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Research article

Environmental deterioration, renewable energy, natural resource rents, and schooling in Türkiye: Does the degree of energy transition matter for environmental quality?

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ABSTRACT

Within the literature on energy and environmental economics, it is generally acknowledged that renewable energy can improve environmental quality; however, certain papers suggest that an optimal level of the usage of renewable energy sources may exist. Consequently, the utilization of renewable energy sources can result in environmental degradation up to a certain threshold. Then, environmental quality can be enhanced through the continued application of renewables. This indicates that the link between renewable energy and environmental devastation is inverted U-shaped.

This paper presents empirical evidence concerning this possible association between renewable energy and environmental destruction in Türkiye, a country where fossil energy predominates in the energy mix. Additionally, the paper investigates the environmental influences of natural resource rents and schooling. This study utilizes annual data from 1971 to 2020 and implements time series methodologies that rely on the Fourier approximation. The paper thus accounts for an undetermined quantity of structural breaks. The results suggest that an inverted U-shaped link occurs between renewable energy and environmental destruction, signifying renewable energy initially contributes to a diminution in environmental quality before subsequently improving it. Additionally, environmental quality is positively associated with natural resource rents and negatively associated with schooling, according to the findings. Furthermore, the findings reveal that schooling worsens the combined effect of renewable energy on environmental degradation. These conclusions are discussed in the paper.

1. Introduction

Energy needs in the world are increasing daily depending on some drivers including economic development, industrialization, population, and technological innovations. The factor playing the main role in meeting this need has been fossil energy sources (FESs) such as oil, natural gas, and coal over the decades. Humanity faces the problem of threats to living life due to the different distribution of FESs in countries, limited reserves, and environmental damage. Consequently, the energy predicament has emerged as a paramount concern for policymakers, and countries have started to search for alternative energy sources. The adverse environmental impacts resulting from climate change, global warming, and air pollution have significantly influenced energy policies on an international scale (Şekercioğlu and Yılmaz, 2012). Alternative sources, also called renewable energy sources (RESs), have great advantages in terms of energy sustainability and energy supply (Tükenmez and Demireli, 2012; Horasan and Kilic, 2022). In addition to ensuring energy sustainability and energy supply, RESs contribute to curtailing the environmental consequences of global warming by limiting carbon dioxide emissions (CO_2Es) (Ocal and Aslan, 2013; Melikoglu, 2013; Yadav et al., 2024). In addition, RESs such as wind, biomass, solar, geothermal, and hydroelectricity provide notable benefits since they are both domestic and endless sources of global energy supply (Çapik et al., 2012). Technological advancements have a favorable impact on the

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development and implementation of new ideas and practices in the renewable energy (RE) industry (Tükenmez and Demireli, 2012). The difficulty of adjusting to technological advancements constrains the utilization of RESs and amplifies the reliance on FESs, which leads to environmental degradation (ED) (Bulut and Muratoglu, 2018).

Due to the diminishing supply of FESs, there is a rise in the prices of FESs, oil prices become unstable, energy crises emerge, and nations seek to implement alternative energy sources to address these issues and alleviate the impacts of climate change (Simsek and Simsek, 2013; Destek and Aslan, 2020). Several emerging and advanced economies have revised their energy strategies to seek out and launch environmentally friendly sources (Acikgoz, 2011; Soto, 2024). Therefore, government policies have an impact on the utilization of RESs (Baris and Kucukali, 2012). RE policy practices that emerged in the twentieth century have gained momentum in the twenty-first century.

Within the literature on energy and environmental economics, expanding and augmenting the utilization of RESs is regarded as the sole means to circumvent the predicaments brought about by the utilization of FESs. In this framework, the positive influence of RE on environmental quality (EQ) has been considered as a presupposition for researchers. In some recent studies, the optimal utilization level of renewable resources has been discussed for the use of RE to reduce environmental damage as expected. Accordingly, Lewis and Wiser (2007), Apergis et al. (2010), Li et al. (2020), Bulut et al. (2021), and Salem et al. (2021) emphasize that EQ cannot be significantly enhanced by RE during its nascent phase of development, which results in a relatively small proportion of RESs in the energy mix in comparison to FESs. Additionally, Dong et al. (2018) underscore the potential influence of the proportion of the use of RE in the energy mix on the RE's coefficient in an econometric model. Therefore, the proportion of RESs in a country may have not attained the critical level, meaning there may be a threshold value for RE utilization at which it commences to reduce ED. This points to a nonlinear/inverted U-shaped link between the use of RE and environmental damage (Li et al., 2020).

Given the proportion of RESs in electricity generation (EG) in recent decades, Türkiye seems to be a good case study to examine this possible inverted U-shaped link between RE and ED. This is because the share of RESs in Türkiye's energy mix has not changed much over the last 50 years. For example, with reference to the Turkish Statistical Institute (TSI, 2024) data, while the proportion of RESs in EG was 37% in 1970, it was 35.8% in 2021. An equally important fact is that while the total share of RESs in EG has not changed, the composition of RESs used in EG in Türkiye has dramatically changed. Accordingly, while the share of hydro in EG decreased from 35.2% to 16.7% in the 1970–2021 period, the share of other RESs augmented from 1.9% to 19.1% in the same period. As can be seen, FESs still dominate EG in Türkiye, while the share of RESs in EG is relatively low. Therefore, the level of RE utilization in Türkiye may not have reached a sufficient level to curtail environmental damage, implying there could be an inverted U-shaped link between RE and ED in Türkiye.

Based on these explanations, the purpose of the present research is to delve into the possible nonlinear influence of RE on ED in Türkiye over the period 1971–2020. The study is expected to make considerable contributions to the existing literature. First, in the extant literature, the inverted U-shaped link between RE and ED is only examined by Li et al. (2020) and Salem et al. (2021) who found evidence in favor of such a relationship for China and the top 10 polluting economies, respectively. This paper is the first to investigate the potential inverted U-shaped association between RE and ED in Türkiye. Hence, there is a serious research gap in the literature. Second, the paper uses two control variables for the empirical model, namely schooling rates and natural resource rents (NRRs). Despite the enhancing empirical literature on the influences of these variables on the environment, only a few research papers have examined the impacts of these variables on ED in Türkiye. Third, time series variables can experience many types of structural breaks, and failing to account for these breaks can result in inefficient findings (Banerjee et al., 2017). According to Becker et al. (2006), some variables are prone to experiencing numerous and diverse structural breaks, both the forms and quantities of which are unknown. As is known, from 1971 to 2020, Türkiye was confronted with a multitude of significant events, including but not limited to military coups, political instability, economic crises, radical shifts in economic policies, natural disasters, etc. In order to account for these breaks in the analyses, breaks for both unit root (UR) and cointegration analyses are considered in this paper. In addition to considering sharp breaks, this paper also incorporates gradual breaks using Fourier-type time series methods to generate efficient outputs. Accordingly, the paper first performs the UR test of Enders and Lee (2012) and then employs the cointegration test propounded by Tsong et al. (2016).

The findings indicate that (i) there exists an inverted U-shaped relationship between RE and ED, (ii) schooling rates increase ED, and NRRs decrease ED, and (v) schooling makes the cumulative effect of RE on ED worse.

The subsequent sections of the study are organized as follows: An overview of the theoretical and empirical literature is provided in Section 2. Section 3 provides an exposition of the model and the data collection. Section 4 provides an explanation of estimation procedures, while Section 5 presents the empirical outputs. Section 6 examines the practical observations and puts forth policy proposals. The paper is concluded in Section 7.

2. Literature review

A multitude of research endeavors have identified the ED caused by energy, NRRs, and schooling in various nations. However, the potential inverted U-shaped link between RESs and ED in Türkiye has not been examined in any of the prior papers. Moreover, the scholarly examination of the effects of NRRs and schooling on ED in Türkiye is limited. This section begins with a summary of the theoretical environmental impacts of RE, NRRs, and schooling. Following this, the present paper provides a review of the empirical literature concerning the effects of these variables on ED in Türkiye.

2.1. Background information

RESs, being clean and environmentally friendly energy sources, are anticipated to positively influence EQ. Countries can make progress toward sustainable development goals by enhancing the quality of life of their citizens through the utilization of RESs (Acikgoz, 2011; Wang, 2024). Several publications in the literature present compelling evidence that RE has the potential to enhance EQ in various countries or groups of countries (see e.g., Ozcan et al., 2020; Sharif et al., 2020; Godil et al., 2021; Ozturk et al., 2023; Işık et al., 2023, among others). Nevertheless, as stated before, recent studies have suggested that there exists an ideal threshold for RE in order to effectively enhance EQ (Lewis and Wiser, 2007; Apergis et al., 2010; Dong et al., 2018; Li et al., 2020; Bulut et al., 2021; Salem et al., 2021). Depending on the extent to which RE is utilized, it can have either a beneficial or negative impact on EQ (Li et al., 2020). Accordingly, EQ can be adversely affected by the intensive use of FESs in the production of materials required to generate RE. As an illustration, the fabrication of solar photovoltaic cells necessitates the combustion of FESs to generate the excessive heat required for cell production (Aman et al., 2015). Moreover, FESs and non-recyclable materials can be used for the infrastructure investments needed to generate energy from RESs (Salem et al., 2021). Therefore, it may be necessary to utilize a certain amount of RE in order to mitigate environmental damage. Consequently, while the implementation of RESs may initially result in adverse environmental effects, energy production from RESs could improve EQ once a certain level of energy production is achieved.

Natural resources serve as the fundamental materials from which products are manufactured. NRRs, as defined by Bilgili et al. (2023), are

the surplus earnings generated by countries from the extraction of natural resources over and above the expenses incurred in the extraction process. NRRs consist of coal rents, mineral rents, forest rents, and oil rents. The impact of NRRs on ED is contingent upon a nation's level of economic development (Caglar et al., 2022). Furthermore, the categorization of natural resources is a critical factor in determining their environmental impact, meaning coal, oil, and mineral rents may lead to environmental pressure, whereas forest rents may contribute to environmental sustainability (Zafar et al., 2019; Pata and Isik, 2021; Caglar et al., 2022). Accordingly, an increase in ED may ensue when a nation utilizes oil, mineral, and coal rents and allocates the subsequent revenues toward bolstering household consumption instead of making investments in infrastructure and capital (Pata and Ertugrul, 2023). Moreover, a surge in NRRs due to price increases could potentially lead to a wealth impact and increased consumer expenditures, thereby exerting pressure on the environment (Pata and Isik, 2021). On the other hand, Majeed et al. (2021) and Pata and Isik (2021) argue that providing cleaner energy sources made from natural resources could reduce the demand for fossil fuels. That is why the way natural resources are used determines how much of an impact they have on the ecosystem.

Some studies suggest that higher levels of education are associated with increased environmental damage. For instance, given higher education is a universal economic activity (Katircioglu, 2010), Katircioglu et al. (2020) denote that an excessive number of students pursue higher education either domestically or internationally. Hence, the provision of transportation infrastructure, dormitories, and additional facilities seem to be necessary to accommodate the needs of college students, which in turn can lead to energy consumption and ED. On the contrary, in certain studies, it has been emphasized that education can enhance EQ. For instance, schooling may generate positive externalities for the environment, as suggested by Eyuboglu and Uzar (2021). Accordingly, the importance of knowledge, information, and talent has significantly increased in modern society, particularly since the late 20th century. Considering education plays an exceptional function in enhancing human capital, awareness of environmental issues can be elevated through education (Ekperiware et al., 2017). Students can pay attention to environmental problems through environmental awareness education and programs including seminars, debates, demonstrations, discussions, and presentations (Kotwal and Dogra, 2022). Hence, similar to how the impacts of NRRs on the environment can vary, schooling can also have distinct effects on EQ.

2.2. Review of empirical studies

This sub-section of the paper presents studies that investigated the influences of RE, NRRs, or schooling on ED in Türkiye.

Bölük and Mert (2015) explored the nexus between renewable EG and CO_2Es using the autoregressive distributed lag (ARDL) method. They found that renewable EG decreased CO_2Es. Bulut (2017) found that both RE and non-renewable EG led to an increase in CO_2Es. Pata (2018) used the ARDL approach via data for the period between 1974 and 2014. He found that RE consumption had no effect on CO_2Es. Sharif et al. (2020) examined the link between ecological footprint and RE use for the period between 1965 and 2017. They found RE consumption decreased ecological footprint in the long term. Bulut et al. (2021), employing the nonlinear smooth transition models and using data over the period 1970–2016, explored that CO_2Es were positively associated with EG from RESs. Yurtkuran (2021) utilized data for the 1970–2017 period and yielded that RE production increased CO_2Es. Shan et al. (2021) studied the influence of green technology innovation and RE on CO_2Es and found that RE and green technology innovation were efficient for increasing EQ. Onifade et al. (2021) examined the effect of RE consumption on CO_2Es. The results showed that RE consumption had a negative influence on CO_2Es. Bulut (2021) used the ARDL method and discovered that RE consumption negatively influenced the ecological footprint for the period 1970–2016. Bilgili et al. (2022) examined the RE alternatives for sustainable growth. They found that the best RE source for sustainable growth was solar energy. Karaaslan and Çamkaya (2022) utilized the ARDL method to investigate the effect of RE consumption on CO_2E and found that RE consumption decreased CO_2Es. Acaroğlu and Güllü (2022) focused on RE and non-RE usage and climate change. Their findings indicated that RE reduced the temperature, meaning RE had a positive impact on the environment. Rahian and Tuspekova (2022) found RE use had a decreasing impact on CO_2Es. Naimoglu and Akal (2023) explored the impact of RE and energy technology on CO_2Es. Their empirical results showed that RE had a negative effect on ED. Dam and Sarkodie (2023) indicated that RE consumption had a stimulating impact on EQ. Adebayo et al. (2023) assessed the RE consumption-carbon emissions association. The authors reported that RE consumption mitigated CO_2Es. Dumrul et al. (2024) investigated RE choices in the context of sustainable development via the institutional fuzzy assessment based on distance to mean solution method and explored the best RESs for Türkiye was solar energy. Mukhtarov (2024) revealed that RE consumption had a negative impact on CO_2Es through the ARDL methodology over the period 1990–2019. Finally, Somoye (2024) found that RE generation reduced CO_2Es.

Throughout the empirical literature, it is evident that two papers investigated the direct effect of schooling on EQ in Türkiye.[1] Accordingly, using data over the period 1983–2017 and employing the ARDL technique, Eyuboglu and Uzar (2021) discovered that higher education decreased CO_2Es. Additionally, Çamkaya et al. (2023) found that education decreased both CO_2Es and ecological footprint through the Fourier ARDL technique for the period 1980–2018.

To the best of our knowledge, the only study that investigated the impacts of NRRs on the environment for Türkiye belongs to Emir and Karlilar (2023). Using data from 1970 to 2017 and utilizing the residual least squares and the dynamic ordinary least squares estimators, they discovered that NRRs positively affected the ecological footprint.

3. Model and data

This research uses a time series analysis to investigate if there is an inverted U-shaped link between RE and ED in Türkiye, based on the justifications given above. Hence, the basic model can be described as

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln RE_t + \beta_2 (\ln RE)_t^2 + \beta_3 RENT_t + \beta_4 SC_t + \varepsilon_t \quad (1)$$

In Eq. (1), CO_2, RE, $(RE)^2$, RENT, SC, and ε stand for CO_2Es (metric tons per capita), EG from RESs (GWh), the square of EG from RESs, total NRRs (% of GDP), gross tertiary school enrolment rates (%), and the error term, respectively.

Furthermore, the paper considers the interaction between RE and schooling and acknowledges that a higher degree of schooling might enhance knowledge and understanding of RE. Hence, the subsequent model is formulated to investigate the influence of schooling on the association between RE and ED:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln RE_t + \beta_2 (\ln RE)_t^2 + \beta_3 RENT_t + \beta_4 \ln RE * SC_t + \varepsilon_t \quad (2)$$

where lnRE*SC is the new variable obtained by multiplying lnRE and SC.

The potential estimation outcomes and rationales for the first model are as follows.

(i) If $\beta_1 < 0$ and $\beta_2 = 0$, RE reduces ED since RESs are clean and environmentally friendly.

[1] In this paper, we consider the papers that directly focused on the impact of schooling on EQ. It must be noted that some recent papers in the extant literature examined the impact of human development, which consists of income, education, and health indicators, on ED in Türkiye (see e.g., Karahan-Dursun, 2024; Uzar and Eyuboglu, 2024, among others).

(ii) If $\beta_1 > 0$ and $\beta_2 < 0$, to mitigate ED, the utilization of RESs must surpass a specific threshold.
(iii) If $\beta_3 < 0$, utilizing NRRs for investments in RE diminishes reliance on FESs and mitigates ED.
(iv) If $\beta_3 > 0$, a rise in NRRs can cause a significant impact on wealth and lead to higher consumer spending, which in turn exacerbates ED.
(v) If $\beta_4 < 0$, an increase in awareness of environmental problems stemming from a rise in schooling reduces ED.
(vi) If $\beta_4 > 0$, a rise in schooling requires more energy consumption for transportation and housing, which in turn intensifies ED.

Additionally, the potential most important estimation results and justifications for the second model are as below.

(i) If $\beta_1 < 0$ and $\beta_4 < 0$, RE mitigates ED and schooling enhances the effectiveness of RE in mitigating ED.
(ii) If $\beta_1 > 0$ and $\beta_4 > 0$, RE use has not yet reached a level that can reduce ED, and schooling exacerbates the incremental impact of RE on ED.

Annual data cover the period 1971–2020. Data for CO_2Es, RENT, and SC are extracted from the World Bank (2024), while data for EG from RESs are obtained from the TSI (2024).

4. Estimation methods

This section presents the approaches used for conducting UR and cointegration tests in the paper. Fig. 1 presents the stages of the empirical strategy of the paper.

4.1. UR analysis

The paper utilizes the UR test of Enders and Lee (2012) to detect both sharp and smooth breaks in an unknown number, using Fourier components. This UR test is called the Fourier LM test since it relies on the Lagrange Multiplier (LM) technique developed by Schmidt and Phillips (1992) and Amsler and Lee (1995). Enders and Lee (2012) initially examine the model below:

$$\Delta y_t = \gamma_0 + \gamma_1 \Delta \sin(2\pi kt/T) + \gamma_2 \Delta \cos(2\pi kt/T) + u_t \quad (3)$$

In Eq. (3), Δ is the first difference operator and k represents a certain frequency. Next, a detrended series is created using the calculated coefficients denoted as $\widetilde{\gamma}_0$, $\widetilde{\gamma}_1$, and $\widetilde{\gamma}_2$:

$$\widetilde{S}_t = y_t - \widetilde{\psi} - \widetilde{\gamma}_0 t - \widetilde{\gamma}_1 \sin(2\pi kt/T) - \widetilde{\gamma}_2 \cos(2\pi kt/T), t = 2, \ldots, T \quad (4)$$

where $\widetilde{\psi} = \widetilde{\gamma}_0 - \widetilde{\gamma}_1 \sin(2\pi kt/T) - \widetilde{\gamma}_2 \cos(2\pi kt/T)$, and y_1 represents the initial observation of y_t. Therefore, the model used to ascertain if a variable has an UR rests on the model below:

$$\Delta y_t = \theta \widetilde{S}_{t-1} + d_0 + d_1 \Delta \sin(2\pi kt/T) + d_2 \Delta \cos(2\pi kt/T) + \varepsilon_t \quad (5)$$

The LM test statistic is employed to test the null hypothesis (NH) of a UR, denoted as $(H_0 : \theta = 0)$. If the obtained statistic is higher than the critical values, then the NH of a UR can be rejected. It must be noted that the critical values are determined by the number of k.

4.2. Cointegration test

Tsong et al. (2016) employ the model illustrated in Eq. (6) to examine the NH of cointegration and, if cointegration is found, to estimate long-run parameters:

$$y_t = \sum_{i=0}^{m} \delta_i t^i + \alpha_k \sin\left(\frac{2k\pi t}{T}\right) + \beta_k \cos\left(\frac{2k\pi t}{T}\right) + x_t'\beta + \upsilon_{1t} \quad (6)$$

where u_t represents the error term, while *ft* corresponds to the Fourier function. Cointegration in the model is indicated when the supplied test statistic is below the critical values. Tsong et al. (2016) examine the suitability of using the Fourier approximation through an F-test statistic as well. If the computed F statistic is found to be greater than the critical values, it is advisable to employ this test to analyze cointegration in the model.

5. Empirical results

The results for the Fourier LM UR test are depicted in Table 1. Accordingly, the NH that there is a UR is rejected for the first difference forms of all series under consideration. This finding implies all variables become stationary at the first difference forms and possible cointegration in the model could be investigated via the cointegration test of Tsong et al. (2016).

The empirical outputs for the cointegration test for the basic model are exhibited in Table 2. Part A reports that (i) the NH that there is no need to use the Fourier terms in the model can be rejected by F-statistic and (ii) the NH of cointegration cannot be rejected by test statistic. The former implies that the Tsong et al. (2016) cointegration test with Fourier terms must be performed to examine the possible cointegration in the model, while the latter means that the long-run parameters can be estimated. This paper employs the fully modified ordinary least squares estimator suggested by Phillips and Hansen (1990). The long-run parameters are exhibited in part B. As is seen, lnRE, $(lnRE)^2$, RENT, and SC respectively have the estimations of 1.275, −0.053, −0.163, and 0.004. Besides, these parameters are significant. Moreover, one of the Fourier terms has a statistically significant coefficient, supporting the employment of the Tsong et al. (2016) cointegration test. The findings of the

Table 1
UR test.

Variable	k	Test statistic
$lnCO_2$	1	−3.569
lnRE	1	−3.456
$(lnRE)^2$	2	−1.088
RENT	1	−3.678
SC	1	−2.548
lnRE*SC	1	−1.925
$\Delta lnCO_2$	2	−5.332*
ΔlnRE	1	−4.624**
$\Delta(lnRE)^2$	1	−5.029*
ΔRENT	2	−4.730*
ΔSC	1	−4.264**
Δ(lnRE*SC)	1	−4.518**

Notes: Δ stands for the first difference operator. *, **, and *** respectively show 1%, 5%, and 10% significance levels.

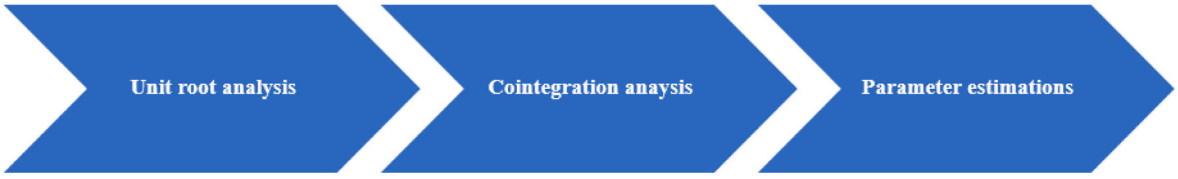

Fig. 1. The empirical strategy of the paper.

Table 2
Cointegration test for the basic model.

Part A: Cointegration test			
Frequency	Min SSR	Test statistic	F-statistic
1	0.153	0.049	9.380*
Part B: Long-term parameters			
Variable	Coefficient	Std. error	t-statistic
lnRE	1.275**	0.526	2.424
$(lnRE)^2$	−0.053***	0.028	−1.877
RENT	−0.163*	0.058	−2.781
SC	0.004*	0.001	3.072
cos	0.018	0.022	0.817
sin	0.053**	0.021	2.465

Note: *, **, and *** indicate 1%, 5%, and 10% significance levels.

paper mean that CO_2Es are positively associated with EG from RESs and schooling and negatively associated with the square of EG from RESs and NRRs.

The empirical outputs for the cointegration test for the model including the interaction of RE and schooling are exhibited in Table 3. As is seen in part A, this cointegration test must be used and cointegration exists in the model. The paper uses the FMOLS methodology to estimate this model. Accordingly, the coefficients of lnRE, $(lnRE)^2$, RENT, and lnRE*SC are 1.160, −0.046, −0.154, and 0.001. Additionally, all parameters except that of $(lnRE)^2$ are statistically significant. The most important finding implied by this estimation is that the utilization of RE has not yet reached a sufficient level to effectively decrease ED, and schooling worsens the cumulative effect of RE on ED. Besides, the insignificant coefficient of $(lnRE)^2$ could be attributed to the phenomenon that schooling amplifies the influence of renewable energy on environmental degradation.

The empirical findings presented in the paper show that RE can increase or decrease CO_2Es in Türkiye based on the level of the utilization of RESs in EG. The literature contains several papers that provide evidence of the positive impact of RE on EQ in Türkiye (Bölük and Mert, 2015; Sharif et al., 2020; Shan et al., 2021; Onifade et al., 2021; Bulut et al., 2021; Karaaslan and Çamkaya, 2022; Acaroğlu and Güllü, 2022; Rahian and Tuspekova, 2022; Naimoglu and Akal, 2023; Dam and Sarkodie, 2023; Adebayo et al., 2023; Mukhtarov, 2024; Somoye, 2024). However, some studies indicate a negative impact of RE on EQ in Türkiye (Bulut, 2017; Bulut et al., 2021; Yurtkuran, 2021). Therefore, the findings of this paper are not surprising and demonstrate the significance of the level of EG from RESs in determining the coefficient of RE. Furthermore, the findings of this paper on the impact of schooling on the environment conflict with those of Eyuboglu and Uzar (2021) and Çamkaya et al. (2023), who found EQ in Türkiye was positively related to schooling. Finally, the findings of this paper on the impact of NRRs on EQ contradict with those of Emir and Karlilar (2023), who discovered that NRRs decreased EQ in Türkiye.

Table 3
Cointegration test for the model that involves the interaction of lnRE and SC.

Part A: Cointegration test			
Frequency	Min SSR	Test statistic	F-statistic
1	0.159	0.048	8.529*
Part B: Long-term parameters			
Variable	Coefficient	Std. error	t-statistic
lnRE	1.160***	0.582	1.993
$(lnRE)^2$	−0.046	0.031	−1.477
RENT	−0.154**	0.062	−2.483
lnRE*SC	0.001**	0.001	2.406
Cos	0.017	0.023	0.710
Sin	0.053**	0.022	2.336

Note: *, **, and *** indicate 1%, 5%, and 10% significance levels.

6. Discussion

This section of the research begins by providing policy recommendations regarding the relationship between NRRs and ED, as well as the association between schooling and ED. Next, the study will focus on the relationship between RE and EQ, which is the primary topic of investigation.

An increase in NRRs in Türkiye does not lead to higher consumption expenditures and environmental pressure through the creation of a wealth effect. Instead, it contributes to the enhancement of EQ. Hence, Türkiye should accelerate the natural resource extraction activities without ignoring the impacts of these activities on the environment. In this way, an increase in NRRs resulting from price increases can have a welfare effect in Türkiye and the funds generated can be used for renewable technology investments. Thus, greater expenditures on renewable technology can lead to an increase in RE production and utilization.

Several studies in the literature offer significant insights into environmental literacy within the education system in Türkiye. For instance, Karatekin (2012) denoted that the texts in social studies textbooks on environmental knowledge are information-dominated. He argues that textbooks should focus on the emotional inclination of students towards the environment and the cognitive abilities they employ when they face an environmental issue. Besides, Görmüş (2019) explored that students had a minimal level of understanding regarding the environment and only carried out their environmental duties on an individual level within a narrow scope. In Türkiye, the first climate and environmental education program applying systems thinking methodology on climate change and environmental education began in 202 (Darüşşafaka Society, 2024). Hence, this paper argues that the number of such programs should be increased in Türkiye and children should be made environmentally aware from primary school onwards. Stated differently, comprehensive environmental literacy courses should be initiated in schools. Besides, seminars and presentations should be prepared and demonstrated on this subject, and students should be taught the environment is a luxury good. Furthermore, in light of the anticipated infrastructure improvements that transpired during the previous pandemic, distance learning may be deemed a viable substitute for certain courses to decrease ED stemming from schooling.

Existing literature acknowledges that implementing more efforts and investments in renewable energy can enhance energy efficiency and foster the development of environmentally sustainable business models. Investing in green energy helps to regulate greenhouse gas emissions, reduce the usage of non-renewable energy, and mitigate environmental damage. Therefore, the selection of renewable energy over non-renewable energy is essential for a nation to achieve its environmentally favorable objectives.

The findings of the study indicate that the use of RE in Türkiye has not yet reached a level that will diminish environmental damage. Therefore, this section of the research paper presents a concise overview of the utilization of RESs in Türkiye, the potential of RE in Türkiye, and the projections made by policymakers regarding the country's RE use.

As Türkiye sustains its socioeconomic development, it is anticipated that Türkiye's energy demand will proceed to increase in the future. Türkiye meets a significant part of its energy demand with FESs, which in turn leads to problems with current account balance and economic dependence as well (Simsek and Simsek, 2013; Mukhtarov et al., 2022). Therefore, ensuring supply security in the field of energy constitutes Türkiye's basic energy policy (Benli, 2013). Within this scope, the Turkish governments developed two main approaches to reduce import dependence and ensure energy security. The first one is to expand coal-fired energy by using domestic resources, and the second one is to increase the role of RE in the economy (Rincon et al., 2019). Within this scope, Türkiye adopted a "More Domestic, More Renewable" motto and determined 7 goals for the 2019–2023 Strategic Plan (MENR, 2020). Some of these objectives were as follows: ensuring sustainable energy

supply security, increasing energy efficiency, technological development in energy and natural resources, making energy markets more predictable, etc.

Greater utilization of renewable resources is primarily critical to reducing Türkiye's external dependence, decreasing pollutant gas emissions, and ensuring energy security (Baris and Kucukali, 2012). Considering the European Union (EU) plays a leading role in RE policy implementation, Türkiye strives to harmonize its energy policies with the EU as a candidate country (Şekercioğlu and Yılmaz, 2012). Recently, liberalization policies for the energy markets have been implemented in Türkiye. As a result of the liberalization of the electricity markets along with developments in the electricity market in Türkiye, both domestic and foreign RE investments have accelerated. Thus, RESs gained great importance in Türkiye with the increasing energy demand and the existence of policies that encouraged the use of RESs (Simsek and Simsek, 2013). Türkiye carried out many reforms in the energy sector as a part of the Electricity Market Law in 2001 and started to support the production and consumption of RE with various incentive practices, such as feed-in tariffs and investment incentives (Bölük and Mert, 2015). In 2014, Türkiye created the National Renewable Energy Activity Plan report with the aim of achieving full membership in the EU. This strategy includes plans for the use of existing RE potential, especially within the scope of 2023 targets (Yurtkuran, 2021). The figures below (Figs. 2 and 3) point to two very important findings for Türkiye. Accordingly, despite liberalization policies and incentives, RE use in EG is still lower than the use of FESs (Fig. 2). In addition, the composition of RE use has changed significantly. Accordingly, the share of hydro in EG from RESs has decreased rapidly in recent decades, while the proportion of other RESs has increased significantly (Fig. 3). Therefore, the use of RESs in EG in Türkiye needs to be encouraged with more policies and incentives.

Türkiye's demand for electrical energy is increasing steadily every year because of enhancing population and industrialization (Dursun and Gokcol, 2014). There exist many RESs to generate electricity in Türkiye, namely hydro, geothermal, solar, wind, solid biomass, biogas, and waste. Put differently, almost all kinds of RESs are available in Türkiye. Türkiye has sufficient potential for RESs, especially in terms of wind, biomass, and solar energy (Yuksel, 2013). Türkiye's Aegean coasts and Northwestern regions are the most suitable places for wind energy investments (Kilickaplan et al., 2017). From 2008 to 2020, the total installed wind power capacity in Türkiye increased from 364 MW to 8800 MW (Ministry of Foreign Affairs of Denmark, 2021), which in turn could increase EG from wind energy. Biomass energy is utilized by almost half of the world's population as heating fuel and cooking. Biomass is a key energy source for many developing countries including Türkiye (Ozturk et al., 2009). Türkiye, which ranks seventh globally in agricultural production, generates substantial quantities of plant and animal waste (Rincon et al., 2019). Biomass energy is also considerable for Türkiye's future energy demands. The quantity of biogas used in energy production is relatively low compared to heating in Türkiye. Total licenses for EG from biogas and biomass have been increasing since 2009 (Simsek and Simsek, 2013), meaning EG from biomass and biogas increased in Türkiye. Due to its geographical location, Türkiye is a lucky country in terms of solar energy potential compared to many other countries (Çapik et al., 2012). Between 2014 and 2023, the total installed solar energy capacity in Türkiye increased from 51 MW to 11, 293 MW (Statista, 2024), meaning there has been a boost in solar energy investments and EG from solar energy over the last decade. Besides, policymakers anticipate that hydrogen energy will play an important role in Türkiye's future energy production (Apak et al., 2017). The Turkish governments aim to escalate the installed capacities through new power plants. According to the Türkiye National Energy Plan report of MENR (2022), Türkiye aims to raise wind and solar energy capacities in particular, given their huge potential. Accordingly, it is aimed to increase the wind energy installed power to 29.6 GW and the solar energy installed power to 52.9 GW in 2035. Fig. 4 shows the targeted levels of installed power capacities in Türkiye by 2035 according to energy sources.

Fig. 5 shows the targeted levels of shares of energy sources in EG in Türkiye by 2035. As is seen, while the share of RESs in EG was 42.4% in 2020, it is aimed to increase this share to 54.8% in 2035. In addition, the aforementioned report states that the share of RESs in EG is envisaged to increase to 69.1% by 2053. This value is also compatible with the expectations of international organizations such as the International Energy Agency, the EU, and the International Renewable Energy Agency.

7. Conclusion

This paper examined the possible inverted U-shaped relationship between EG from RESs and CO_2Es in Türkiye using annual data from 1971 to 2020. The paper tested the effects of NRRs and schooling on CO_2Es as well. The paper performed time series techniques relying on the Fourier approach to capture structural breaks. The paper explored that there existed an inverted U-shaped link between RE and CO_2Es, implying RE first led to an increase in CO_2Es and then decreased CO_2Es when it reached a threshold value. The findings also implied that NRRs decreased CO_2Es, while schooling increased CO_2Es. These findings have important implications. Finally, the paper discovered that schooling exacerbated the cumulative impact of RE on ED.

The findings for the impact of RE on ED show that Türkiye should further benefit from RESs for the path of sustainable development as it

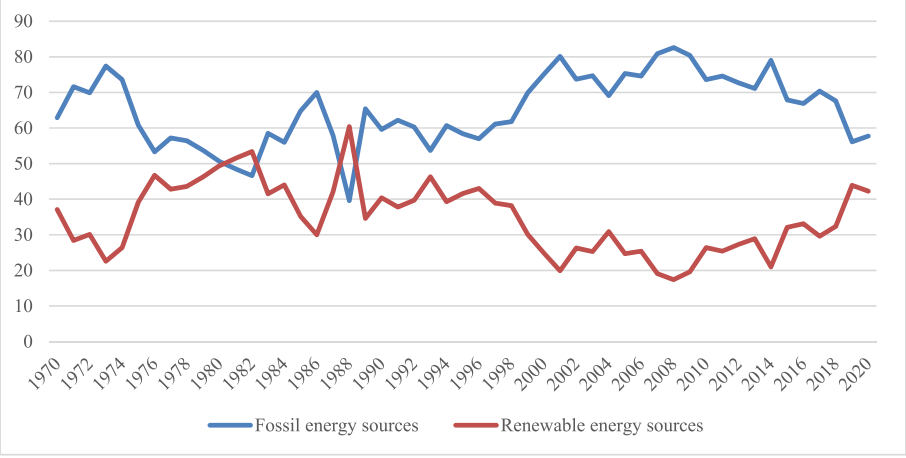

Fig. 2. The shares of FESs and RESs in EG in Türkiye (%, 1970–2020).
Source: TSI (2024).

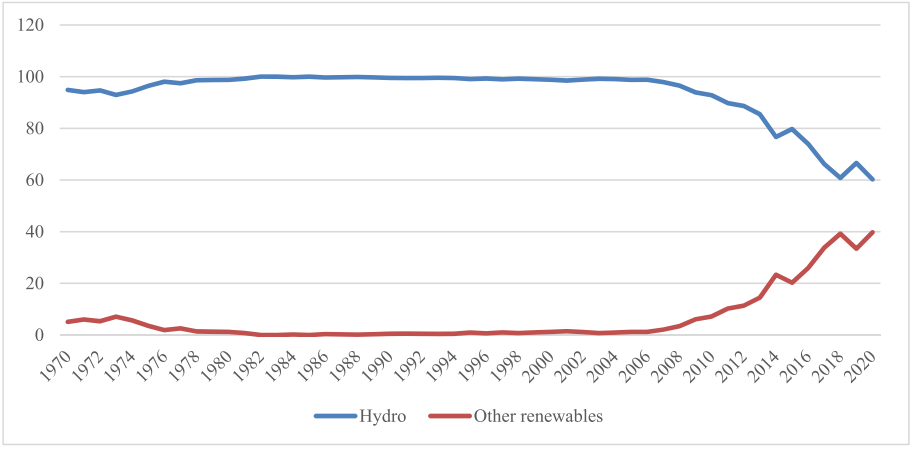

Fig. 3. The shares of hydro and other RESs in EG from RESs in Türkiye (%, 1970–2020).
Note: Other RESs include geothermal, solar, wind, solid biomass, biogas, and waste.
Source: TSI (2024).

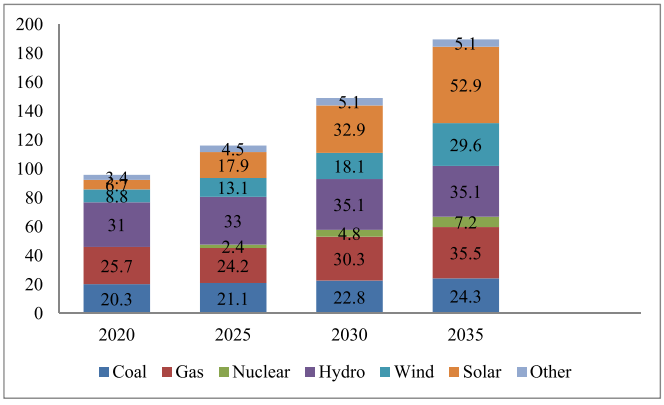

Fig. 4. Installed power by energy sources in Türkiye by 2035 (GW).
Source: MENR (2022).

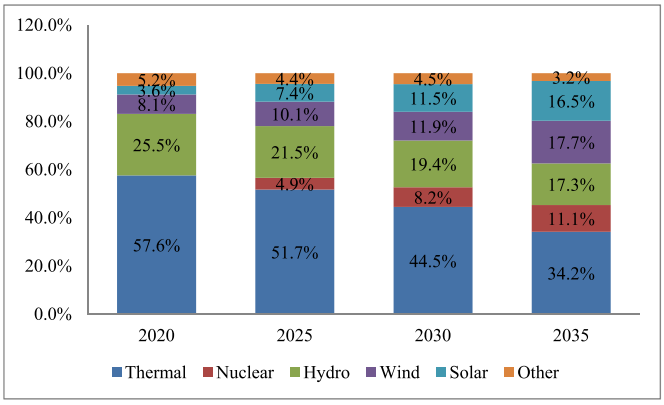

Fig. 5. Share of EG by energy sources in Türkiye by 2035 (%).
Source: MENR (2022).

has significant potential regarding RESs. Further utilization of RESs can (i) decrease CO_2Es after the utilization of RESs attains a certain value, (ii) decrease import dependence on energy and make energy supply sustainable, and (iii) positively affect the current account balance in Türkiye.

Despite its contributions, this paper has some limitations. Accordingly, this analysis takes nonlinearity in the variable into account but does not address nonlinearity in the coefficients. Furthermore, numerous elements have an impact on EQ. Hence, in nations where FESs play a dominant role in total energy production and consumption, future research can investigate the potential inverted-U link between RE and ED by employing nonlinear methodologies and different control variables. Thus, policymakers in these countries can gain extra motivation while allocating resources and designing energy policies if scholars find evidence in favor of the inverted U-shaped link between RE and ED.

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CRediT authorship contribution statement

Umit Bulut: Writing – original draft, Supervision, Software, Methodology, Data curation, Conceptualization. **Melike Atay-Polat:** Writing – original draft, Validation, Investigation. **Ahsen Seda Bulut:** Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare no competing interests.

Data availability

Data will be made available on request.

List of Abbreviations

Abbreviation Explanation
ARDL Autoregressive distributed lag

CO_2Es	CO_2 emissions
ED	Environmental degradation
EG	Electricity generation
EQ	Environmental quality
EU	European Union
FESs	Fossil energy sources
FMOLS	Fully modified ordinary least squares
LM	Lagrange multiplier
MENR	Republic of Türkiye Ministry of Energy and Natural Resources
NH	Null hypothesis
NRRs	Natural resource rents
RE	Renewable energy
RESs	Renewable energy sources
TSI	Turkish Statistica Institute
UR	Unit root

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