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Revisiting the environmental Kuznets curve: evidence from Turkey

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Abstract

This paper uncovers the link between economic development and environmental degradation in Turkey by employing two distinct methods. We test the so-called EKC hypothesis for four various outcomes, including carbon dioxide emissions, wastewater, sulfur dioxide, and particulate matter by implementing time-series and panel data models. Fully modified ordinary least squares provide an N-shaped linkage between environmental degradation, such as carbon dioxide emissions and economic growth between 1961 and 2014. The random- and fixed-effects models indicate that there exists an N-shaped connection between wastewater and particulate matter quality indicators and economic growth spanning 1992 and 2013. However, we find inverted N-shaped relationship between SO_2 and economic growth over the same period. Our findings urge policymakers in Turkey to take precautions by implementing national policies to fight against pollution to increase environmental quality.

Keywords Pollution · Economic development · The environmental Kuznets curve · Fourier approximation · Turkey

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1 Introduction

Environmental quality is of great importance in today's world. Since the 1990s, researchers all around the world have paid a considerable amount of time to understand the relationship between environmental pollution and economic growth. Grossmann and Krueger (1991) tried to explain the link between the environment and income. The so-called environmental Kuznets curve (EKC) argues that in the beginning stages of economic growth, countries will experience environmental degradation up to a certain level where the peak will occur. Afterward, growing nations will start experiencing declining environmental degradation, while their gross domestic products (GDPs) are on the rise. This relationship the EKC hypothesizes between environmental quality and economic development indicates an inverse U pattern between these two variables.

Grossmann and Krueger (1991), in their seminal work, advocate three distinct channels, including scale, composition, and technological effects, to explain the linkage between the high-quality environment and income. The scale effect indicates in the early stages of economic development; a country consumes a high amount of natural resources (i.e., inputs) to produce more goods. This way, the country is going to be able to increase its GDP while creating environmental issues. In the second stage of economic development, the composition effect will come into play, changing the production structure of the country, shifting its production from industrial and agricultural segments to the service sector (Ozcan et al. 2018). Lastly, the new environmentally friendly technologies will make the production less detrimental to the environment (Onafowora and Owoye 2014).

Current evidence provides mixed results on the validity of the EKC hypothesis. Some studies argue that the EKC is valid in 14 Asian nations (Apergis and Ozturk 2015) and the Spanish economy (Esteve and Tamarit 2012). However, Azam and Khan (2016) advocate that the EKC hypothesis is not valid in some upper- and middle-income countries, including the USA and the Republic of China. However, Wolde-Rufael and Idowu (2017) argue that the EKC hypothesis exists in China and India. Therefore, it is of great importance to note that single-country analyses can give more supportive results on the connection of income and environment (De Bruyn et al. 1998; Ang 2007; Dinda 2004; Lindmark 2002) as each country's economic environment will be taken into consideration in these analyses.

In this study, we employ two distinct methods, including time-series and panel data analyses, in order to uncover the relationship between environment and economic growth. We endeavor to verify the EKC hypothesis by using four different outcomes, such as carbon dioxide (CO2) emissions, sulfur dioxide (SO_2), wastewater (WW), and particulate matter (PM). We implement Tsong et al.'s (2016) cointegration test with Fourier approximation throughout 1961–2014 to test the EKC hypothesis in a time-series model framework. Additionally, we apply fixed-effects and random-effects models to 81 provinces of Turkey between 1992 and 2013 to account for province-level effects. By doing so, we provide more disaggregated evidence on economic degradation–economic growth nexus from local economies.

In the 1980s, Turkey opened its borders to foreign countries to promote international trade. Trade openness has been of great importance in Turkey's economic development since then. In the 1990s, it experienced numerous financial crises that occurred due to adverse economic policies. Because of these developments, the average growth rate of the Turkish economy between 1990 and 2001 was limited around 3.39% annually. In 2001, new fiscal and monetary policies were introduced, while new structural changes have been made to the financial sector to secure the country's financial transactions. As a result of these economic reforms, the Turkish economy started its recovery from the financial crisis. It demonstrated spectacular GDP growth rates as of 2002 up until 2013, indicating an average annual growth rate of about 6%, which was similar to that of emerging economies for the same period.

This rapid economic growth increases standards of living among Turkish citizens, while it can lead to serious environmental issues such as air pollution. This high economic development attracts attention to study the rapid economic growth of Turkey on environmental effects, especially after 2002, whether economic development is environmentally friendly or not. This study will display where Turkey is located on the curve, which will help policymakers to implement some precautions if necessary. The United Nations (UN) reports that Turkey is the country with the most dramatic increase in gas emissions. Between 1990 and 2004, about 74% of the greenhouse effect was experienced due to these gas emissions (Apergis and Ozturk 2015).

We contribute to the current literature in three distinct ways: First, our paper is the first testing the EKC in Turkey by employing the Fourier SHIN cointegration test in a time-series setting. The main advantage of this test is that it considers unknown numbers and forms of structural breaks, which takes advantage of getting rid of defining precise dates and kinds of structural changes. Unlike many other studies in the literature, our model specification to test the EKC hypothesis in time-series setting allows considering an unknown number of structural breaks with various forms and patterns.

Second, we study the EKC hypothesis with various environmental measures, including wastewater, PM, SO_2, and CO_2, for the Turkish provinces by utilizing fixed- and random-effects panel data regression models. Since it may not be enough to employ only air quality measures as environmental indicators to test the EKC, we provide new evidence to the literature by including wastewater pollution in the analysis. The originality of our paper comes from the fact that we implement panel data models by using province-level data to identify the validity of the EKC for various environmental indicators, on which there is insufficient research concerning Turkey. Besides, a significant benefit of implementing panel data models is that it allows capturing the province-specific factors in the regression analysis, which cannot be accounted for in time-series applications.

Thirdly, past studies concerning Turkey only looked at the existence of the EKC in the context of the whole country by implementing only time-series analysis. To the best of our knowledge, only one study by Akbostancı et al. (2009) looks at the existence of the EKC in Turkey by implementing time-series and panel data models on the provincial level. However, in their time-series model, they only consider the period until 2003. In their panel data model, they only study the period until 2001. As a significant contribution to the literature, our study examines the EKC by adding the period of rapid economic growth between 2002 and 2013 for Turkey in the analysis using disaggregated data at the province level.

2 Literature review

Grossmann and Krueger (1991) examined the effects of the North American Free Trade Agreement on environmental quality indicators and revealed the existence of the EKC. After their significant contribution to the literature, many researchers have begun investigating the linkage that the EKC assumes. Current evidence on the EKC hypothesis provides contradictory results. Acar et al. (2018) examine whether the EKC hypothesis held for OECD, Middle East, developing countries, and OPEC between 1970 and 2016 and found no evidence of the EKC. Ang (2007) investigated the relationship between carbon dioxide emissions and GDP between 1960 and 2000 for France and found a quadratic linkage between these two variables. Jebli et al. (2016) studied the OECD countries whether the EKC hypothesis is valid and discovered the existence of the hypothesis; however, Özokcu and Özdemir (2017) found an N-shaped connection. Olale et al. (2018) argue that technological change and province characteristics are significant determinants of the level of greenhouse gas emissions.

Recently, Bilgili et al. (2016) test the EKC by considering renewable energy, and they argue that the EKC holds for the OECD between 1977 and 2010. By implementing the Pedroni panel cointegration test, they found that the consumption of renewable energy decreases pollution. Later, Liddle and Messinis (2018), using a reduced-form linear model which has advantages on multiple endogenous breaks, uncover the link between GDP and pollutants for 21 OECD countries between 1870 and 2010. Sarkodie (2018) studied the determinants of environmental degradation for 17 African countries and concluded that the EKC holds.

Our second part of the analysis endeavors to understand whether the EKC hypothesis holds when disaggregated data used for Turkish provinces. Benefitting from disaggregated data allows us to avoid aggregation bias that may cause incorrect EKC estimations. Xu (2018) showed that results obtained from such studies might mislead governments in combating environmental degradation, and it is found that estimation used disaggregated data does not support the EKC with SO_2 emissions. There also exist other studies using several local pollutants such as SO_2 (Kaufmann et al. 1998; Jayanthakumaran and Liu 2012; Wang et al. 2016), PM_{10} (Carson et al. 1997; Khanna and Plassmann 2004; Egli 2002; Orubu and Omotor 2011), and wastewater (Tao et al. 2008; Li et al. 2016) in the EKC literature. The results found by Fodha and Zaghdoud (2010) indicate that there exists an N-shaped relationship between CO_2 per capita and GDP per capita, while the relationship between SO_2 emissions and economic growth exhibits a curve of an inverse N-shaped. The common point of these studies is that different local pollutants have different relationships with economic development. For instance, Xu et al. (2019) investigate the effects of economic growth on several air pollutants such as SO_2, NO_x, and $PM_{2.5}$, and they find that an inverse "U"-shaped or inverse "N"-shaped relationship existed in China's eastern and central regions, while a "U"-shaped relationship existed in China's western region, between GDP per capita and air pollutants. These results indicate that the relationship between air pollutants and economic growth depends on regional factors and the variables used in the study.

Here, we summarize some of the related studies concerning Turkey. Ozturk and Acaravci (2010) investigate the relationship between economic growth, carbon emissions, energy use, and employment in Turkey and show a long-run relationship between variables. Pata (2018) explores the short-run and long-run dynamic relationship among income per capita, carbon emissions, several energy sources, and financial development and argues that economic growth is the primary driver of environmental pollution. Soytas and Sari (2009) argue that Turkey should continue investing in economic growth without considering carbon emissions. Ozatac et al. (2017) argue that there exists a linkage between trade, financial development, urbanization, and energy usage by employing the conditional Granger causality test. Hence, they propose a carbon tax and environmentally friendly technology to reduce environmental degradation. Akbostanci et al. (2009) found that there appears to be an N-shaped relationship between carbon dioxide emissions and GDP per capita, indicating the nonexistence of the EKC.

Furthermore, Balibey (2015) examines the validity of the EKC hypothesis in Turkey between 1974 and 2011 and finds that economic growth causes the degradation of the environment and that the cubic model provides an N-shaped relationship between per capita income and CO_2 emissions. Shahbaz et al. (2013) study the relationship between CO_2 emissions, energy intensity, economic growth, and globalization for the period 1970–2010 for Turkey. Their outcome validates the existence of the EKC hypothesis in Turkey for the specified period. Beşe and Kalayci (2019) test the EKC hypothesis for three developing countries between 1971 and 2014, including Egypt, Kenya, and Turkey, and their results do not validate the presence of the EKC hypothesis for these three nations. Ozturk and Acaravci (2013) study the long-run relationship between energy, growth, openness, financial development, and carbon emissions in Turkey for the period 1960–2007. Their results indicate that as income increases, the level of CO_2 emissions initially increases. However, after the stabilization point, the level of CO_2 emissions decreases with more income.

There are other studies, including financial development, trade openness, urbanization (Halicioglu 2009; Katircioglu and Taspinar 2017), gross fixed capital formation, and labor (Soytas and Sari 2009) to the traditional EKC estimation. Bölük and Mert (2015) investigate whether renewable energy sources could be a solution for reducing environmental degradation, and their findings reveal that alternative energy production methods mitigate carbon emissions in Turkey.

To conclude, the previous studies of the EKC for the Turkish economy have suffered from a lack of considering structural breaks as smooth and gradual processes, and no previous research has controlled for the wastewater emissions in the reduced-form EKC models.

3 Data and methodology

3.1 Data

In this study, we explore the link between economic development and pollution for Turkey by implementing two distinct methods. We implement a time-series model for which we utilize annual data on CO_2 emissions (per capita metric tons), the energy consumption (per capita oil equivalent in kilograms), and gross domestic product per capita (adjusted for \$2010 in thousands) over the period 1961–2014.[1]

As for the panel model, we obtained annual data on four variables for 81 provinces of Turkey during 1992–2013.[2] We collect the province-level gross domestic product (adjusted for \$2005 in millions) data from Başıhoş (2016). The Turkish Statistical Institute (TurkStat) and the Ministry of Environment and Urbanization[3] provide information on environmental indicators, including SO_2, PM, and wastewater. We have data restrictions on the environmental indicators in terms of provinces and the time, which limits the scope of this study.

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[1] We extend Akbostanci et al.'s (2009) analysis where they utilize CO_2 emissions and income data up until 2003. The energy consumption data include the primary energy consumption before transformation to other end-use fuels. We obtained the data from the World Bank World Development Indicators (WDI).

[2] We extend Akbostanci et al.'s (2009) panel data analysis in terms of both environmental indicators and time by including wastewater data as an environmental indicator beside SO_2 and PM and using more years, where they only utilize two environmental indicators including SO_2 and PM_{10} emissions and income up until 2003.

[3] Up to 2011, the data for SO_2 and PM are available at TurkStat. The Ministry of Environment and Urbanization supplies them after 2011.

Table 1 Descriptive statistics

Variables	Mean	SD	Min	Max	Observation
Panel regression variables					
Wastewater (WW)	38,372.87	96,188.29	372	1,118,741	648
Sulfur dioxide (SO_2)	55.31792	43.25198	1	276	1038
Particulate matter (PM)	59.35121	28.31106	8	242	1072
GDP (in billions)	5.444861	11.54873	0.1319915	116.9562	1782
Time-series regression variables					
CO_2	2.423008	1.128005	0.612272	4.491479	55
ENERGYUSE	909.5151	351.9341	385.4712	1585.400	55
GDP_PC (in thousands)	6.705083	2.648818	3.134779	13.31246	55

In the time-series model, CO_2 emissions are in per capita metric tons, energy consumption is in per capita oil equivalent in kilograms, and the primary energy consumption before transformation to other end-use fuels and GDP displays the GDP per capita in thousand US dollar. In panel models, SO_2 and PM are measured in microgram cubic meters, $\mu g/m^3$, and wastewater is measured in thousand cubic meters. GDP_PC is the income measure in constant 2005 US dollars (in billions)

Table 1 displays the descriptive statistics for variables included in the time-series regression model and panel data regression model.

3.2 Methodology

3.2.1 Model specifications

The EKC hypothesizes a linkage between economic development and pollution. Traditional models utilize polynomial equations to study the EKC hypothesis, which is also called a parametric model or reduced-form function. Using reduced-form equations in studying the EKC hypothesis has some advantages such that they have a sound basis for testing the EKC, and its results are easy to interpret. We implement time-series, fixed- and random-effects models to investigate whether the EKC holds for Turkey or not. In doing so, we utilize four distinct outcome variables, including CO_2 emissions, WW, SO_2, and PM.

In the first step of our model specification, we examine the EKC for Turkey by implementing time-series analysis. In a time-series analysis, we estimate the following model.

$$E_t = \beta_0 + \beta_1 \mathrm{GDP\_PC}_t + \beta_2 \mathrm{GDP\_PC}_t^2 + \beta_3 \mathrm{GDP\_PC}_t^3 + \beta_4 \mathrm{ENERGYUSE}_t + \varepsilon_t, \quad (1)$$

where E_t shows the environmental indicator, which is the CO_2 emissions; GDP is the per capita income, the ENERGYUSE is the primary energy consumption before transformation to other end-use fuels, and ε_t is the unobserved error term.

In the second step of our empirical analysis, we use fixed- and random-effects models by utilizing various outcome variables, including CO_2 emissions, WW, SO_2, and PM. We estimate the reduced-form equation for our time-series model following the literature (Dinda 2004; De Bruyn et al. 1998). The estimating equation of the fixed- and random-effects models is represented as follows:

$$E_{it} = \beta_0 + \beta_1 \mathrm{GDP}_{it} + \beta_2 \mathrm{GDP}_{it}^2 + \beta_3 \mathrm{GDP}_{it}^3 + \varepsilon_{it}, \quad (2)$$

where the subscripts i and t stand for the provinces and the year, respectively. E_{it} represents the pollution, including sulfur dioxide (SO_2) and particulate matter (PM). Besides, we add wastewater (WW) as a pollutant. SO_2 and PM are measured in microgram cubic meters, µg/m^3, and wastewater is measured in thousand cubic meters. Here, GDP is the income measure in constant 2005 US dollars (in billions).

Furthermore, Song et al. (2008) list seven functional forms between income and pollution dependent upon the coefficients of the parameters β_1, β_2, and β_3:

1. $\beta_1 > 0, \beta_2 = 0, \text{and } \beta_3 = 0 \rightarrow$ linear and monotonically increasing,
2. $\beta_1 < 0, \beta_2 = 0, \text{and } \beta_3 = 0 \rightarrow$ linear and monotonically decreasing,
3. $\beta_1 = 0, \beta_2 = 0, \text{and } \beta_3 = 0 \rightarrow$ a level relationship,
4. $\beta_1 > 0, \beta_2 \langle 0, \text{and } \beta_3 \rangle 0 \rightarrow$ an N-shaped,
5. $\beta_1 \langle 0, \beta_2 \rangle 0, \text{and } \beta_3 < 0 \rightarrow$ an inverse N-shaped,
6. $\beta_1 \langle 0, \beta_2 \rangle 0, \text{and } \beta_3 = 0 \rightarrow$ a U-shaped,
7. $\beta_1 > 0, \beta_2 < 0, \text{and } \beta_3 = 0 \rightarrow$ an inverse U-shaped, which indicates that the hypothesis holds.

3.2.2 Time-series model

3.2.2.1 Fourier KPSS (FKPSS) unit root test Fourier KPSS unit root test is first introduced by Becker et al. (2006). Their empirical testing procedure starts with the following data generating process:

$$y_t = \partial_t + d_t + \varepsilon_t, \tag{3}$$

where

$$\partial_t = \partial_{t-1} + \omega_t. \tag{4}$$

In these equations, ω_t are i.i.d errors with a variance of σ_ω^2. Here, the Fourier terms launced into the equation with d_t component.

$$d_t = \gamma_0 + \alpha_k \sin(2k\pi t|T) + \beta_k \cos(2k\pi t|T), \tag{5}$$

where k represents the particular number of frequencies, t stands for the time trend, and T is the number of observations.

The FKPSS test statistics to test the null hypothesis of the stationarity is calculated as follows:

$$\tau_{\text{FKPSS}}(k) = \left(\frac{1}{T^2}\right)\left(\frac{\sum_{t=1}^{T} \hat{S}_t^2}{\sigma_\omega^2}\right). \tag{6}$$

Here, $\hat{S}_t = \sum_{t=1}^{t} \hat{\vartheta}_{1t}$ is the partial sum of the residuals from Eq. (3). Also, the significance of the Fourier terms $\alpha_k = \beta_k = 0$ is tested against $\alpha_k = \beta_k \neq 0$ by using a conventional F test procedure.

3.2.2.2 Fourier SHIN (FSHIN) cointegration test Current literature takes advantage of a variety of methods to explain the link between economic development and environmental quality indicators. We examine pollution and income relationship by implementing two distinct methods. In the time-series analysis, our study utilizes a cointegration test in a

Fourier form. A distinct advantage of the cointegration test with the Fourier approximation is that it takes into consideration unknown numbers and forms of structural breaks. We then estimate the EKC with the fully modified ordinary least squares (FMOLS) estimator.

In a time-series context, we employ Tsong et al.'s (2016) cointegration test, namely Fourier SHIN (FSHIN), to study whether the EKC is valid for Turkey. We first check the stationarity of carbon dioxide emissions and per capita GDP before utilizing the cointegration estimation. We use Augmented Dickey–Fuller, Phillips–Perron, and unit root tests in our analyses.

In the cointegration analysis, the FSHIN cointegration test is employed, whose power is independent of the form, date, and the number of structural changes. Structural breaks are approximated via Fourier function. Suppose that we have the following cointegration regression (Tsong et al. 2016):

$$y_t = \alpha_t + x_i^{'}\beta + \varepsilon_t, \quad t = 1, 2, 3, \ldots, T. \tag{7}$$

Here, $\varepsilon_t = \gamma_t + \vartheta_{1t}$, $\gamma_t = \gamma_{t-1} + \omega_t$, $\gamma_0 = 0$, and $x_t = x_{t-1} + \vartheta_{2t}$. Also, ω_t is (0, σ_ω^2) and *iid*. The deterministic component, α_t, is identified as follows:

$$\alpha_t = \sum_{i=0}^{m} \delta_i t^i + f_t, \tag{8}$$

with $m = 0$ or $m = 1$ and

$$f_t = \gamma_k \sin\left(\frac{2k\pi t}{T}\right) + \beta_k \cos\left(\frac{2k\pi t}{T}\right), \tag{9}$$

ω_{1t} and ω_{2t} are the stationary, k indicates the optimal number of frequencies, t refers to the trend, T is the observation number, and π is the constant.

The following two steps calculate this test statistic of FSHIN cointegration test, which is labeled as CI_f^m:

$$y_t = \sum_{i=0}^{m} \delta_i t^i + \gamma_k \sin\left(\frac{2k\pi t}{T}\right) + \beta_k \cos\left(\frac{2k\pi t}{T}\right) + x_t^{'}\beta + \vartheta_{1t}, \tag{10}$$

$$\mathrm{CI}_f^m = T^{-2}\hat{\varphi}_1^{-2} \sum_{t=1}^{T} S_t^2. \tag{11}$$

Here, $S_t = \sum_{t=1}^{t} \hat{\vartheta}_{1t}$ is the partial sum of the residuals from Eq. (10), and $\hat{\varphi}_1^2$ shows the consistent estimator of the long-term variance of ϑ_{1t}. The test is structured under the null hypothesis of cointegration and the alternative hypothesis of non-cointegration.

3.2.3 Panel DATA MODel

3.2.3.1 Cross-sectionally augmented Dickey–Fuller (CADF) unit root test

CADF unit root test considers both cross-sectional dependence and the heterogeneity across panel units. In general, the CADF test modifies the Augmented Dickey–Fuller (ADF) regression and inserts lagged and differenced values of individual series into the model. The CADF test provides individual test statistics for panel units and the cross-sectionally Augmented Im–Pesaran–Shin (CIPS) statistics is the average of the CADF statistics (Pesaran, 2007).

The data generating process for a dynamic heterogenous panel data model is demonstrated as follows:

$$y_{it} = \left(1 - \varphi_i\right)\mu_i + \varphi_i x_{i,t-1} + \vartheta_{it}. \tag{12}$$

Here, *i* stands for the panel units and t represents the time, for $i=1\ldots, N$; $t=1\ldots, T$. Therefore, x_{it} shows the observation on *i*th cross-sectional unit at time *t*.

As noted, CADF test procedure launces the lagged and differenced values of the series, the CADF test statistics is calculated by estimating the following estimation by ordinary least square.

$$\Delta y_{it} = \delta_i + \gamma_i y_{i,t-1} + \sum_{j=1}^{p_i} a_{ij}\Delta y_{i,t-j} + b_i t + c_i \bar{y}_{t-1} + \sum_{j=0}^{p_i} \eta_{ij} y_{i,t-j} + \varepsilon_{i,t}. \tag{13}$$

Inclusion of the lagged values to the estimation procedure solves the potential autocorrelation problem. In the final step, the CIPS statistics is calculated by calculating the simple average of the CADF statistics for each individual panel unit.

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{N}\text{CADF}_i, \tag{14}$$

where *N* is the number of cross-sectional units in the panel.

3.2.3.2 Fixed-effects and random-effects panel data models We follow past studies (Dutt 2009; Zhang and Zhao 2014; Olale et al. 2018) and estimate the EKC model by implementing fixed-effects panel data regressions with robust standard errors, which are clustered at the provincial level. For the two (SO_2 and PM) out of three outcome measures, we implement a fixed-effects panel data regression model. At the same time, we utilize a random-effects panel data regression model for the remaining outcome variable (WW) based on the Hausman specification test results (see Hausman test results in "Appendix", Table 8). A significant benefit of the fixed-effects model is that it allows for the estimated constant terms to be specific for each province while capturing the province-specific factors in the regression analysis.

When the focus is on the specific set of N units (i.e., number of firms, provinces), the fixed-effects model is a suitable specification. The panel data model is as follows (Baltagi 2005):

$$y_{it} = \beta_0 + \beta x_{it} + \vartheta_{it}\ \text{for}\ i = 1, 2, 3, \ldots, N\ \text{and}\ t = 1, 2, 3, \ldots, T. \tag{15}$$

Here, $\vartheta_{it} = \mu_i + u_{it}$ and μ_i represent the unobservable unit-specific effects and u_{it} denotes the remainder disturbance. Note that μ_i is time invariant, and it considers any unit-specific effect not included in the model. Hence, the specific regression is:

$$y_{it} = \beta_0 + \beta x_{it} + \mu_i + u_{it}. \tag{16}$$

To eliminate the effect of μ_i, first, we take the average over time and obtain:

$$\bar{y}_i = \beta_0 + \beta \bar{x}_i + \mu_i + \bar{u}_i. \tag{17}$$

Subtracting (17) from (16) gives as follows:

$$y_{it} - \bar{y}_i = \beta\left(x_{it} - \bar{x}_i\right) + \left(u_{it} - \bar{u}_i\right). \tag{18}$$

In a reduced form, we can write the above equation as:

$$\tilde{y}_{it} = \beta\tilde{x}_{it} + \tilde{u}_{it} \text{ for } i = 1, 2, 3, \dots, N \text{ and } t = 1, 2, 3, \dots, T. \tag{19}$$

Here, $\tilde{y}_{it} = y_{it} - \bar{y}_i$ and $\tilde{x}_{it} = x_{it} - \bar{x}_i$.

The pooled ordinary least squares estimate Eq. (19), and we obtain fixed-effects estimators. The formula for fixed-effects estimators is given as follows:

$$\hat{\beta}_{fe} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{x}_{it}^{\prime}\right)^{-1}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{x}_{it}^{\prime}\tilde{y}_{it}\right). \tag{20}$$

On the other hand, the random-effects model is specified as follows (Gujarati, 2003):

$$y_{it} = \beta_{0i} + \beta x_{it} + u_{it}. \tag{21}$$

Here, the β_{0i} is not treated as fixed; instead, it is assumed to be random. The β_{0i} has a mean of β_0. The intercept value for an individual panel unit is described as:

$$\beta_{0i} = \beta_0 + e_i \text{ where } i = 1, 2, \dots, N. \tag{22}$$

The error term, e_i, has zero mean and variance of σ_e^2.

By substituting (21) into (22), we get the random-effects model as follows:

$$y_{it} = \beta_0 + \beta x_{it} + w_{it}, \tag{23}$$

where $w_{it} = e_i + u_{it}$. The random-effects estimators are handled by estimating Eq. (23) with generalized least squares (GLS).

4 Empirical findings and discussion

4.1 Results of time-series model

This study aims to estimate the EKC model defined in Eq. (1) in a time-series setting. Since the estimations will turn to be spurious when series are not stationary, we first need to identify their unit root properties. Table 2 illustrates the Fourier KPSS (FKPSS) unit root test.

According to Table 2, we can reject the null hypothesis and conclude that in both level and trend models, variables are not stationary in their level values. Then, we take the first differences of variables and find that the null hypothesis cannot be rejected. Therefore, we decide that variables are stationary in their first differences, and the order of integration is $I(1)$ as well. Thus, we can study the cointegration relationship between the variables. The study follows the FSHIN test in cointegration analysis, which is summarized in Table 3.

Table 3 reports that the F-statistics is higher than the critical value[4] and in fact implies that trigonometric terms are significant. The FSHIN cointegration test results in both model with constant and the model with constant and time trend indicate that the

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[4] Tsong et al. (2016) report the critical values.

Table 2 Fourier KPSS unit root test results

Level				Trend			
Variables	Frequency	FKPSS	Fstat	Variables	Frequency	FKPSS	Fstat
CO2	1	0.438**	34.561^{τ}	CO2	3	0.292	13.170^{τ}
GDP	1	0.447**	26.612^{τ}	GDP	1	0.260	56.149^{τ}
ENERGYUSE	1	0.435**	32.687^{τ}	ENERGYUSE	1	0.131	15.560^{τ}
ΔCO2	5	0.399	2.386	ΔCO2	5	0.014	2.602
ΔGDP	5	0.149	2.052	ΔGDP	1	0.024	1.461
ΔENERGYUSE	5	0.428	2.396	ΔENERGYUSE	5	0.013	2.814

In the level model, 5% critical value for the FKPSS test in Frequency 1 is 0.1720 and in Frequency 5 is 0.4626. In the trend model, 5% critical value for the FKPSS test in Frequency 1 is 0.0546 and in Frequency 3 is 0.1423. Critical values for the *F* test for in the level and trend models are 4.929 and 4.972, respectively. **Represents the rejection of the null of stationarity. $^{\tau}$Indicates that Fourier terms are significant

Table 3 FSHIN cointegration test results

	Model with constant	Model with constant and time trend
Frequency	2	3
Min SSR	0.069	0.028
FSHIN-TEST (CI_f^m)	0.030**	0.086***
F_{test}	53.260	9.214

In the model with constant, FSHIN cointegration test for 2-frequency 5% critical value is 0.097. In the model with constant and time trend, FSHIN cointegration test for 3-frequency 1% critical value is 0.099. 5% critical value for F_{test} is 4.066 and 4.019, respectively. ** and ***represent that the null of cointegration cannot be rejected at 5% and 1%, respectively

Table 4 Long-run estimation results

Estimators	Variables	Coefficients	Prob. values	Standard errors	*t*-statistics
FMOLS	Intercept	− 1.331942***	0.000	0.117281	− 11.35685
	GDP	0.379915***	0.000	0.060434	6.286433
	GDP^2	− 0.026648***	0.000	0.006332	− 4.208198
	GDP^3	0.000600**	0.030	0.000273	2.199591
	ENERGYUSE	0.002547***	0.000	0.000201	12.69375

*** and **Denote statistical significance at 1% and 5%, respectively. Standard errors are corrected by heteroskedasticity and autocorrelation consistent HAC method

null of cointegration cannot be rejected, and hence, we conclude that pollution, income, and energy use variables are cointegrated in the long run. Furthermore, we proceed with estimating the EKC model with the FMOLS estimator, for which the results are illustrated in Table 4.

Table 5 Cross-sectional dependence tests results

Variable	Breusch–Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
SO_2	12,959.48***	120.741***	118.812***	39.286***
PM	20,461.11***	213.931***	212.002***	126.719***
WW	63,978.97***	754.535***	752.607***	252.516***
GDP	68,701.79***	813.205***	811.277***	262.080***

***Denotes statistical significance at 1%

Results of the EKC model in Table 4 show that the positive coefficient of GDP and the negative coefficient of GDP^2 are statistically significant at 1%. The positive coefficient of GDP^3 is significant at 5% level. The coefficient of ENERGYUSE is also positive and significant at 1%. In this case, the results specify $\beta_1 > 0, \beta_2 \langle 0, \beta_3 \rangle 0$, which implies the N-shaped relationship and does not favor the EKC hypothesis. When we solve this equation,[5] we find that the first and the second turning points for the N-shaped curve are \$11,957 and \$17,652, respectively, which indicates the Turkish economy exceeds the first turning point and is at a decreasing portion of the curve. Besides, the positive coefficient of the ENERGYUSE documents that energy consumption decreases environmental quality. This finding also represents the increasing need for the use of clean energy in Turkey.

4.2 Results of panel data models

4.2.1 Cross-sectional dependence and panel unit root tests

Before proceeding to examine the potential evidence for the EKC hypothesis in Turkish provinces, we need to decide the order of integration of variables via the unit root test. On the other hand, the form of the unit root test is determined by whether the provinces are cross-sectionally dependent or not. If there is a cross-sectional dependence (CD) across provinces, we need to employ second-generation unit root tests. The study first utilizes the set of cross-sectional dependence tests. The results of these tests are displayed in Table 5.

This study employs the LM test of Breusch and Pagan (1980), CDLM and CD tests proposed by Pesaran (2004), and adjusted LM test of Pesaran et al. (2008). It appears that the null of the no cross-sectional dependence is rejected for all series in a set of CD tests. In other words, our results provide an evidence favoring the cross-sectional dependence across provinces. These findings denote that the first-generation unit root tests may provide biased results. Thus, the second-generation unit root tests are more suitable for evaluating the level of integration between variables.

The existence of cross-sectional dependency across provinces leads us to use a kind of second-generation unit root test. Therefore, we use a cross-sectionally augmented Dickey–Fuller (CADF) test that is proposed by Pesaran (2007). The results of the unit root analysis are shown in Table 6.

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[5] It is a procedure that we use to find the turning points. Since we have a third-degree polynomial equation, first we take the derivate of the function and then we set the quadratic equation to zero to find the roots.

Table 6 CADF unit root test results

Variables	CIPS statistics	
	Constant	Constant and trend
SO_2	– 2.638***	– 2.813***
PM	– 2.281***	– 2.704**
WW	– 2.418***	– 2.191
GDP	– 3.270***	– 3.264***

Critical values of CIPS statistic for constant model are – 2.20, – 2.08, and – 2.01 for 1%, 5%, and 10%, respectively, and the critical values for constant and trend model are – 2.72, – 2.59, and – 2.53 for 1%, 5%, and 10%, respectively. ***, **, and * represent the stationarity with these significance levels. Δ denotes the first difference. A maximum lag is chosen as 2, and SIC determines optimum lag

Table 7 Fixed- and random-effects regression results

Variables	Model 1 WW	Model 2 PM	Model 3 SO_2
C	1883.558 (0.44)	40.155 (0.00)	146.122 (0.00)
GDP	5891.148*** (0.00)	5.160*** (0.00)	– 22.938*** (0.00)
GDP^2	– 0.022 (0.55)	– 0.0000797** (0.03)	0.0003984*** (0.00)
GDP^3	4.06E – 07* (0.09)	3.98E – 10* (0.06)	– 2.08E – 09*** (0.00)
R^2	0.9826	0.050	0.323
Observations (Unbalanced)	648	1.072	1.038
Groups	81	81	81

***, **, *Denote the statistical significance at 1%, 5%, and 10%, respectively. Numbers in parentheses denote probability values. According to the Hausman specification test results, correct estimation methods are the fixed-effects model for PM and SO_2 and the random-effects model for WW

Table 6 denotes that the null of non-stationarity cannot be rejected for all series in their level values. Thus, one can conclude that these series are stationary in their levels.

We estimate Eq. (2) for WW, PM, and SO_2 by utilizing fixed- and random-effects panel data models whether the EKC hypothesis holds for these variables in Turkish provinces in a given period. Estimation results for all outcome variables are reported in Table 7.

4.2.2 Panel regression results

Results of the model for WW, Model 1, display that all estimations, except the coefficient for the GDP^2 term, are statistically significant at the 1% and 10% levels, respectively. The coefficients of GDP, GDP^2, and GDP^3 alternate in sign. The slope of the income is first positive, then turns to negative (although statistically insignificant), and finally becomes positive again. However, when we solve for the roots of the Model 1 in Table 7, we find that there exists a monotonically increasing relationship between wastewater and economic growth, implying that the EKC hypothesis does not hold.

We also present the results for PM, Model 2, in Table 7. The coefficients of GDP and GDP^2 are significant at the 1% level and at the 5% level, respectively, and the coefficient of GDP^3 is significant at the 10% level. Moreover, the coefficients of GDP, GDP^2, and GDP^3 alternate in sign, and these results provide further support for an N-shaped relationship between PM and income in Turkey. Also, the findings reported for Model 2 suggest that the first and second turning points are $55,174.13 and $78,326.60, respectively. Hence, PM quality measure will continue to degrade the environment when the GDP of the Turkish provinces is between $0 and $55,174.13. We can argue that for Turkish provinces reaching the first turning point, air pollution will be declining as income increases up until $78,326.60.

In contrast to the findings for WW and PM environmental measures, results for SO$_2$ are quite different. Although the coefficients of GDP, GDP^2, and GDP^3 alternate in sign, the coefficient of income is the first negative, then turns to positive, and finally becomes negative such that $\beta_1 \langle 0, \beta_2 \rangle 0$, and $\beta_3 < 0$. These findings denote an inverted N-shaped relationship between SO$_2$ and income. For Model 3, the calculated first turning point would be $43,836.9, which means that SO$_2$ measure decreases when the GDP of the Turkish provinces is between $0 and $43,836.9. When the GDP of the Turkish provinces reaches this turning point, air quality tends to decline as income increases until it hits $83,855.4.

In this respect, similar to the findings of the time-series model, the results for panel data models do not report supportive evidence for the EKC. Results for WW and PM quality indicators in panel data models seem to suggest monotonically increasing and an N-shaped relationship, respectively, while the findings for SO$_2$ imply an inverse N-shaped pattern.

4.3 Discussion

This study investigates whether the EKC is valid in the case of Turkey. For this purpose, we test the EKC hypothesis by implementing both time-series (1961–2014) and panel data (1992–2013) models by utilizing various outcome variables, including carbon dioxide emissions, wastewater, sulfur dioxide, and particulate matter.

The empirical results for the time-series model indicate an N-shaped relationship in the long run, which contrasts with Akbostancı et al.'s (2009) study, which states a monotonic increase for Turkey. Many other studies in other contexts support this relationship that we found between the environmental quality indicator and economic growth (Apergis and Ozturk 2015; Jebli et al. 2016; Esteve and Tamarit 2012).

Time-series outcomes show that the first turning point of the curve for CO$_2$ emissions is calculated to be at $11,957, which means that CO$_2$ emissions started to decrease after climbing over per capita income of $11,957 since Turkey's per capita income is calculated to be at $12,127 in 2014. Therefore, we could say that before it gets worse in terms of environmental indicators, Turkey's environmental quality is going to be better as its GDP continues to grow.

According to our findings, the EKC seems to be invalid for Turkey and indicates an N-shaped relationship, which is compatible with the EKC literature (de Bruyn et al. 1998; Dinda et al. 2000; De Bruyn and Opschoor 1997; Sengupta 1997; Grossmann and Krueger 1993). As a contribution to the EKC literature, we also test whether the EKC holds for other types of environmental indicators such as wastewater pollution. As a result, contrary to the study by Song et al. (2008), where they find an inverse N relationship, our findings report a monotonically increasing relationship between wastewater pollution and income.

Our results show an N-shaped relationship for PM emission, unlike Dinda (2004), who argued that the PM environmental quality indicator supports the EKC hypothesis. Besides, our results for the PM pollutant are consistent with Akbostancı et al.'s (2009) findings for Turkey, suggesting an N-shaped relationship. The probable explanation for an N-shaped relationship for the PM pollution could be that Turkey's innovation (efficiency improvement) did not progress at the same rate as its production growth, as Dinda (2004) proposed.

Moreover, we report that an inverted N-shaped relationship exists between SO_2 emissions and economic growth in Turkey. This finding contradicts Kaufmann et al. (1998), Jayanthakumaran and Liu (2012), Wang et al. (2016), and Xu et al. (2019), whose results provide evidence of the EKC hypothesis. However, our results are parallel with the findings of Xu et al. (2019), showing an inverse "N"-shaped relationship between GDP per capita and SO_2 in the central region of China. Moreover, Fodha and Zaghdoud (2010) support these findings for Tunisia.

Furthermore, our findings reveal that energy use is a prominent driver of CO_2 emissions in Turkey, which ruins the environmental quality. Thus, Turkey should invest in renewable energy industries to achieve a high-quality environment through less traditional energy consumption. For example, nuclear energy, even if it is not a safe option, can be a feasible alternative for Turkey's future energy strategies. As has been indicated by Iwata et al. (2010), nuclear energy is an alternative energy source for reducing gas emissions besides its massive risks. Moreover, other alternatives, such as geothermal energy and wind power, should be taken into consideration by Turkey for sustainable energy consumption.

Last but not least, Turkey has the largest boron reserve in the world, with a share of 73% of the total reserves (ETİMADEN 2020). Boron products are used in a widespread industry from hygiene, chemistry, air, and space to the energy sector. Demirbas (2005) argues that Boron is very safe and contains more energy than petroleum. Furthermore, the main advantage of Boron comes from the fact that it has a possibility for the fuel of the future for a real zero-emission vehicle. Balat (2007) also suggests benefitting from boron as a chemical fuel for environmentally friendly economic development. Therefore, investing in the boron industry and products might be a persistent and very efficient way of energy production in Turkey.

5 Conclusion

Turkey has witnessed high economic growth through globalization period, which has been remarkable all over the world after the 1980s. Another wave of high economic growth in Turkey was seen after the devastating financial crisis in 2001. All these facts have led Turkey to increase energy demand, which is the main reason for environmental pollution (Richmond and Kaufmann 2006; Acaravci and Ozturk 2010). According to the United Nations (UN), Turkey is the country with the most dramatic increase in gas emissions. Between 1990 and 2004, about 74% of the greenhouse effect was experienced due to these gas emissions (Apergis and Ozturk 2015). Besides, Turkey's CO_2 emissions have more than doubled since 1990, closely following its economic growth (OECD, 2020). Thus, understanding the impact and causality patterns of energy–growth–emission is a strategic concern in the formulation of both energy and environmental policies in Turkey.

In light of all this, we examine whether the EKC hypothesis holds for Turkey in the long run by implementing two distinct methods. For this purpose, we utilize different outcome measures, including carbon dioxide emissions, wastewater, sulfur dioxide, and particulate matter. Put differently, we tested whether the EKC holds for Turkey as one of the emerging economies. Most studies take advantage of carbon dioxide emissions, sulfur dioxide, and particulate matter to test the EKC hypothesis in their analyses. We extend those studies by including wastewater as an alternative pollutant indicator to our regression analyses.

Overall, the Fourier SHIN cointegration test in a time-series setting indicates an N-shaped pattern for the CO_2 emission, which suggests that the EKC appears to be not working for Turkey. Also, panel data estimations at the provincial level reveal that the EKC is still not valid for the other pollutant indicators, including wastewater, particulate matter, and SO_2, showing a monotonically increasing, an N-shaped, and an inverse N-shaped relationship, respectively. The positive linear pattern is observed in the study of WW, meaning that WW is increasing as the economy grows. Therefore, we can conclude that weak or no measures have been taken in Turkey to reduce the deterioration of environmental quality arisen by WW discharge. Thus, the government should encourage the recycling of wastewater discharged and could maintain an environmentally friendly economic development by doing so.

Household fuel consumption for heating, fossil fuel plants, and diesel vehicles are the leading producers of sulfur dioxide. PM also results from burning fossil fuels, diesel motors, construction and industrial operations, and dust from the ground. High economic activity is closely related to energy consumption for production at all sub-components of GDP. Therefore, PM and SO_2 emissions, which fluctuate over the years in Turkey, should be well observed in terms of public health and economic degradation.

Considering all the criticisms and our findings, one should not only rely on the EKC hypothesis, which states that the best policy to deal with environmental quality degradation is to do nothing because economic growth/development will solely be able to solve the problem. Another lesson that we learn from the EKC analyses is that the EKC may not hold for all air pollutants. Besides, efforts should be devoted to individual countries based on smaller habitats such as regions, provinces, and districts, which will give better results in explaining the development of pollution and economic growth in specific countries. According to our findings, we can undoubtedly claim governments across the world should take precautions urgently by implementing national and local policies such as taxation to fight against pollution to reduce environmental degradation.

Although central and local governments have taken severe energy and environmental measures in recent years, those policy actions have not been sufficient to tackle air and environmental pollution due to the high demand for energy consumption. Therefore, we propose some additional steps for achieving these objectives. As a country where vital geothermal sources and renewable energy sources like wind and solar energy exist in abundance, Turkey should give firms and companies incentives to use these resources.

Moreover, countries need to act together for a sustainable environment. If only one country in the world prioritizes the environment and the others do not, the world cannot realize a high-quality environment in the long term. According to the theory of public finance, the environment is a global public good, meaning that the environmental damage of one country may harm the atmosphere of another country. Therefore, only the joint action of all governments will allow the implementation of policies that will cause fewer environmental problems while achieving economic growth.

For future studies, this paper can be improved benefiting from more recent data whenever they are available, particularly for provinces, in Turkey.

Appendix

See Table 8.

Table 8 Hausman test results for model selection

Variable	Hausman test result	Suitable model
Wastewater	Prob > $X^2 = 0.4163$	RE
SO_2	Prob > $X^2 = 0.0000$	FE
PM	Prob > $X^2 = 0.0000$	FE

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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