Total Final Energy Consumption	Renewable energy consumption is the proportion of energy produced from renewable sources to total final energy use.

Table 3 provides a summary of the variables' descriptive statistics:

Table 3. Descriptive statistics of variables.

	CO_2 Emissions	GDP Per Capita Growth	Population Growth	Renewable Energy Consumption
Number of observations	32	32	32	32
Mean	2.8615	3.2684	1.4266	16.6843
Standard Deviation	0.9275	4.5619	0.2485	4.4377
Variance	0.8604	20.8116	0.0617	19.6936
Skewness	0.2233	−0.8515	−0.4117	0.5355
Kurtosis	1.7231	2.9996	3.395	1.7896
Minimum	1.5414	−7.1382	0.7967	11.4
Maximum	4.5524	10.4294	1.8934	24.4

Descriptive statistics include means, standard deviations, variances, skewness-kurtosis values, and maximum and minimum values of the variables.

3.2. Findings

In this study, indicators affecting CO_2 emissions in Türkiye were examined using OLS and quantile regression methods. Data analysis was performed using the STATA program. Graphs were drawn using RStudio. While the average relationships between variables were examined with the OLS method, the changes in the relationships between variables at three different quantiles, 0.25, 0.50, and 0.75, were analyzed with the quantile regression method. By comparing the findings between the two methods, how the relationships between variables differ under various conditions and distributions will be evaluated. First, OLS model estimates were obtained and the results are given in Table 4.

Table 4. OLS model estimation results.

Dependent Variable: CO_2 Emission				
Variables	**Coefficient**	**Standard Error**	**t**	***p*-Value**
Constant	6.0405	0.4658	12.97	0.000
GDP Per Capita Growth	0.0008	0.0166	0.05	0.959
Population Growth	−0.0452	0.5242	−0.09	0.932
Renewable Energy Consumption	−0.1868	0.0294	−6.34	0.000

Quantile regression estimation results are summarized in Table 5:

Table 5. Quantile regression model results.

Quantile	Variables	Coefficient	Standard Error	t	*p*-Value
0.25	Constant	3.973	0.3446	11.53	0.000
	GDP Per Capita Growth	0.0024	0.0123	0.20	0.841
	Population Growth	1.4638	0.3878	3.77	0.001
	Renewable Energy Consumption	−0.2139	0.0217	−9.82	0.000
0.50	Constant	5.0572	0.7171	7.05	0.000
	GDP Per Capita Growth	−0.0048	0.0256	−0.19	0.852
	Population Growth	0.5626	0.8070	0.70	0.852
	Renewable Energy Consumption	−0.1863	0.0453	−4.11	0.000
0.75	Constant	7.3721	0.7022	10.50	0.000
	GDP Per Capita Growth	−0.0033	0.0250	−0.13	0.896
	Population Growth	−0.7652	0.7903	−0.97	0.341
	Renewable Energy Consumption	−0.1812	0.0444	−4.08	0.000

In the light of empirical data, some remarkable findings have been obtained. First of all, when compared to the OLS method, it is clear that the quantile regression model is more flexible and less restrictive because the slope coefficient can vary in different quantiles of the dependent variable.

When we look at the OLS regression results, the average effects of the independent variables on CO_2 were determined and these effects were expressed with a single value. However, the quantile regression results show how the effects of the independent variables on CO_2 changed at three different quantile points of the data set. These results show that in the top, middle, and bottom of the data set, the impacts of the independent variables vary.

When the quantile regression and OLS model results are evaluated together, it is seen that the GDP growth per capita does not play a significant role in the increase or decrease of CO_2 emissions. The increase in the population rate affects CO_2 emissions only in the years when emissions are low, i.e., at the 0.25 quantile point, and this relationship is positive. A one-unit increase in the population rate increases CO_2 emissions by 1.4638 units. According to all quantile points of the OLS model and the quantile regression model, using renewable energy helps to lower CO_2 emissions. The effect of this variable in all models was found to be quite close to each other.

The coefficient estimates obtained from OLS and quantile regression models are presented below in a comparative manner, with separate graphs for each variable. Figures 3–5 allow us to visually examine how the effects of the independent variables differ according to the selected quantiles throughout the distribution at the 95% confidence interval.

The red horizontal line denotes the coefficient estimated via OLS, whereas the black line illustrates the regression coefficients of the independent variables on the dependent variable across different quantiles. The graphs clearly show that quantile regression provides a more comprehensive analysis.

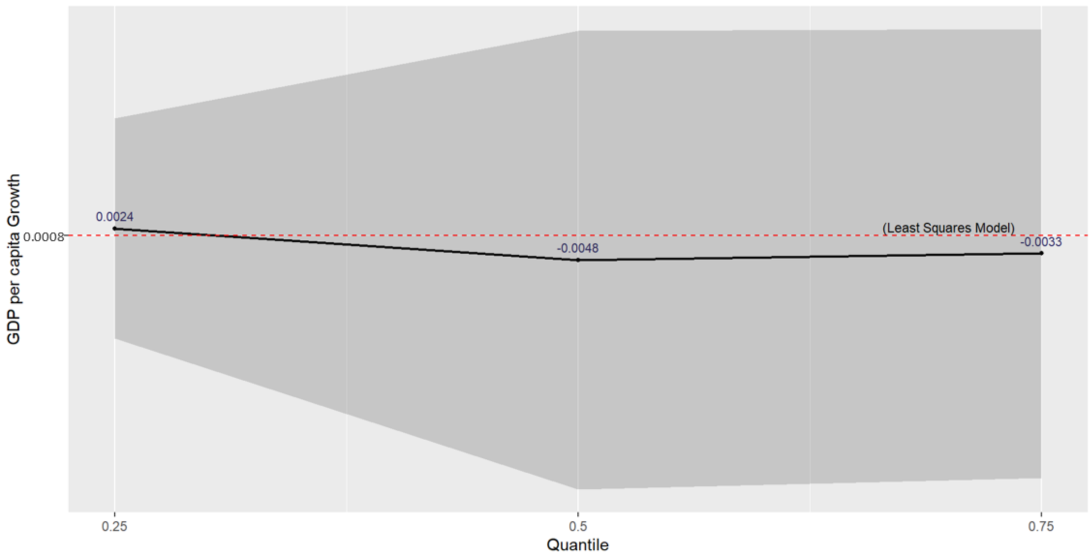

Figure 3. Graph of coefficient estimates for GDP per capita growth.

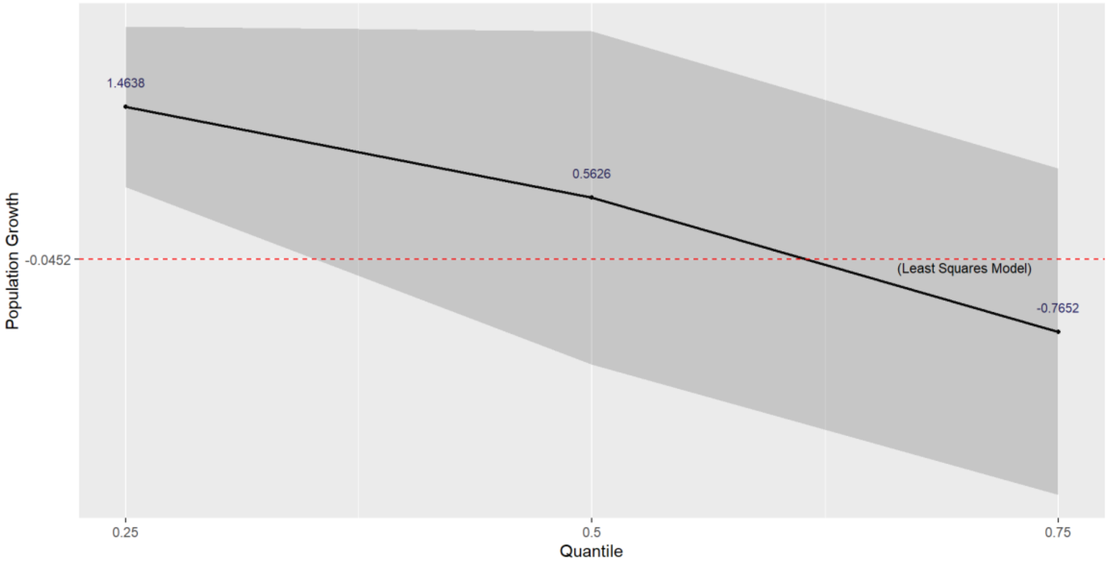

Figure 4. Graph of coefficient estimates for population growth.

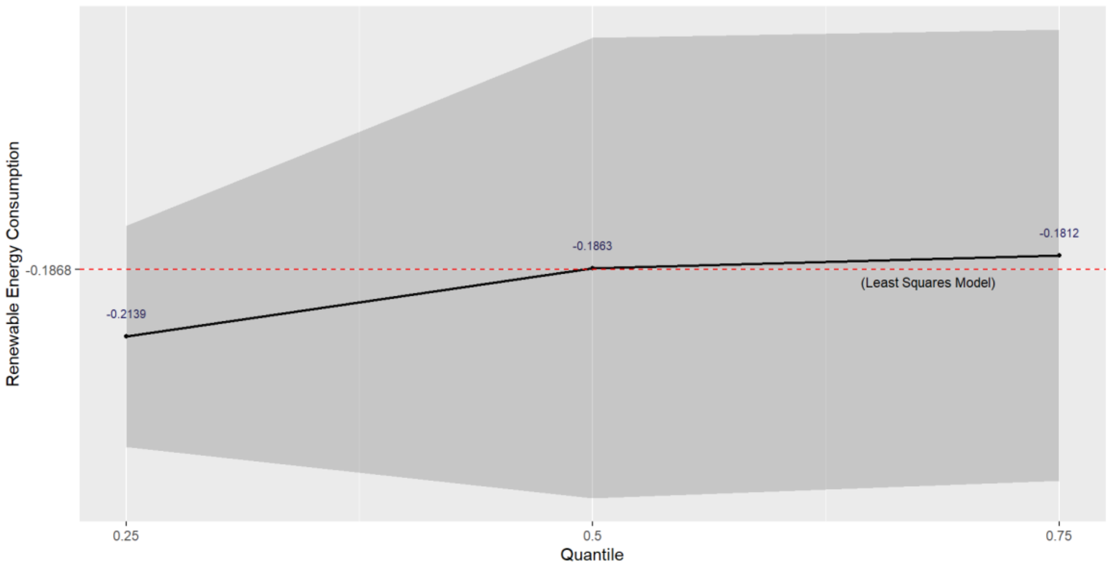

Figure 5. Graph of coefficient estimates for renewable energy consumption.

4. Conclusions and Discussion

Climate change, a global problem in recent years, has attracted serious attention in the scientific world and research in this field, especially on reducing CO_2 emissions, is rapidly increasing. Studies on the social and economic reasons for the increase in emissions worldwide are of critical importance for policy makers. The current study reveals the relationship between economic growth, population growth, renewable energy consumption and CO_2 emissions in Türkiye using the quantile regression method, one of the powerful regression methods. Many studies in this field use classical regression methods that examine average effects, and these methods ignore how the relationship between variables changes at different points in the distribution. Unlike classical methods, quantile regression is a powerful tool that examines differences in distribution in detail. In our study, estimates were obtained for the OLS in order to more clearly reveal the advantages and limitations of the quantile regression approach and all results were compared.

When we evaluate the performance and findings of all models together, the effect of GDP growth per capita on CO_2 emissions is not found to be significant in both models. While many studies support the significant effect of GDP growth on CO_2 emissions, our results reveal that economic growth does not show the expected effect on emissions. Various factors may have balanced the effect of economic growth on emissions in Türkiye. Consistent with the findings of [40], the fact that economic growth is not related to CO_2 emissions is an indication that environmentally friendly growth activities are being implemented. It can also be said that there is a tendency towards renewable energy sources in the use of energy resources required for growth. It would be useful to investigate all potential reasons for this situation.

When the literature is examined, it is expected that population growth will increase CO_2 emissions. However, according to the model results, the increase in the population rate was found to be significant only in years when emissions were low. In Türkiye, the years when CO_2 emissions were low coincide with years when technological developments and renewable energy use were low. Over time, the progress in these two factors in particular may lead to the expected relationship between population growth and CO_2 emissions not being observed in years when emissions are medium and high. It is expected that this result will provide scientists with a new research area to work on.

There are studies in the literature that reach different conclusions regarding the relationship between renewable energy consumption and CO_2 emissions. While Zoundi (2017) [41] emphasized that the negative effect of renewable energy consumption on CO_2 emissions gradually increases in the long term, Apergis et al. (2023) [42] stated that there is a negative relationship between the two variables in both the short and long term. Rehman et al. (2023) [43] pointed out that their study's two variables did not significantly correlate with one another. The results obtained from our study support similar findings in the literature by revealing the negative effect of renewable energy consumption on CO_2 emissions. Unlike other studies, the quantile regression method used in the study is not limited to the mean alone but also reveals that the relationship is valid at different points of the distribution, and provides the opportunity to examine how the relationship changes throughout the distribution.

Studies on CO_2 emissions are extremely important at both academic and political levels. Within the scope of combating global warming and climate change, it has become imperative to determine policies to reduce CO_2 emissions in a more effective and data-based manner. The analysis methods used and the limitations of these methods may lead to different results in the literature. It is observed that the results obtained by classical regression methods are insufficient to explain the relationship between CO_2 emissions in Türkiye and the factors affecting emissions. This paper aims to guide policy makers in decision-making processes for reducing or controlling CO_2 emissions by using the quantile regression method, which allows us to understand the dynamic relationships at different levels of CO_2 emissions in Türkiye in more detail. The fact that the effects of various factors become evident or limited at low, medium and high emission levels will enable the design of sustainable development policies in a clear and accurate manner. In future studies, it is thought that the inclusion of environmental uncertainties in the estimation process will contribute to the literature in order to model the factors affecting CO_2 emissions more accurately and robustly. In this context, adaptive control and fuzzy logic systems are among the important methods that can be considered in decision-making processes under uncertainty [44]. In addition, cost optimization and robust control strategies applied in supply chains [45] can be applied on CO_2 emissions in order to manage uncertainties and cost factors correctly. When the proposed methods are used together with quantile regression, it is expected to be effective in the long term for decisions to be taken to reduce CO_2 emissions in Türkiye.

Author Contributions: The literature search of the article was carried out by S.T. and data acquisition and analysis were carried out by K.N.Ö. Both authors contributed equally to all stages of the work. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The study data were obtained from the Turkish Statistical Institute (https://www.tuik.gov.tr/Home/Index, accessed on 9 October 2024) and World Bank Indicator (https://databank.worldbank.org/source/world-development-indicators, accessed on 9 October 2024).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Moalla, M. Energy Consumption, CO_2 Emissions, and Economic Growth Nexus: ARDL Analysis for Turkiye. *Kent Akad. Derg.* **2023**, *16*, 19–37. [CrossRef]
2. Ofori-Sasu, D.; Abor, J.Y.; Agyekum Donkor, G.N.; Otchere, I. Renewable energy consumption and carbon emissions in developing countries: The role of capital markets. *Int. J. Sustain. Energy* **2023**, *42*, 1407–1429. [CrossRef]
3. Kaya, K.; Şenel, M.C.; Koç, E. Dünyada ve Türkiye'de Yenilenebilir Enerji Durumu-Genel Değerlendirme. *Technol. Appl. Sci. (NWSATAS)* **2018**, *13*, 219–234.
4. Türkyılmaz, T. Geliştirilen Yeni Bir Yazılım ile Rüzgar ve Güneş Enerji Sistemlerinin Analizi ve Uygulaması. Ph.D. Thesis, Bilecik Şeyh Edebali Üniversitesi, Fen Bilimleri Enstitüsü, Bilecik, Türkiye, 2020.
5. Seydioğulları, H.S. Sürdürülebilir Kalkınma için Yenilenebilir Enerji. *Planlama* **2013**, *23*, 19–25.
6. Karagöl, E.T.; Kavaz, İ. Dünyada ve Türkiye' de Yenilenebilir Enerji. *Analiz* **2017**, *197*, 1–28.
7. Emek, Ö.F.; Atay Polat, M. Examining the Relationship between Carbon Emission and Economic Growth in G7 Countries. In *Macro Aspects of Environmental Economics*; Durgun, B., Ed.; Özgür Publications: Gaziantep, Türkiye, 2023; pp. 131–145. [CrossRef]
8. İklim Değişikliği Bakanlığı. Kyoto Protokolü. 2024. Available online: https://iklim.gov.tr/kyoto-protokolu-i-35# (accessed on 4 August 2024).
9. Çoban, O.; Şahbaz Kılınç, N. Yenilenebilir Enerji Tüketimi ve Karbon Emisyonu İlişkisi: TR Örneği. *Sos. Bilim. Enstitüsü Derg.* **2015**, *38*, 195–208.
10. TURKONFED. 2024. Available online: https://turkonfed.org/tr/detail/4245/2022-sera-gazi-istatistikleri-yayinlandi (accessed on 9 September 2024).
11. Our World in Data. 2023. Available online: https://ourworldindata.org/co2-and-greenhouse-gas-emissions (accessed on 8 September 2024).
12. Zaekhan; Nachrowi, N.D. The Impact of Renewable Energy and GDP Per Capita on Carbon Dioxide Emission in the G-20 Countries. *Econ. Financ. Indones.* **2012**, *60*, 145–174.
13. Çetintaş, H.; Bicil, İ.M.; Türköz, K. Türkiye'de CO_2 Salınımları Enerji Tüketimi ve Ekonomik Büyüme İlişkisi. *Finans Polit. Ekon. Yorumlar* **2016**, *53*, 57–67.
14. Mapapu, B.; Andrew, P. Carbon emissions and economic growth in South Africa: A quantile regresison analysis. *Int. J. Energy Econ. Policy* **2018**, *8*, 195–202.
15. Caporale, G.M.; Claudio-Quiroga, G.; Gil-Alana, L.A. CO_2 Emissions and GDP: Evidence From China. Economics and Finance Working Paper Series (No:1915). 2019; pp. 1–27. Available online: https://www.brunel.ac.uk/economics-and-finance/research/pdf/1915-Sep-GMC-CO2-Emissions-and-GDP-Evidence-from-China.pdf (accessed on 9 October 2024).
16. Altinoz, B.; Apergis, N.; Aslan, A. Energy Consumption, Carbon Dioxide Emissions and Economic Growth: Fresh Evidence From Panel Quantile Regressions. *Energy Res. Lett.* **2020**, *1*, 17075. [CrossRef]
17. Keho, Y. An Empirical Study of Some Driving Factors of CO_2 Emissions: Evidence from Quantile Regression. *Bull. Appl. Econ.* **2020**, *7*, 87–95. [CrossRef]
18. Khan, H.; Khan, I.; Binh, T.T. The Heterogeneity of Renewable Energy Consumption, Carbon Emission and Financial Development in The Globe: A Panel Quantile Regression Approach. *Energy Rep.* **2020**, *6*, 859–867. [CrossRef]
19. Akyol, M.; Mete, E. Çevresel teknolojik inovasyonların CO_2 emisyonu üzerindeki etkisi: OECD ülkeleri örneği. *İstanbul İktisat Derg.-Istanb. J. Econ.* **2021**, *71*, 569–590. [CrossRef]
20. Alotaibi, A.A.; Alajlan, N. Using Quantile Regression to Analyze the Relationship between Socioeconomic Indicators and Carbon Dioxide Emissions in G20 Countries. *Sustainability* **2021**, *13*, 7011. [CrossRef]
21. Barak, D.; Tunc, A. How do environmental protection expenditures affect health status? Evidence from panel quantile regression. *KAÜİİBFD* **2022**, *13*, 1036–1068. [CrossRef]
22. Baskaya, M.M.; Samour, A.; Tursoy, T. The Financial Inclusion, Renewable Energy And CO_2 Emissions Nexus In The Brics Nations: New Evidence Based On The Method Of Moments Quantile Regression. *Appl. Ecol. Environ. Res.* **2022**, *20*, 2577–2595. [CrossRef]
23. İlarslan, K.; Yıldız, M. Yenilenebilir enerji yatırımlarının finansal belirleyicileri üzerine karşılaştırmalı bir analiz: Asya-Pasifik ve Latin Amerika ülkeleri. *Bus. Manag. Stud. Int. J.* **2022**, *10*, 1397–1415. [CrossRef]
24. Qudrat-Ullah, H.; Nevo, C.M. Analysis of the Dynamic Relationships among Renewable Energy Consumption, Economic Growth, Financial Development, and Carbon Dioxide Emission in Five Sub-Saharan African Countries. *Energies* **2022**, *15*, 5953. [CrossRef]
25. Uğurlu, E. Impacts of Renewable Energy on CO_2 Emission: Evidence from the Visegrad Group Countries. *Sciendo-Politics Cent. Eur.* **2022**, *18*, 295–315. [CrossRef]

26. Akyüz, H.E. CO_2 Emisyonu ve Birincil Enerji Tüketimi Arasındaki İlişkinin Kantil Regresyon Modeli ile İncelenmesi. *Düzce Üniversitesi Bilim Ve Teknol. Derg.* **2023**, *11*, 1529–1545. [CrossRef]
27. Lyazzat, K.; Abubakirova, A.; Igilikovna, O.A.; Zhanargul, T.; Suleimenovna, S.B. The Relationship between Energy Consumption, Carbon Emissions and Economic Growth in ASEAN-5 Countries. *Int. J. Energy Econ. Policy* **2023**, *13*, 265–271. [CrossRef]
28. Rehman, S.; Ullah, A.; Azim, F.; Khan, H.U.R. Impact of financial development, energy consumption and urbanization on CO_2 emissions from buildings using quantile ARDL model. *J. Infrastruct. Policy Dev.* **2023**, *7*, 2166. [CrossRef]
29. Abbas, M.; Yang, L. Measuring the long-run effect of economic growth, population aging, and unemployment on carbon emissions in South Asia. *Pak. J. Commer. Soc. Sci. (PJCSS)* **2024**, *18*, 113–133.
30. Türk, M.M.; Barışık, S. CO_2 emisyonunun ekonomik büyüme ve kentleşme ile etkileşimi: BRICS-T ülkeleri örneği. *Manas Sos. Araştırmalar Derg.* **2024**, *13*, 510–533. [CrossRef]
31. Aldoukhi, M.A.; Gupta, S.M. A robust closed loop supply chain network design under different carbon emission policies. *J. Pamukkale Univ. Eng. Sci.* **2019**, *25*, 1020–1032. [CrossRef]
32. Zhang, S.; Hou, Y.; Zhang, S.; Zhang, M. Fuzzy control model and simulation for nonlinear supply chain system with lead times. *Complexity* **2017**, *2017*, 2017634. [CrossRef]
33. Zhang, S.; Zhang, C.; Zhang, S.; Zhang, M. Discrete switched model and fuzzy robust control of dynamic supply chain network. *Complexity* **2018**, *2018*, 3495096. [CrossRef]
34. Zhang, S.; Zhang, P.; Zhang, M. Fuzzy emergency model and robust emergency strategy of supply chain system under random supply disruptions. *Complexity* **2019**, *2019*, 3092514. [CrossRef]
35. Koenker, R.; Bassett, G., Jr. Regression quantiles. *Econom. J. Econom. Soc.* **1978**, *46*, 33–50. [CrossRef]
36. Abid, N.; Ahmad, F.; Aftab, J.; Razzaq, A. A blessing or a burden? Assessing the impact of climate change mitigation efforts in Europe using quantile regression models. *Energy Policy* **2023**, *178*, 113589. [CrossRef]
37. Öztürk, K.N.; Yiğit, Ö.E. Makroekonomik ve Sosyal Göstergelerin Mutluluk Üzerindeki Etkilerinin Araştırılması: Panel Kantil Regresyon Yaklaşımı. *Bilecik Şeyh Edebali Üniversitesi Sos. Bilim. Derg.* **2024**, *9*, 62–78. [CrossRef]
38. Koenker, R. Quantile regression: 40 years on. *Annu. Rev. Econ.* **2017**, *9*, 155–176. [CrossRef]
39. Long, H.; Feng, G.F.; Gong, Q.; Chang, C.P. ESG performance and green innovation: An investigation based on quantile regression. *Bus. Strategy Environ.* **2023**, *32*, 5102–5118. [CrossRef]
40. Yağış, O. Gelir Eşitsizliği ve CO_2 Emisyonu İlişkisi: Panel Veri Analizi. *Dicle Üniversitesi Sos. Bilim. Enstitüsü Derg.* **2024**, *36*, 412–435. [CrossRef]
41. Zoundi, Z. CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renew. Sustain. Energy Rev.* **2017**, *72*, 1067–1075. [CrossRef]
42. Apergis, N.; Kuziboev, B.; Abdullaev, I.; Rajabov, A. Investigating the association among CO_2 emissions, renewable and non-renewable energy consumption in Uzbekistan: An ARDL approach. *Environ. Sci. Pollut. Res.* **2023**, *30*, 39666–39679. [CrossRef]
43. Rehman, A.; Alam, M.M.; Ozturk, I.; Alvarado, R.; Murshed, M.; Işık, C.; Ma, H. Globalization and renewable energy use: How are they contributing to upsurge the CO_2 emissions? A global perspective. *Environ. Sci. Pollut. Res.* **2023**, *30*, 9699–9712. [CrossRef]
44. Ge, J.; Zhang, S. Adaptive inventory control based on fuzzy neural network under uncertain environment. *Complexity* **2020**, *2020*, 6190936. [CrossRef]
45. Zhang, S.; Li, S.; Zhang, S.; Zhang, M. Decision of Lead-Time Compression and Stable Operation of Supply Chain. *Complexity* **2017**, *2017*, 7436764. [CrossRef]