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RESEARCH ARTICLE

Investigation of the effect of human capital on environmental pollution: empirical evidence from Turkey

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Abstract
Reducing environmental pollution is a highly important issue that must be resolved globally. Improving human capital (HC) can significantly contribute to lowering environmental pollution. Using the Fourier ADL (FADL) method, this study examines the long-term effect of HC on carbon emissions (CO_2 emissions) and ecological footprint (EF) in Turkey from 1980 to 2018. In addition, the study examined the long-term effects of economic growth (GDP), financial development (FD), and globalization (KOF) on CO_2 emissions and EF. According to empirical results, HC has a negative effect on both CO_2 emissions and EF. Furthermore, the findings indicate that GDP and FD have a positive effect on CO_2 emissions and EF, whereas KOF has no statistically significant effect on CO_2 emissions and negative EF. According to the FFFF-TY causality test results, there is bidirectional causality between FD and EF and a unidirectional causality from HC to EF and from EF to KOF. This study underlines the importance of human capital in improving environmental quality in Turkey. In this context, the results of this study will assist policy makers in the development of precise policies to enhance human capital in order to improve environmental quality.

Keywords CO_2 emissions · Ecological footprint · Human capital · FADL · FFFF-TY

Introduction

Recently, actions have been taken to raise awareness of and address climate change, such as the Kyoto Protocol and the Paris Climate Agreement. Despite these efforts, there has not yet been a sharp decrease in global polluting emissions such as anthropogenic greenhouse gases (GHG), carbon dioxide (CO2), nitrous oxide (NOx), and other sources of environmental pollution (Akadiri et al. 2020). This situation stands out as a key roadblock to sustainable growth for many economies worldwide. These barriers are triggered by GHG

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Highlights
- Investigate the effect of human capital on environmental pollution.
- In addition, investigate the effects of economic growth, financial development, and globalization on environmental pollution.
- Human capital improves environmental quality.
- Real income and financial development positively impact pollutant.
- Globalization negatively impacts pollutant.

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emissions, affecting a variety of economic factors such as per capita income, financial development, and globalization.

Grossman and Krueger (1991) investigated the relationship between environmental pollution and income for the first time. The environmental Kuznets curve (EKC) hypothesis is used to investigate the relationship. The EKC hypothesis suggests that there is an inverted U-shaped relationship between per capita income and environmental pollution, and it assumes that environmental pollution will increase up to a certain point with the increase in per capita income, and after that point it will begin to decrease. With increasing economic growth, the initial amount of waste generation increases, and therefore, toxicity, i.e., pollution, increases with it. In the next stages of growth, some structural changes are implemented with the increase of environmental awareness, the implementation of environmental regulations, and the development of technological infrastructure. Thus, environmental damage is stabilized and minimized over time. In short, the EKC hypothesis assumes that once per capita income surpasses a specific threshold, environmental quality will steadily improve (Dinda 2004). Recently, researchers have made substantial use of this hypothesis.

The level of income is not the sole factor that affects environmental pollution. Pollution is also affected by financial development. This effect is double-sided. First, an increase in foreign direct investment and energy consumption through improvements in market conditions may contribute to economic growth (Dasgupta et al. 2001). Such an increase in economic growth may adversely affect environmental pollution. Second, through financial development, money can be made available for technology that is good for the environment and efficient, and renewable energy sources with minimal harm to the environment can be promoted (Juan 2011; Shahbaz et al. 2016).

Globalization is another factor that contributes to environmental pollution. Globalization has three environmental effects: scale, composition, and technical impact (Copeland and Taylor 2013). The scale effect is the increase in economic activity as a result of globalization's increased production and consumption of goods and services (Le et al. 2016). As this increase may increase the pressure on the environment, environmental quality may deteriorate (Kwabena Twerefou et al. 2017). The composition effect can be described as the relocation of polluting companies from industrialized to developing countries where environmental regulations are weak (Rezza 2013; Solarin et al. 2017; Bilgili et al. 2020). In this case, the gases released from polluted industries have negative effects on the environment. Acquisition of energy-efficient technologies from international markets can explain the technical impact (Copeland and Taylor 2004; Dasgupta et al. 2006). In this regard, the quality of the environment can be improved by the transfer of technology from developed countries. Furthermore, environmental management regulations implemented in developed countries can help improve environmental quality (Jayadevappa and Chhatre 2000).

Environmental pollution studies that examine the effects of human capital have recently gained prominence. Human capital has three distinct effects on the quality of the environment (Yao et al. 2019). The first is the income effect. According to this effect, the growth in human capital results in an increase in labor productivity. This increase also supports economic growth (Romer 1990). The effect of economic growth on environmental quality varies depending on a country's EKC standing (Grossman and Krueger 1995). The second is the technological effect. According to the technical effect, the availability of much cleaner and greener energy sources will increase, and the carbon footprint will decrease as a result of technological progress (Cagno and Trianni 2013; Li and Ullah 2022). Third is the physical capital effect. Investments in human capital can have an indirect effect on pollution by increasing physical capital. In addition, human capital can contribute to the completion of investments in physical capital by increasing technology-oriented capital. Technology-driven capital can reduce energy intensity. Technology-driven capital can also help the environment by making it easier to save energy (Fallon and Layard 1975; Li and Ullah 2022).

Researching the effects of human capital on environmental pollution is crucial for achieving sustainable development and environmental goals. Existing literature assumes that human capital is an important factor in reducing environmental pollution. It is essential to do research on this issue in order to draw the attention of both researchers and policy makers in this direction. This issue serves as the main source of motivation for the study. This study aims to examine the effects of economic growth (GDP), financial development (FD), globalization (KOF), and human capital (HC) on environmental pollution in Turkey.

Turkey is the country with the highest rate of CO_2 emission growth among the 42 countries included in the scope of the Kyoto Protocol (UNFCCC 2012). The crisis of 2002 in Turkey led to structural and financial reforms. One of the primary objectives of these reforms was to make the financial system more effective and durable (Cetin et al. 2018). With the decisions made on January 24, 1980, Turkey abandoned its import substitution industrialization strategy and adopted export-based economic policies. The Turkish economy has become a part of the global economic system as a result of this policy. Along with the acceleration of its economic growth in recent years, Turkey's investments in education and health have also attracted attention. According to the UNDP report published in 2022, Turkey ranks 54th out of 189 countries in terms of a "very high level of human development." These issues constitute the main motivation for conducting such a study on Turkey (UNDP 2022).

The following are the contributions of this study to the literature: (a) To the best of our knowledge, this is the first study to examine the long-term effects of GDP, FD, KOF, and HC on CO_2 emissions and EF in Turkey. (b) As evidenced by the published research, structural breaks are typically disregarded. In this study, a Fourier-based framework was developed for unit root, cointegration, and causality analyses, and overlooked structural fractures were taken into account. (c) Using both CO_2 emissions and ecological footprint (EF) as an environmental pollution indicator in the study, the effects of GDP, FD, KOF, and HC were evaluated independently. According to Al-Mulali and Ozturk (2015), CO_2 emissions represent a small part of environmental pollution. However, EF is a more reliable and comprehensive indicator of environmental pollution. In addition to being globally comparable, EF can measure the impact of human activities in terms of soil, air, and water. Therefore, EF has been favored over CO_2 emissions in recent years (Al-Mulali and Ozturk 2015; Solarin and Al-Mulali 2018). (d) The study employed the FD and KOF indices. This provides the study with a robust and comprehensive analysis. The FD index developed by the International Monetary Fund deals with the market and financial institutions in terms of accessibility, efficiency, and depth. On the contrary, in the previous literature, only the ratio of private loans to GDP was used as an FD indicator (Ozturk and Acaravci 2013; Pata 2018a; Godil et al. 2020; Xu et al. 2021), and the complex and multidimensional structure of FD has been neglected. Similarly, utilizing international trade alone as an indication of KOF disregards the multidimensional nature of KOF, including its financial, political, and foreign direct investment dimensions (Park et al. 2018; Pata 2019). (e) Researching the effect of HC on environmental pollution will serve as a guide for both developed and developing countries, including Turkey. Because HC may be an important argument that policy makers can utilize in the future to raise environmental awareness and minimize pollution.

The remainder of the article is as follows: Section 2 presents the literature review. Section 3 describes the dataset and empirical methodology. Section 4 shows the empirical results. Section 5 presents the discussion, and finally, Section 6 concludes the article and offers policy recommendations.

Review of literature

In recent years, the issue of environmental pollution has risen to the forefront of the agendas of both developed and developing countries due to the accelerating rate of global warming. Many studies on environmental pollution have developed as a result of scholars' increased interest in this subject. In this study, where we investigated the effect of GDP, FD, KOF, and HC on CO_2 emissions and EF, the literature we discussed was presented in four subsections: (i) CO_2 emissions and the relationship between EF and GDP, (ii) CO_2 emissions and the relationship between EF and FD, (iii) CO_2 emissions and the relationship between EF and KOF, and (iv) CO_2 emissions and the relationship between EF and HC.

CO_2 -EF and GDP

Apergis and Payne (2010) examined the relationship between CO_2 emissions and GDP using the panel VECM in 11 countries for the period 1992–2014. The results indicate that the EKC hypothesis holds true for eleven countries, i.e., that GDP increases CO_2 emissions up to a certain amount and then decreases. Ahmed and Long (2012), Kanjilal and Ghosh (2013), Bouznit and del Pablo-Romero (2016), and Liu et al. (2019) obtained similar results. However, Mikayilov et al. (2018) could not confirm the existence of EKC in the CO_2 emission-GDP relationship. In addition, Wang and Li (2019), Raggad (2020), Godil et al. (2021), Shahbaz et al. (2021), and Karaaslan and Çamkaya (2022) found that the increase in GDP increases CO_2 emissions. In contrast, several studies (Neve and Hamaide 2017; Rehman and Rashid 2017) did not find a statistically significant relationship between CO_2 emissions and GDP.

Recent studies have investigated the relationship between EF as an indicator of pollution and GDP. Al-mulali et al. (2015b), who tested the existence of EKC in 93 countries on a worldwide scale, found that there is an inverse U-shaped relationship between EF and GDP. Mrabet and Alsamara (2017), Baloch et al. (2019), Sharif et al. (2020), and Ahmed et al. (2021) revealed that GDP has a positive effect on EF.

CO_2-EF and FD

In addition to GDP, studies investigating the effect of FD on environmental pollution have also been conducted. Some studies show that FD increases CO_2 emissions (Zhang 2011; Solarin et al. 2017; Pata 2018a, b; Cetin et al. 2018; Karasoy 2019; Gök 2020; Zhao et al. 2021; Rjoub et al. 2021), while other studies conclude that FD has a reducing effect on CO_2 emissions (Tamazian et al. 2009; Jalil and Feridun 2011; Shahbaz et al. 2013; Al-mulali et al. 2015a, 2016; Sharif et al. 2019). On the other hand, there are also studies that found that there is no statistically significant relationship between FD and CO_2 emissions (Ozatac et al. 2017; Salahuddin et al. 2018; de Souza et al. 2018; Akca 2021).

Considering the studies investigating the effect of FD on EF, Uddin et al. (2017) conducted a study for the 27 highest emitting countries, Hafeez et al. (2019) for One Belt and Road countries, and Godil et al. (2020) for Turkey, and they have revealed in their studies that FD has a negative effect on EF. On the other hand, Baloch et al. (2019) conducted a study for One Belt and Road countries, Rahman et al. (2019) for 16 Central and Eastern European countries, and Gokmenoglu et al. (2021) and Köksal et al. (2020) for Turkey; and they have found that FD has a positive effect on EF.

CO_2-EF and KOF

Paramati et al. (2017) examined the effect of KOF on CO_2 emissions in EU, G20, and OECD countries. The empirical evidence indicates that KOF has a negative effect on CO_2 emissions. In their analysis of 87 high-, middle- and low-income countries, Shahbaz et al. (2019) found that KOF will reduce CO_2 emissions only in 16 high- and middle-income countries. Yang et al. (2021) has found similar results in his study conducted for OECD countries and Sharif et al. (2020) for Malaysia and Destek and Ozsoy (2015) in their studies conducted for Turkey. However, Adebayo and Acheampong (2021) conducted a study for Australia, Yurtkuran (2021) for Turkey, and Xia et al. (2022) for 67 developed and developing countries, and they found that KOF increased CO_2 emissions. On the other hand, Haseeb et al. (2018), Akdiri et al. (2019), and Akadiri et al. (2020) revealed that KOF has no statistical effect on CO_2 emissions.

Sabir and Gorus (2019) investigated the effect of KOF on EF in South Asian countries using data from 1975 to 2017 and Bayer and Hanck and ARDL methods. The study indicates that KOF has a positive effect on EF. Similar findings were obtained by Langnel and Amegavi (2020), Suki et al. (2020), Kirikkaleli et al. (2021), and Mehmood (2022). However, Pata and Yilanci (2020), Bilgili et al. (2020), Ansari et al. (2021), and Usman et al. (2022) found that KOF had a negative effect on EF. In their study conducted for Malaysia, Ahmed et al. (2019) did not find a statistically significant relationship between KOF and EF. Another study conducted by Apaydin et al. (2021) with a sample of 130 countries found a similar result.

CO_2-EF and HC

In the empirical literature, studies examining the effects of HC on CO_2 emissions and EF have emerged recently. For example, Bano et al. (2018) examined the effect of HC on CO_2 emissions in Pakistan using annual time series data for the period 1971–2014. The study's findings indicate that HC has a negative effect on CO_2 emissions. Wang et al. (2019), Yao et al. (2020), Pata and Caglar (2021), and Li and Ullah (2022) obtained similar findings in their studies. Zafar et al. (2019) examined the effect of HC on EF for the USA; Ahmed et al. (2020) for G7; Bilgili et al. (2020) for Turkey; Nathaniel et al. (2021) for BRICS; Pata et al. (2021) for 10 countries; and Chen et al. (2021) for 110 countries; and they have found that there was a negative effect.

Data and empirical methodology

Data

In this study, annual time series data for Turkey between 1980 and 2018 were used. In the empirical study, environmental pollution was modeled using multivariate analysis. CO_2 and EF are the dependent variables used in the analysis. Independent variables are GDP, FD, KOF, and HC. The variables are CO_2 (carbon emissions per capita, metric tons), EF (ecological footprint per capita, global hectares), GDP (real GDP per capita, constant 2015 USD), FD (financial development index), KOF (globalization index), and HC (education-based index). CO_2 variable was selected by taking the studies of (Al-mulali et al. 2015a; Solarin et al. 2017; Bano et al. 2018; Yang et al. 2021; Xia et al. 2022) into account, while EF variable was selected by taking the studies of (Mrabet and Alsamara 2017; Hafeez et al. 2019; Langnel and Amegavi 2020; Mehmood 2022) into account, GDP variable by taking the studies of (Pata 2018a, 2019; Akca 2021; Usman et al. 2022) into account, FD variable by taking the studies of (Rahman et al. 2019; Pata and Yilanci 2020) into account, KOF variable by taking the studies of (Paramati et al. 2017; You and Lv 2018; Adebayo and Acheampong 2021) into account, and lastly HC variable by taking the studies of (Ahmed et al. 2020; Pata and Caglar 2021; Rahman et al. 2021) into account, respectively. CO_2 and GDP data were obtained from World Development Indicators (WBI 2022), EF data from Global Footprint Network (GFN 2022), FD data from International Monetary Fund (IMF 2022), KOF data from Gygli et al. (2019), and HC data from Penn World Tables version 9.0 developed by Feenstra et al. (2015), respectively. Our empirical analysis includes the maximum number of observations based on data availability.

Empirical methodology

Our empirical analysis based on the studies of Bano et al. (2018), Wang et al. (2019), Bilgili et al. (2020), Godil et al. (2020), and Pata and Caglar (2021) considers two models that examine the relationship between environmental pollution indicators (CO_2 emissions and EF), GDP, FD, KOF, and HC for Turkey. These models are as follows:

$$CO_{2t} = \left(GDP_t, FD_t, KOF_t, HC_t\right) \tag{1}$$

$$EF_t = \left(GDP_t, FD_t, KOF_t, HC_t\right) \tag{2}$$

The natural logarithms of the variables were taken so that the log-linear model, as stated by Bano et al. (2018), yields more consistent results compared to the simple regression model and in order to avoid the problem of varying variance. The models with logarithmic transformation (Eqs. 1 and 2) can be rewritten as:

$$\ln CO_{2t} = \gamma_0 + \gamma_1 \ln GDP_t + \gamma_2 \ln FD_t + \gamma_3 \ln KOF_t + \gamma_4 \ln HC_t + \varepsilon_t \quad (3)$$

$$\ln EF_t = \gamma_0 + \gamma_1 \ln GDP_t + \gamma_2 \ln FD_t + \gamma_3 \ln KOF_t + \gamma_4 \ln HC_t + \varepsilon_t \quad (4)$$

where *ln* represents the logarithmic transformation and $t = 1980,\ldots\ldots..,2018$. Also, $\mathcal{E}t$ represents error term. γ_1 in Eqs. 1 and 2 is the coefficient of the real GDP per capita variable. γ_2 and γ_3 are coefficients of the FD and KOF variables, respectively. γ_4 is the coefficient of the variable HC.

Cointegration test

Perron (1989) emphasized that in unit root tests, deviant results may occur if structural breaks are not taken into account. Many unit root tests have been developed in the literature that take into account structural breaks after this study. Examples of this are the studies of Zivot and Andrews (1992), Lumsdaine and Papell (1997), and Narayan and Popp (2010). On the other hand, structural breaks can be identified not only by unit root tests but also by cointegration tests. Similar biased results may occur if these breaks are not taken into account. In this regard, cointegration tests developed by Gregory and Hansen (1996) and Hatemi-J (2008) take structural breaks into account in the analysis of long-term relationships. The majority of these studies model structural breaks using dummy variables. Because dummy variables take two values, 0 and 1, it only considers sudden breaks. Furthermore, these studies usually allow for a predetermined number of structural breaks. Using Gallant's (1981) Fourier function, Banerjee et al. (2017) developed the standard ADL test and introduced the Fourier ADL (FADL) method. This method offers several advantages. These advantages are as follows: (i) it is possible to make a long-term forecast by taking into account structural breaks with an unknown time and number. (ii) Since structural breaks are represented by a time-varying constant term ($d(t)$), there are no power losses resulting from the usage of the dummy variable. (iii) Both sudden and soft breaks are taken into account.

Fourier method with a single frequency used in the FADL method can be written as follows:

$$d(t) = \alpha_0 + \gamma_1 \sin\left(\frac{2k\pi t}{T}\right) + \gamma_2 \cos\left(\frac{2k\pi t}{T}\right) \quad (5)$$

where k represents number of frequencies, t = trend, T = number of observations, sin and cos trigonometric terms, and $\pi = 3.1416$. By adding Eq. 5 to the standard ADL test, the FADL method can be obtained. This method can be written in the following format:

$$\Delta y = \alpha_0 + \gamma_1 \sin\left(\frac{2k\pi t}{T}\right) + \gamma_2 \cos\left(\frac{2k\pi t}{T}\right) + \gamma_3 \left(y_{t-1} + \omega x_{t-1}\right) + \gamma_4 \sum_{i=1}^{q} \Delta y_{t-i} + \gamma_5 \sum_{i=1}^{p} \Delta x_{t-i} + v_t \quad (6)$$

In Eq. 6 above, it is assumed that there is only one regressor for ease of representation. In Eq. 6, α_0, γ_1, γ_2, γ_3, γ_4, and γ_5 parameters and i represent a certain delay length, q and p maximum delay lengths, and v_t error term, respectively. The error for the optimal k, $1 \le k \le 5$, here can be determined according to the minimum value of the sum of squares. The optimal lag length is chosen according to the minimum value of the Akaike information criterion (AIC). After k is determined, the null hypothesis $\left(H_0 : \gamma_3 = 0\right)$ that there is no cointegration is tested against the alternative hypothesis $\left(H_1 : \gamma_3 \neq 0\right)$ that there is cointegration. If the t value of γ_3, which is $\left(t^F_{ADL}\left(\hat{k}\right)\right)$, is smaller than the AIC value created by Banerjee et al. (2017), the null hypothesis can be rejected, and it is decided that there is cointegration.

Causality test

With the study of Enders and Jones (2016), structural changes began to be taken into account in causality analyses. After determining the stationarity levels of the series in Enders and Jones's (2016) causality analysis, the differences of the series with unit roots, if any, should be taken. Taking the differences between the series can cause a long-term loss of information. Nazlioglu et al. (2016) developed the Fourier Toda-Yamamoto causality analysis, which allows for different orders of integrated series and structural changes. In this causality analysis, the frequency number k takes an integer value between $1 \le k \le 5$. According to Christopoulos and Leon-Ledesma's (2011) study, a frequency with an integer value can detect temporary breaks, whereas fractional frequencies can detect permanent breaks. In consideration of this situation, Pata and Yilanci (2020) created the fractional frequency flexible Fourier form Toda-Yamamoto (FFFF-TY) causality test. This test has two important features. First, this test allows causality analysis between series integrated with different orders. The second one allows for permanent breaks in the causality test as it considers the fractional frequencies when determining the ideal value of k. The bivariate FFFF-TY approach can be written as follows:

$$Y_t = \beta_0 + \beta_1 \sin\left(\frac{2\pi kt}{T}\right) + \beta_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{l+d_{\max}} \theta_i Y_{t-i} + \sum_{i=1}^{l+d_{\max}} \Phi_i X_{t-i} + u_t \tag{7}$$

$$X_t = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{l+d_{\max}} \varphi_i Y_{t-i} + \sum_{i=1}^{l+d_{\max}} \theta_i X_{t-i} + u_t \tag{8}$$

where l is the optimal lag length of the VAR model and d max is the maximum degree of integration of the variables. In addition, k, t, and T represent the frequency, trend, and number of observations that take a value between [0.1, 0.2, 0.3,…..,5], respectively. In this approach, the null hypothesis stating that there is no causality is tested by using Wald statistics against the alternative hypothesis stating that there is causality. When testing, critical values are obtained through bootstrap simulation. Figure 1 presents an overview of our estimation procedure.

Empirical results

It is important to identify the variables' integration levels before using the FADL cointegration approach. The FADL method can be used if all the variables included in the model are integrated *(I(1))* in the first difference. In this study, the integration levels of the variables were determined using two tests: augmented Dickey-Fuller (ADF) (Dickey and Fuller 1979) and Fourier ADF (FADF) (Christopoulos and León-Ledesma 2010). By adding Fourier functions to the basic ADF test, the second test takes into account multiple structural breaks. Table 1 presents both the ADF and FADF results. According to the ADF and FADF results presented in Table 1, it can be seen that all the variables are integrated in the first difference, that is, they are *I(1)*. Based on these results, the FADL method can be applied.

Table 2 shows the results of the FADL cointegration method. According to these results, the $t^F_{ADL}\left(\hat{k}\right)$ statistics established confirm the long-term cointegration relationship

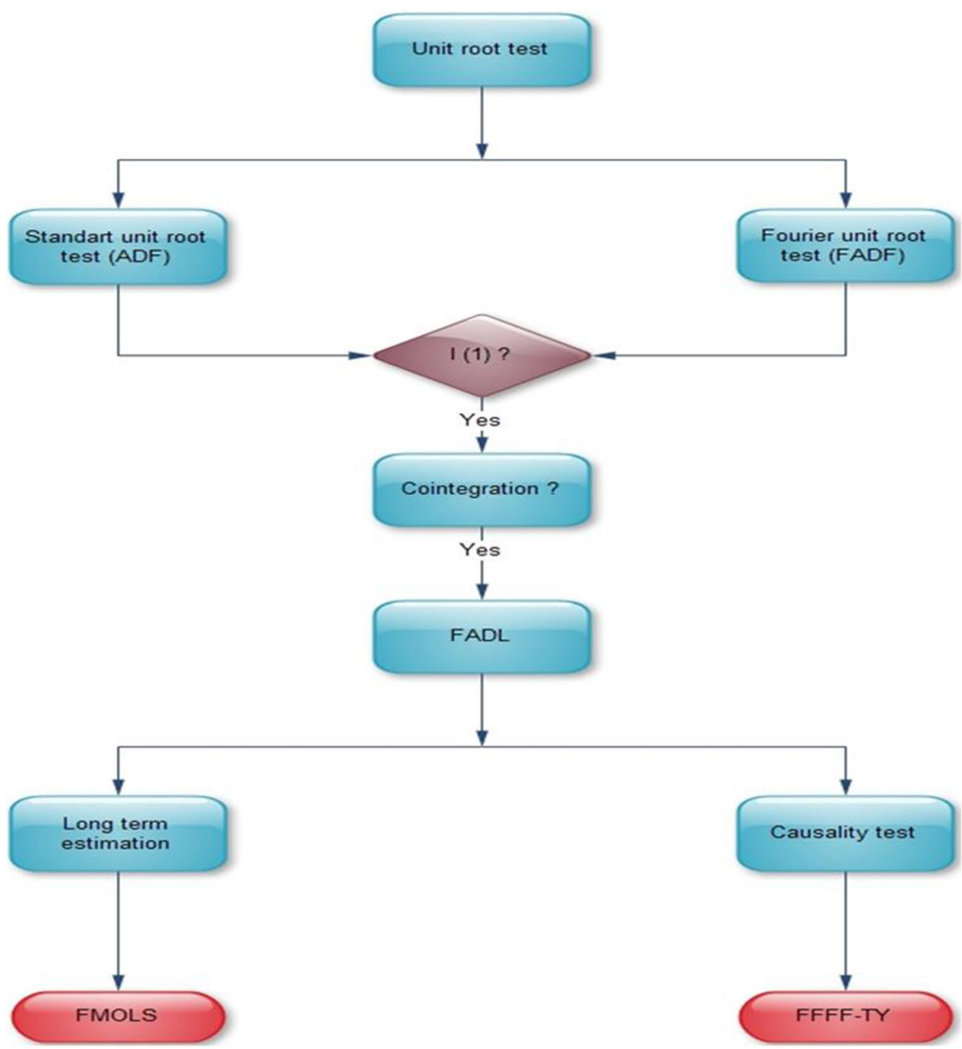

Fig. 1 Methodological framework

Table 1 FADF and ADF summary

Variables	$\widehat{k}$	FADF	ADF			
			Level		First differences	
			t stat	*p* value	*t* stat	*p* value
$lnCO_2$	1	−1.494(0)	−1.265	0.636	−7.282***	0.000
lnEF	1	−2.338(0)	−0.989	0.747	−10.982***	0.000
lnGDP	1	−0.937(0)	0.218	0.970	−6.578***	0.000
lnFD	1	−1.290(1)	−2.339	0.166	−6.278***	0.000
lnKOF	1	−1.181(0)	−1.857	0.348	−5.598***	0.000
lnHC	1	−0.072(1)	0.049	0.957	−6.325***	0.000

1%, 5%, and 10% significance level are highlighted by (***), (**), and (*) sequentially. FADF test critical values *(k=1)* are −3.52, −3.85, and −4.43 at 10%, 5%, and 1% level, respectively. [Obtained from Christopoulos and León-Ledesma (2010)].

Table 2 Fourier-ADL cointegration summary

Models	$t^F_{ADL}\left(\widehat{k}\right)$	$\widehat{k}$	Lags	AIC	Results
$lnCO_2=f$(lnGDP, lnFD, lnKOF, lnHC)	−5.844***	3	ADL(2, 2, 2, 1, 3)	−3.710	cointegrated
lnEF = f(lnGDP, lnFD, lnKOF, lnHC)	−4.968**	3	ADL(2, 1, 3, 1, 3)	−3.145	cointegrated

1%, 5%, and 10% significance level are highlighted by (***), (**), and (*) sequentially. Critical values for Fourier ADL (2017) cointegration test *(r=4, k=3)* are −5.024, −4.298, and −3.908, at 1%, 5%, and 10% level, respectively. *r* = number of independent variables

Table 3 Long-term estimation summary

Models	$lnCO_2=f$(lnGDP, lnFD, lnKOF, lnHC)		lnEF = f(lnGDP, lnFD, lnKOF, lnHC)	
Variables	Coefficients	*p* value	Coefficients	*p* value
lnGDP	3.682***	0.0016	3.511**	0.0110
lnFD	3.091***	0.0015	1.876**	0.0237
lnKOF	−7.652***	0.0028	−2.792	0.1096
lnHC	−6.512***	0.0061	−9.753**	0.0165
c	8.081**	0.0393	−9.426	0.1487
cos	−0.056***	0.0091	−0.056*	0.0520
sin	−0.079***	0.0040	−0.005	0.7183

***, **, and *: show significance at 1%, 5%, and 10% levels, respectively

in both models. In other words, there is a long-term relationship between CO_2 emissions and Turkey's GDP, FD, KOF, and HC values. A similar relationship is also valid for the model in which EF is the dependent variable

The findings from long-term relationships are shown in Table 3. The long-term effects of GDP, FD, KOF, and HC on CO_2 emissions are statistically significant. A 1% increase in GDP results in a 3.682% increase in CO_2 emissions. This result is consistent with the findings of Wang and Li (2019), Raggad (2020), and Karaaslan and Çamkaya (2022). Similarly, a 1% increase in FD increases CO2 emissions by 3.091%. In contrast to the findings of Tamazian et al. (2009), Jalil and Feridun (2011), and Al-Mulali et al. (2016), this result supports the findings of Solarin et al. (2017), Pata (2018a), Pata (2018b), Karasoy (2019), and Zhao et al. (2021). However, increases in KOF and HC have a negative effect on CO_2 emissions. A 1% increase in KOF will reduce CO_2 emissions by 7.652%. In contrast to the findings of the study of Adebayo and Acheampong (2021) conducted for Australia, and the study of Yurtkuran (2021) conducted for Turkey, this result is consistent with the findings of the study of Paramati et al. (2017) conducted for EU, G20, and OECD countries; the study of Shahbaz et al. (2019) conducted for 87 high-, middle-, and low-income countries; the study of Yang et al. (2021) conducted for OECD countries; and the study of Destek et al. (2015) conducted for Turkey, respectively. A 1% increase in HC will reduce CO_2 emissions by 6.512%. This result is consistent with the findings of Bano et al. (2018), Wang et al. (2019), Yao et al. (2020), Pata and Caglar (2021), and Li and Ullah (2022).

As shown in Table 3, GDP, FD, and HC are statistically significant in the model where EF is the dependent variable, while KOF is negative but not statistically significant. A 1% increase in GDP increases EF by 3.511%. This result is consistent with the findings of Al-mulali et al. (2015b), Mrabet and Alsamara (2017), Baloch et al. (2019), and Ahmed et al. (2021). Similarly, a 1% increase in FD appears to increase EF by 1.876%. In contrast to the findings of Uddin et al. (2017) and Godil et al. (2020), this result is consistent with the findings of the study of Baloch et al. (2019) conducted for BRI countries, the study of Rahman et al. (2019) conducted for 16 Central and Eastern European countries, and the study of Köksal et al. (2020) conducted for Turkey, respectively. On the other hand, a 1% increase in HC reduces EF by 9.753%. This result supports the findings of Zafar et al. (2019), Ahmed et al. (2020), Bilgili et al. (2020), Nathaniel et al. (2021), Pata et al. (2021), and Chen et al. (2021). Finally, it was found that KOF did not have a statistically significant effect on EF. A similar result was found by Ahmed et al. (2019) and Apaydin et al. (2021).

The FFFF-TY causality analysis results are shown in Tables 4 and 5.

According to the results presented in Table 4, there is a bidirectional causality relationship between KOF and FD. On the other hand, a unidirectional causality relationship was found from HC to KOF. Finally, a unidirectional causality relationship from FD to HC was determined.

According to the results presented in Table 5, there is a bidirectional causality relationship between FD and EF. Similarly, there is a bidirectional causality relationship between KOF and FD. The results also show that there is a unidirectional causality from HC to EF. In addition, the results show that there is a unidirectional causality relationship from EF to KOF. Furthermore, there is a one-way causality relationship from FD to GDP and from HC to KOF, respectively.

Discussion

In this study, it was determined that environmental pollution indicators (CO_2 emissions and EF) have a long-term relationship with GDP, FD, KOF, and HC. The study also revealed that an increase in GDP will result in an increase in environmental pollution. The reason for this is the structure of economic activities in Turkey. In terms of Turkey's economic growth, the manufacturing industry with 19.1% and transportation services with 7.9% stand out as the two most significant sectors (TSI 2022). The manufacturing sector and transportation services rely heavily on nonrenewable energy sources (fossils) for operating activities (MENR 2022). These sectors will support economic growth by producing more output, which will lead to an increase in their energy demands. In this way, the increase in Turkey's GDP will lead to an increase in the consumption of energy derived from fossil fuels, which would have a negative effect on the environment.

In addition, the study demonstrates a significant and positive long-term relationship between environmental pollution

Table 4 FFFF-TY causality summary (CO_2)

Null hypothesis	W-statistics	Bootstrap prob. value	k	Frequency
$\ln GDP \neq > \ln CO_2$	1.840	0.7598	4	0.1
$\ln FD \neq > \ln CO_2$	7.016	0.260	4	0.1
$\ln KOF \neq > \ln CO_2$	7.255	0.248	4	0.1
$\ln HC \neq > \ln CO_2$	6.415	0.290	4	0.1
$\ln CO_2 \neq > \ln GDP$	2.459	0.669	4	0.1
$\ln CO_2 \neq > \ln FD$	11.329	0.128	4	0.1
$\ln CO_2 \neq > \ln KOF$	7.282	0.247	4	0.1
$\ln CO_2 \neq > \ln HC$	8.346	0.204	4	0.1
$\ln FD \neq > \ln GDP$	3.355	0.548	4	0.1
$\ln KOF \neq > \ln GDP$	4.650	0.412	4	0.1
$\ln HC \neq > \ln GDP$	4.330	0.441	4	0.1
$\ln GDP \neq > \ln FD$	0.940	0.909	4	0.1
$\ln KOF \neq > \ln FD$	15.530*	0.072	4	0.1
$\ln HC \neq > \ln FD$	4.667	0.409	4	0.1
$\ln GDP \neq > \ln KOF$	6.072	0.297	4	0.1
$\ln FD \neq > \ln KOF$	22.346**	0.030	4	0.1
$\ln HC \neq > \ln KOF$	47.917***	0.005	4	0.1
$\ln GDP \neq > \ln HC$	0.529	0.963	4	0.1
$\ln FD \neq > \ln HC$	21.601**	0.029	4	0.1
$\ln KOF \neq > \ln HC$	7.843	0.220	4	0.1

***, **, and *: show significance at 1%, 5%, and 10% levels, respectively. Optimal p and k were selected automatically using the AIC

Table 5 FFFF-TY causality summary (EF)

Null hypothesis	W-statistics	Bootstrap prob. value	k	Frequency
$\ln GDP \neq > \ln EF$	7.185	0.250	4	0.1
$\ln FD \neq > \ln EF$	15.673*	0.069	4	0.1
$\ln KOF \neq > \ln EF$	12.254	0.106	4	0.1
$\ln HC \neq > \ln EF$	13.290*	0.092	4	0.1
$\ln EF \neq > \ln GDP$	3.634	0.521	4	0.1
$\ln EF \neq > \ln FD$	14.869*	0.073	4	0.1
$\ln EF \neq > \ln KOF$	14.931*	0.073	4	0.1
$\ln EF \neq > \ln HC$	3.999	0.471	4	0.1
$\ln FD \neq > \ln GDP$	13.770*	0.088	4	0.1
$\ln KOF \neq > \ln GDP$	7.178	0.258	4	0.1
$\ln HC \neq > \ln GDP$	10.166	0.155	4	0.1
$\ln GDP \neq > \ln FD$	1.650	0.790	4	0.1
$\ln KOF \neq > \ln FD$	20.881**	0.038	4	0.1
$\ln HC \neq > \ln FD$	3.358	0.546	4	0.1
$\ln GDP \neq > \ln KOF$	12.590	0.106	4	0.1
$\ln FD \neq > \ln KOF$	32.659**	0.013	4	0.1
$\ln HC \neq > \ln KOF$	25.256**	0.024	4	0.1
$\ln GDP \neq > \ln HC$	1.395	0.835	4	0.1
$\ln FD \neq > \ln HC$	7.443	0.239	4	0.1
$\ln KOF \neq > \ln HC$	4.515	0.431	4	0.1

***, **, and *: show significance at 1%, 5%, and 10% levels, respectively. Optimal p and k were selected automatically using the AIC indicators and FD. This relationship can be attributed to the increase in human demands with FD and the allocation of resources to industries that cause environmental pollution through the financial sector. In fact, Turkey, which has followed an export-driven growth model since 1980, has begun to transition into a more globally focused economy. This has led to an increase in the exports of Turkey. In other words, it has increased international demand. According to the most recent data released by the Turkish Statistical Institute in 2022, the manufacturing sector's share of foreign trade was 94.9%. As indicated previously, the Turkish manufacturing sector makes substantial use of fossil fuels. Therefore, the manufacturing industry becomes the trigger of environmental degradation by producing more with exports. Furthermore, infrastructure projects can be promoted by granting medium- and long-term development loans, which are crucial for the country's growth, through FD. In recent years, Turkey has begun implementing infrastructure projects involving roads, bridges, and railroads. This situation worsens EF, such as soil and water resources, and consequently environmental degradation. In addition, FD provides access to cheap loans. This can lead to the purchase of products (such as houses and cars) that are likely to have a negative effect on the environment.

Another finding from the study is that KOF has a long-term effect on reducing CO_2 emissions. This result demonstrates that the technical effect is valid in Turkey. To be more precise, it is possible that Turkey may have transferred advanced environmentally friendly technologies from international markets. In addition, Turkey, an EU candidate country, is a party to many agreements on climate change on a global scale (such as the Kyoto Protocol, Paris Agreement, and Montreal Protocol). Because of these two things, it is possible that globalization has caused Turkey's CO_2 emissions to go down.

The most significant result of this study is the positive contribution of HC in reducing environmental pollution. If HC levels increase, environmental pollution in Turkey will decrease. This suggests that improving HC will contribute significantly to lowering environmental pollution in the long run. A highly educated population can help build a more resourceful, innovative, productive, and environmentally conscious society, thus improving environmental quality. It is anticipated that societies with high HC will be receptive to initiatives for the development and application of renewable technologies. This situation can contribute to achieving a sustainable economic structure together with a decrease in pollution.

Conclusions and policy implications

The study's findings offer important implications for policy makers. First, given the mitigating role of human capital in environmental degradation, Turkey's policy makers should prepare the path for increased investment in human capital. For instance, the proportion of education expenditures to GDP can be raised. Second, additional funding can be made available and access to education can be facilitated, particularly for the poor who have difficulty gaining access to education and training activities. Increasing human capital through this access may result in a more qualified, talented, and productive workforce in the coming years. This workforce can play a significant role in reducing environmental pollution by adopting sophisticated production processes and renewable technologies in place of conventional production techniques. In this way, Turkey can achieve a sustainable economic system. Thirdly, energy saving, climate change, recycling, and renewable energy issues should be included in the education curriculum throughout the entire educational activity, starting with primary education, in order to reduce human-based pressures on the environment. These issues should be presented to other residents via public service announcements on television, seminars, and training at public education institutions, in addition to being included in the curriculum. In addition, funding should be provided for nongovernmental organizations' efforts to raise environmental awareness. Thus, environmental awareness should be promoted among all stakeholders in a country. Furthermore, both the public and private sectors should be encouraged to employ environmentally friendly modern technologies and industrial processes to improve environmental quality. In this way, it will be possible to reduce environmental pollution without sacrificing economic growth in Turkey.

In this study, human capital was only measured on the basis of education, depending on the availability of data. Measuring the effects of human capital on environmental pollution indicators for various countries using different human capital metrics could be an interesting subject for future research.

Author contribution Serhat Çamkaya: conceptualization, methodology, data curation, writing—original draft, formal analysis, visualization. Abdulkerim Karaaslan: investigation, conceptualization, methodology, supervision, writing—review and editing. Fatih Uçan: writing—original draft, conceptualization.

Data availability The analyzed during the current study, CO_2 and GDP data were obtained from World Development Indicators (WBI 2022, https://databank.worldbank.org/source/world-development-indicators). EF data were obtained from Global Footprint Network (GFN 2022, https://data.footprintnetwork.org/?_ga=2.240210627.1391976908.1659978425-751733324.1659978425#/). FD data were obtained from International Monetary Fund (IMF 2022, https://data.imf.org/?sk=388dfa60-1d26-4ade-b505-a05a558d9a42). KOF data were obtained from Gygli et al. (2019, https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-gslobalisation-index.html) and HC data from Penn World Tables version 9.0 developed by Feenstra et al. (2015, https://fred.stlouisfed.org/series/HCIYISTRA066NRUG), respectively.

Declarations

Ethics approval We declare that all ethical guidelines for authors have been followed by all authors. Ethical approval is not required as this study uses data shared with the public.

Consent to participate All authors have given their consent to participate in submitting this manuscript to this journal.

Consent for publication Written consent was sought from each author to publish the manuscript.

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References

Adebayo TS, Acheampong AO (2021) Modelling the globalization-CO2 emission nexus in Australia: evidence from quantile-on-quantile approach. Environ Sci Pollut Res 29:9867–9882. https://doi.org/10.1007/s11356-021-16368-y

Ahmed K, Long W (2012) Environmental Kuznets curve and Pakistan: an empirical analysis. Procedia Econ Financ 1:4–13. https://doi.org/10.1016/S2212-5671(12)00003-2

Ahmed Z, Wang Z, Mahmood F et al (2019) Does globalization increase the ecological footprint? Empirical evidence from Malaysia. Environ Sci Pollut Res 26:18565–18582. https://doi.org/10.1007/s11356-019-05224-9

Ahmed Z, Zafar MW, Ali S, Danish, (2020) Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain Cities Soc 55:102064. https://doi.org/10.1016/j.scs.2020.102064

Ahmed Z, Zhang B, Cary M (2021) Linking economic globalization, economic growth, financial development, and ecological footprint: evidence from symmetric and asymmetric ARDL. Ecol Indic 121:107060. https://doi.org/10.1016/j.ecolind.2020.107060

Akadiri SS, AdewaleAlola A, Olasehinde-Williams G, UdomEtokakpan M (2020) The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Sci Total Environ 708:134653. https://doi.org/10.1016/j.scitotenv.2019.134653

Akadiri SS, Alola AA, Akadiri AC (2019) The role of globalization, real income, tourism in environmental sustainability target. Evidence from Turkey. Sci Total Environ 687:423–432. https://doi.org/10.1016/j.scitotenv.2019.06.139

Akca H (2021) Environmental Kuznets Curve and financial development in Turkey: evidence from augmented ARDL approach. Environ Sci Pollut Res 28:69149–69159. https://doi.org/10.1007/s11356-021-15417-w

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. https://doi.org/10.1016/j.energy.2015.03.004

Al-Mulali U, Solarin SA, Ozturk I (2016) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat Hazards 80:1729–1747. https://doi.org/10.1007/s11069-015-2050-x

Al-mulali U, Tang CF, Ozturk I (2015a) Does financial development reduce environmental degradation? Evidence from a panel study of 129 countries. Environ Sci Pollut Res 22:14891–14900. https://doi.org/10.1007/s11356-015-4726-x

Al-mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015b) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol Indic 48:315–323. https://doi.org/10.1016/j.ecolind.2014.08.029

Ansari MA, Haider S, Masood T (2021) Do renewable energy and globalization enhance ecological footprint: an analysis of top renewable energy countries? Environ Sci Pollut Res 28:6719–6732. https://doi.org/10.1007/s11356-020-10786-0

Apaydin Ş, Ursavaş U, Koç Ü (2021) The impact of globalization on the ecological footprint: do convergence clubs matter? Environ Sci Pollut Res 28:53379–53393. https://doi.org/10.1007/s11356-021-14300-y

Apergis N, Payne JE (2010) The emissions, energy consumption, and growth nexus: Evidence from the commonwealth of independent states. Energy Policy 38:650–655. https://doi.org/10.1016/j.enpol.2009.08.029

Baloch MA, Zhang J, Iqbal K, Iqbal Z (2019) The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environ Sci Pollut Res 26:6199–6208. https://doi.org/10.1007/s11356-018-3992-9

Banerjee P, Arčabić V, Lee H (2017) Fourier ADL cointegration test to approximate smooth breaks with new evidence from Crude Oil Market. Econ Model 67:114–124. https://doi.org/10.1016/j.econmod.2016.11.004

Bano S, Zhao Y, Ahmad A et al (2018) Identifying the impacts of human capital on carbon emissions in Pakistan. J Clean Prod 183:1082–1092. https://doi.org/10.1016/j.jclepro.2018.02.008

Bilgili F, Ulucak R, Koçak E, İlkay SÇ (2020) Does globalization matter for environmental sustainability? Empirical investigation for Turkey by Markov regime switching models. Environ Sci Pollut Res 27:1087–1100. https://doi.org/10.1007/s11356-019-06996-w

Bouznit M, del Pablo-Romero MP (2016) CO2 emission and economic growth in Algeria. Energy Policy 96:93–104. https://doi.org/10.1016/j.enpol.2016.05.036

Cagno E, Trianni A (2013) Exploring drivers for energy efficiency within small- and medium-sized enterprises: first evidences from Italian manufacturing enterprises. Appl Energy 104:276–285. https://doi.org/10.1016/j.apenergy.2012.10.053

Cetin M, Ecevit E, Yuce AG (2018) The impact of economic growth, energy consumption, trade openness, and financial development on carbon emissions: empirical evidence from Malaysia. Environ Sci Pollut Res 25:36589–36603. https://doi.org/10.1007/s11356-021-14930-2

Chen Y, Lee CC, Chen M (2021) Ecological footprint, human capital, and urbanization. Energy Environ 1–4.https://doi.org/10.1177/0958305X211008610

Christopoulos DK, Leon-Ledesma MA (2011) International output convergence, breaks, and asymmetric adjustment. Stud Nonlinear Dyn Econom 15:67–97. https://doi.org/10.2202/1558-3708.1823

Christopoulos DK, León-Ledesma MA (2010) Smooth breaks and nonlinear mean reversion: Post-Bretton Woods real exchange rates. J Int Money Financ 29:1076–1093. https://doi.org/10.1016/j.jimonfin.2010.02.003

Copeland BR, Taylor MS (2013) Trade and the environment: theory and evidence. Princeton University Press, New Jersey

Copeland BR, Taylor MS (2004) Trade, growth, and the environment. J Econ Lit 42:7–71

Dasgupta S, Hamilton K, Pandey KD, Wheeler D (2006) Environment during growth: accounting for governance and vulnerability. World Dev 34:1597–1611. https://doi.org/10.1016/j.worlddev.2005.12.008

Dasgupta S, Laplante B, Mamingi N (2001) Pollution and capital markets in developing countries. J Environ Econ Manage 42:310–335. https://doi.org/10.1006/jeem.2000.1161 de Souza ES, de Freire F, S, Pires J, (2018) Determinants of CO2 emissions in the MERCOSUR: the role of economic growth, and renewable and non-renewable energy. Environ Sci Pollut Res 25:20769–20781. https://doi.org/10.1007/s11356-018-2231-8

Destek MA, Ozsoy FN (2015) Relationships between economic growth, energy consumption, globalization, urbanization and environmental degradation in Turkey. Int J Energy Stat 03:1550017. https://doi.org/10.1142/S2335680415500179

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74:427–431. https://doi.org/10.1080/01621459.1979.10482531

Dinda S (2004) Environmental kuznets curve hypothesis: a survey. Ecol Econ 49:431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Enders W, Jones P (2016) Grain prices, oil prices, and multiple smooth breaks in a VAR. Stud Nonlinear Dyn Econom 20:399–419. https://doi.org/10.1515/snde-2014-0101

Fallon PR, Layard PRG (1975) Capital-skill complementarity, income distribution, and output accounting. J Polit Econ 83:279–302

Feenstra RC, Robert I, Marcel PT (2015) The next generation of the Penn World Table. Am Econ Rev 105:3150–3182

Gallant RA (1981) On the bias in flexible functional forms and an essentially unbiased form: the Fourier flexible form. J Econom 15:211–245. https://doi.org/10.1016/0304-4076(81)90115-9

GFN (2022) Global Footprint Network. https://data.footprintnetwork.org/#/countryTrends?cn=223&type=BCpc,EFCpc. Accessed 12 July 2022

Godil DI, Sharif A, Rafique S, Jermsittiparsert K (2020) The asymmetric effect of tourism, financial development, and globalization on ecological footprint in Turkey. Environ Sci Pollut Res 27:40109–40120. https://doi.org/10.1007/s11356-020-09937-0

Godil DI, Yu Z, Sharif A et al (2021) Investigate the role of technology innovation and renewable energy in reducing transport sector <scp> CO_2 </scp> emission in China: a path toward sustainable development. Sustain Dev 29:694–707. https://doi.org/10.1002/sd.2167

Gök A (2020) The role of financial development on carbon emissions: a meta regression analysis. Environ Sci Pollut Res 27:11618–11636. https://doi.org/10.1007/s11356-020-07641-7

Gokmenoglu KK, Taspinar N, Rahman MM (2021) Military expenditure, financial development and environmental degradation in Turkey: a comparison of CO2 emissions and ecological footprint. Int J Financ Econ 26:986–997. https://doi.org/10.1002/ijfe.1831

Gregory AW, Hansen BE (1996) Tests for cointegration in models with regime and trend shifts. Oxf Bull Econ Stat 58:555–560. https://doi.org/10.1111/j.1468-0084.1996.mp58003008.x

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. Working paper, vol 3914. NBER, Cambridge

Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110:353–377. https://doi.org/10.1080/02255189.1999.9669857

Gygli S, Haelg F, Potrafke N, Sturm J-E (2019) The KOF Globalisation Index – revisited. Rev Int Organ 14:543–574. https://doi.org/10.1007/s11558-019-09344-2

Hafeez M, Yuan C, Shahzad K et al (2019) An empirical evaluation of financial development-carbon footprint nexus in One Belt and Road region. Environ Sci Pollut Res 26:25026–25036. https://doi.org/10.1007/s11356-019-05757-z

Haseeb A, Xia E, Danish, et al (2018) Financial development, globalization, and CO2 emission in the presence of EKC: evidence from BRICS countries. Environ Sci Pollut Res 25:31283–31296. https://doi.org/10.1007/s11356-018-3034-7

Hatemi-J A (2008) Tests for cointegration with two unknown regime shifts with an application to financial market integration. Empir Econ 35:497–505. https://doi.org/10.1007/s00181-007-0175-9

IMF (2022) International Money Fund. https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B. Accessed 12 June 2022

Jalil A, Feridun M (2011) The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ 33:284–291. https://doi.org/10.1016/j.eneco.2010.10.003

Jayadevappa R, Chhatre S (2000) International trade and environmental quality: a survey. Ecol Econ 32:175–194. https://doi.org/10.1016/S0921-8009(99)00094-4

Juan Z (2011) R&D for environmental innovation and supportive policy: the implications for new energy automobile industry in China. Energy Procedia 5:1003–1007. https://doi.org/10.1016/j.egypro.2011.03.177

Kanjilal K, Ghosh S (2013) Environmental Kuznet's curve for India: evidence from tests for cointegration with unknown structural-breaks. Energy Policy 56:509–515. https://doi.org/10.1016/j.enpol.2013.01.015

Karaaslan A, Çamkaya S (2022) The relationship between CO2 emissions, economic growth, health expenditure, and renewable and non-renewable energy consumption: empirical evidence from Turkey. Renew Energy 190:457–466. https://doi.org/10.1016/j.renene.2022.03.139

Karasoy A (2019) Drivers of carbon emissions in Turkey: considering asymmetric impacts. Environ Sci Pollut Res 26:9219–9231. https://doi.org/10.1007/s11356-019-04354-4

Kirikkaleli D, Adebayo TS, Khan Z, Ali S (2021) Does globalization matter for ecological footprint in Turkey? Evidence from dual adjustment approach. Environ Sci Pollut Res 28:14009–14017. https://doi.org/10.1007/s11356-020-11654-7

Köksal C, Işik M, Katircioğlu S (2020) The role of shadow economies in ecological footprint quality: empirical evidence from Turkey. Environ Sci Pollut Res 27:13457–13466. https://doi.org/10.1007/s11356-020-07956-5

Kwabena Twerefou D, Danso-Mensah K, Bokpin GA (2017) The environmental effects of economic growth and globalization in Sub-Saharan Africa: a panel general method of moments approach. Res Int Bus Financ 42:939–949. https://doi.org/10.1016/j.ribaf.2017.07.028

Langnel Z, Amegavi GB (2020) Globalization, electricity consumption and ecological footprint: an autoregressive distributive lag (ARDL) approach. Sustain Cities Soc 63:102482. https://doi.org/10.1016/j.scs.2020.102482

Le T-H, Chang Y, Park D (2016) Trade openness and environmental quality: international evidence. Energy Policy 92:45–55. https://doi.org/10.1016/j.enpol.2016.01.030

Li X, Ullah S (2022) Caring for the environment: how CO2 emissions respond to human capital in BRICS economies? Environ Sci Pollut Res 29:18036–18046. https://doi.org/10.1007/s11356-021-17025-0

Liu J, Qu J, Zhao K (2019) Is China's development conforms to the Environmental Kuznets Curve hypothesis and the pollution haven hypothesis? J Clean Prod 234:787–796. https://doi.org/10.1016/j.jclepro.2019.06.234

Lumsdaine RL, Papell DH (1997) Multiple trend breaks and the unit-root hypothesis. Rev Econ Stat 79:212–218

Mehmood U (2022) Biomass energy consumption and its impacts on ecological footprints: analyzing the role of globalization and natural resources in the framework of EKC in SAARC countries. Environ Sci Pollut Res 29:17513–17519. https://doi.org/10.1007/s11356-021-16586-4

MENR (2022) Minister of Energy and Natural Resources. https://enerji.gov.tr/eigm-raporlari

Mikayilov JI, Galeotti M, Hasanov FJ (2018) The impact of economic growth on CO2 emissions in Azerbaijan. J Clean Prod 197:1558–1572. https://doi.org/10.1016/j.jclepro.2018.06.269

Mrabet Z, Alsamara M (2017) Testing the Kuznets curve hypothesis for Qatar: a comparison between carbon dioxide and ecological footprint. Renew Sustain Energy Rev 70:1366–1375. https://doi.org/10.1016/j.rser.2016.12.039

Narayan PK, Popp S (2010) A new unit root test with two structural breaks in level and slope at unknown time. J Appl Stat 37:1425–1438. https://doi.org/10.1080/02664760903039883

Nathaniel SP, Yalçiner K, Bekun FV (2021) Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. Resour Policy 70:101924. https://doi.org/10.1016/j.resourpol.2020.101924

Nazlioglu S, Gormus NA, Soytas U (2016) Oil prices and real estate investment trusts (REITs): Gradual-shift causality and volatility transmission analysis. Energy Econ 60:168–175. https://doi.org/10.1016/j.eneco.2016.09.009

Neve M, Hamaide B (2017) Environmental Kuznets curve with adjusted net savings as a trade-off between environment and development. Aust Econ Pap 56:39–58. https://doi.org/10.1111/1467-8454.12078

Ozatac N, Gokmenoglu KK, Taspinar N (2017) Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey. Environ Sci Pollut Res 24:16690–16701. https://doi.org/10.1007/s11356-017-9317-6

Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ 36:262–267. https://doi.org/10.1016/j.eneco.2012.08.025

Paramati SR, Apergis N, Ummalla M (2017) Financing clean energy projects through domestic and foreign capital: the role of political cooperation among the EU, the G20 and OECD countries. Energy Econ 61:62–71. https://doi.org/10.1016/j.eneco.2016.11.001

Park Y, Meng F, Baloch MA (2018) The effect of ICT, financial development, growth, and trade openness on CO2 emissions: an empirical analysis. Environ Sci Pollut Res 25:30708–30719. https://doi.org/10.1007/s11356-018-3108-6

Pata UK (2018a) Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: testing EKC hypothesis with structural breaks. J Clean Prod 187:770–779. https://doi.org/10.1016/j.jclepro.2018.03.236

Pata UK (2019) Environmental Kuznets curve and trade openness in Turkey: bootstrap ARDL approach with a structural break. Environ Sci Pollut Res 26:20264–20276. https://doi.org/10.1007/s11356-019-05266-z

Pata UK (2018b) The influence of coal and noncarbohydrate energy consumption on CO2 emissions: revisiting the environmental Kuznets curve hypothesis for Turkey. Energy 160:1115–1123. https://doi.org/10.1016/j.energy.2018.07.095

Pata UK, Aydin M, Haouas I (2021) Are natural resources abundance and human development a solution for environmental pressure? Evidence from top ten countries with the largest ecological footprint. Resour Policy 70:101923. https://doi.org/10.1016/j.resourpol.2020.101923

Pata UK, Caglar AE (2021) Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. Energy 216:119220. https://doi.org/10.1016/j.energy.2020.119220

Pata UK, Yilanci V (2020) Financial development, globalization and ecological footprint in G7: further evidence from threshold cointegration and fractional frequency causality tests. Environ Ecol Stat 27:803–825. https://doi.org/10.1007/s10651-020-00467-z

Perron P (1989) The great crash, the oil price shock, and the unit root hypothesis. Econometrica 57:1361. https://doi.org/10.2307/1913712

Raggad B (2020) Economic development, energy consumption, financial development, and carbon dioxide emissions in Saudi Arabia: new evidence from a nonlinear and asymmetric analysis. Environ Sci Pollut Res 27:21872–21891. https://doi.org/10.1007/s11356-020-08390-3

Rahman MM, Nepal R, Alam K (2021) Impacts of human capital, exports, economic growth and energy consumption on CO2 emissions of a cross-sectionally dependent panel: evidence from the newly industrialized countries (NICs). Environ Sci Policy 121:24–36. https://doi.org/10.1016/j.envsci.2021.03.017

Rahman S, Chen S, Saud S et al (2019) Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter? Environ Sci Pollut Res 26:31856–31872. https://doi.org/10.1007/s11356-019-06343-z

Rehman MU, Rashid M (2017) Energy consumption to environmental degradation, the growth appetite in SAARC nations. Renew Energy 111:284–294. https://doi.org/10.1016/j.renene.2017.03.100

Rezza AA (2013) FDI and pollution havens: evidence from the Norwegian manufacturing sector. Ecol Econ 90:140–149. https://doi.org/10.1016/j.ecolecon.2013.03.014

Rjoub H, Odugbesan JA, Adebayo TS, Wong W-K (2021) Sustainability of the moderating role of financial development in the determinants of environmental degradation: evidence from Turkey. Sustainability 13:1844. https://doi.org/10.3390/su13041844

Romer PM (1990) Endogenous technological growth. J Polit Econ 98:71–102

Sabir S, Gorus MS (2019) The impact of globalization on ecological footprint: empirical evidence from the South Asian countries. Environ Sci Pollut Res 26:33387–33398. https://doi.org/10.1007/s11356-019-06458-3

Salahuddin M, Alam K, Ozturk I, Sohag K (2018) The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. Renew Sustain Energy Rev 81:2002–2010. https://doi.org/10.1016/j.rser.2017.06.009

Shahbaz M, Hye QMA, Tiwari AK, Leitão NC (2013) Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. Renew Sustain Energy Rev 25:109–121. https://doi.org/10.1016/j.rser.2013.04.009

Shahbaz M, Kumar Mahalik M, Jawad Hussain Shahzad S, Hammoudeh S (2019) Testing the globalization-driven carbon emissions hypothesis: international evidence. Int Econ 158:25–38. https://doi.org/10.1016/j.inteco.2019.02.002

Shahbaz M, Shahzad SJH, Ahmad N, Alam S (2016) Financial development and environmental quality: the way forward. Energy Policy 98:353–364. https://doi.org/10.1016/j.enpol.2016.09.002

Shahbaz M, Sharma R, Sinha A, Jiao Z (2021) Analyzing nonlinear impact of economic growth drivers on CO2 emissions: designing an SDG framework for India. Energy Policy 148:111965. https://doi.org/10.1016/j.enpol.2020.111965

Sharif A, Afshan S, Chrea S et al (2020) The role of tourism, transportation and globalization in testing environmental Kuznets curve in Malaysia: new insights from quantile ARDL approach. Environ Sci Pollut Res 27:25494–25509. https://doi.org/10.1007/s11356-020-08782-5

Sharif A, Raza SA, Ozturk I, Afshan S (2019) The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. Renew Energy 133:685–691. https://doi.org/10.1016/j.renene.2018.10.052

Solarin SA, Al-Mulali U (2018) Influence of foreign direct investment on indicators of environmental degradation.

Environ Sci Pollut Res 25:24845–24859. https://doi.org/10.1007/s11356-018-2562-5
Solarin SA, Al-Mulali U, Musah I, Ozturk I (2017) Investigating the pollution haven hypothesis in Ghana: an empirical investigation. Energy 124:706–719. https://doi.org/10.1016/j.energy.2017.02.089
Suki NM, Sharif A, Afshan S, Suki NM (2020) Revisiting the Environmental Kuznets Curve in Malaysia: the role of globalization in sustainable environment. J Clean Prod 264:121669. https://doi.org/10.1016/j.jclepro.2020.121669
Tamazian A, Chousa JP, Vadlamannati KC (2009) Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. Energy Policy 37:246–253. https://doi.org/10.1016/j.enpol.2008.08.025
TSI (2022) Turkish Statistical Institute. https://data.tuik.gov.tr. Accessed 26 July 2022
Uddin GA, Salahuddin M, Alam K, Gow J (2017) Ecological footprint and real income: panel data evidence from the 27 highest emitting countries. Ecol Indic 77:166–175. https://doi.org/10.1016/j.ecolind.2017.01.003
UNDP (2022) United Nations Development Programme. https://hdr.undp.org/data-center/country-insights#/ranks. Accessed 18 May 2022
UNFCCC (2012) National greenhouse gas inventory data for the period 1990—2010. https://unfccc.int/resource/docs/2012/sbi/eng/31.pdf. Accessed 12 May 2022
Usman M, Balsalobre-Lorente D, Jahanger A, Ahmad P (2022) Pollution concern during globalization mode in financially resource-rich countries: do financial development, natural resources, and renewable energy consumption matter? Renew Energy 183:90–102. https://doi.org/10.1016/j.renene.2021.10.067
Wang Z-X, Li Q (2019) Modelling the nonlinear relationship between CO2 emissions and economic growth using a PSO algorithm-based grey Verhulst model. J Clean Prod 207:214–224. https://doi.org/10.1016/j.jclepro.2018.10.010
Wang Z, Rasool Y, Asghar MM, Wang B (2019) Dynamic linkages among CO2 emissions, human development, financial development, and globalization: empirical evidence based on PMG long-run panel estimation. Environ Sci Pollut Res 26:36248–36263. https://doi.org/10.1007/s11356-019-06556-2
WBI (2022) World Bank Indicators. https://databank.worldbank.org/source/world-development-indicators. Accessed 12 July 2022
Xia W, Apergis N, Bashir MF et al (2022) Investigating the role of globalization, and energy consumption for environmental externalities: empirical evidence from developed and developing economies. Renew Energy 183:219–228. https://doi.org/10.1016/j.renene.2021.10.084
Xu X, Huang S, An H (2021) Identification and causal analysis of the influence channels of financial development on CO2 emissions. Energy Policy 153:112277. https://doi.org/10.1016/j.enpol.2021.112277
Yang X, Li N, Mu H et al (2021) Study on the long-term impact of economic globalization and population aging on CO2 emissions in OECD countries. Sci Total Environ 787:147625. https://doi.org/10.1016/j.scitotenv.2021.147625
Yao Y, Ivanovski K, Inekwe J, Smyth R (2019) Human capital and energy consumption: evidence from OECD countries. Energy Econ 84:104534. https://doi.org/10.1016/j.eneco.2019.104534
Yao Y, Ivanovski K, Inekwe J, Smyth R (2020) Human capital and CO2 emissions in the long run. Energy Econ 91:104907. https://doi.org/10.1016/j.eneco.2020.104907
You W, Lv Z (2018) Spillover effects of economic globalization on CO2 emissions: a spatial panel approach. Energy Econ 73:248–257. https://doi.org/10.1016/j.eneco.2018.05.016
Yurtkuran S (2021) The effect of agriculture, renewable energy production, and globalization on CO2 emissions in Turkey: a bootstrap ARDL approach. Renew Energy 171:1236–1245. https://doi.org/10.1016/j.renene.2021.03.009
Zafar MW, Zaidi SAH, Khan NR et al (2019) The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. Resour Policy 63:101428. https://doi.org/10.1016/j.resourpol.2019.101428
Zhang Y-J (2011) The impact of financial development on carbon emissions: an empirical analysis in China. Energy Policy 39:2197–2203. https://doi.org/10.1016/j.enpol.2011.02.026
Zhao J, Zhao Z, Zhang H (2021) The impact of growth, energy and financial development on environmental pollution in China: new evidence from a spatial econometric analysis. Energy Econ 93:104506. https://doi.org/10.1016/j.eneco.2019.104506
Zivot E, Andrews DWK (1992) Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. J Bus Econ Stat 10:25–44. https://doi.org/10.1198/073500102753410372