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RESEARCH ARTICLE

Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey

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Abstract

The preponderance of emerging economies confronts significant trade-offs between economic growth and environmental sustainability considerations, and Turkey is no exception. This study draws strength from the United Nations Sustainable Development Goals (UN-SDGs-7,11,12 & 13). To this end, the present study explores the role of the environmental Kuznets curve (EKC) hypothesis for the case of Turkey for annual frequency data from 1970 to 2020. The present study leverages on the novel dynamic autoregressive-distributed lag (DARDL) methodology and Bayer and Hanck combined cointegration test. The combined Bayer and Hanck cointegration test alongside ARDL bounds test traces equilibrium relationship between economic growth, urbanization, FDI, energy use, and CO_2 emission over the investigated period. Empirical results from the DARDL simulation analysis validates the EKC hypothesis. These results suggest that environmental quality is being compromised for economic growth at the earlier stage of economic growth (scale stage). The EKC phenomenon is affirmed as a 1% increase in economic growth increase emission level by 0.1580% and quadratic economic growth decrease emission by 0.1095% in the short and long run, respectively. Similarly, urbanization and energy used in both the short and long run also worsen environmental quality while FDI influx in the long run improves environmental quality in Turkey. These outcomes have far-reaching environment-urbanization growth implications. From a policy lens, the current study subscribed to the environmental stick policies and investment on strategies on a paradigm shift from fossil-fuel energy consumption base to renewables. Further insights are highlighted in the concluding section.

Keywords Environmental sustainability · Carbon-reduction · EKC · Dynamic ARDL simulation · Turkey

Introduction

Recent years have seen a considerable rise in the negative consequences of ecological deterioration as a consequence of climate change. As per National Aeronautics and Space

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Administration (NASA 2020) anthropogenic Climate Warming statistics, climate change has grown by around 0.9 °C during the nineteenth century to the current. The statistics also revealed that heat has reached its maximum stress since 2010, owing to environmental consequences generated by the combination of human operations with the ecosystem. An additional consequence of worldwide warming has been the melting of glaciers, the rising of ocean levels, and the heating of the seas' temperatures. The melting of glaciers in Greenland and Antarctica totaled 413 tonnes across the timespan 1993–2016. The heat of the oceans rose by 0.4 °C (National Centers for Environmental Information 2019). As a result of their effect on water availability, food security, healthcare, and the ecosystem, worldwide heating and temperature change have an influence on the livelihoods of all humans on the earth. Because of the severity of the worldwide ecological repercussions of global heating and temperature change, it is possible that a rise in population mortality as a consequence of starvation, water scarcity, health complications, violence, and other contributing causes would occur (Stern, 2006).

Additionally, various human operations and environmental catastrophes connected with the environment's atmosphere, freshwater supply, and land are becoming progressively connected with serious environmental deterioration (Alola et al., 2021; Gyamfi et al., 2020; Bekun et al., 2021a; Bekun, 2022). It is vital to note that polluted air generated by greenhouse gas pollutants currently remains the most significant contributor to global warming. Several researches have been conducted in order to better understand this scenario. In recent years, there has been a significant rise in the number of investigations on ecological deterioration and economic advancement. First and foremost, Kuznets (1955) developed the Kuznets Curve (KC), which was eventually refined into the Environmental Kuznets Curve (EKC) in a further investigation (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Arrow et al., 1996). According to the EKC hypothesis, when economic growth increases as a result of structural and technical advancements, environmental degradation decreases.

Moreover, energy has been recognized as an essential part of economic growth and progress across the globe. This is evident in the high and determined request for energy bases ranging from oil, natural gas, electricity, coal, etc., through the global economy (Samu et al., 2019). The incessant and high demand for energy sources suggests that there are positive impacts and correlations between energy use and economic growth. However, there is ongoing discussion over the direction of the link that exists between these factors that are often controlled by the forms of the economies (that is, either developing, transition, or developed economies). Energy sources can be broadly grouped into non-renewables such as uranium, coal, crude oil, natural gas, and nuclear energy; and renewable energy which includes biomass, hydro, solar, wind, tidal, and geothermal energy. Within the broad category of the two energy sources, renewable energy is considered an alternative cleaner energy source given that non-renewable energy sources are prone to degrading environmental quality through carbon dioxide emissions which are majorly attributed to fossil fuels.

For an emerging economy as Turkey with energy use estimated at 70 gigajoules (GJ) per person per year, which is the world average, its total primary energy use is about six billion GJ with over 80% sourced from fossil fuels (Turkstart Report 2020); it is tempting to suggest that energy use is responsible for the increase in the economic output in Turkey especially as it is considered a newly industrialized country. The rapid economic growth witnessed across countries with large energy reserves is indicative of the potential impact that this sector holds on the entire economy. Suffice to say that energy use is essential to the economic prosperity of Turkey as well as across other countries (Shahbaz et al., 2013; Apergis and Payne, 2010). It appears from this information that the rise in CO_2 emissions and fossil fuel usage in Turkey is not unconnected to the economy. For lack of a better expression, economic growth creates ecological damage unavoidable up to a certain point.

In light of this objective, the purpose of this research is to examine the link involving economic growth, energy consumption, urbanization, foreign direct investment (FDI), and environmental devastation in Turkey for various phases of economic growth within the framework of the EKC theory. Per this theory, environmental emissions rise in an economy throughout its initial stages of development until, at a particular point, the condition of the environment begins to improve in tandem with the expansion of the economy. As a result, the relationship involving economic growth as well as environmental degradation is shaped like an inverted U (Esteve and Tamarit, 2012). Despite the fact that there have been a number of researches conducted on EKC theory, the evidence supporting this concept is unclear. This is due to the fact that the accuracy of this theory is dependent on the attributes of each unique economy as well as the stage of advancement in that particular country. As a result, the EKC hypothesis study, which includes appropriate criteria, is significant for policymakers since it gives critical awareness about environmental stability. The current study also bridges the gap in the literature by incorporating key macroeconomic variables such as energy consumption, urbanization, and foreign direct investment which is still not certain in the literature. To fill this gap, this study uses advanced and robust econometric technique. The dynamic ARDL simulation technique (Jordan and Philips, 2018a, b), which is an innovative econometric tool, is utilized to evaluate the relationship between the variables. This present econometric technique has several advantages and is well-suited for generating reliable, valid, and robust forecasts. Furthermore, the information gathered will be more policy-relevant. In addition, this research will aid policymakers in creating suitable environmental and energy policies while considering the effects of FDI, economic growth, energy use, and urbanization.

The remaining sections of the paper are as follows. The "Literature review" section presents a highlighted review of the existing literature, particularly in the context of the EKC hypothesis. The "Data, model, and empirical technique" section includes a data description as well as an example of the empirical methodology of dynamic ARDL simulations, which provides estimation in the EKC hypothesis approach. The findings are discussed in the "Results and interpretation" section, and the research is summarized in the "Empirical results and discussion" section. Lastly, the "Conclusion and policy direction" section deals with the conclusion and policy recommendation for policymakers.

Literature review

Foreign direct investment and CO_2 emission

Sung et al. (2018) used panel data (2002–2015) from the 28 subsectors of the Chinese manufacturing sector to examine how FDI impacts a country's CO_2 emission levels. Evidence of FDI's impact on CO_2 emissions was found in the panel framework study, which shows that FDI improves environmental quality in the host nation. Using PMG-ARDL models, Essandoh et al. (2020) looked at the short-term and long-term dynamics of CO_2 emissions and FDI across 52 nations from 1991 to 2014. According to this research, in the long and short run, FDI reduces CO_2 emissions.

FDI also has long and short-term implications on CO_2 emissions in fifteen developing Asian nations from 1990 to 2013, according to Hanif et al. (2019). The findings suggested that FDI contributes to environmental deterioration and increases carbon emissions at the national level. It has also been shown that FDI is linked to increased CO_2 emissions in the Middle East and North Africa (MENA) area, according to Shahbaz et al. (2019). The findings of Jebli et al. (2019) from a panel of 22 Central and South American nations covering the period 1995–2010 suggest that FDI contributes to the decrease of CO_2 emissions.

Koçak and Şarkgüneşi (2018) used an environmental Kuznets curve (EKC) model to examine the possible influence of FDI on CO_2 emissions in Turkey between 1974 and 2013. The result reported a positive impact of FDI on CO_2 emissions. An empirical finding using multiple econometric estimations from 1970 to 2014 in Turkey revealed the significant impact of FDI on CO_2 emissions in Turkey (Karimov, 2020). A similar outcome is attained from the Bildirici (2021) study, which examined the relationship between FDI and CO_2 in China, India, Israel, and Turkey for 43 years from 1975 to 2017.

Urbanization and CO_2 emission

According to Cetin et al. (2018) who examined the correlation between urbanization and CO_2 emissions in Turkey from 1960 to 2014, the empirical findings revealed that CO_2 emissions are the outcome of urbanization. Aslan et al. (2021) used a dynamic ARDL approach to examine the relationship between urbanization and CO_2 emissions from 1960 to 2015 and found a link between long-term urbanization and CO_2 that was both positive and statistically significant. Furthermore, the research found that if urbanization expanded by 1%, then CO_2 emissions increased by 0.02%. Long-term and causative impacts of Turkey's urbanization on CO_2 emissions were studied by Kalmaz and Kirikkaleli (2019) using data from 1960 to 2015. The ARDL, FMOLS, and DOLS estimators were used to capture long-term impacts in the research. Results from the study found a link between energy consumption and CO_2 emissions.

Using time-series data from 1972 to 2014, the effect of urbanization on CO_2 emissions in Pakistan was studied. Based on the results of ARDL bound testing, urbanization increases CO_2 emissions over the long and short term, according to the researchers' conclusions (Ali et al., 2019). Mahmood et al. (2020) studied the impact of urbanization on CO_2 emissions in Saudi Arabia for the period 1968–2014 and their results reveal that urbanization has an elastic influence on CO_2 emissions, which harms the environment. According to Ahmad et al. (2021), China's urbanization and CO_2 emissions are linked in a variety of dynamic ways at various stages of development. As a result, data from 1999 to 2018 was analyzed for 27 Chinese provinces. The result revealed a long- and short-term causal link between urbanization and CO_2 emissions.

Lv and Xu (2019) used the Pooled Mean Group (PMG) technique to investigate the diverse impacts of urbanization on CO_2 emissions in 55 middle-income countries between 1992 and 2012. According to the results, urbanization has both a short-term and long-term negative effect on CO_2 emissions. Kirikkaleli and Kalmaz (2020) used both old and new econometric methodologies to investigate the long-term influence of urbanization on CO_2 emissions in Turkey from 1960 to 2016. The results showed the importance of urbanization in simulating CO_2 emissions.

Energy use and CO_2 emission

Several researches in the environment-energy-growth literature sought to identify CO_2 emission drivers. Dogan and Seker (2016a) examined the effects of energy usage on CO_2

emissions in the European Union adopting the EKC model from 1980 to 2012. The data supported the EKC hypothesis which revealed that non-renewable energy increases CO_2 emissions. Chen et al. (2019) investigated the link between non-renewable energy and CO_2 emissions in China during 1980–2014 using autoregressive distributed lag (ARDL) bounds testing and VECM Granger causality test. The study found that increasing energy use increases CO_2 emissions. Kang et al. (2019) examined the association between energy use (NRES, hydropower, or coal) and CO_2 emissions in India from 1965 to 2015 and found energy use has a huge influence on CO_2 emissions.

Dogan and Ozturk (2017) investigated the impact of energy use on CO_2 emissions in the USA during the period 1980–2014 and long-run ARDL model projections show that increasing energy usage contributes to CO_2 emissions. To investigate the impact of non-renewable energy consumption on CO_2 emissions in the EKC model, Dogan and Seker (2016a) used heterogeneous panel estimate approaches with cross-section dependency. The study concluded that non-renewable energy usage contributed to CO_2 emissions. Dogan and Seker (2016b) also used the EKC model to examine the consequences of energy use on CO_2 emissions for the European Union from 1980 to 2012. A similar result showed that energy use also increased CO_2 emissions. There is a long-term correlation between these two variables in Sub-Saharan Africa, spanning the years 1980 to 2011 (Inglesi-Lotz and Dogan, 2018).

Erdogan et al. (2020) studied the relationship between energy consumption and CO_2 emissions in 25 Organization for Economic Co-operation and Development (OECD) nations between 1990 and 2014 and, according to the study's findings, energy use increases CO_2 emissions. Reports by Akadiri and Adebayo (2021), Anwar et al. (2021), and Zaidi et al. (2018) all arrive at the same conclusion about the considerable influence of energy use on CO_2 emissions.

EKC and CO_2 emission

The EKC hypothesis was typically examined in the 2000s with a focus on CO_2 emissions and several other factors like energy consumption, foreign direct investment, and urbanization. Scholars started to employ these factors, in addition to CO_2 emissions, to solve the unobserved heterogeneity challenge. Using panel data analysis, several studies proved the existence of the EKC hypothesis: Mehmood (2021) for Pakistan, India, Bangladesh, and Sri Lanka; Liu et al. (2019) for 125 countries; Lin et al. (2021) for 30 Chinese provinces; Karahasan and Pinar (2021) for Turkish provinces; Abbasi et al. (2020) for eight Asian countries; Murshed et al. (2020a) for six South Asian economies; and Murshed et al. (2020b) for 12 OPEC countries.

In essence, these empirical findings present an important informative potency due to their focus on CO_2 emissions. Uzar and Eyuboglu's (2019) research emphasized the relevance of EKC in the long-term reduction of CO_2 emissions in Turkey. In addition, empirical investigations by Pata (2018), in Turkey using the ARDL technique tested the EKC hypothesis. A similar result was published, demonstrating a link between EKC and CO_2 emissions.

This study adds to the expanding body of knowledge on environmental degradation in a variety of ways: The first distinction of this research is that it employed the EKC hypothesis as a general theoretical framework that tests the CO_2 emissions and variables, such as energy use, FDI, and urbanization. An effective strategy for combating pollution and climate change requires appropriate findings on CO_2 emission. The second unique aspect of this research is the consideration of the impact on CO_2 emissions in Turkey. Third, sophisticated time-series data econometric approaches are used to evaluate the drivers of CO_2 emissions.

Data, model, and empirical technique

Data description and model

This study makes use of annual time series data from 1970 to 2020 in the respect of Turkey as a case country. The outcome variable is CO_2 emissions, which serve as a proxy for environmental quality. The existence of the EKC hypothesis is validated using economic growth proxied by GDP per capita to capture the scale effect and the square of GDP per capita to represent the technique effect. FDI, the urban population as a proxy for urbanization, and energy consumption are the other relevant control variables. All data were obtained from the World Bank's World Development Indicator (WDI) database, with the exception of carbon emissions in 2020, which were gathered from the Our World in Data website (https://ourworldindata.org) based on the Global Carbon Project. Table 1 summarizes the data sources and their descriptions.

This study pursues the robust empirical technique extensively utilized in the previous studies under the EKC hypothesis umbrella to disaggregate the environmental effects of FDI, energy use, and urbanization for Turkey. According to the EKC hypothesis, economic growth makes a significant contribution to the deterioration of environmental quality in the early stages of development because more emphasis was placed on achieving higher income rather than minimizing environmental decay. People became progressively ecologically sensitive as civilization progressed, particularly during the modern industrialized stage, and governments enacted environmental regulations aimed at improving environmental quality (Udeagha and Ngepah, 2021). As a result, the

Table 1 Description of studied variables

Variable	Symbol	Description	Source
CO_2 emission	CO_2	CO_2 emission (Metric tonnes per capita)	WDI
Economic growth	GDP	Gross domestic product (GDP) per capita	WDI
Foreign direct investment	FDI	Share of GDP	WDI
Urbanization	UR	Urban population (share of total population)	WDI
Energy use	EU	kg of oil equivalent per capita	WDI

logic behind the positive sign of a link between economic growth and environmental degradation and the negative sign of association between the technique effect (square of economic growth) and environmental degradation is intuitively explained. Given that, the conventional EKC hypothesis is stated as follows, in accordance with earlier research (Sharif et al., 2020; Islam et al., 2021; Gyamfi et al., 2021a, b, c; Steve et al., 2021; Ohajionu et al., 2022; Ramzan et al., 2022):

$$CO_2 = \int \left(GDP, GDP^2\right) \tag{1}$$

where CO_2 is the carbon dioxide emission, and GDP and GDP^2 are the gross domestic product (GDP) per capita and square of GDP per capita, respectively. When Eq. (1) is used to log-linearize, the following equation is obtained:

$$\ln CO_2 = \alpha_0 + \beta_1 \ln GDP + \beta_2 \ln GDP^2 + \varepsilon_t \tag{2}$$

Given the context of the EKC hypothesis, theoretical expectations demand that $\beta_1 > 0$ and $\beta_2 < 0$ be met for legitimizing an inverted U-shape relationship between economic growth and environment. However, including only one regressor in the model may lead to spurious results and misleading conclusions. As a result, after examining the prior literature, other control variables such as FDI, urbanization, and energy use were introduced into the model to address the research gap. The choice of the variables for the present study are in line with previous empirical literature. However, we distinct by holistically combining the variables which draws motivation from the UNSDGs such an energy variable (SDG-7), economic growth (SDG-8), and climate change mitigation (SDG-13). To address the hypothesized objective, our expanded EKC model is presented in Eq. (3) in the following way:

$$\ln CO_2 = \alpha_0 + \beta_1 \ln GDP + \beta_2 \ln GDP^2 + \ln FDI + \ln UR + \ln EU + \varepsilon_t \tag{3}$$

where lnFDI is the natural logarithm of foreign direct investment, lnUR denotes the natural logarithm of urbanization, and lnEU is the natural logarithm of energy use, whereas ε_t captures the error term. This study followed several standard phases of time series data analysis, as shown in Fig. 1.

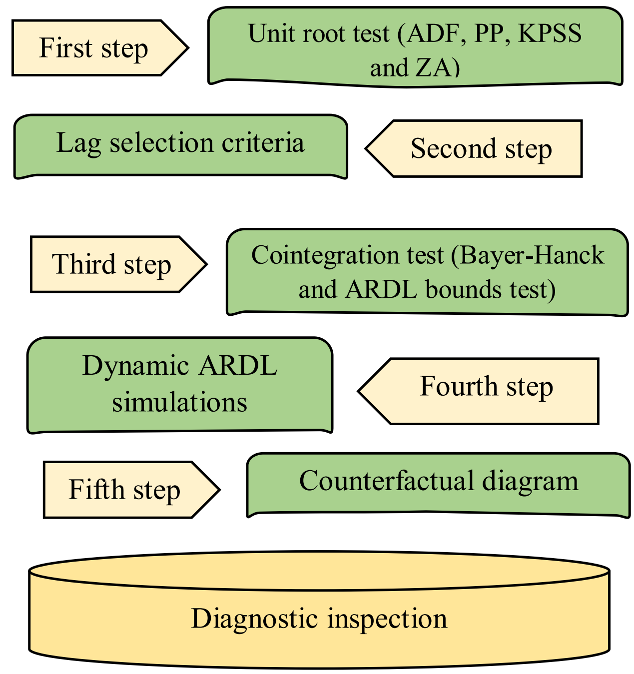

Fig. 1 Methodological flow diagram

Econometric method

The short- and long-term coefficients of the variables under consideration were estimated using the novel dynamic ARDL simulations model (Jordan and Philips, 2018a, b). This model is able to stimulate and plot graphs of (positive and negative) changes in variables automatically, as well as estimate their long- and short-term associations. It is necessary to run a stationarity test in order to determine the order of integration among variables before adopting the novel dynamic ARDL simulations approach. In light of this, we use Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) standard unit root tests. After determining the stationarity properties of all variables, we proceeded on to the estimation of linear cointegration. This study uses the Bayer and Hanck (2013) combined cointegration test to analyze long-term cointegration among variables. This technique incorporates several individual tests such as Engle and Granger (1987), Boswijk (1995), Banerjee et al. (1998), and Johansen (1991). The Fisher equation is written as follows:

$$EG - JOH = -2\left[\ln(\rho EG) + (\rho JOH)\right] \quad (4)$$

$$EG - JOH - BO - BDM = -2\left[\ln(\rho EG) + (\rho JOH) + (\rho BO) + (\rho BDM)\right] \quad (5)$$

ρBDM, ρBO, ρJOH, and ρEG, are the odds of diagnosing individual cointegration tests.

The ARDL bounds testing (Pesaran et al., 2001) procedure is considered in this research to assess the robustness of Bayer and Hanck's (2013) cointegration test. The ARDL bounds testing technique can be implemented with the variables at different orders of integration either I(0) or I(1), in contrast to typical cointegration tests. This approach has the advantage of producing effective findings in investigations with small sample sizes. Furthermore, both short- and long-run coefficients can be computed at the same time. To determine ARDL bounds, the following model was created:

$$\begin{aligned}\Delta(\ln CO_2)_t = \theta_0 &+ \sum_{i=1}^{t}\theta_1\Delta\ln CO_{2t-i} + \sum_{i=1}^{t}\theta_2\Delta\ln GDP_{t-i} + \sum_{i=1}^{t}\theta_3\Delta\ln GDP^2_{t-i} \\ &+ \sum_{i=1}^{t}\theta_4\Delta\ln FDI_{t-i} + \sum_{i=1}^{t}\theta_5\Delta\ln UR_{t-i} + \sum_{i=1}^{t}\theta_6\Delta\ln EU_{t-i} \\ &+ \lambda_1\ln CO_{2t-1} + \lambda_2\ln GDP_{t-1} + \lambda_3\ln GDP^2_{t-1} + \lambda_4\ln FDI_{t-1} \\ &+ \lambda_5\ln UR_{t-1} + \lambda_6\ln EU_{t-1} + u_t\end{aligned} \quad (6)$$

where t denotes the lag length, t−i is the optimal lags derived applying the Akaike information criteria (AIC), $u_t$signifies the error term, Δ is the first difference operator, and the long-term association is examined by the λ. In the bound testing strategy, a hypothesis test is necessary to formulate a long-run nexus among the variables under review. The null and alternative hypotheses are no cointegration (H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$), and evidence of cointegration ($H_{alternative}$: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq 0$), respectively. In this approach, the derived F statistics are compared to the lower and upper bound critical values. When the estimated F statistics are less than the upper bound value, the null hypothesis is not refuted. The rejection of the null hypothesis occurs whenever the estimated F statistics is greater than the upper bound critical value, suggesting that the variables have a long-term relationship (Khan et al., 2019; Abbasi and Adedoyin, 2021; Islam et al. 2021).

The dynamic ARDL simulations approach devised by Jordan and Philips (2018a, b) was used to estimate the long-run and short-run coefficients in this research. This model was created to unravel the limits of the existing ARDL model while looking at the long-run and short-run relationships between the variables being researched. Apart from that, the dynamic simulated ARDL approach may estimate, simulate, and create graphs to project counterfactual changes in one predictor variable and their influence on the dependent variable while the other regressors remain constant (Jordan and Philips, 2018a, b; Abbasi et al., 2021). The series included in the model should be integrated at I(1) and have cointegration among them to execute the dynamic ARDL simulations technique (Jordan and Philips, 2018a, b), and the study's variables adhered to the pre-requisite. For the parameters vector of a multivariate normal distribution, this study used 5000 simulations in the dynamic ARDL error correction term technique. The dynamic ARDL model's equational form, including the error correction term, is as follows:

$$\begin{aligned}(\ln CO_2)_t = \psi_0 &+ \delta_0\ln CO_{2t-1} + \phi_1\Delta\ln GDP_t + \delta_1\ln GDP_{t-1} + \phi_2\Delta\ln GDP^2_t \\ &+ \delta_2\ln GDP^2_{t-1} + \phi_3\Delta\ln FDI_t + \delta_3\ln FDI_{t-1} + \phi_4\Delta\ln UR_t \\ &+ \delta_4\ln UR_{t-1} + \phi_5\Delta\ln EU_t + \delta_5\ln EU_{t-1} + \xi ECT_{t-1} + u_t\end{aligned} \quad (7)$$

where ECT_{t-1} denotes the error correction term. Besides, ξ is the ECM coefficient, which should be statistically significant with a negative sign. Finally, different model diagnostic tests, such as CUSUM and CUSUMsq, were used to check model stability. The serial correlation was also detected using the Breusch-Godfrey Lagrange Multiplier (LM) test, while heteroscedasticity was assessed using the Breusch-Pagan-Godfrey and ARCH test. Finally, the Ramsey reset test is used to see if the model has been expressed correctly.

Results and interpretation

This section focuses on the discussion of empirical outcomes. The section starts with a preliminary analysis of summary statistics and correlation coefficient analysis. Table 2 presents the basic measure of central tendency and dispersion of the variables under review where we observe that GDP per capita shows highest average and FDI with least average over investigated period. We also observe that all series are positively skewed over the examined period. In terms of dataset peaks as reported by Kurtosis, all variables show light tails except for FDI. The normality analysis test shows that all series are normally distributed, which is desirable as we fail to reject the Jarque-Bera probability. Subsequently, we seek to explore the pairwise correlation between the study variables, as highlighted at the bottom of Table 2. A strong statistical ($p < 0.01$) significant level is seen between GDP and CO_2. This suggests that higher economic growth comes with its environmental cost. A similar positive trend is observed between FDI and CO_2 and other study variables. However, there is a criticism of Pearson correlation analysis; thus, there is a need for more econometrics analysis, which is sorted in the next step of the present study.

Next, the present study proceeds to explore the stationarity traits of the study variables by conducting the ADF and PP unit root test and confirmatory non-unit root test of KPSS, as outlined in Table 3. All stationarity tests and

Table 2 Descriptive statistics and correlation matrix

	CO_2	GDP	FDI	UR	EU
Mean	2.9578	6435.1910	0.8821	58.9654	1080.6490
Median	2.8119	5793.2860	0.9568	61.8565	1028.4170
Maximum	5.1272	12004.3800	3.6235	75.6300	1751.4460
Minimum	1.2226	3336.4920	0.0195	38.2340	522.1994
Std. dev.	1.0899	2539.7560	0.9568	11.9603	353.8787
Skewness	0.2797	0.8169	1.2364	−0.3743	0.3417
Kurtosis	1.9500	2.5462	3.3849	1.7641	1.9530
Jarque-Bera	2.8629	4.1169	7.5721	2.6938	2.8600
Probability	0.2120	0.1104	0.0477	0.2638	0.2120
Correlation					
CO_2	1				
GDP	0.7099[a]	1			
FDI	0.8111[a]	0.7606[a]	1		
UR	0.7727[a]	0.7723[a]	0.7652[a]	1	
EU	0.8167[a]	0.6369[b]	0.7288[a]	0.8038[a]	1

[a] and [b] denote the significance at 1% and 5% levels, respectively

confirmatory tests of KPSS are in harmony with stationarity after the first difference. Thus, our study dataset passes the test of I~(I) and not I~(2). Thus, the need to investigate long-run properties is pertinent. Prior to analysis of long-run equilibrium, we explore the lag length criterion to enable the best performing model, i.e., the most parsimonious model, which, in our study case, is the lag two based on the Akaike information criterion (AIC) which is in line with study structure as reported in Table 4. For long-run analysis, our study uses the novel Bayer and Hanck (2013) combined cointegration test alongside the ARDL bounds test as presented in Table 5 and Table 6, respectively. Each test confirms the long-run equilibrium relationship between study variables over the investigated period.

The next step is the baseline regression presented in Table 7 that simultaneously highlights the short- and long-run dynamics of the relationship between, FDI, urbanization, energy use, and economic growth on CO_2 emission of Turkey. From the baseline regression, the current study validates the presence of EKC. This EKC validity suggests

Table 3 Unit root test

	ADF test		PP test		KPSS test	
Variable	Level	Difference	Level	Difference	Level	Difference
$\ln CO_2$	−2.1134	−6.5256[a]	−2.1007	−6.5611[a]	0.9411[a]	0.3302[c]
lnGDP	−1.6935	−5.0023[a]	−1.7329	−5.6602[a]	0.9165[a]	0.5562[b]
$\ln GDP^2$	−2.7392	−4.9578[a]	−2.0026	−4.8881[a]	0.9486[a]	0.3826[c]
lnFDI	−2.7962	−5.7446[a]	−2.2763	−7.1189[a]	0.8956[a]	0.1113
lnUR	−1.1067	−4.9539[a]	−2.8882	−8.9928[a]	0.5567[b]	0.1909[c]
lnEU	−2.6181	−6.5602[a]	−2.5144	−4.9936[a]	0.8722[a]	0.2403[c]

[a], [b], and [c] define significance levels of 1%, 5%, and 10%, respectively. The critical values and probability of the KPSS test are based on Kwiatkowskie, Phillipse, Schmidte, and Shin (1992)

Table 4 Lag length criteria for ARDL model

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	196.1279	NA	1.06e−10	−8.6128	−7.6967	−8.1627
1	438.6489	422.4323	1.88e−14	−17.7308	−16.2175[c]	−16.7963
2	477.3482	158.8772[c]	1.13e−14[c]	−17.9695[c]	−15.4480	−17.2815[c]
3	495.4142	123.7968	1.78e−14	−17.6693	−14.6605	−16.8744

LR, sequential modified LR test statistic; *FPE*, final prediction error; *AIC*, Akaike information criterion; *SIC*, Schwarz information criterion; *HQ*, Hannan-Quinn information criterion. [c]Symbolizes lag order selected by the criterion

Table 5 Results of Bayer-Hanck (2013) cointegration test

Estimated model: $\ln CO_2 = f$ (lnGDP, $\ln GDP^2$, lnFDI, lnUR, lnEU)					
Fisher type	Test statistics	CV@1%	CV@5%	CV@10%	Decision
EG-JOH	22.8662[a]	16.8943	11.2534	9.3402	Cointegrated
EG-J-BO-BDM	32.8760[a]	28.4452	18.1762	15.6471	Cointegrated

[a]indicates the results are significant at the 1% level

Table 6 Results of ARDL bounds test

F-statistics	Level of significance	Lower Bound I(0)	Upper Bound I(1)	Long-run relationship
4.7858	10%	2.31	3.45	Present
	5%	2.73	3.86	
	2.5%	2.98	4.21	
	1%	3.44	4.72	

Table 7 Findings of dynamic ARDL simulations model. Dependent variable: CO_2 emission

Variables	Coefficient	Standard error	T-stat.
Cons.	1.6410[a]	0.5390	3.05
lnGDP	0.3292[b]	0.1337	2.46
△lnGDP	0.1580[b]	0.0630	2.51
$lnGDP^2$	−0.1095[b]	0.0475	−2.30
$\triangle lnGDP^2$	−0.0570[c]	0.0320	−1.78
lnFDI	−0.0915[b]	0.0429	−2.13
△lnFDI	0.0010	0.0070	0.21
lnUR	0.9341[a]	0.1611	5.81
△lnUR	0.5511[a]	0.185	2.97
lnEU	0.4469[a]	0.0818	5.46
△lnEU	0.1085[c]	0.0565	1.92
ECT(−1)	−0.5378[a]	0.1586	−3.39
R^2	0.6259	Prob > F	0.000[a]
Adjusted R^2	0.4792	N	50
Simulation		5000	

[a], [b], and [c] denote significance at 1%, 5%, and 10% levels, respectively

that emphasis on economic growth is still prioritized compared to environmental quality. This outcome resonates with the study of Bekun et al. (2021b and c) for the case of Sub-Saharan Africa and E7 economics, respectively, as well as Onifade et al. (2021) for the E7 economics. Furthermore, our study lends credence that a 1% increase in economic growth worsens the quality of the environment by 0.3292% and 0.1580% for a long and short run by ($p < 0.05$) statistical rejection level. This result raises concerns for decoupling the economic growth trajectory for environmental quality. For FDI influx to Turkey in the short run, there exists a non-significant though positive detrimental threat on the quality of the environment. This result is in line with the study of Gökmenoğlu and Taspinar (2016) while, in the long-run, FDI flow shows desirable traits to improve the quality of the environment. The plausible logic is probably that the country needs a cleaner environment, awareness, that is, more caution for inflow of FDI that jeopardizes the quality of the environment even though it green FDI. The similar findings also observed by Kisswani and Zaitouni (2021) for Malaysia and Singapore.

In a similar fashion, increase in the urban population in terms of urbanization of the Turkish economy, although it sounds good and desirable, has a detrimental environmental cost, as outlined in Table 7. A 1% increase in urbanization or, as urbanization intensifies, it worsens the quality of the environment by 0.9341% and 0.5511% in both the long and short run and the magnitude of the coefficient shows it grows from short to long run. The detrimental impact of untamed urban cities corroborates with the studies by Al-Mulali and Ozturk (2015) and Ozatac et al. (2017). This finding also resonates with the study of Islam et al. (2021) for Bangladesh. From a policy direction and lens, the detrimental contribution of economic growth, urbanization, and FDI can be mitigated by more focus on cleaner growth strategies in terms of economic growth while, for FDI influx, research, and development in cleaner FDI inflow should be pursued by stringent environmental laws and regulations. On the other hand, for urbanization, education on research and development about the cleaner environment are welcome strategies. The pace of adjustment is captured by the error correction term (ECT). Its calculated value is statistically significant and negative, indicating that the variables under consideration have a long-term association. The ECT projected value of -0.53 indicates that 53% of the disequilibrium is rectified in the long run.

The dynamic ARDL simulations robotically illustrate the projections of real regressor change and its effect on the regressand while holding other explanatory factors constant. This study demonstrates the 10% increase and decrease in the independent variables and its effect on the CO_2 in Turkey. The impulse response graph illustrating the connection between economic growth and CO_2 emissions is shown in Fig. 2. In the short run, a 10% rise or decline in economic growth unfailingly worsens the Turkish environment. However, as time passes, the environmental damage caused by increased economic expansion becomes more apparent. On the flipside, for every 10% reduction in economic expansion, carbon dioxide levels fall, and the environment heals itself. Even so, a 10% reduction in economic growth will not be enough to entirely eliminate environmental deterioration.

Given that FDI plays such a significant role in the Turkish economy, its environmental impact is unavoidable. Environmental degradation invariably tracks on the positive side in the short run with every 10% rise or decrease in FDI (Fig. 3), while a 10% rise in FDI does more environmental damage in the long run than a 10% decline. Indeed, FDI is to blame for Turkey's continued environmental degradation. Thus, policymakers should pay close attention to future FDI inflows into the Turkish economy in order to improve the quality of the environment in the long run.

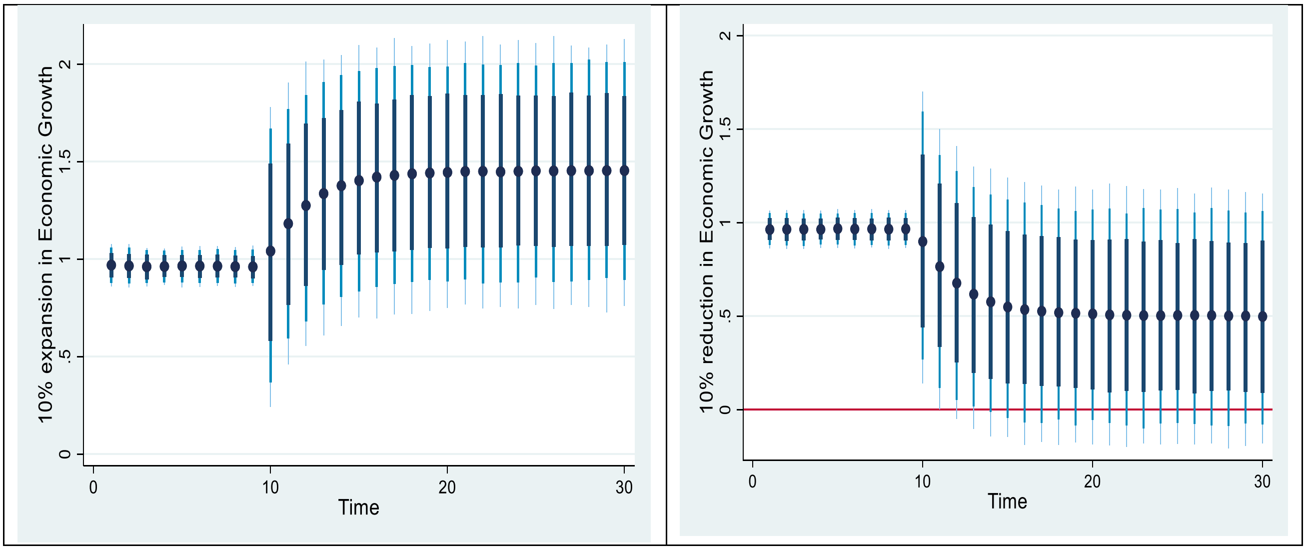

Fig. 2 Economic growth and environmental degradation. The above figure signifies ± 10% in GDP per capita and its effect on carbon dioxide emission in Turkey. The dots represent the forecasted value, whereas the deep blue to light blue lines indicate the 75%, 90%, and 95% confidence intervals, respectively

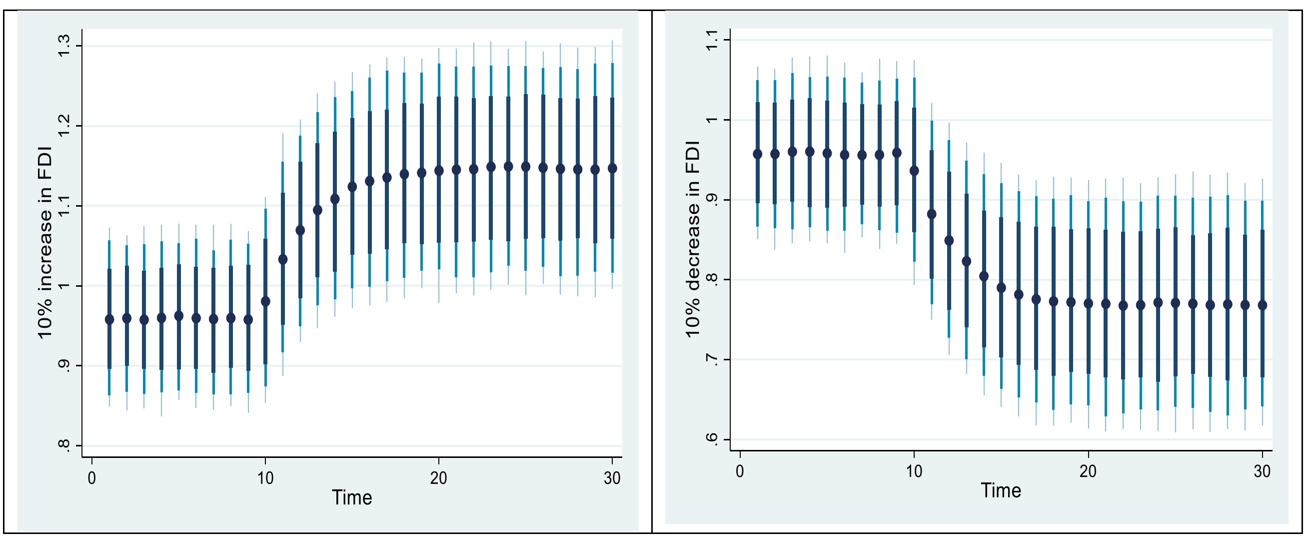

Fig. 3 Foreign direct investment and environmental degradation. The above figure shows ± 10% in foreign direct investment and its effect on carbon dioxide emission in Turkey. The dots specify the forecasted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

Figure 4 shows how carbon dioxide levels will alter in response to positive and negative changes in the urban population. It is obvious that a 10% increase or decrease in the urban population does not result in any momentous change in environmental performance in the short term. However, every 10% increase in urban population damages environmental quality over time by increasing carbon dioxide emission levels in the atmosphere. While environmental quality improves with every 10% reduction in urban population to the horizon, it is still insufficient to totally offset carbon dioxide emissions and provide a cleaner environment.

The impulse response graph of energy use and CO_2 emissions in Turkey is shown in Fig. 5. The graph of energy consumption shows that a 10% rise in energy consumption is strongly connected with an unfavorable impact on environmental quality in the long and short term. However, a 10% reduction has a negative impact on CO_2 emissions in the long and short run. This implies that increasing energy use in Turkey degrades environmental quality. Therefore, Turkey should keep an eye on the transition of the renewable energy consumption from fossil fuels to uphold environmental quality.

Table 8 highlights the fitness of the baseline model, as the model satisfactory passes all diagnostic tests ranging from serial correlation, ARCH test, and heteroscedasticity to model specification test. Thus, our fitted model is suitable

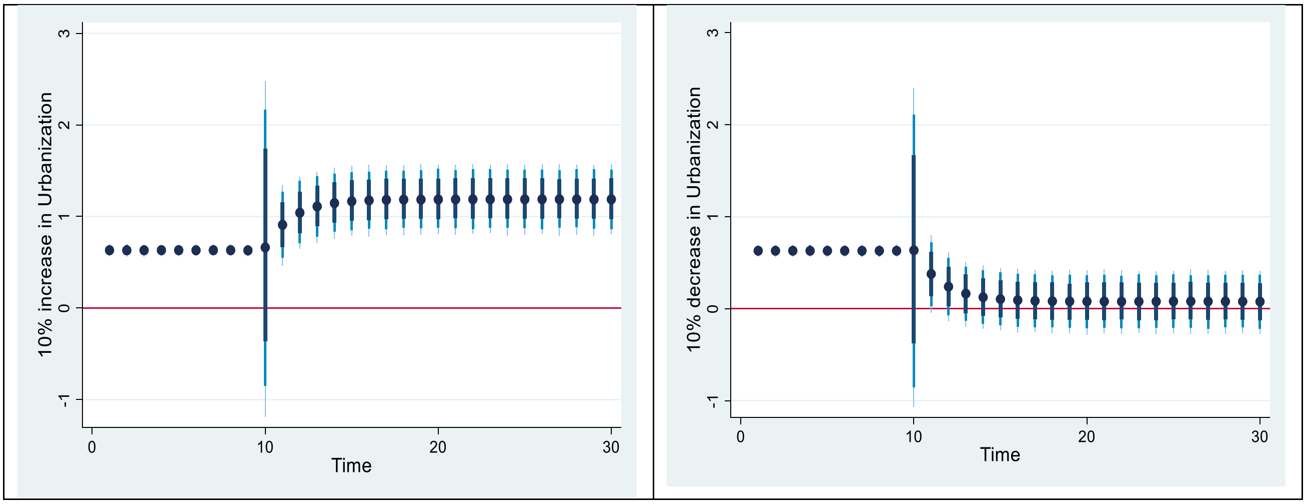

Fig. 4 Urbanization and environmental degradation. The above figure signifies ± 10% in urban population and its effect on carbon dioxide emission in Turkey. The dots specify the forecasted value, whereas the deep blue to light blue lines illustrate the 75%, 90%, and 95% confidence intervals, respectively

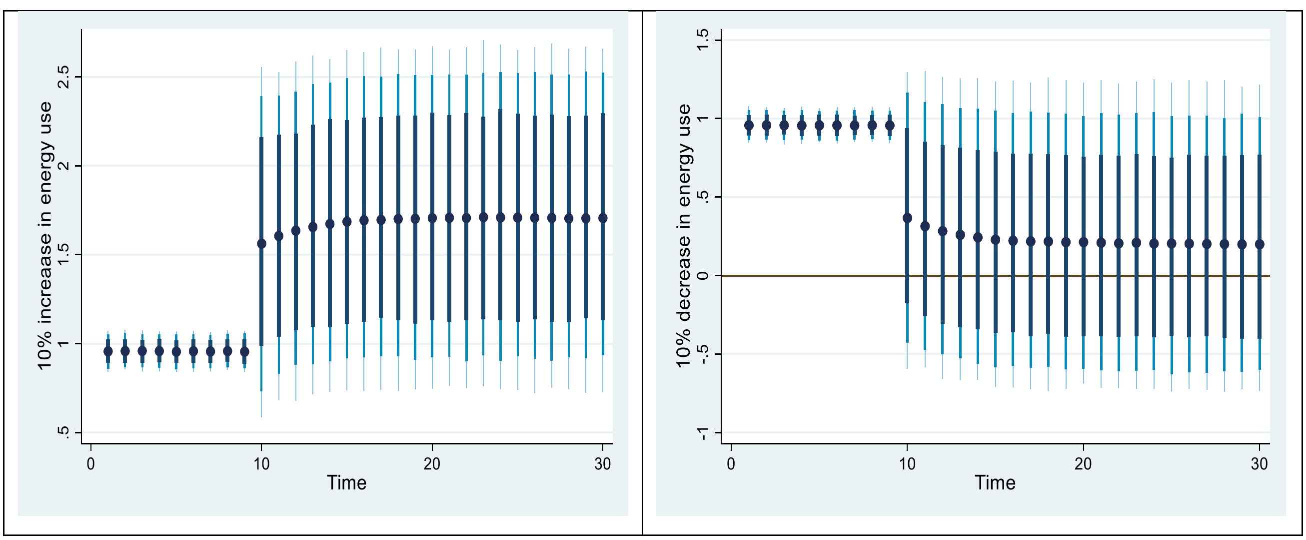

Fig. 5 Energy consumption and environmental degradation. The above diagram shows ±10% in energy use and its effect on carbon dioxide emission in Turkey. The dots specify the predicted value, whereas the deep blue to light blue lines show the 75%, 90%, and 95% confidence intervals, respectively

Table 8 Residual diagnostic test

Diagnostic test	Chi-square (*P*-value)	Findings
Breusch-Godfrey serial correlation LM	0.3290	No evidence of serial auto correlations
Breusch-Pagan-Godfrey	0.5297	No evidence of heteroscedasticity
ARCH test	0.3962	No problem of heteroscedasticity
Ramsey RESET test	0.5063	Model accurately specified

for policy formulation and direction. For model stability, see Fig. 6 which presents the CUSUM and CUSUMsq graphs where blue lines are satisfactory within the 5% boundary indicating the fitted model is stable.

Conclusion and policy direction

Concluding remarks

Global warming is connected through channels of urbanization and foreign direct investment (FDI) influx comes with environmental and economic growth consequences. Thus, the present study focuses on a single country on FDI-urbanization economic growth nexus in an environmental Kuznets curve (EKC) environment for annual frequency data from 1970 to 2020. This study leverages on novel estimation techniques such as dynamic autoregressive-distributed lag (DARDL) methodology and Bayer and Hanck (2013) combined cointegration test. The empirical analysis confirms the long-run equilibrium relationship between the study's highlighted variables. Our study outcomes give credence to the EKC phenomena in the case of Turkey. This suggests that, in Turkey, emphasis is on economic growth at the expense of environmental quality. We also found empirical validity for the pollution haven (PHH) hypothesis in the short run and the halo effect in the long run for Turkey. Thus, the government officials in the country are cautioned of the effect of PHH and the scale effect evidence in Turley on economic growth-emission level tradeoff as FDI influx increases. To this end, environmental steps are needed to circumvent the adverse impact of urban population and economic growth on environmental quality.

Policy recommendations

In terms of policy implications, the findings here imply that a stable economic growth strategy in Turkey is necessary in order to attain the intended eco-efficiency target, as previously stated. Sustainable development is crucial for a country like Turkey, which aspires to be one of the world's top ten economies and to become a member of the European Union in the near future. It is well-acknowledged that environmental pollutants are a significant impediment to sustainability in this country. The people must be educated on the importance of environmental degradation, and necessary reforms must be implemented so that GDP per capita reaches the tipping point, in order to minimize emissions. CO_2 pollution can be reduced by employing carbon capture and storage technology, as well as by increasing the level of carbon levies. To that end, policymakers must develop urbanization strategies in order to curb uncontrolled urbanization, which is one of Turkey's most pressing concerns, as well as to mitigate environmental degradation.

The employment of robotic systems, clean-fuel vehicles, and CO_2 recycling technologies (for example, in the iron and steel, equipment, and petrochemical industries) should be encouraged and supported by local authorities in order to minimize energy usage and CO_2 pollution rates. The authorities must also gradually adapt to a changing manufacturing sector that includes a substantial share of the steel production from the viewpoint of the industrialized society by modifying the technical invention as the industry sector

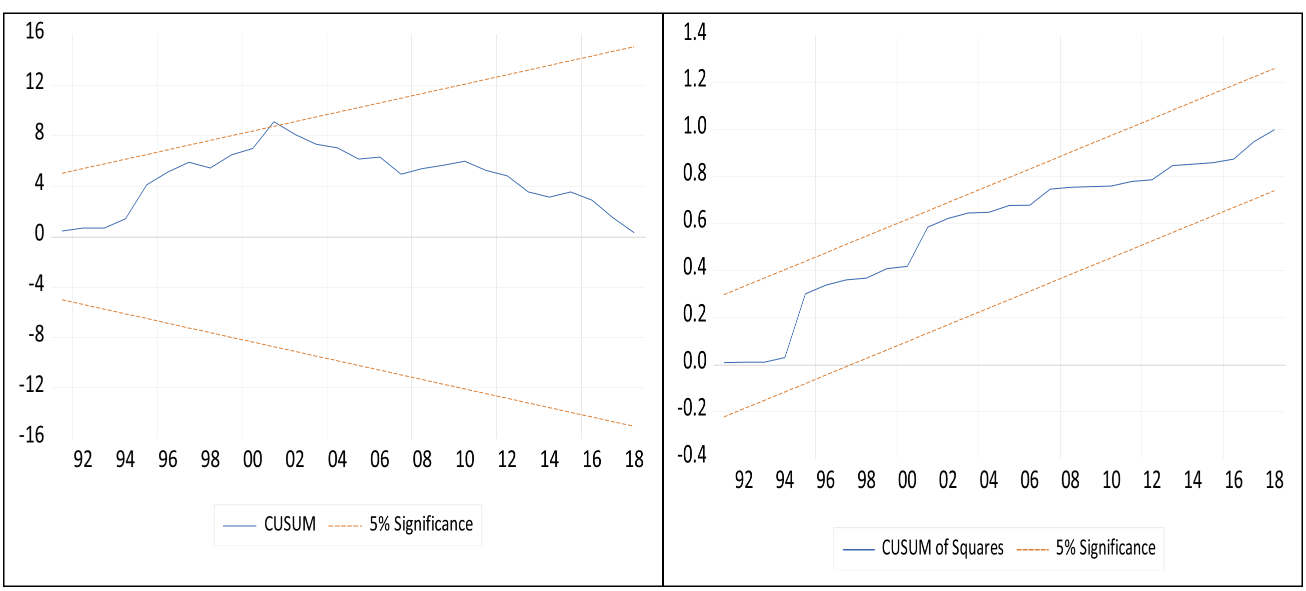

Fig. 6 CUSUM and CUSUM square test

transforms. Turkey should promote the development of tertiary industry through technological innovation, foreign direct investment, and urbanization strategies in order to meet the need for economic growth while also developing a low-carbon economy. Given the current state of the environment, the Turkish government should continue to invest in green-field initiatives and high-tech solutions that address environmental problems. It is critical for Turkish authorities to create and implement policies requiring Turkish firms receiving foreign direct investment to employ and promote environmentally friendly technology.

Although, the present study has explored an extended version of the EKC while accounting for other key determinant of environmental degradation such FDI, energy use, and urbanization. Future studies can advance the literature by exploring other neglected indicators such as demographic indicators, like population. Additionally, future studies can explore the theme in a non-linear environment.

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Data availability The data for this present study are sourced from world development indicators (WDI) available at www.data.worldbank.org.

Author contribution Festus Victor Bekun was responsible for the conceptualization, methodology, and writing the results section. Bright Akwasi Gyamfi was responsible for formal analysis and writing the literature review section. Md. Emran Hossain managed the data curation and preliminary analysis. Phillips O. Agboola was responsible for proofreading and manuscript editing. The author(s) read and approved the final manuscript.

Declarations

Ethics approval Authors mentioned in the manuscript have agreed for authorship read and approved the manuscript and given consent for submission and subsequent publication of the manuscript.

Consent to participate Note Applicable

Consent for publication Applicable

Competing interests The authors declare no competing interests.

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