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Beyond the Structural Change: Does Technology Obsolescence Effect Exist in the Economy of Turkey?

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ABSTRACT

The implications of economic activities on the quality of environment have gained a long theoretical and empirical debate among scholars and decision-makers, using perhaps the most sophisticated analytical techniques, however, no consensus is yet to be reached on a specific pattern of the relations. Deviating from the attendant literature, this study conducts a comprehensive empirical investigation for the relationship between economic growth and environmental quality for Turkey using a cubic polynomial function under the framework of extended form of EKC hypothesis. The study employed Autoregressive Distributed Lag model for the annual data extending the period 1996-2022. The findings reveal that the relationship between economic growth (GDP) and environmental quality is inverted N-shaped. Additionally, the results uncover that public expenditure on research and development (R&D) has no reliable power to explain the variation in environmental quality, while the population growth rate contributes to reducing pollution. Among numerous policy suggestions, the study recommends that an expansion in green investment can increase the effectiveness of sustainability policies, and financial sector can play a promising role through regulated expansion of domestic credit and bank credit to the private sector to promote the development and diffusion of environmentally sound technologies.

1. Introduction

Over the past two decades, the most prominent concerns dominating global public discourse revolve around pressing issues such as global warming, environmental deterioration, and the pursuit of sustainable development. These matters are intricately intertwined with significant political, social, cultural, and demographic factors. The common concern of scientists, politicians, the business world, and relevant other stakeholders is that today's relations of consumption and production are no longer environmentally sustainable [1].

Scholars have extensively attempted to identify the causes of environmental degradation. Several factors that affecting the quality of environment have been identified, including, economic growth

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[2], renewable energy consumption [3], green investment [4], technological innovation [5], urban population growth [6], globalization [7], financial development and financial inclusion [8], foreign direct investment [9], income inequality and institutional quality [10], economic policy uncertainty and geopolitical risk [11], gender equality [12], human capital [13], oil price volatility and oil market uncertainty [14], political and economic freedom [15] poverty alleviation strategies [16], agricultural land expansion and deforestation [17], and natural resources rent [18].

Energy is by far regarded as the potential driver for economic development due to its vital role in the sectors that constitute the bulk of economies such manufacturing and transportation. However, energy is found to be responsible for 73.2% of GHG emissions which considered the major cause of climate change and global warming, followed by agriculture, land-use (18.4%), industry (5.2) and waste (3.2) [19]. Since energy-related products have become fundamental factor for the economies, it becomes challenging for the policymakers to balance the competing ends of economic development and combat pollution through the restriction of energy usage. Economic activities, especially energy intensive based production, have been considered as the main contributing factor for the deterioration of the environment. Therefore, since the emergence of seminal work of Kuznets [20], the relationship between economic outcomes and environment has been raising a lively debates in academics and policymaking circles as well [21].

The EKC framework has been widely used as the theoretical foundation for the research on the nexus between environment and economic growth, which over the years has contributed significantly to formulating sustainability policies and natural resources management. The initial argument of the Environmental Kuznets Curve (EKC) hypothesis suggests that economic growth initially worsens environmental quality. This is because growth demands increased resource consumption and production (known as the scale effect), leading to higher levels of waste and pollution. However, as the economy advances, there is a shift from energy-intensive activities to services and less polluting technology-based industries. This transition involves replacing older and more polluting technologies with cleaner alternatives which ultimately resulting in an improvement in environmental quality creating an invested U-shaped relationship between economic activity and environment as depicted in Fig 1 [22].

However, this argument has started to lose power to withstand against the newly discovered phenomena that appears beyond technique and composition effect as asserted by standard EKC hypothesis. It has been found that the incontestable positive effect of technology replacement in the economic structure beyond the scale effect may not be entirely valid and/or necessarily sustainable due to the so-called Technology Obsolescence Effect. If the potential of innovation is fully exhausted, then technological obsolescence effect might outweigh the scale effect which ultimately damage environment creating an N-shape relationship between economy and environment [22]. This fact raises the level of debate on the growth-pollution nexus and shifted the attention beyond structural change (technique and composition effect) leading to considerable policy changes and investment strategies.

Therefore, motivated by the limited research on the possible existence of technology obsolescence effect, this study is an additional attempt to look beyond of technique and composition effect for the economy of Turkey over the period 1996-2022 by employing Autoregressive Distributed Lag model (ARDL). The outcomes of this study are expected to extend the literature in several ways; **First**, this study is the first to examine the extended from of EKC hypothesis for Turkey. Turkey is one of the fastest growing emerging economies, however, the country is found to be 15th among the twenty most polluting nations in terms of carbon emissions [23], which has been raising many concerns about the sustainability policies. As Turkey's economy is highly energy dependent, any restriction in energy consumption could end up with a severe economic slowdown. This dilemma requires pondering upon new strategies beyond that controlling the conventional determinants of its growth model. Technology innovation and green investment are considered promising solutions. Thus, the outcomes of this study can provide draw important insights as decision-making reference. **Second**, the existing research that analyzed the relationship between economic growth and environmental quality beyond the technique and composition effect most relied on carbon emissions as a proxy for environmental sustainability. Carbon emissions, however, only represent air pollution, thus a comprehensive study should cover different spheres of environment such as carbon footprint, grazing land, built-up land, fishing ground, etc. In this respect, this study is the first to use ecological footprint instead of carbon emissions as it holistically measures the quality of environment considering over six dimensions. **Third**, this study incorporates the public expenditure on research and development in the N-shape of EKC. Research and development are expected to play a significant role in decreasing the levels of pollution given its potential in delaying the appearance of technical obsolescence. According to Alvarez-Herranz et al. [24], research and development can improve environmental quality in several ways; (i) Research and development (R&D) have the potential to facilitate the creation of cleaner and more efficient energy technologies like solar, wind, and hydropower, which generate minimal to no CO_2 emissions. (ii) R&D endeavors can also result in advancements in energy storage systems, ultimately enhancing the dependability and affordability of renewable energy sources. (iii) The research and development can play a pivotal role in the evolution of carbon capture and storage technologies, which entail capturing CO_2 emissions from industrial processes and power plants and safely storing them underground, thereby curbing their release into the atmosphere. (iv) R&D activities can stimulate enhancements in energy efficiency, consequently lowering the energy requirements for diverse tasks and, consequently, mitigating CO_2 emissions.

The remaining sections are organized as follows: the upcoming section portrays important literature on the subject and theoretical framework. The third section highlights methodology and data. Section four accommodates the estimation outputs and discussions. The conclusion and policy implications are given in the final section.

2. Theoretical framework and related literature

Over years, since the seminal work of Kuznets [20] and Grossman and Krueger [25], a myriad research has empirically investigated the relationship between economic growth and environmental quality for different nations using several estimation strategies and time frames. By an in-depth search through the pertinent literature, one can conclude two research spectrums; The initial examination of spectra focused on investigating the interplay between economic outputs and environmental quality within the context of the Environmental Kuznets Curve (EKC) framework. In accordance with the EKC hypothesis, the initial phases of economic growth tend to exacerbate environmental pollution due to the heightened demand for additional resources and energy, a phenomenon known as the scale effect. This surge in economic activity leads to increased waste and pollution. However, as economic development advances, a transformation process ensues, shifting the focus from energy-intensive activities to service-oriented sectors and replacing outdated technologies with cleaner alternatives. This transition results in the emergence of an inverted U-shaped relationship between economic activities and environmental impact, wherein economic growth initially contributes to environmental degradation but eventually leads to environmental improvement (Fig 1). Thus, more environmentally friendly and cleaner technology-based activities emerge [26]. These two effects are expressed as compositional and technical effects which has been

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validated by many scholars e.g., Bilgili et al. [27] for 36 Asian countries, Espoir and Sunge [27]. Contrarily, some researchers have reported evidence against the EKC postulation [28-33].

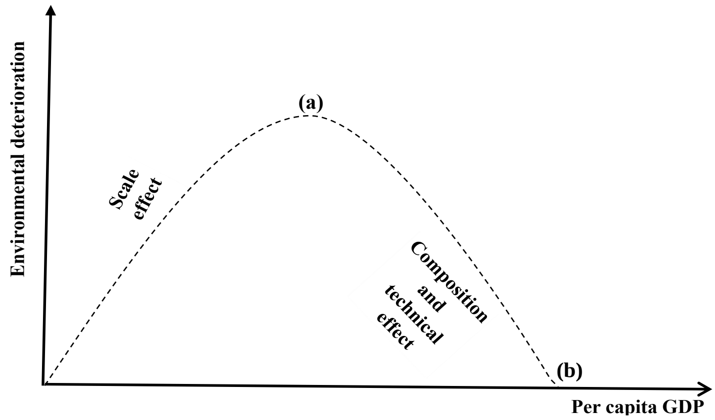

Fig. 1. An inverted U-shaped pattern

Furthermore, certain critics underscore that the complete disappearance of innovative activities could introduce a scenario where the influence of technological obsolescence surpasses that of the scale effect, potentially resulting in an elevation of environmental pollution. In such a circumstance, it is conceivable that a protracted N-shaped relationship (as illustrated in Fig 2) might materialize between economic growth and environmental pollution [34]. This argument has served as a catalyst for numerous scholars to embark on an assessment of the relationship between economic growth and environmental pollution that extends beyond considerations of composition and technical aspects, with the aim of uncovering the potential influence of technological obsolescence. For instance, Gyamfi et al. [35] employed a PMG-ARDL estimator to explore an N-shaped EKC in the seven emerging economies. Shahbaz et al. [36] confirmed the existence of an N-shaped Environmental Kuznets Curve (EKC) pattern, indicating that a nation can undergo a transient reduction in pollution during a particular phase of economic growth. Nevertheless, upon attaining another income threshold, a subsequent upturn in pollution levels is expected to transpire. Similarly, Zeraibi et al. [37] mentioned that the CO_2 emissions in China portray an N-shape. Koc and Bulus [38] also concluded an N-shaped for South Korea. Awan et al. [22] found an N-shape pattern in transport sector for high income nations. Shahbaz et al. [39] also documented that the connection between economic growth and CO2 emissions in the United States exhibited an N-shaped pattern.

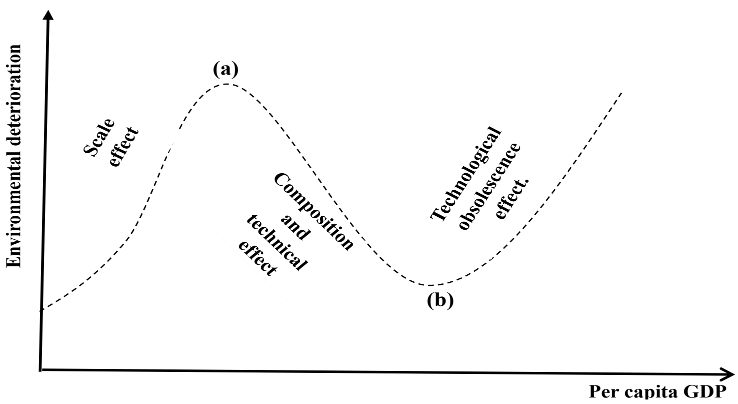

Fig. 2. A cubic polynomial reveals an N shape pattern

In more extreme cases, Sterpu et al. [40] analyzed the relationship between economic growth and environment for EU members, the authors found that an inverted N-shaped, confirming the absence of technology obsolescence effect (Fig 3). Ali et al. [41], investigated the relationship between carbon dioxide emissions (CO2e), gross domestic product (GDP), the extent of land allocated to cereal crops, and the value-added in the agriculture sector in Pakistan. The findings of the short-run analysis indicate a negative correlation between carbon dioxide emissions and gross domestic product (GDP), and this correlation is statistically insignificant thus confirming a flat behavior indicates no existence of a relationship between GDP and the environment (as shown in Fig 4).

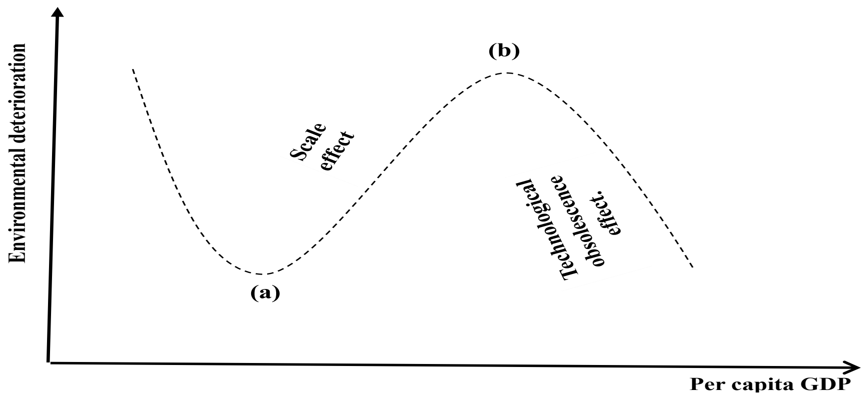

Fig. 3. A cubic polynomial reveals an inverted N shape pattern

Second, some analysts argue that the conventional framework of U-shape and N-shaped EKC do not provide a real-time dynamic relation between economic activities and environmental quality led to the emergence of a decoupling analysis. In order to delve into the factors responsible for varying degrees of decoupling relationships, decoupling research integrates various decomposition analyses, including structural decomposition, production decomposition, and index decomposition [42]. The Tapio [43] index has been widely utilized by researchers for decoupling analysis as it provides more comprehensive view on the relations through eight possible combinations of decoupling status [44].

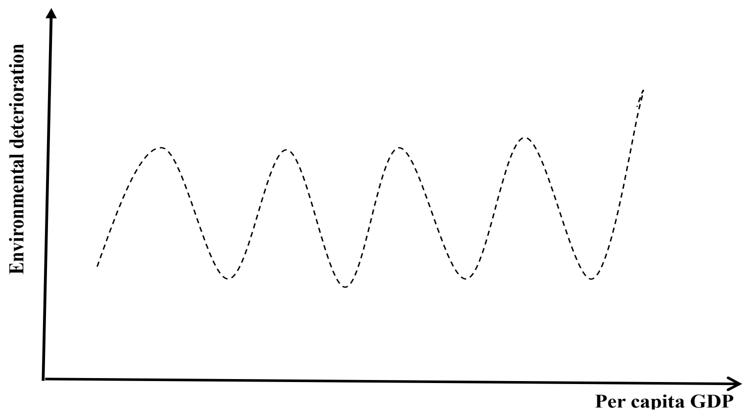

Fig. 4. Flat behavior indicates no relation exists.

However, by critically evaluating the literature one report that no consensus has been reached among the scholars (Table 1). For instance, from a global scale, Shuai et al. [44] employed the Tapio index to examine the decoupling dynamics between economic output and CO_2 emissions across 133 economies spanning the years 2000 to 2014. The findings of their study led to the conclusion that economic growth progressively decouples from CO2 emissions over time. Chen et al. [45] likewise applied the Tapio index to assess the decoupling relationship between per capita GDP and CO2 emissions within the OECD region for the time frame of 2001-2015. Their analysis revealed instances of both recessive decoupling and robust decoupling. A group of researchers has investigated the decoupling status at the country level. for example, using the Logarithmic Mean Divisia Index technique, Wang et al. [46] quantified the extent of decoupling in both China and the United States during the period from 2000 to 2014. Their analysis unveiled a pattern of expansive but weak decoupling in China, while in the United States, they identified instances of weak and robust decoupling. Wu et al. [47] noted the presence of a robust decoupling relationship between economic development and carbon intensity in China, as evidenced by their analysis of provincial-level data spanning the years 2001 to 2015. Wang and Su [48] identified instances of both robust and fragile decoupling between carbon emissions and economic growth.

Table 1
Summary of the existing literature

Ref.	Time and location	Methodology	Result
[49]	1990-2020, China	ARDL	GDP $\rightarrow^{(-)} CO_2$e
[50]	1970-2017. China	NARDL	GDP $\rightarrow^{(-)} CO_2$e
[26]	1991-2017, 36 Asian nations	FMOLS, GMM	GDP $\rightarrow^{(-)} CO_2$e
[51]	1971-2016, OECD	FMOLS, DOLS	GDP $\rightarrow^{(-)} CO_2$e
[27]	1996-2019, African countries	DSP	GDP $\rightarrow^{(-)} CO_2$e
[52]	1975-2016, Brazil	FMOLS and DOLS	GDP $\rightarrow^{(-)} CO_2$e
[53]	1965-2018, Turkey,	RALS-EG	GDP $\rightarrow^{(-)} CO_2$e
[54]	1980-2014, South Africa	ARDL	GDP $\rightarrow^{(-)} CO_2$e
[55]	1995-2014, MENA countries	MLR	GDP $\rightarrow^{(-)} CO_2$e
[56]	1981–2005, MENA nations	Bootstrap tests of Smith	GDP $\rightarrow^{(-)} CO_2$e
[57]	1995-2012, 18 EU Countries	ECM	GDP $\rightarrow^{(-)} CO_2$e
[58]	1980-2009, Malaysia	ARDL and VECM	GDP $\rightarrow^{(-)} CO_2$e
[29]	1970-2014, Turkey	ARDL	GDP $\rightarrow^{(+)} CO_2$e
[30]	2001-2016, China	STIRPAT	GDP $\rightarrow^{(+)} CO_2$e
[31]	1995-2016, African countries	AMG	GDP $\rightarrow^{(+)} CO_2$e
[33]	1980-2019, India	ARDL	GDP $\rightarrow^{(+)} CO_2$e
[59]	1990-2017, African nations	FLSPE	GDP $\rightarrow^{(+)} CO_2$e
[60]	1992–2013, Azerbaijan	RDLBT, DOLS, FMOLS	GDP $\rightarrow^{(+)} CO_2$e
[61]	1950–2016, China	Wavelet	GDP $\rightarrow^{(+)} CO_2$e
[62]	1971-2016, Saudi Arabia	MWTY	GDP $\rightarrow^{(+)} CO_2$e
[63]	1992-2013, Azerbaijan	DARDL	GDP $\rightarrow^{(+)} CO_2$e
[32]	1979-2017, NIE	FMOLS, DOLS	GDP $\rightarrow^{(+)} CO_2$e
[37]	1980-2018, China	ARDL	$GDP^3 \rightarrow^{(+)} CO_2$e
[38]	1971-2017, South Korea,	ARDL	$GDP^3 \rightarrow^{(+)} CO_2$e
[36]	1974-2016, Vietnam,	ARDL, VECM	$GDP^3 \rightarrow^{(+)} CO_2$e
[40]	1990-2016, 28 EU economies	Panel Cointegration	$GDP^3 \rightarrow^{(+)} CO_2$e

[39]	1960-2016, United States	ARDL and VECM	$GDP^3 \to^{(+)} CO_2$e
[35]	1995-2018, 7 emerging	PMG-ARDL	$GDP^3 \to^{(-)} CO_2$e

Note: GDP $\to^{(-)}$ CO_2e reveals the validity of EKC hypothesis. GDP $\to^{(+)}$ CO_2e implies the absence of the EKC postulation. $GDP^3 \to^{(+)}$ CO_2e represents the validity of N-shaped EKC. $GDP^3 \to^{(-)}$ CO_2e discloses the absence of N-shape of EKC.

2. Methodology

To scrutinize the relationship between economic growth and quality of environment in Turkey, this study utilizes a time series data on the annual basis between 1996 and 2022 selected according to data availability. Table 2 outlines the full description for the study data and their sources, and Fig 5 plots our purposed variables. For the empirical study, we begin with a general theoretical framework to identify different relationships between environmental destruction and levels of income. Following Alvarez-Herran [24], Grossman and Krueger [25]:

$$EFP_t = B_0 + B_1 GDP_t + Z_t + e_t \tag{1}$$

Where the EFP is the ecological footprint representing the quality of environment. Unlike previous research that used CO_2 emissions as a proxy for environmental quality, this study considers ecological footprint as it includes different aspects of environment structure. It consists of six elements representing several spheres of environment including built-up land, carbon footprint, cropland, fishing grounds, forest products, grazing land [64]. GDP represents economic growth. e_t indicates the error term. Additionally, Z_t shows other control variables. In this research, research, and development (R&D) expenditure and population growth (POPG) rate have been added to our model. Public R&D expenditure has been widely considered as an indicator for innovation. Thus, the extended function for estimation can be rewritten as follows:

$$EFP_t = B_0 + B_1 GDP_t + B_2 GDP_t^2 + B_3 GDP_t^3 + B_4 R\&D_t + B_5 POPG_t + e_t \tag{2}$$

To estimate equation (2), this study employes applied the Autoregressive Distributed Lag model (ARDL). Several reasons were the derive motives behind the model selection. Firstly, this model does not necessitate that all variables are integrated of order zero or I (0). Secondly, it estimates both short-run and long-run models simultaneously. Additionally, it is worth noting that the Autoregressive Distributed Lag (ARDL) method tends to yield superior results in cases of small sample sizes when compared to other multivariate methods. To assess the presence of cointegration relationships among the variables in both model (1) and model (2), the unrestricted error correction model (ECM) formulated by Pesaran [65], can be defined as follows:

$$\Delta EFP_t = \gamma_0 + \gamma_1 EFP_{t-1} + \gamma_2 GDP_{t-1} + \gamma_3 Z_{t-1} + \sum_{i=1}^{p} \gamma_4 \Delta EFP_{t-i} + \sum_{i=1}^{p} \gamma_5 \Delta GDP_{t-i} + \sum_{i=1}^{p} \gamma_6 \Delta Z_{t-i} + \Theta ECT_{t-i} + \nu_t \tag{3}$$

$$\Delta GDP_t = \lambda_0 + \lambda_1 GDP_{t-1} + \lambda_2 GDP_{t-1}^2 + \lambda_3 GDP_{t-1}^3 + \lambda_4 lnEFP_{t-1} + \lambda_5 R\&D_{t-1} + \lambda_6 POPG_{t-1} + \sum_{i=1}^{p} \lambda_7\, \Delta GDP_{t-i} + \sum_{i=1}^{p} \lambda_8\, \Delta GDP_{t-1}^2 + \sum_{i=1}^{p} \lambda_9\, \Delta GDP_{t-1}^3 + \sum_{i=1}^{p} \lambda_{10}\, \Delta EFP_{t-i} + \sum_{i=1}^{p} \lambda_{11}\, \Delta \mathrm{R\&D}_{t-i} + \sum_{i=1}^{p} \lambda_{12}\, \Delta \mathrm{POPG}_{t-i} + \Theta ECT_{t-i} + \nu_t \tag{4}$$

In this context, equations (3) and (4) represent the Autoregressive Distributed Lag (ARDL) models. The selection of lag lengths (p) is determined based on the Akaike Information Criterion (AIC). The bound test for cointegration is conducted based on the joint null hypothesis of no cointegration $H_0 := \lambda = 0$ against the alternative of cointegration $H_1: \lambda \neq 0$. The Wald F-statistic is utilized to assess the presence of a cointegration relationship among the chosen variables. It is compared to both the lower and upper critical value thresholds. When the F-statistic surpasses the upper critical threshold, it leads to the rejection of the null hypothesis indicating the presence of cointegration. Conversely, if the F-statistic falls below the lower critical threshold, the null hypothesis cannot be dismissed, suggesting the absence of cointegration. In the event of a cointegration relationship, an error correction model (ECM) can be computed. The error correction model elucidates short-term dynamics and the speed of adjustment.

Table 2
Data description and sources

Variable	Measurement	Sources
Economic growth	GDP per capita (constant 2015 US$)	World Bank (World Development Indicators)
Environmental quality	Human-related pressure on biologically productive green and blue areas, measured in global hectares	World Bank (World Development Indicators)
Population	Population growth (annual %)	World Bank (World Development Indicators)
Technology innovation	Research and development expenditure (% of GDP)	World Bank (World Development Indicators)

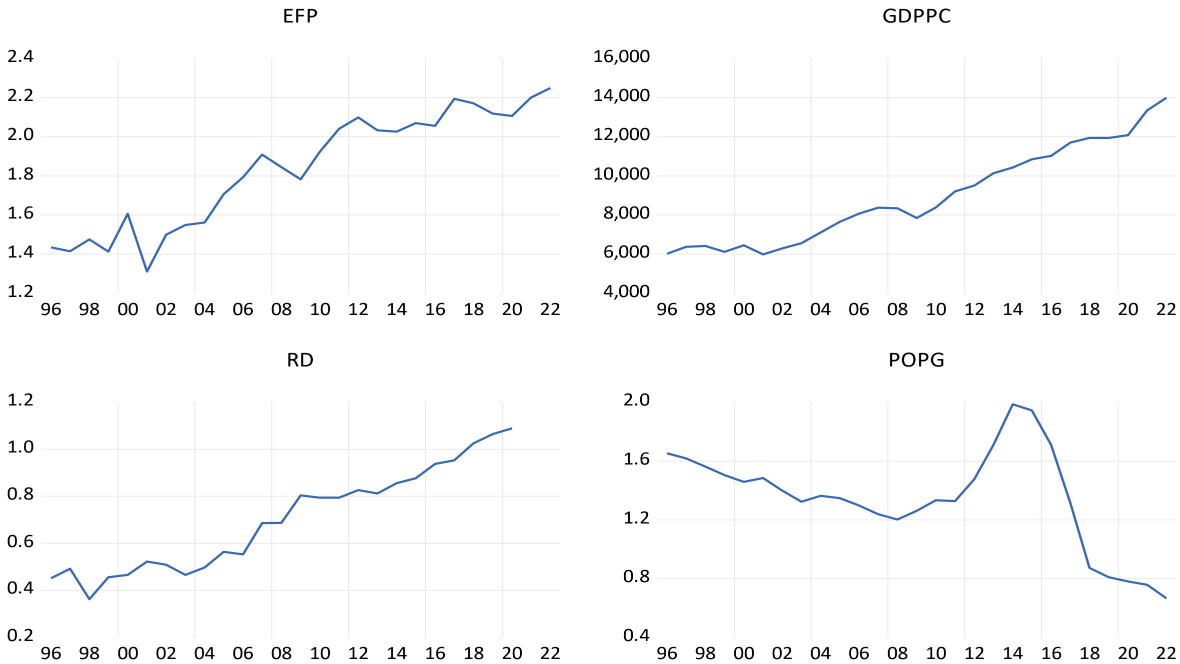

Fig. 5. Trends of the study variables

3. Results and discussion

Initially, the analysis is set off with preliminary information in which some important descriptive statistics and dispersion measures for the underlying series are explored. According to Table 3, by far, economic growth is variable with the highest average varied between 13990.75 and 5993.829 during the sample period with standard deviation 2457.604. Environmental degradation, which proxied by ecological footprint demonstrates the second highest average variable fluctuated notably between 1.312043 and 2.247912. Population growth rate and research and development expenditure show the lowest variables with the mean values of 1.347985 and 0.701699 correspondingly. The R&D which is measured by public expenditure for research and development/innovation shows some significant changes varied between 1.088930 and 0.361980 with standard deviation of 0.219994. The population growth rate on the other side demonstrates an almost normal increase from 1.985939 to 0.665237 with the standard deviation of 0.340337.

Prior to performing the ARDL analysis, the stochastic properties of the purposed variables have been explored. In that respect, after the correlation matrix in Table 4 showed a strong interconnection among the selected variables, we considered both PP and ADF unit root tests. Table 5 reports the unit root tests results. Obviously, both PP and ADF panel unit root test demonstrate first-order integration for all the study variables at different conventional levels of significance (1%, 5%, 10%) except for population growth rate in which PP test results indicate a nonstationary variable. Relying on this fact, the study proceeds to identify whether the cointegration exists among the study variables. The Bound testing for cointegration results in Table 6 reports the presence of long run relationship between economic growth, environmental quality, research, and development spendings and population growth rate. The F-statistic (6.426747) is found to be greater than the critical values at conventional levels of significance (5%, 2.5%,1%) for cointegration test.

Table 3
Descriptive statistics

	EFP	GDPPC	GDP^2	GDP^3	RD	POPG
Mean	1.836411	8969.593	86269720	8.84E+11	0.701699	1.347985
Median	1.908664	8377.149	70176632	5.88E+11	0.687410	1.347579
Maximum	2.247912	13990.75	1.96E+08	2.74E+12	1.088930	1.985939
Minimum	1.312043	5993.829	35925989	2.15E+11	0.361980	0.665237
Std. Dev.	0.294932	2457.604	46934752	7.07E+11	0.219994	0.340337
Skewness	-0.300247	0.431438	0.735397	1.055364	0.202881	-0.339630
Kurtosis	1.645355	1.959305	2.454240	3.210480	1.742888	2.748940
Jarque-Bera	2.470114	2.056052	2.768724	5.061910	1.817680	0.589978
Probability	0.290818	0.357712	0.250484	0.079583	0.402991	0.744540
Sum	49.58309	242179.0	2.33E+09	2.39E+13	17.54248	36.39559
SumSq. Dev.	2.261612	1.57E+08	5.73E+16	1.30E+25	1.161535	3.011569
Obs	27	27	27	27	25	27

Table 4
Correlation Matrix

	EFP	GDPPC	GDP^2	GDP^3	POPG	RD
EFP	1.0000					
GDPPC	0.9454	1.0000				
GDP2	0.9177	0.9960	1.0000			
GDP3	0.8855	0.9851	0.9965	1.0000		
POPG	0.2415	-0.2732	0.2941	0.3187	1.0000	
RD	0.9189	0.9575	0.9522	0.9406	-0.3402	1.0000

Table 5
Unit root test

	ADF test		PP test	
Variable	Constant	Constant and trend	Constant	Constant and trend
EFP	-0.867839	-3.394797	-0.546431	-3.366029***
GDPPC	1.580209	-2.231290	1.674302	-1.335049
GDP2	2.700462	-0.322452	3.872662	0.327241
GDP3	3.597882	0.744687	6.808379	2.128068
POPG	-2.473796	-2.933089	-1.141750	-1.495122
RD	0.991213	-2.272147	0.634194	-3.182597
ΔEFP	-7.548273*	-3.237627	-9.189804*	-9.065633*
ΔGDPPC	-4.055391*	-4.731052*	-4.062950*	-4.726716*
ΔGDP2	-3.370370**	-3.964621**	-3.387231**	-4.569664*
ΔGDP3	-2.799495***	-4.136273*	-2.823538***	-3.992180**
ΔPOPG	-3.056482**	-3.139571	-2.173168	-2.190162
ΔRD	-7.051828*	-7.531593	-6.950387*	-7.361959*

Note: Δ represents the first differences of the variables. ∗∗∗, ∗∗ and ∗ indicate 1%, 5% and 10% significance, respectively.

Table 6
Bound testing for cointegration

Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	6.426747	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

As the cointegration relation exists between the study variables, the study performs the Autoregressive distributed lag model (ARDL) for a cubic polynomial function with one lagged value selected based on AIC. Starting with long run estimates, the results indicate that economic growth holds a significant impact on environment quality. In particular, per capita real GDP initially leads to a decrease in environmental pollution. A one percent increase in GDPPC leads to a -0.003085 decline in environmental pollution (EFP). Moreover, as economic growth advances (GDP^2), it leads to an increase in the deterioration of the environment causing more concerns about environmental sustainability. However, more structural change (GDP^3) results in improving the quality of environment creating and inverted N-shaped relationship between economic growth and environment. The following equation provides a testable form of the cubic polynomial function:

$$EFP_t = 9.682666 - 0.0023 * GDP_t + 4.12E.07GDP_t^2 - 1.68\text{E}.11GDP_t^3 + 0.112446\ R\&D_t - 0.336162\ POPG_t + 7.1705 \quad (5)$$

These outcomes are in line with those of Sterpu et al. [40] who examined the nexus between economic growth and environment for 28 countries of EU members. The authors confirmed an inverted N-shaped, which validated the absence of technology obsolescence effect as shown in Figure 3. Yet, our results contradict those of, Gyamfi et al. [35] for seven emerging economies, Shahbaz et al. [36], Zeraibi et al. [37] for China, Koc and Bulus [38] for South Korea, Awan et al. [22] for high income nations, and Shahbaz et al. [39] for the United States.

Validity of invested N-shape may better reflect the effectiveness of environmental measures that exist in our study case, thus, the advancement of technology innovation does not promote the over the exploitation of natural resources so that to surge the degradation of environment [66]. Another possible explanation is that the R&D expenditure on energy efficiency and renewable electricity generation accompanied by environmental awareness play a critical role in reversing the constant undesirable effect of economic activities on environment [67], Energy efficiency pertains to the utilization of technology and design strategies aimed at diminishing the energy demand necessary for a specific task or operation. Achieving this goal involves various approaches, including enhancing the energy efficiency of structures, transportation systems, and industrial procedures, as well as creating more efficient household appliances and consumer electronics [24].

Moving on to other results, we found that research and development expenditure has no significant effect on ecological footprint. This output may validate the argument put forward by green paradox in which the technology innovation may contribute to exacerbating the quality of environment or demonstrating insignificant effect. Such cases may arising out due to a weak institutional quality, hence, the structural change must accompanied by a complete institutional reforms [68]. The population growth rate is found to contribute positively to improving the quality of the environment. A one percent increase in the growth rate leads to a 0.336162 decline in environmental pollution.

The adjustment coefficient (ECT: -1.350342) for our cubic function is found to be significant and negative thus confirming the convergence of a model to its long run equilibrium. ECT describes the short-term dynamics, illustrating how quickly a variable adjusts in response to deviations from the long-term equilibrium. The adjustment coefficient plays a crucial role in achieving long-term convergence. In order for the system to revert to its long-term equilibrium, it is essential for at least one of the adjustment parameters to exhibit a statistically significant deviation from zero; otherwise, there would be no error correction mechanism in place. The model is further evaluated by some diagnostic and stability tests in Tables 7 and 8, and Figs 6 and 7. The diagnostic tests indicate the absence of Serial Correlation, Heteroskedasticity, and specification error given the rejection of null hypothesis. CUSUM test CUSUMSQ tests reveal that the model stable given its value is fluctuating within the 5% boundaries.

Table 7
ARDL Long Run Form and Bounds Test

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.682666	3.851164	2.514218	0.0248
EFP (-1)	-1.350342	0.220435	-6.125818	0.0000
GDPPC. (-1)	-0.003085	0.001323	-2.332340	0.0351
GDP2(-1)	4.12E-07	1.58E-07	2.604231	0.0208
GDP3(-1)	-1.68E-11	6.05E-12	-2.770315	0.0150
RD	0.112446	0.188820	0.595520	0.5610
POPG	-0.336162	0.099858	-3.366387	0.0046
D(GDPPC)	-0.001258	0.001129	-1.113930	0.2841
D(GDP2)	1.86E-07	1.34E-07	1.387209	0.1871
D(GDP3)	-7.71E-12	5.17E-12	-1.490986	0.1581

Table 8
Diagnostic test results.

	Statistic	Probably
Breusch-Godfrey Serial Correlation LM Test	0.261489	0.7742
Heteroskedasticity Test: Breusch-Pagan-Godfrey	0.770998	0.6452
Ramsey RESET Test	0.619568	0.5462

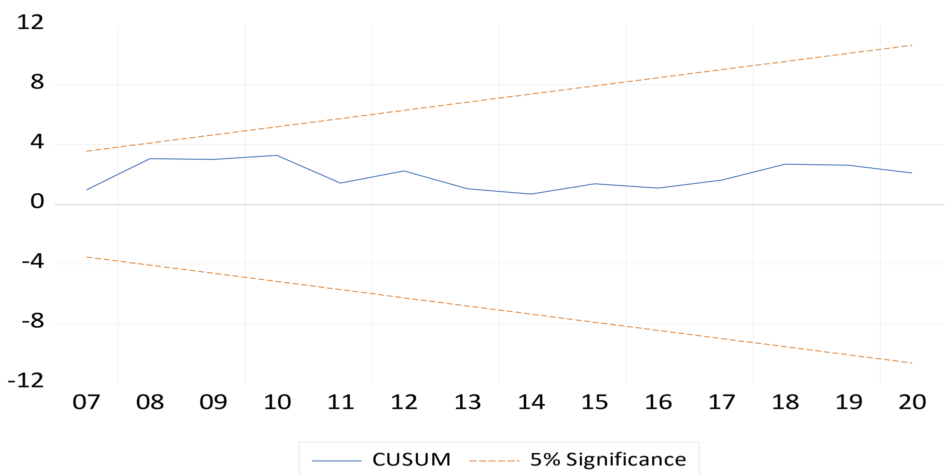

Fig. 6. CUSUM test

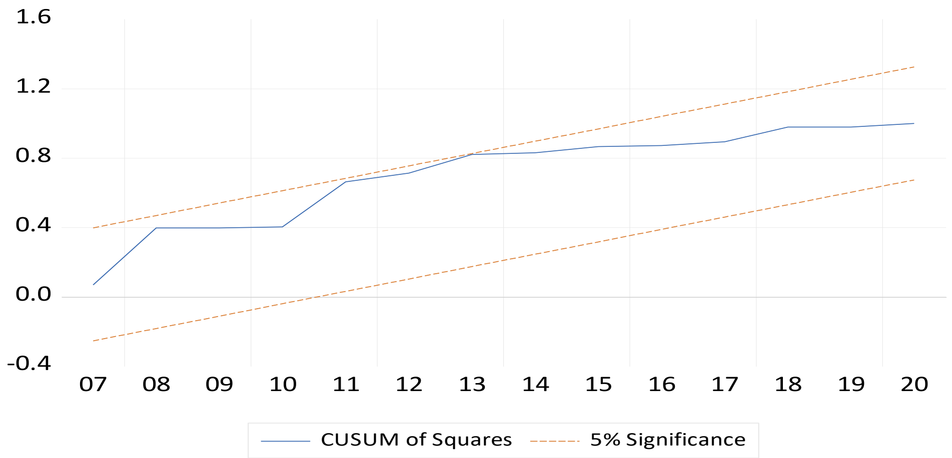

Fig. 7. CUSUMSQ test

4. Conclusions

The nexus between economic growth and environmental quality has caught the attention of scholars since the seminal work of Kuznets in fiftieth last century. An enormous volume of empirical research has examined the relationship between GDP as a proxy for economic activity and CO2 emissions as proxy for environment. Although different techniques and data types have been utilized, no agreement is yet to be reached. Recent debate suggests that a constant dependence on technological innovation in the economic structure does not always ensure sustainability of economic and environment. This argument has come to light after the technology obsolescence effect has been noticed in many economies. Thus, the researchers have started to look at the GDP-pollution nexus beyond the technique and composition effect as suggested by EKC framework.

This study is another endeavor to figure out whether the technology obsolescence effect exists in the economy of Turkey using ARDL model for the annual data extending the period 1996-2022. By overlooking the introductory tests' result such as correlation, stationarity, and cointegration, the outputs reveal that (i) An inverted N-shape exists for the case of Turkey. (ii) Research and Development expenditure has no reliable power to explain the variation in ecological footprint in Turkey. (iii) population growth rate can contribute positively to improving the quality of environment.

Accordingly, this study calls for several policies. First, an expansion in green investment can increase the effectiveness of sustainability policies. Thus, the financial sector can play a promising role through regulated expansion of domestic credit and bank credit to the private sector, which promotes the development and diffusion of environmental sound technologies. Second, the development of clean technologies must be accompanied by institutional reform and developing tools for increasing environmental awareness and green growth strategies. Third, increasing the share of renewable energy in the energy mix as well as improving energy efficiency can speed up the process towards environmental targets. Lastly, since this research analyzed this nexus between environment and economic growth using ARDL model, future research may consider more sophisticated methodologies especially nonparametric ones such as wavelets coherence transformations and quantile on qualities three-dimension based approaches.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data used for this study has been deposited in public data repository "figshare" named "final data" and can be accessed via the link https://figshare.com/s/765687125149611b5056.

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