



# Exploring how economic growth, renewable energy, internet usage, and mineral rents influence CO<sub>2</sub> emissions: A panel quantile regression analysis for 27 OECD countries

Cem Işık<sup>a,b,c,\*</sup>, Umit Bulut<sup>d,e</sup>, Serdar Ongan<sup>f</sup>, Hasibul Islam<sup>g</sup>, Muhammad Irfan<sup>h,i,j,k</sup>

<sup>a</sup> Department of Economics, Faculty of Economics and Administrative Sciences, Anadolu University, Tepebaşı, Eskişehir, Turkey

<sup>b</sup> Adnan Kassar School of Business, Lebanese American University, Byblos, Lebanon

<sup>c</sup> Azerbaijan State University of Economics (UNEC) Clinic of Economics, Baku, Azerbaijan

<sup>d</sup> Department of Economics, Faculty of Economics and Administrative Sciences, Kirsehir Ahi Evran University, Kirsehir, Turkey

<sup>e</sup> Azerbaijan State University of Economics (UNEC), Research Center for Monetary Economics, Baku, Azerbaijan

<sup>f</sup> Department of Economics, University of South Florida, Tampa, USA

<sup>g</sup> Department of Business Administration, Varendra University, Rajshahi, Bangladesh

<sup>h</sup> Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon

<sup>i</sup> European Center of Economics, Azerbaijan State University of Economics (UNEC), Istiqlaliyyat Str. 6, Baku, Azerbaijan

<sup>j</sup> Faculty of Economics & Administrative Sciences, European University of Lefke, Lefke, Northern Cyprus, TR-10, Mersin, Turkey

<sup>k</sup> School of Business Administration, ILMA University, Karachi, 75190, Pakistan

## ARTICLE INFO

### Keywords:

The Environmental Kuznets curve  
CO<sub>2</sub> emissions  
WWW  
Environmental degradation  
Renewable energy consumption

## ABSTRACT

This study aims to investigate the impacts of renewable energy consumption, internet usage, mineral rent, and economic growth on CO<sub>2</sub> emissions across 27 OECD nations between 2001 and 2020. We employ a panel quantile regression technique to discover the heterogeneous effects of these variables for the various quantile levels of environmental destruction. The panel quantile regression approach found the Environmental Kuznets curve dominated countries in which CO<sub>2</sub> emissions were low. Additionally, the negative relationship between renewable energy consumption and CO<sub>2</sub> emissions yielded in the paper suggests the potential benefits of incentivizing and investing in renewable sources. Internet usage demonstrates a negative impact on CO<sub>2</sub> emissions, showcasing the role of digital technologies in promoting sustainability. Accordingly, internet use improves environmental quality due to more efficient, sustainable, and eco-friendly practices, which increase productivity. However, a positive association between mineral rents and environmental deterioration emphasizes the necessity of strategic policies to balance economic benefits with environmental preservation. Our study provides policy-makers with valuable insights into tailoring effective strategies for sustainable development, renewable energy adoption, digitalization, and natural resource utilization while addressing environmental degradation.

## 1. Introduction

The global community finds itself at a critical juncture in the contemporary era, grappling with environmental degradation's intricate web of challenges (henceforth, ED). As the planet faces escalating threats from climate change, pollution, and resource depletion, understanding the multifaceted drivers of ED becomes imperative for devising effective mitigation and sustainability strategies (Solangi and Jianguo, 2023). The present paper sheds light on the interconnected dynamics of renewable energy, internet usage, mineral rents, and their collective

influence on ED. Climate change is the foremost challenge confronting nations worldwide in the new millennium. The imperative to diminish global carbon dioxide (CO<sub>2</sub>) production represents a pervasive environmental menace, necessitating a collective international response to formulate a substantive solution; otherwise, the escalating trajectory of CO<sub>2</sub> emissions will pose an even more formidable challenge (Allen et al., 2018). The consistent rise in the average global temperature is rendering habitats increasingly inhospitable and economically burdensome, presenting a significant threat to public health in all nations, whether developed or developing, affluent or impoverished (Watts et al., 2021).

\* Corresponding author. Department of Economics, Faculty of Economics and Administrative Sciences, Anadolu University, Tepebaşı, Eskişehir, Turkey.

E-mail addresses: [cemisik@anadolu.edu.tr](mailto:cemisik@anadolu.edu.tr) (C. Işık), [ubulut@ahievran.edu.tr](mailto:ubulut@ahievran.edu.tr) (U. Bulut), [serdarongan@usf.edu](mailto:serdarongan@usf.edu) (S. Ongan), [bahasibul@vu.edu.bd](mailto:bahasibul@vu.edu.bd) (H. Islam), [irfansahar@bit.edu.cn](mailto:irfansahar@bit.edu.cn) (M. Irfan).

<https://doi.org/10.1016/j.resourpol.2024.105025>

Received 12 January 2024; Received in revised form 29 February 2024; Accepted 19 April 2024

Available online 22 April 2024

0301-4207/© 2024 Elsevier Ltd. All rights reserved.

Renewable energy is key in addressing ED and achieving sustainable development. Reducing reliance on conventional energy sources, contributing to ED, and posing a severe risk to the world's energy security is driving this shift away from fossil fuels. Worldwide investments in renewable technologies are increasing rapidly, and a statistically significant negative relationship between renewable energy consumption and ED has been found in several countries, including the USA, China, Japan, Brazil, Canada, Germany, and South Korea (Hadj et al., 2023). Some factors, such as implementing laws and regulations, preventing corruption, and utilizing information and communication technologies (ICTs), strengthen the beneficial impact of renewable energy in mitigating ED. Governments should consider subsidizing green energy to mitigate ecological degradation further (Sharif et al., 2020). Overall, renewable energy is considered a crucial element of the sustainable paradigm and can contribute to addressing environmental challenges and promoting a more sustainable future (Işık et al., 2024a, 2024b, 2024c, 2024d; Ongan et al., 2022).

The digital age has witnessed an unprecedented surge in internet usage, fundamentally transforming how societies communicate, work, and access information (Radulescu et al., 2024). However, the burgeoning demand for digital connectivity and the infrastructure required to support it may have unexplored environmental implications. The intricate relationship between internet usage and ED is marked by a dual nature, embodying both positive and negative implications. While some studies underscore the environmental costs associated with increased electricity consumption and CO<sub>2</sub> emissions stemming from extensive internet usage (Ozpolat, 2021), others point to a counterintuitive trend where heightened internet engagement correlates with a fall in ED (Magazzino et al., 2021). Moreover, this impact extends beyond direct environmental consequences, influencing pro-environmental behaviors such as heightened environmental knowledge and perception of pollution threats (Liu et al., 2021). The evaluation of this connection is complex, contingent upon factors like the specific environmental issue and the demographic composition of the population (Hadj et al., 2023). As society becomes increasingly interconnected through digital technologies, unraveling the nuanced dynamics of internet usage and its environmental impacts becomes essential for informed decision-making and sustainable development.

Furthermore, mineral rents, which include gold, zinc, tin, lead, copper, iron, silver, phosphate, silver, and nickel and are derived from the extraction and exploitation of natural resources, have historically played an essential role in the economic development process, and have a significant influence on ED. The nuanced interplay between these mineral rents and their environmental impact has been the subject of considerable scrutiny. It is underscored by their intrinsic role in shaping economic prosperity and ED (Aladejare, 2022). Throughout history, these mineral resources have served as fundamental drivers of economic growth, contributing to the formation and sustenance of industries, infrastructure, and technological advancements. However, this economic boon has not transpired without ecological consequences. The extraction and utilization of mineral rents have been associated with a substantial ecological footprint, manifesting in deforestation, habitat disruption, soil degradation, and water contamination, posing a formidable challenge to environmental preservation. Hence, the environmental toll of mining activities raises concerns about the sustainability of such practices. This research aims to elucidate the nexus between mineral rents and ED, scrutinizing the ecological consequences of resource extraction and the potential trade-offs between economic gains and environmental preservation.

The existing body of research has independently examined the determinants of ED, such as renewable energy (Qing et al., 2024; Hadj et al., 2023; Simionescu et al., 2023), internet usage (Ozpolat, 2021; Magazzino et al., 2021), and mineral rents (Aladejare, 2022). However, studies specifically investigating the combined impact of these three factors on ED within the context of OECD countries remain largely unexplored. This study sets the following research questions (RQs):

RQ1: How is renewable energy consumption associated with ED across 27 OECD countries?

RQ2: To what extent does internet usage affect ED in 27 OECD countries?

RQ3: What roles do mineral rents play in influencing ED across 27 OECD countries?

In the present study, we focus on these RQs for 27 OECD countries using annual data from 2001 to 2020. Considering the heterogeneity of the data, we employ the panel quantile (PQ) regression method to address challenges associated with inefficiency and bias in results. This approach yields comprehensive outcomes by capturing subtleties at both the distribution's midpoint and extreme points. When traditional models may encounter difficulties due to heterogeneity or the oversight of extreme values, the quantile regression method emerges as a resilient and effective analytical tool. It rectifies inefficiencies and biases and provides researchers with a more nuanced comprehension of the entire distribution, thereby augmenting the reliability and depth of empirical findings.

This research introduces several significant contributions to literature. First, it stands out as pioneering research to analyze the influences of renewables consumption, internet usage, and mineral rents on ED for the OECD countries. This study also tested the well-known EKC hypothesis. This hypothesis, characterized by an inverted U-shaped relationship between ED and economic growth, provides a lens to understand how these variables interact over time. Examining renewable energy adoption, the study explores whether initial ED gives way to improvement as societies progress. Similarly, the analysis considers internet usage and mineral rents by evaluating if technological advancements and sustainable resource management offset their early contributions to ED as economies mature. This study aims to contribute a nuanced understanding of the complex dynamics shaping environmental outcomes in the context of evolving economic and technological landscapes.

The subsequent sections of this research are structured as follows: Section 2 summarizes the literature review and theoretical foundations. In Section 3, the model and data set are presented. The econometric strategy/estimation method is given in Section 4. Results are outlined in Section 5. Section 6 delves into a discussion and draws conclusions. The study's policy implications and suggestions for future research are delineated in Section 7.

## 2. Literature review

Numerous research initiatives have separately discovered the impacts of renewable energy consumption, internet usage, mineral rents, and economic growth on ED. However, a critical gap in the literature still exists for a more detailed investigation of these variables collectively. Therefore, we aim to highlight the gap by investigating the combined effects of renewables consumption, internet usage, and mineral rents on ED. Focusing specifically on OECD countries, this study tries to thoroughly analyze the intricate interplay between these factors, contributing valuable insights for researchers, policymakers, and stakeholders concerned with sustainable development and environmental conservation.

### 2.1. Theoretical background

In this subsection, this paper makes some inferences about the possible impacts of renewable energy, internet usage, and mineral rents on CO<sub>2</sub> emissions, focusing on the theoretical and empirical contributions of the previous studies. Renewables are clean and eco-friendly energy sources, meaning renewable consumption is expected to negatively affect ED. Many papers in the literature provide strong evidence that renewable energy can improve environmental quality in different countries or country groups (see, e.g., Işık et al., 2018; Sharif et al.,

2019; Amin et al., 2020a, 2020b; Ozcan et al., 2020; Ulucak et al., 2020; Sharif et al., 2020, 2020a; M. Ahmad et al., 2021; Godil et al., 2021; Sadiq et al., 2022; Ozturk et al., 2023; Işık et al., 2024e; Zhang et al., 2024).

The impact of internet usage on ED can be positive or negative, implying the effect of internet usage on environmental quality is unclear. On the one hand, a rise in internet utilization leads to an increase in online shopping and in the number of vehicles to deliver the purchased stuff to customers, which in turn could raise transportation-based CO<sub>2</sub> emissions (Al-Mulali et al., 2015). Moreover, as global electricity consumption rises because internet usage and fossil sources play a considerable role in electricity generation, internet use increasingly impacts CO<sub>2</sub> emissions (Salahuddin et al., 2016). Although new technological devices, namely LCDs, tablets, and laptops, use less energy than conventional devices, the rapid growth of demand for these devices can increase electricity consumption (Ozcan and Apergis, 2018). Similarly, internet use can improve environmental quality as the further utilization of the internet can increase productivity and decrease energy intensity (Awan et al., 2022). Besides, environmental destruction can be reduced through internet utilization since (i) goods that are sold on the internet are stored in depots which use less energy compared to shopping malls, (ii) online shopping results in fewer vehicles in traffic and traffic density decreases, and (iii) people can buy or sell second-hand goods on the internet which can save energy (Al-Mulali et al., 2015). Lastly, teleconferences and working remotely, which can be executed through the internet, can cause less energy usage, and positively influence environmental quality (Ozcan and Apergis, 2018). Within this scope, some papers in the extant literature find that internet use can enhance environmental quality (see, e.g., Al-Mulali et al., 2015; Ozcan and Apergis, 2018; Awan et al., 2022, among others), whereas some others detect that internet use worsens environmental quality (see, e.g., Salahuddin et al., 2016). On the other hand, Yi et al. (2023) concluded that internet usage increases individuals' perception of environmental pollution. Gyau et al. (2024) used the panel quantile autoregressive distributed lag (PQARDL) technique for the sub-Saharan Africa (SSA) region and found that internet use mitigates transport-based emissions.

Finally, mineral rents are expected to negatively affect environmental quality. Mineral rents, coal rents, oil rents, and forest rents are natural resource rents. As Bilgili et al. (2023) stress, natural resources are the raw materials utilized to generate products, and natural resources rents are defined as the difference between total income countries obtained through the extraction of natural resources and the cost of the extraction process. The influence of total natural resources rent on ED depends on the development of a country. Moreover, the type of natural resources is essential in assessing the impact of the resources on the environment (Pata and Isik, 2021). Although there is an expanding empirical literature focusing on the impacts of natural resources rents on the environment, previous papers used aggregated data for natural resources and investigated the impacts of total natural resources rents on the environment (see, e.g., Bekun et al., 2019; Ulucak et al., 2020; Pata and Isik, 2021; Erdogan, 2024; Liu et al. (2024); He et al., 2024). To our knowledge, the only study investigating the effects of mineral rents on environmental destruction belongs to Bilgili et al. (2023), who find that mineral rents worsen environmental quality.

Following Bilgili et al. (2023), we expect mineral rents to negatively affect the environment for the following reasons. First, tin, lead, zinc, iron, copper, and nickel are utilized in many heavy industry activities leading to environmental pollution, such as paper, cardboard, and cellulose industry, organic chemicals and petrochemicals, alkalis, chlorine, and inorganic chemicals, fertilizers, oil refineries, iron and steel foundries, motor vehicle and aircraft coating, and glass, cement, and asbestos production, etc. Second, minerals, such as gold and silver, are considerable components of wealth. In this way, an increase in mineral rents based on the increases in the prices of gold and silver may create a wealth effect and exacerbate consumption expenditures, which in turn can put pressure on the environment (Pata and Isik, 2021).

## 2.2. Empirical studies

Like this study, some previous empirical studies focusing on the Environmental Kuznets Curve hypothesis also examined the impacts of renewable energy, internet usage, or mineral rents on ED in several countries. For instance, Saqib et al. (2023) made a study that delved into the ecological footprint of the USA, focusing on digital financial inclusion and non-renewable and renewable energy usage as critical determinants. Utilizing data from 2005 to 2020, the analysis employed the quantile autoregressive lag (QARDL) method and Granger causality. The findings revealed a negative association between the examined variables and the ecological footprint of the USA. Notably, fossil energy consumption and growth positively influenced the ecological footprint, supporting the idea that certain aspects of economic advancement contributed to ED.

Moreover, this research aligned with the theory of the EKC, illustrating an initial stage where economic advancement is associated with an uptick in the ecological footprint, followed by a potential decline as environmental consciousness and sustainable practices evolve. Isik et al. (2023) demonstrated that renewables consumption accelerated the decrease in CO<sub>2</sub> emissions in G-7 countries but discovered no supportive outcome for the EKC hypothesis in BRIC countries. In a parallel context, Golpîra et al. (2023) explored the EKC hypothesis across 37 OECD nations between 1960 and 2019. The PQ regression approach indicated that economic growth did not significantly impact emissions. Instead, a U-shaped curve was evident in the central quartile, while an N-shaped curve emerged in the upper quartile. Cointegrating regressions further revealed that economic growth, fossil fuel consumption, and population negatively influenced the environment, with an encouraging finding indicating that renewable energy consumption led to a decline in CO<sub>2</sub>. The study's robustness was confirmed through panel causality tests, and individual country estimates underscored significant variability within the sample. Li et al. (2024) used a panel quantile (PQ) regression model for 38 countries and supported the EKC hypothesis. Prempeh (2024) used the Driscoll-Kraay panel regression and panel quantile estimation techniques for 10 countries. The author found evidence for the N-shaped EKC hypothesis.

Adebayo et al. (2021) investigated the correlation between technological innovation and natural resource rents within a multivariate framework, employing moments quantile regression (MMQR) on a dataset encompassing 10 newly industrialized countries (NICs) over the period 1990–2018. The findings validate the presence of the EKC hypothesis in NICs across various quantiles. Moreover, across all quantiles, technological innovation and the consumption of renewables contribute positively to environmental quality in NICs. Moreover, the joint impact of natural resource rents and technological innovation is a mitigating factor against ED, especially in higher quantiles (0.1–0.90). The study reveals that technological innovation indirectly influences the environment through the natural resource pathway, fostering sustainable exploration of resources in NICs. The study strongly advocates for endorsing technological innovation, sustainable use of natural resources, and accelerating economic growth rates by promoting the sustainable transformation of consumption and production in NICs.

The EKC hypothesis was developed based on the abundance of natural resources (NAT). Bekun et al. (2019) supported this hypothesis by identifying an inverse relationship between ED and the availability of natural resources rent in sixteen European Union nations. According to the findings, the excessive use of natural resources accelerated economic growth, leading to CO<sub>2</sub> emissions. To counteract this, adopting renewable energy sources acts as a protective measure for the environment against using fossil fuels, showcasing the EU's dedication to environmental conservation. Similarly, Huang et al. (2021) employed the QARDL technique to analyze the short- and long-term impacts of natural resource rents, urbanization, and financial development on CO<sub>2</sub> in the USA. Their empirical findings revealed that natural resource rents, urbanization, and financial sector growth significantly contributed to ED

across various regions. The study found a similar result as follows: historical levels of natural resource rents significantly impacted the historical levels of CO<sub>2</sub> emissions in the short run. [Tufail et al. \(2021\)](#) further argued that fiscal decentralization and institutional quality positively contributed to the level of environmental quality, whereas natural resource rents were associated with increased CO<sub>2</sub>.

The alignment of the EKC theory with renewable energy consumption, internet usage, and mineral rent suggested that initial stages of economic development might lead to heightened ED, particularly evident in mineral rent-driven activities and the environmental impact of expanding internet usage. However, as societies progress, there is a discernible turning point where adopting sustainable practices, technological innovation, and a transition to renewable energy sources contribute to a noteworthy decline in environmental harm. Studies exemplified by [Isik et al. \(2023\)](#) and [Adebayo et al. \(2021\)](#) emphasized the pivotal role of renewable energy in mitigating ED and showcased the potential for technology and mineral rents to act as mitigating factors ([Bilgili et al., 2023](#)). These findings underscored the pressing need for policy frameworks integrating environmental considerations, directing energy choices, technological advancements, and resource extraction practices toward sustainability to foster a balanced coexistence between economic development and environmental preservation. [Simionescu \(2024\)](#) utilized the ARDL model for V4 countries and found that renewable energy consumption reduces CO<sub>2</sub> emissions.

[Ben Jebli et al. \(2016\)](#) examined the relationship among carbon emissions, GDP, renewable energy consumption, non-renewable energy consumption, and international trade in 25 OECD nations using data from 1980 to 2010. Granger causality tests for the short run revealed bidirectional causality between renewables consumption and imports and unidirectional causality from exports to renewable energy, trade to CO<sub>2</sub> emissions, and output to renewable energy. Long-run bidirectional causal relationships were also found in the study. The hypothesis ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) estimators confirmed the EKC hypothesis and suggested that increasing trade and renewable energy use was an effective strategy to combat global warming.

In contrast, [Boluk and Mert \(2015\)](#) found a negative relationship when investigating the impact of renewable energy sources on greenhouse gas emissions in Turkey using the ARDL approach and the EKC hypothesis. They found a negative long-term correlation between renewable electricity production and CO<sub>2</sub> emissions. They found no evidence to support the EKC effect. The study also suggested a U-shaped association between per capita greenhouse gas and income, with a peak GDP per capita of 9920 US Dollars outside the sample period. The study posits the potential and indispensability of renewable energy sources in mitigating emissions in Turkey. In a parallel context, [Cerqueira Ben Jebli et al. \(2016\)](#) discovered the dynamic causal relationships between carbon emissions and real GDP, non-renewable electricity generation, and renewable electricity generation in Italy, utilizing data from 1960 to 2011. Their findings substantiated the EKC hypothesis, demonstrating that economic growth led to a gradual reduction in pollution. Furthermore, per capita renewable electricity production decreased carbon emissions in the short and long run. These results underscored the pivotal role of renewable electricity production as a crucial solution for curbing pollutant emissions over time, emphasizing the significance of sustainable energy production.

[Bilgili et al. \(2016\)](#) reviewed the EKC hypothesis by concentrating on the effect of renewable consumption on environmental quality. They utilized a panel dataset encompassing 17 OECD nations from 1977 to 2010 and employed panel FMOLS and DOLS models. The results affirmed the EKC hypothesis, revealing that GDP per capita and its squared term positively and negatively affected CO<sub>2</sub> emissions, respectively, while non-fossil energy consumption exhibited a negative impact on carbon dioxide emission. Notably, the validity of the EKC is found to be consistent across varying individual income levels. The study posited that nations could mitigate their contributions to global warming by

implementing policies that ensured equitable access to renewable energy resources and enhanced technologies in the renewable energy sector, consequently fostering economic growth.

Previous empirical research found Internet usage to impact environmental degradation (ED) significantly. [Ozpolat \(2021\)](#) showed that the association between ED and internet use was negative, indicating that increased internet usage led to decreased ED. The investigation scrutinized the influence of internet usage on ED within G-7 countries over the time frame from 1990 to 2015. The research revealed a negative relationship between internet usage and ED. Factors such as energy consumption and GDP per capita were also identified as contributors to degradation, meaning these variables exacerbated ED. The study identified a causal relationship (bidirectional) between energy use, internet use, and ecological footprint, indicating a mutual influence between these variables. Additionally, a unidirectional causal relationship was observed from GDP, trade, and financial development index to ecological footprint, suggesting that changes in these economic factors might impact ED unilaterally.

[Wang et al. \(2021\)](#) explored the impact of internet use on residents' engagement in practices aimed at improving the living environment, particularly in developing countries. Drawing on extensive household survey data from China, the study employed the attitude-behavior context theory to examine the treatment effects of internet use on the adoption of integrated flushing toilets and centralized disposal of domestic waste. The findings revealed internet usage enhanced the possibility of adopting integrated flushing toilets and centralized disposal of domestic waste by 24.5% and 19.0%, respectively. However, counterfactual results suggested a slightly higher increase, with the possibility of adopting these practices rising by 28.8% and 26.4%. Furthermore, the study uncovered regional variations, highlighting a more pronounced impact in less developed and urban areas. [Wathuge and Sedera \(2022\)](#) examined the influence of internet usage on the environment with a focus on price affordability. Utilizing a population-based survey and a polynomial regression analysis involving 326 individuals, the research sought to elucidate the connection between internet prices and environmental awareness. The findings reveal that affordability plays a moderating role in the relationship between environmental awareness and internet usage.

Oil rents, forest rents, mineral rents, and coal rents constitute the definite categories of natural resources rents. These terms delineate the financial returns derived from exploiting and utilizing distinct natural resources, encompassing minerals, forests, oil, and coal. Such rents bear substantial significance in national economies, influencing diverse facets such as economic development, environmental sustainability, and societal dynamics. [Agboola et al. \(2021\)](#) examined the relationship between carbon dioxide emissions, oil rent, and natural resource rents in Saudi Arabia between 1971 and 2016. The research indicated that both natural resource rents and oil rents contributed positively to economic development, with the effect of oil rent being comparatively less pronounced. Concurrently, economic growth and non-renewable energy consumption adversely impact environmental quality. The paper suggested that Saudi Arabia should consider incorporating green and sustainable energy sources into its energy portfolio.

Additionally, [Zaidi et al. \(2018\)](#) observed a linkage between carbon dioxide emissions, non-renewable energy, and economic growth in Pakistan from 1970 to 2016. The study highlighted that economic growth stimulated non-renewable energy consumption, resulting in ED. Surprisingly, the research found no significant correlation between renewable energy consumption and carbon dioxide emissions. The researcher found that oil rents exacerbated ED by elevating nitrous oxide and carbon dioxide emissions. In a study conducted by [Dogan and Seker \(2016\)](#), an examination of the relationships among financial development, urbanization, trade openness, energy consumption, GDP, and carbon dioxide emissions was undertaken using data spanning the period from 1960 to 2010 for the USA. Upon establishing the cointegration of these factors, the study concluded that urbanization and

energy consumption contributed to increased carbon dioxide emissions. The researchers recommended the implementation of an effective energy policy in the nation. In a separate study by [Dogan et al. \(2020\)](#) focusing on the economic structure of European regions from 1980 to 2014, the outcomes revealed an inverse U-shaped relation between CO<sub>2</sub> and economic growth.

Furthermore, [Dogan and Seker \(2016\)](#) validated the EKC hypothesis for the EU over recent decades. They employed advanced econometric techniques, utilizing trade openness, real income, non-renewable energy, and renewable energy as explanatory variables and CO<sub>2</sub> emissions as the dependent variable. Their approach involved panel data models. The results indicated that CO<sub>2</sub> emissions were increased by non-renewable energy and decreased by trade and renewable energy. [Pata et al. \(2024\)](#) utilized the Fourier FMOLS estimator for different countries and supported the EKC hypothesis. They also found that found renewable energy technologies are cointegrated with CO<sub>2</sub> emissions.

### 3. Model and data set

This paper examines the influences of renewable energy consumption, internet usage, and mineral rents on environmental degradation (ED) for 27<sup>1</sup> OECD nations between 2001 and 2020 within an EKC framework. The study considers some OECD nations because no data is available for some of them. The countries in the sample are exhibited in Annex 1. The empirical model in the paper is established below:

$$\ln\text{CO}_{2it} = \delta_0 + \delta_1 \ln Y_{it} + \delta_2 (\ln Y)_{it}^2 + \delta_3 \text{RENEW}_{it} + \delta_4 \text{INTERNET}_{it} + \delta_5 \text{MINRENT}_{it} + \varepsilon_{it} \quad (1)$$

where CO<sub>2</sub>, Y, Y<sup>2</sup>, RENEW, INTERNET, MINRENT, and  $\varepsilon$  stand for carbon dioxide emission emissions (metric tons per capita), GDP per capita (constant 2015 USD), the square of GDP per capita, renewable energy consumption (% of total final energy consumption), individuals using the internet (% of total population), mineral rents (% of GDP), and the error term, respectively. As is seen, the natural logarithmic values are used for CO<sub>2</sub> emissions per capita, GDP per capita, and the square of GDP per capita. Besides, mineral rents are defined as the value of production for a stock of minerals at world prices minus their total costs of production. Minerals included in the calculation are phosphate, bauxite, silver, nickel, copper, iron, zinc, lead, gold, and tin. All series are extracted from the [World Bank \(2023\)](#).

As was previously stressed, if  $\delta_1 > 0$  and  $\delta_2 = 0$ , a rise in economic activities leads to a rise in ED. Besides, the EKC prevails if  $\delta_1 > 0$  and  $\delta_2 < 0$ . As renewables are clean and eco-friendly energy sources,  $\delta_3$  is expected to be statistically significant and negative. The sign of  $\delta_4$  can be positive or negative, implying the theoretical effect of internet usage on environmental quality is not clear. Finally, we expect the coefficient of mineral rents, namely  $\delta_5$ , to be positive.

### 4. Econometric strategy

A panel data set consists of a group of cross-sectional units (people, households, countries, etc.) that are observed over time ([Hill et al., 2011](#)). In other words, panel data sets are repeated observations on the same set of cross-sectional units ([Johnston and Dinardo, 1996](#)). A basic panel data model can be described as follows ([Greene, 2003](#); [Baltagi, 2005](#)):

$$y_{it} = \alpha + \beta x_{it} + u_{it} \quad i = 1, \dots, N; \quad t = 1, \dots, T \quad (2)$$

where  $i$  represents cross-sectional units/the cross-sectional dimension

<sup>1</sup> 27 OECD countries are Australia, Austria, Canada, Chile, Colombia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, The Republic of South Korea, Luxembourg, Mexico, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Turkey, UK, USA.

and  $t$  denotes time/the time-series dimension. The traditional panel data estimators, such as the pooled regression, fixed effects, and random effects models, might yield inefficient and biased results if the data set displays heterogeneity ([Binder and Coad, 2011](#); [Kocak et al., 2019](#)). Additionally, these approaches provide researchers with the midpoint of the distribution, and the distribution's terminal points are ignored by these methods ([Kocak et al., 2019](#)). However, a fundamental advantage of a panel data model is that it allows researchers great flexibility in economic modeling ([Greene, 2003](#)). Hence, the quantile regression technique can offer more efficient outcomes compared to the traditional models mentioned above. Accordingly, the quantile regression technique allows the coefficients to vary with different quantiles ([Wang et al., 2019](#)). Put differently, the quantile regression method can provide different coefficients for independent variables depending on the values of the dependent variable in the empirical model. Due to this advantage, the quantile regression approach has been widely employed in econometric analyses over the last decades ([Lin and Xu, 2017](#)). The seminal paper by [Koenker and Bassett \(1978\)](#) introduces the quantile regression approach, which regards data heterogeneity and presents results for the midpoint and the distribution's extreme points ([Kocak et al., 2019](#)). This methodology is expressed as follows:

$$Q_{y_i}(\tau|x_i) = x_i^T \beta_\tau \quad (3)$$

In Eq. (3),  $y_i$  is the conditional quantile,  $x_i$  denotes a vector of independent variables, and  $\beta_\tau$  indicates the coefficients of independent variables. Moreover,  $\tau$  serves as the quantile index, taking values between 0 and 1. In this study, following [Koenker \(2004\)](#) and [Kocak et al., \(2019\)](#), we outline the quantile model for a panel data analysis as the following:

$$Q_{y_i}(\tau|\alpha_i, x_{it}) = \alpha_i + x_{it}^T \beta(\tau) \quad (4)$$

In Eq. (4), the individual-specific effects are represented by the parameter  $\alpha_i$ . To concurrently estimate the model at various quantiles, the following process is suggested by [Koenker \(2004\)](#):

$$\min_{(\alpha, \beta)} \sum_{k=1}^K \sum_{t=1}^T \sum_{i=1}^N w_{it} p_{rk} (y_{it} - \alpha_i - x_{it}^T \beta(\tau_k)) \quad (5)$$

Here, the letters  $K$ ,  $T$ , and  $N$  respectively denote the number of quantiles, the time span, and the number of cross-section units. Assuming  $y_{it} - \alpha_i - x_{it}^T \beta(\tau_k) = \varphi$ , the weights are expressed as follows ([Wang et al., 2019](#)):

When  $\varphi < 0$ ,  $w_{it} = \tau$ .

When  $\varphi > 0$ ,  $w_{it} = 1 - \tau$ .

[Koenker and Bassett \(1982\)](#) also test whether the parameter estimations for different quantiles are equal via the following null hypothesis:

$$H_0 = \beta(\tau_1) = \beta(\tau_2) = \dots = \beta(\tau_k) \quad (6)$$

The null hypothesis is subjected to examination through the Wald test. Rejecting this hypothesis suggests the parameters exhibit significant differences across quantiles, providing support for the adoption of the PQ method.

### 5. Results

Descriptive statistics for the variables under consideration are demonstrated in [Table 1](#). Accordingly, all descriptive statistics except standard deviation and Jarque-Bera of  $(\ln Y)^2$  are greater than those of other variables. Besides,  $\ln \text{CO}_2$  appears to have the lowest descriptive statistics apart from Jarque-Bera. Finally, the rejection of the null hypothesis regarding the normal distribution of the data for all variables is suggested by the Jarque-Bera statistics at the 1% significance level, indicating the dataset deviates from a normal distribution. Therefore, utilizing the PQ regression method for estimating coefficients in the model concerning the Jarque-Bera statistics is warranted.

**Table 1**  
Descriptive statistics.

| Variable           | Mean    | Median  | Max.    | Min.   | Std. Dev. | Jarque-Bera |
|--------------------|---------|---------|---------|--------|-----------|-------------|
| lnCO <sub>2</sub>  | 1.979   | 2.032   | 3.243   | 0.307  | 0.548     | 38.684      |
| lnY                | 10.223  | 10.441  | 11.630  | 8.295  | 0.724     | 28.764      |
| (lnY) <sup>2</sup> | 105.046 | 109.017 | 135.256 | 68.822 | 14.544    | 18.889      |
| RENEW              | 17.402  | 12.540  | 61.290  | 0.690  | 13.949    | 170.901     |
| INTERNET           | 65.777  | 71.670  | 98.459  | 2.854  | 23.357    | 58.577      |
| MINRENT            | 0.519   | 0.029   | 16.870  | 0.000  | 1.751     | 38.613      |

Note: \* denotes significance at 1% level.

The correlation matrix is exhibited in Table 2. As is seen, there is a lack of high correlation among the explanatory variables, except for the correlation between lnY and (lnY)<sup>2</sup>, indicating the absence of a multicollinearity issue in the established model. Hence, Eq. (1) can be estimated via the PQ regression approach.

The results derived from the PQ regression technique can be found in Table 3. Accordingly, the rejection of the null hypothesis through the slope equality test that states the slope parameters are identical across quantiles at the 1% significance level implies that there are variations in the slope parameters across different quantile values. Subsequently, this paper concentrates on the results of parameter estimations. The PQ regression approach yields the following outcomes: (i) GDP per capita enhances CO<sub>2</sub> emissions per capita for the countries with low CO<sub>2</sub> emissions per capita and high CO<sub>2</sub> emissions per capita. (ii) The square of GDP per capita reduces CO<sub>2</sub> emissions per capita for the countries with low CO<sub>2</sub> emissions per capita. (iii) CO<sub>2</sub> emissions per capita are negatively related to renewable energy consumption at all quantile levels. (iv) Internet usage has a decreasing influence on CO<sub>2</sub> emissions per capita for the countries where CO<sub>2</sub> emissions per capita are low. (v) Mineral rents do not affect CO<sub>2</sub> emissions per capita in countries with high CO<sub>2</sub> emissions per capita, whereas they amplify CO<sub>2</sub> emissions in other countries.

After presenting the results of the PQ regression model in the table, the paper visually demonstrates the outputs of the PQ regression analysis via Fig. 1.

In addition to the previously presented findings, further insights can be gleaned from Table 3 and Fig. 1. The additional outcomes are outlined below:

- (i) The EKC hypothesis dominates only in countries with the lowest CO<sub>2</sub> emissions per capita (20th quantile level), while a rise in GDP per capita results in a rise in CO<sub>2</sub> emissions in countries with the highest CO<sub>2</sub> emissions per capita (80th quantile level).
- (ii) CO<sub>2</sub> emissions per capita are further influenced by renewables consumption in countries with high CO<sub>2</sub> emissions per capita (80th quantile level).
- (iii) The sensitivity of CO<sub>2</sub> emissions per capita to internet usage is higher in countries with the lowest CO<sub>2</sub> emissions per capita (20th quantile level).
- (iv) CO<sub>2</sub> emissions per capita are more affected by mineral rents in countries with the lowest CO<sub>2</sub> emissions per capita (20th quantile level).

**Table 2**  
Correlation matrix.

| Variable           | lnCO <sub>2</sub> | lnY    | (lnY) <sup>2</sup> | RENEW | INTERNET | MINRENT |
|--------------------|-------------------|--------|--------------------|-------|----------|---------|
| lnCO <sub>2</sub>  | 1                 |        |                    |       |          |         |
| lnY                | 0.726             | 1      |                    |       |          |         |
| (lnY) <sup>2</sup> | 0.721             | 0.999  | 1                  |       |          |         |
| RENEW              | -0.328            | 0.105  | 0.114              | 1     |          |         |
| INTERNET           | 0.341             | 0.609  | 0.605              | 0.246 | 1        |         |
| MINRENT            | -0.118            | -0.196 | -0.194             | 0.121 | -0.109   | 1       |

**Table 3**  
PQ regression results.

| Variable           | Quantile levels (τ) |                     |                    |                    |                    |
|--------------------|---------------------|---------------------|--------------------|--------------------|--------------------|
|                    | 20th                | 40th                | 50th               | 60th               | 80th               |
| lnY                | 4.016*<br>(0.000)   | 1.051***<br>(0.069) | 0.547<br>(0.294)   | 0.775<br>(0.164)   | 1.814**<br>(0.025) |
| (lnY) <sup>2</sup> | -0.173*<br>(0.000)  | -0.021<br>(0.451)   | 0.004<br>(0.869)   | -0.006<br>(0.797)  | -0.056<br>(0.149)  |
| RENEW              | -0.013*<br>(0.000)  | -0.014*<br>(0.000)  | -0.014*<br>(0.000) | -0.015*<br>(0.000) | -0.017*<br>(0.000) |
| INTERNET           | -0.003*<br>(0.000)  | -0.001*<br>(0.064)  | -0.001<br>(0.269)  | -0.001<br>(0.710)  | -0.001<br>(0.686)  |
| MINRENT            | 0.019*<br>(0.000)   | 0.018*<br>(0.009)   | 0.018**<br>(0.010) | 0.017**<br>(0.012) | 0.024<br>(0.193)   |

Slope equality test's results.

Wald test statistic: 92.680\* (0.000)

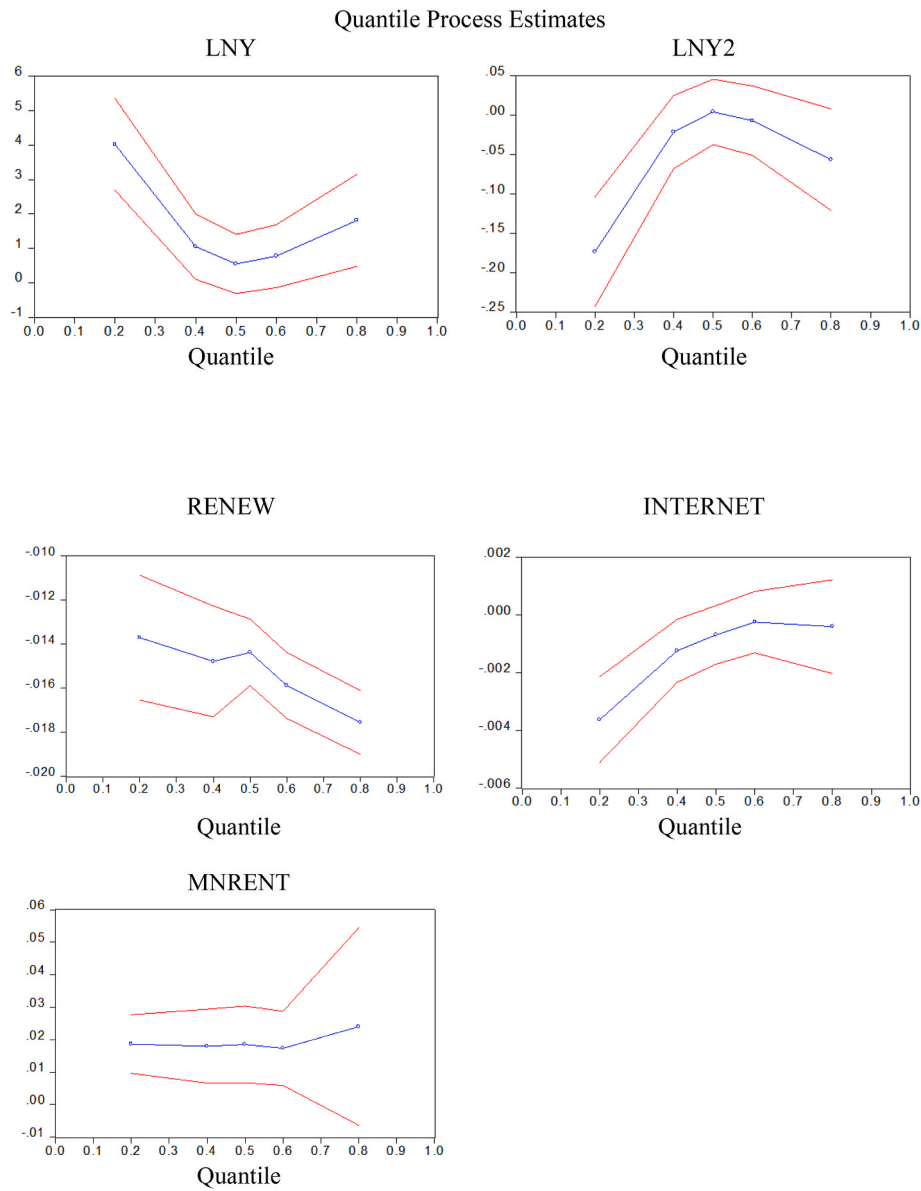
Notes: Values in parentheses indicate prob. values. \*, \*\*, \*\*\* denote 1%, 5% and 10% significance, respectively.

The findings obtained from Table 3 and Fig. 1 reveal that the results seriously differ by the quantile levels. This means that the level of CO<sub>2</sub> emissions is highly considerable in exploring the possible influences of internet utilization and mineral rents on CO<sub>2</sub> emissions.

## 6. Discussion and conclusion

The comprehensive research analysis reveals a multifaceted relationship between renewable energy consumption, internet usage, and mineral rent utilization in shaping CO<sub>2</sub> emissions across 27 OECD nations. We discovered some compelling findings by performing a quantile distribution between the 20th and 80th quantile levels. The EKC hypothesis shows a significant and positive association between GDP per capita (lnY) and CO<sub>2</sub> emissions at various income levels, specifically the 20th, 40th, and 80th quantiles. This implies that as a country's economy grows, CO<sub>2</sub> emissions also increase. Besides, the EKC appears to dominate in countries where CO<sub>2</sub> emissions are relatively low. This means that countries with low CO<sub>2</sub> emissions can decrease CO<sub>2</sub> emissions after income attains a threshold value. Previous researchers found similar results about the linkage between income and CO<sub>2</sub> emissions (Sultana et al., 2023).

The association between renewables consumption and CO<sub>2</sub> emissions can be interpreted within the framework of the EKC hypothesis. Initially, as a nation's income increases, there might be a rise in CO<sub>2</sub> emissions due to the higher energy demands associated with industrialization and growth. However, as the economy grows and income reaches a certain level, the EKC hypothesis suggests that the relationship between economic growth and CO<sub>2</sub> emissions becomes negative. In this later stage, increased awareness of environmental issues, technological advancements, and policy interventions may lead to a shift toward environmentally friendly and more sustainable energy sources, such as renewables. As a result, the negative relationship implies that the higher adoption of renewable energy is related to lower CO<sub>2</sub> emissions, aligning with the downward slope of the inverted U-shaped curve proposed by the EKC hypothesis. This scenario represents a transition towards environmentally friendly practices as economies advance beyond a certain development threshold (Godil et al., 2021).



Note: Blue lines demonstrate the coefficients, while red lines depict the 90% confidence intervals.

Fig. 1. PQ regression parameters' dynamics.

Note: Blue lines demonstrate the coefficients, while red lines depict the 90% confidence intervals.

Internet usage negatively affects CO<sub>2</sub> emissions, particularly when examining the 20th and 40th quantiles. Within the frame of the EKC hypothesis, this finding implies a nuanced interaction between economic development, internet usage, and environmental impact. The negative relationship suggests that an increase in internet usage is associated with a decrease in CO<sub>2</sub> emissions. This could be interpreted as an indication that, at these levels, the adoption and utilization of information and communication technologies, like the internet, might contribute to more efficient and sustainable practices, potentially leading to lower carbon emissions.

The analysis outcomes signify a positive relationship between the rents generated from minerals and environmental degradation (ED) in the 27 OECD countries. While this finding suggests that the substantial income from mineral rents could boost government revenue, it also increases CO<sub>2</sub> emissions. Furthermore, rents derived from natural resources encompassing oil, forests, and minerals contribute to economic growth, as highlighted by [Agboola et al. \(2021\)](#) and [Sinha and Sengupta](#)

[\(2019\)](#). This outcome is not surprising as the extraction of minerals and oil serves as a direct catalyst for the augmentation of economic growth, subsequently causing a surge in CO<sub>2</sub> emissions. Therefore, a prudent approach is advisable when considering the sustainability and desirability of the achieved economic growth, especially at the expense of ED, potential.

### 7. Policy and practical implications

The research outcomes carry significant policy implications across various dimensions. In line with the EKC hypothesis, the positive relationship between income and CO<sub>2</sub> suggests that policies to mitigate environmental impact should accompany economic development strategies. Governments should consider implementing sustainable practices, investing in green technologies, and introducing regulatory measures to ensure that economic growth does not occur at the expense of increased carbon emissions. Furthermore, the negative association

between renewable energy and CO<sub>2</sub> emissions underscores the potential benefits of promoting and investing in renewables. Policymakers can use this insight to develop and strengthen incentives for renewable energy adoption, fostering a transition to sustainable and eco-friendly energy practices. The negative relationship between internet usage and CO<sub>2</sub> emissions highlights the role of digital technologies in promoting environmental efficiency. Encouraging the adoption of eco-friendly technologies and practices within the digital sector may contribute to a more sustainable development trajectory. However, the positive correlation between mineral rent utilization and ED requires a careful and strategic approach. Policymakers should explore measures to balance the economic benefits of mineral rents with environmental preservation efforts, such as implementing sustainable extraction practices, enforcing environmental regulations, and diversifying revenue sources. These policy implications emphasize the need for an integrated and comprehensive approach to address the environmental challenges associated with economic development, energy, digitalization, and natural resource utilization.

This paper recommends some new research topics to scholars. Accordingly, as Zhang and Meng (2019) and Wang and Xu (2021) denote, there might be an inverted U-shaped relationship between internet usage and ED, meaning environmental quality first worsens and then improves based on internet usage. This topic is worth examining, considering the possible positive and negative impacts of internet usage on the environment, explained in Section 2. Besides, the influences of other natural resource rents, such as forest rents, oil rents, and coal rents, on the environment can be separately analyzed in future studies. Finally, some recent studies stress artificial intelligence (AI) for energy industry and management and energy system optimization (e.g., Zahraee et al., 2016; Abdalla et al., 2021; Ahmad et al., 2021; Li et al., 2023; among others). Future studies can consider AI for making energy-based analyses.

The following practical implications were produced in line with the study's results: (i) the negative relationship between internet use and CO<sub>2</sub> emissions reveals the necessity of adopting and promoting environmentally friendly technologies in the digital sector. (ii) the positive relationship between mineral rent usage and environmental degradation reveals the need to balance the economic benefits of mineral lease use with environmental protection efforts.

Due to data availability, only 27 of the 38 OECD countries could be included as sample countries in this study. Therefore, the study's empirical findings should be regarded and interpreted within the context of these 27 countries listed in the text rather than for all OECD countries. The absence of these countries can be acknowledged as a limitation of this study.

#### CRediT authorship contribution statement

**Cem Işık:** Conceptualization, Data curation, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft. **Umit Bulut:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Serdar Ongan:** Investigation, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Hasibul Islam:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Validation. **Muhammad Irfan:** Validation, Visualization, Writing – original draft, Writing – review & editing.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

Data will be made available on request.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.resourpol.2024.105025>.

#### References

- Abdalla, A.N., Nazir, M.S., Tao, H., Cao, S., Ji, R., Jiang, M., Yao, L., 2021. Integration of energy storage system and renewable energy sources based on artificial intelligence: an overview. *J. Energy Storage* 40, 102811.
- Adebayo, T.S., Akadiri, S.S., Adedapo, A.T., Usman, N., 2021. Does interaction between technological innovation and natural resource rent impact environmental degradation in newly industrialized countries? New evidence from method of moments quantile regression. *ESPR* 29, 3162–3169. <https://doi.org/10.1007/s11356-021-17631-y>.
- Agboola, M.O., Bekun, F.V., Joshua, U., 2021. Pathway to environmental sustainability: nexus between economic growth, energy consumption, CO<sub>2</sub> emission, oil rent and total natural resources rent in Saudi Arabia. *Resour. Pol.* 74 (C), 102380 <https://doi.org/10.1016/j.resourpol.2021.102380>.
- Ahmad, M., et al., 2021. Heterogeneous links among urban concentration, non-renewable energy use intensity, economic development, and environmental emissions across regional development levels. *Sci. Total Environ.* 765, 144527.
- Ahmad, T., et al., 2021. Artificial intelligence in sustainable energy industry: status Quo, challenges and opportunities. *J. Clean. Prod.* 289, 125834.
- Al-Mulali, U., et al., 2015. The global move toward Internet shopping and its influence on pollution: an empirical analysis. *ESPR* 22 (13), 9717–9727.
- Aladejare, S.A., 2022. Natural resource rents, globalization, and environmental degradation: new insight from 5 richest African economies. *Resour. Pol.* 78, 102909 <https://doi.org/10.1016/j.resourpol.2022.102909>.
- Allen, M., et al., 2018. Special Report: Global Warming of 1.5 C. Intergovernmental Panel on Climate Change (IPCC).
- Amin, A., et al., 2020a. Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. *Clean Technol. Environ. Policy* 22, 1725–1734.
- Amin, A., et al., 2020b. The impacts of different proxies for financialization on carbon emissions in top-ten emitter countries. *Sci. Total Environ.* 740, 140127.
- Awan, A., et al., 2022. The impact of renewable energy, internet use and foreign direct investment on carbon dioxide emissions: a method of moments quantile analysis. *Renew. Energy* 189 (C), 454–466.
- Baltagi, B., 2005. *Econometric Analysis of Panel Data*, third ed. John Wiley & Sons, Inc, USA.
- Bekun, F.V., et al., 2019. Toward a sustainable environment: nexus between CO<sub>2</sub> emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Sci. Total Environ.* 657, 1023–1029.
- Ben Jebli, M., et al., 2016. Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecol. Indic.* 60, 824–831. <https://doi.org/10.1016/j.ecolind.2015.08.031>.
- Bilgili, F., et al., 2016. The dynamic impact of renewable energy consumption on CO<sub>2</sub> emissions: a revisited Environmental Kuznets Curve approach. *Renew. Sustain. Energy Rev.* 54 (C), 838–845. <https://doi.org/10.1016/j.rser.2015.10.080>.
- Bilgili, F., et al., 2023. Disaggregating the impact of natural resource rents on environmental sustainability in the MENA region: a quantile regression analysis. *Resour. Pol.* 85, 103825.
- Binder, M., Coad, A., 2011. From Average Joe's happiness to Miserable Jane and Cheerful John: using quantile regressions to analyze the full subjective well-being distribution. *J. Econ. Behav. Organ.* 79 (3), 275–290.
- Boluk, G., Mert, M., 2015. The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach. *Renew. Sustain. Energy Rev.* 52, 587–595. <https://doi.org/10.1016/j.rser.2015.07.138>.
- Cerdeira Bento, J.P., Moutinho, V., 2016. CO<sub>2</sub> emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. *Renew. Sustain. Energy Rev.* 55 (C), 142–155. <https://doi.org/10.1016/j.rser.2015.10.151>.
- Dogan, E., Seker, F., 2016. Determinants of CO<sub>2</sub> emissions in the European Union: the role of renewable and non-renewable energy. *Renew. Energy* 94 (C), 429–439. <https://doi.org/10.1016/j.renene.2016.03.078>.
- Dogan, E., et al., 2020. The analysis of 'Financial Resource Curse' hypothesis for developed countries: evidence from asymmetric effects with quantile regression. *Resour. Pol.* 68, 101773 <https://doi.org/10.1016/j.resourpol.2020.101773>.
- Erdogan, S., 2024. On the impact of natural resources on environmental sustainability in African countries: a comparative approach based on the EKC and LCC hypotheses. *Resour. Pol.* 88, 104492.
- Godil, D.I., et al., 2021. Investigate the role of technology innovation and renewable energy in reducing transport sector CO<sub>2</sub> emission in China: a path toward sustainable development. *Sustain. Dev.* 29 (4), 694–707.
- Golpira, H., et al., 2023. Examining the energy-environmental Kuznets curve in OECD countries considering their population. *ESPR* 30 (41), 94515–94536. <https://doi.org/10.1007/s11356-023-28923-w>.
- Greene, W., 2003. *Econometric Analysis*, fourth ed. Prentice Hall, New Jersey.

- Gyau, B.E., Li, Y., Adu, D., 2024. Investigating the impact of ICT on transport-based CO<sub>2</sub> emissions: empirical evidence from a quantile cointegration regression analysis. *Environ. Sci. Pollut. Res.* 31, 4606–4629. <https://doi.org/10.1007/s11356-023-31395-7>, 2024.
- Hadji, T.B., et al., 2023. Renewable energy for achieving environmental sustainability: institutional quality and information and communication technologies as moderating factors. *ESPR* 30 (30), 75799–75816. <https://doi.org/10.1007/s11356-023-27568-z>.
- He, Y., Wang, S., Chen, N., 2024. Mineral rents, natural resources depletion, and ecological footprint nexus in high emitting countries: panel GLM analysis. *Resour. Pol.* 89 <https://doi.org/10.1016/j.resourpol.2023.104472>.
- Hill, R.C., Griffiths, W.E., Lim, G.C., 2011. *Principles of Econometrics*, fourth ed. John Wiley & Sons, Inc, USA.
- Huang, S.Z., et al., 2021. The impact of natural resource rent, financial development, and urbanization on carbon emission. *ESPR* 30 (15), 42753–42765. <https://doi.org/10.1007/s11356-021-16818-7>.
- Isik, C., et al., 2018. A nexus of linear and non-linear relationships between tourism demand, renewable energy consumption, and economic growth: theory and evidence. *Int. J. Tourism Res.* 20 (1), 38–49.
- Isik, C., et al., 2023. Renewable energy, economic freedom and economic policy uncertainty: new evidence from a dynamic panel threshold analysis for the G-7 and BRIC countries. *Stoch. Environ. Res. Risk Assess.* 37 (9), 3367–3382. <https://doi.org/10.1007/s00477-023-02452-x>.
- İşık, C., Ongan, S., Islam, H., Jabeen, G., Pinzon, S., 2024a. Is economic growth in East Asia Pacific and South Asia ESG factors based and aligned growth? *Sustain. Dev.* 1–14. <https://doi.org/10.1002/sd.2910>.
- İşık, C., Ongan, S., Islam, H., Pinzon, S., Jabeen, G., 2024b. Navigating sustainability: Unveiling the interconnected dynamics of ESG factors and SDGs in BRICS-11. *Sust. Dev.* 1–15. <https://doi.org/10.1002/sd.2977>.
- İşık, C., Ongan, S., Islam, H.A., 2024c. A new pathway to sustainability: Integrating economic dimension (ECON) into ESG factors as (ECON-ESG) and aligned with sustainable development goals (SDGs). *J. Ekonomi.* 34–39. <https://doi.org/10.58251/ekonomi.1450860>.
- İşık, C., Kuziboev, B., Ongan, S., Saidmatov, O., Mirkhoshimova, M., Rajabov, A., 2024d. The volatility of global energy uncertainty: Renewable alternatives. *Energy*, 131250. <https://doi.org/10.1016/j.energy.2024.131250>.
- İşık, C., et al., 2024e. Renewable energy, climate policy uncertainty, industrial production, domestic exports/re-exports, and CO<sub>2</sub> emissions in the USA: a SVAR approach. *Gondwana Res.* 127, 156–164.
- Johnston, J., Dinardo, J., 1996. *Econometric Methods*, fourth ed. McGraw-Hill/Irwin, USA.
- Kocak, E., et al., 2019. Is there a trade-off between sustainable society targets in Sub-Saharan Africa? *Sustain. Cities Soc.* 51, 101705.
- Koenker, R., 2004. Quantile regression for longitudinal data. *J. Multivariate Anal.* 91 (1), 74–89.
- Koenker, R., Bassett, Jr.G., 1978. Regression quantiles. *Econometrica* 46 (1), 33–50.
- Koenker, R., Bassett, Jr.G., 1982. Robust tests for heteroscedasticity based on regression quantiles. *Econometrica* 50 (1), 43–61.
- Li, J., et al., 2023. Methods and applications for artificial intelligence, big data, internet of things, and Blockchain in smart energy management. *Energy AI* 11, 1–18.
- Li, R., Wang, Q., Guo, J., 2024. Revisiting the environmental Kuznets Curve (EKC) hypothesis of carbon emissions: exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity. *J. Environ. Manag.* 351 <https://doi.org/10.1016/j.jenvman.2023.119663>.
- Lin, B., Xu, B., 2017. Which provinces should pay more attention to CO<sub>2</sub> emissions? Using the quantile regression to investigate China's manufacturing industry. *J. Clean. Prod.* 164, 980–993.
- Liu, P., et al., 2021. The influence of Internet use on pro-environmental behaviors: an integrated theoretical framework. *Resour. Conserv. Recycl.* 164, 105162 <https://doi.org/10.1016/j.resconrec.2020.105162>.
- Liu, H., Chau, K.Y., Duong, N.T., Hoang, N.K., 2024. Fintech, financial inclusion, mineral resources and environmental quality. An economic advancement perspective from China and Vietnam. *Resour. Pol.* 89 <https://doi.org/10.1016/j.resourpol.2024.104636>.
- Magazzino, C., et al., 2021. The nexus between information technology and environmental pollution: application of a new machine learning algorithm to OECD countries. *Util. Pol.* 72, 101256 <https://doi.org/10.1016/j.jup.2021.101256>.
- Ongan, S., İşık, C., Bulut, U., Karakaya, S., Alvarado, R., Irfan, M., Hussain, I., 2022. Retesting the EKC hypothesis through transmission of the ARMEY curve model: An alternative composite model approach with theory and policy implications for NAFTA countries. *Environ. Sci. Pollut. Res.* 29 (31), 46587–46599. <https://doi.org/10.1007/s11356-022-19106-0>.
- Ozcan, B., Apergis, N., 2018. The impact of internet use on air pollution: evidence from emerging countries. *ESPR* 25 (5), 4174–4189.
- Ozcan, B., et al., 2020. Energy consumption, economic growth and environmental degradation in OECD countries. *Econ. Modell.* 84 (C), 203–213.
- Ozpolat, A., 2021. How does internet use affect ecological footprint?: an empirical analysis for G7 countries. *Environ. Dev. Sustain.* 24 (11), 12833–12849. <https://doi.org/10.1007/s10668-021-01967-z>.
- Ozturk, I., et al., 2023. Investigating the impact of environmental governance, green innovation, and renewable energy on trade-adjusted material footprint in G20 countries. *Resour. Pol.* 86, 104212.
- Pata, U.K., Isik, C., 2021. Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting. *Resour. Pol.* 74, 102313.
- Pata, U.K., Kartal, M.T., Erdogan, S., 2024. Analyzing the EKC hypothesis for technologically advanced countries: the role of ICT and renewable energy technologies. *J. Clean. Prod.* 426 <https://doi.org/10.1016/j.jclepro.2023.139088>.
- Prempeh, K.B., 2024. The role of economic growth, financial development, globalization, renewable energy and industrialization in reducing environmental degradation in the economic community of West African States. *Cogent. Econ. Finance* 12, 1. <https://doi.org/10.1080/23322039.2024.2308675>.
- Qing, L., et al., 2024. Towards the vision of going green in South Asian region: the role of technological innovations, renewable energy and natural resources in ecological footprint during globalization mode. *Resour. Pol.* 88, 104506.
- Radulescu, M., et al., 2024. Optimizing mineral identification for sustainable resource extraction through hybrid deep learning enabled FinTech model. *Resour. Pol.* 89, 104692.
- Sadiq, M., et al., 2022. Does nuclear energy consumption contribute to human development? Modeling the effects of public debt and trade globalization in an OECD heterogeneous panel. *J. Clean. Prod.* 375, 133965.
- Salahuddin, M., et al., 2016. The effects of Internet usage and economic growth on CO<sub>2</sub> emissions in OECD countries: a panel investigation. *Renew. Sustain. Energy Rev.* 62 (C), 1226–1235.
- Saqib, N., et al., 2023. Unraveling the interrelationship of digitalization, renewable energy, and ecological footprints within the EKC framework: empirical insights from the United States. *Sustainability* 15 (13), 10663. <https://doi.org/10.3390/su151310663>.
- Sharif, A., et al., 2019. The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. *Renew. Energy* 133 (C), 685–691.
- Sharif, A., et al., 2020. The renewable energy consumption-environmental degradation nexus in Top-10 polluted countries: fresh insights from quantile-on-quantile regression approach. *Renew. Energy* 150, 670–690. <https://doi.org/10.1016/j.renene.2019.12.149>.
- Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., Sinha, A., 2020a. Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: evidence from Quantile ARDL approach. *Sustain. Cities Soc.* 57, 102138.
- Simionescu, M., 2024. Pollution and renewable energy consumption in the V4 countries. *Environ. Sci. Pollut. Control Ser.* 31 (16), 1954–1963.
- Simionescu, M., et al., 2023. The role of renewable energy policies in TACKLING energy poverty in the European Union. *Energy Pol.* 183, 113826.
- Sinha, A., Sengupta, T., 2019. Impact of natural resource rents on human development: what is the role of globalization in Asia Pacific countries? *Resour. Pol.* 63, 101413 <https://doi.org/10.1016/j.resourpol.2019.101413>.
- Solangi, Y.A., Jianguo, D., 2023. Examining challenges and solutions for environmental and natural resource management with a focus on mineral resources. *Resour. Pol.* 86, 104085 <https://doi.org/10.1016/j.resourpol.2023.104085>.
- Sultana, T., et al., 2023. Does globalization escalate the carbon emissions? Empirical evidence from selected next-11 countries. *Energy Rep.* 10, 86–98. <https://doi.org/10.1016/j.egyr.2023.06.020>.
- Tufail, M., et al., 2021. Do fiscal decentralization and natural resources rent curb carbon emissions? Evidence from developed countries. *ESPR* 28 (35), 49179–49190. <https://doi.org/10.1007/s11356-021-13865-y>.
- Ulucak, R., Danish, Ozcan, B., 2020. Relationship between energy consumption and environmental sustainability in OECD countries: the role of natural resources rents. *Resour. Pol.* 69, 101803.
- Wang, J., Xu, Y., 2021. Internet usage, human capital and CO<sub>2</sub> emissions: a global perspective. *Sustainability* 13 (15), 8268. <https://doi.org/10.3390/su13158268>.
- Wang, S., et al., 2019. Examining the multiple impacts of technological progress on CO<sub>2</sub> emissions in China: a panel quantile regression approach. *Renew. Sustain. Energy Rev.* 103 (C), 140–150.
- Wang, X., et al., 2021. Predicting residents' adoption of living environment improvement practices toward sustainable development: the role of internet use. *J. Environ. Plann. Manag.* 66 (3), 621–641. <https://doi.org/10.1080/09640568.2021.2000373>.
- Wathuge, A., Sedera, D., 2022. Saving the environment from the internet: a polynomial mitigation model of reducing individual internet consumption through internet pricing and environmental awareness. *Australas. J. Inf. Syst.* 26 <https://doi.org/10.3127/ajis.v26i0.3239>.
- Watts, N., et al., 2021. The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises. *Lancet* 397 (10269), 129–170. [https://doi.org/10.1016/s0140-6736\(20\)32290-x](https://doi.org/10.1016/s0140-6736(20)32290-x).
- World Bank, 2023. World Bank Open Data. <https://data.worldbank.org/>. (Accessed 15 December 2023).
- Yi, C., Han, J., Long, C., 2023. Does internet use increase public perception of environmental pollution?—evidence from China. *Soc. Indic. Res.* 166 (3), 665–685.
- Zahraee, S.M., et al., 2016. Application of artificial intelligence methods for hybrid energy system optimization. *Renew. Sustain. Energy Rev.* 66 (C), 617–630.
- Zaidi, S.A.H., et al., 2018. The role of renewable and non-renewable energy consumption in CO<sub>2</sub> emissions: a disaggregate analysis of Pakistan. *ESPR* 25 (31), 31616–31629. <https://doi.org/10.1007/s11356-018-3059-y>.
- Zhang, Z., Meng, X., 2019. Internet penetration and the environmental Kuznets curve: a cross-national analysis. *Sustainability* 11 (5), 1358. <https://doi.org/10.3390/su11051358>.
- Zhang, Y., Radmehr, R., Ali, E.B., Samour, A., 2024. Natural resources, financial globalization, renewable energy, and environmental quality: novel findings from top natural resource abundant countries. *Gondwana Res.* <https://doi.org/10.1016/j.gr.2023.12.016>.