Testing the EKC Hypothesis Using Ecological Footprint by Considering Biocapacity and Human Capital in Türkiye: A Dynamic Analysis

Pınar KARAHAN-DURSUN, pkarahan@anadolu.edu.tr

Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, Bursa/Türkiye

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Summary: The study aims to investigate the validity of the environmental Kuznets curve (EKC) hypothesis, which asserts the inverted U-shaped relationship between economic growth and environmental pollution. The study uses ecological footprint (EF) as a measure of environmental degradation over the 1970–2017 period in Türkiye. Unlike the current literature for Türkiye, this study involves biocapacity and human capital in the growth–environment nexus and utilizes dynamic analysis. In this context, the Bound test, autoregressive distributed lag (ARDL) model, and Kalman filter approach are applied. The result of the Bound test confirms the cointegration relationship between the variables. The findings of the ARDL model indicate that the EKC hypothesis prevails, and biocapacity affects EF positively, whereas human capital mitigates environmental degradation by decreasing EF. The results of the dynamic analysis using the Kalman filter technique also validate the EKC hypothesis and show that the dynamic effect of economic growth on EF is significantly positive and stable for the analyzed period.

Keywords: EKC hypothesis, ecological footprint, Kalman filter
Jel Codes: Q5, C32

The EKC (environmental Kuznets curve) hypothesis suggests the existence of an inverted U-shaped relationship between environmental degradation and economic growth. As stated by Mehmet Akif Destek, Recep Ulucak, and Eyup Dogan (2018), in the EKC framework, the important question is what indicator should be utilized to represent environmental degradation.

This study investigates the validity of the EKC hypothesis using ecological footprint (EF), which is considered to be a more comprehensive measure than CO_2 emissions as a proxy for environmental degradation, in the case of Türkiye. In fact, Türkiye has experienced an ecological deficit since 1983, which indicates the unsustainability of resource use. Accordingly, detecting the drivers of EF is essential for the policies that strive to ensure stability between the environment and economic growth. This study differentiates from Türkiye's existing literature in two ways. First, this study investigates the environment–growth nexus through the inclusion of biocapacity and human capital into the empirical analysis. Second, the study is the first study to employ dynamic analysis via the Kalman filter approach for the EKC framework in Türkiye.

The rest of the study is organized as follows: Section 1 provides the literature review on the EKC hypothesis. Section 2 presents the data and econometric methodology. Section 3 reports the empirical results. Finally, Section 4 provides the conclusion.

1. Literature Review

The EKC hypothesis exerts that environmental quality deteriorates in the early stages of economic growth; after income reaches a turning point, the relationship reverses and economic growth starts to improve the environmental quality (David I Stern, 2004; Marie-Sophie Hervieux & Olivier Darné, 2015). Put differently, in the EKC framework, in the early stage of economic growth, it is assumed that the awareness of environmental problems is low or negligible, and there is no existence of environment-friendly technologies. As economic growth increases, people achieve a higher standard of living, and their demand for a clean environment rises. Economic growth impacts environmental quality through three effects: scale, composition, and technique (Gene M. Grossman & Alan B. Krueger, 1991). The scale effect, which is the initial stage of the curve, means that economic growth leads to worsening environmental quality by increasing the need to produce more resources, and it eventually leads to the generation of harmful pollutants (Recep Ulucak & Faik Bilgili, 2018). The composition effect implies that the changes in the structure of the economy gradually increase cleaner activities that produce less pollution. Finally, the technique effect of economic growth claims that the polluting production process is replaced by upgraded cleaner technology (Soumyananda Dinda, 2004; Marco Bagliani, Giangiacomo Bravo, & Silvana Dalmazzone, 2008).

The related literature mostly uses CO_2 emissions as measures of environmental degradation to examine the EKC hypothesis. However, EF has recently been used to measure environmental degradation. EF measures the ecological assets that a given population requires to produce the natural resources it consumes and to absorb its waste, particularly carbon emissions (Global Footprint Network). EF developed by Mathis Wackernagel and William Rees (1998) is considered a more comprehensive measure of environmental degradation because it has six subcomponents, namely, cropland, grazing land, fishing grounds, forest land, built-up land, and carbon footprint (David Lin et al., 2018; Mehmet Akif Destek & Samuel Asumadu Sarkodie, 2019).

1.1. International Related Literature

The presence of the EKC hypothesis has been extensively investigated by empirical studies for specific countries or country groups by utilizing different econometric methods and period samples. Tables 1, 2, and 3 present the summary of the literature on the EKC hypothesis with different results. As seen from these tables, some use

CO_2 emissions as an indicator of environmental degradation (Cem Isik, Serdar Ongan, & Dilek Ozdemir, 2019; Raul Arango Miranda et al., 2020; Jing Gao, Wen Xu, & Lei Zhang, 2021; Sadeq J. Abul & Elma Satrovic, 2022), whereas some of them utilize EF as a proxy for environmental pollution (Destek & Sarkodie, 2019; Eyup Dogan et al., 2020; Abdullah Emre Caglar, Mehmet Mert, & Gulden Boluk, 2021). Furthermore, both CO_2 emissions and EF are also utilized as indicators of environmental degradation by Zouhair Mrabet and Mouyad Alsamara (2017); Mufutau Opeyemi Bello, Sakiru Adebola Solarin, and Yuen Yee Yen (2018); Halil Altınbas and Yacouba Kassouri (2020); and Mohd Arshad Ansari (2022).

Table 1 offers some studies that invalidate the EKC hypothesis, whereas Table 2 shows some studies that corroborate the EKC hypothesis. Moreover, the other mixed results on the presence of the inverted U-shaped hypothesis are in Table 3. One of them, Pendo Kivyiro and Heli Arminen (2014) tested the validity of the EKC hypothesis for six Sub-Saharan African countries for the 1971–2009 period, and they detected the existence of inverted U-shaped relationship between income and CO_2 emissions only for three countries. Ioannis Kostakis, Sarantis Lolos, and Eleni Sardianou (2017) investigated the validity of the EKC hypothesis for Brazil and Singapore over the 1970–2010 period and captured the inverted U-shaped linkage between income and CO_2 emissions only for Singapore. For Korea, Japan, and China over the 1990–2013 period, Hongbo Liu et al. (2018) suggested an inverted U-shaped relationship between income and EF only for Korea and Japan. Destek and Sarkodie (2019) tested the EKC hypothesis for 11 countries for the 1977–2013 period and corroborated the EKC hypothesis in panel estimation. However, the study detects the U-shaped relationship between income and EF for five countries. Sefa Awaworyi Churchill et al. (2018) used panel data estimation for 20 OECD countries for the 1870–2014 period and detected that some countries provide evidence of the EKC hypothesis. For 10 US states, Isik, Ongan, and Ozdemir (2019) stated that the EKC hypothesis is confirmed only for Florida, Illinois, Michigan, New York, and Ohio. Raul Arango Miranda et al. (2020) searched the presence of the EKC hypothesis among the North American Free Trade Agreement (NAFTA) countries for the 1990–2016 period. They suggested that the EKC hypothesis is corroborated for Mexico and the U.S.A.; however, the inverted U-shaped hypothesis is not valid for Canada.

The obtained mixed result may depend upon the environmental indicators used. Mrabat and Alsamara (2017) employed both CO_2 emissions and EF as indicators of environmental deterioration in Qatar between 1980 and 2011. The results of the autoregressive distributed lag (ARDL) model with structural breaks reveal the existence of an inverted U-shaped nexus when using EF. Bello, Solarin, and Yen (2018) used four measures of environmental degradation, namely, EF, carbon footprint (CF), water footprint (WF), and CO_2 emissions, for Malaysia during the 1971–2016 period. They confirmed the inverted U-shaped relationship between income and all environmental degradation indicators except EF. Altıntas and Kassouri (2020) applied both the CO_2 emissions and EF as indicators of environmental degradation for 14 European countries covering the period from 1990 to 2014. The results indicate an inverted U-shaped relationship between income and

EF. For ASEAN countries, Ansari (2022) concluded that the EKC hypothesis is valid when using EF; however, the hypothesis is not valid when using CO_2 emissions.

The related literature also investigates the validity of the EKC hypothesis for the components of EF. Sevil Asici and Ahmet Atıl Acar (2016) considered a panel of 116 countries by utilizing the production and import footprints over the 2004–2008 period. They depicted an inverted U-shaped relationship only between income and the ecological footprint of production (EFP). Yong Wang et al. (2013) investigated the validity of the EKC hypothesis for 150 countries considering the ecological footprint of consumption (EFC) and EFP. Their results do not confirm the existence of the inverted U-shaped relationship for both consumption and production of footprint.

Moreover, the EKC hypothesis is also examined by considering the income levels of countries. Usama Al-Mulali et al. (2015a) investigated the validity of the EKC hypothesis for countries classified as low-income, lower middle-income, upper middle-income, and high-income countries for the period between 1980 and 2008. As a result of the panel fixed effect and the generalized method of moments (GMM), they found that the EKC hypothesis is valid for upper middle- and high-income countries, whereas it is not confirmed for low-income and lower middle-income countries. Ilhan Ozturk, Usama Al-Mulali, and Behnaz Saboori (2016) supported the results of Usama Al-Mulali et al. (2015a) by verifying the EKC hypothesis only for middle-income and high-income countries during the 1988–2008 period by employing the GMM method. On the other hand, Ulucak and Bilgili (2018) categorized 45 countries into low-income, middle-income, and high-income countries using EF for the 1961–2013 period and confirmed the existence of the EKC hypothesis in each income group countries.

The related summary also considers the several factors that may affect environmental degradation. These analyzed driving factors include renewable and nonrenewable energy consumption (Sakiru Adebola Solerin et al., 2017; Destek, Ulucak, & Dogan, 2018; Isik, Ongan, & Ozdemir 2019; Caglar, Mert, & Boluk, 2021), biocapacity (Yong Wang et al., 2013; Asici & Acar, 2016; Shujah-Ur-Rahman et al., 2019; Khattak Danish et al., 2019; Ulucak & Bilgili, 2019), trade openness (Sakiru Adebola Solerin et al., 2017; Mrabet & Alsamara, 2017; Destek, Ulucak, & Dogan, 2018), financial development (Churchill et al., 2018; Shujah-Ur-Rahman et al., 2019; Destek & Sarkodie, 2019), urbanization (Bello, Solarin, & Yen, 2018; Ahmet & Wang, 2019; Daniel Balsalobre-Lorente, Nuno Carlos Leitão, & Festus Victor Bekun, 2021), population (Churchill et al., 2018; Eyup Dogan et al., 2020; Sagib & Benhmad, 2020), human capital (Shujah-Ur-Rahman et al., 2019; Ulucak & Bilgili, 2019; Khattak Danish et al., 2019; Mustafa Kocaoglu et al., 2023), foreign direct investment inflows (Sakiru Adebola Solerin et al., 2017; Ibrahim Bakirtas, & Mumin Atalay Cetin, 2017; Shahbaz, Balsalobre-Lorente, & Sinha, 2019), and information and communications technology (ICT) (Atif Jahanger et al., 2023; Mustafa Kocaoglu et al., 2023).

Table 1. Summary of some empirical studies concluding that the EKC hypothesis is not valid.

Author(s)	Period	Country	Environmental Variable(s)	Methodology
Bagliani, Bravo, and Dalmazzone (2008)	2001	141 countries	EF	OLS, Weighted LS
Wang et al (2013)	2005	150 countries	EFC, EFP	Spatial econometric method
Chandran and Tang (2013)	1971–2008	ASEAN-5 countries	CO_2	Johansen cointegration, GC
Hervieux and Darné (2015)	1961–2007	7 Latin America countries	EF	OLS
Mert and Boluk (2016)	2002–2010	21 Kyoto Annex countries	CO_2	PMG, Panel causality
Bakırtas and Cetin (2017)	1982–2011	MIKTA countries	CO_2	PVAR, GC, System GMM
Danish et al. (2019)	1971–2014	Pakistan	EF	ARDL with structural breaks, GC
Eyup Dogan et al. (2020)	1980–2014	BRICS countries	EF	FMOLS, DOLS, AMG
Caglar, Mert, and Boluk (2021)	The beginning changes–2014	Top 10 pollutant countries	EF	Panel ARDL

Table 2. Summary of some empirical studies concluding that the EKC hypothesis is valid.

Author(s)	Period	Country	Environmental Variable(s)	Methodology
Tang and Tan (2015)	1976–2009	Vietnam	CO_2	VECM, GC
Solerin et al. (2017)	1980–2012	Ghana	CO_2	ARDL
Destek et al. (2018)	1980–2013	15 EU countries	EF	Panel Mean Group estimator
Shujah-Ur-Rahman et al. (2019)	1991–2014	16 CEE countries	EF	DSUR
Ulucak and Bilgili (2018)	1961–2013	45 countries	EF	CUP-FM, CUP-BC

Shahbaz et al. (2019)	1990–2015	MENA countries	CO_2	GMM
Ahmed and Wang (2019)	1971–2014	India	EF	ARDL
Godil et al. (2020)	2000–2019	U.S.A.	CO_2	QARDL
Sagib and Benhmad (2020)	1995–2015	22 European countries	EF	Panel data
Balsalobre-Lorente, Leitão, and Bekun (2021)	1995–2015	Portugal, Italy, Greece, and Spain	CO_2	Panel data
Gao, Xu, and Zhang (2021)	1995–2010	18 Mediterranean Countries	CO_2	Panel data
Abul and Satrovic (2022)	1995–2014	10 Southeastern European Countries	CO_2	Panel data

Table 3. Summary of some empirical studies having mixed results.

Author(s)	Period	Country	Environmental Variable(s)	Methodology
Kivyiro and Arminen (2014)	1971–2009	6 Sub-Sharan African countries	CO_2	ARDL
Al-Mulali et al. (2015)	1980–2015	93 countries	EF	Panel FE, GMM
Ozturk, Al-Mulali, and Saboori (2016)	1988–2008	144 countries	EF	GMM
Asici and Acar (2016)	2004–2008	116 countries	EFP, EFM	Panel FE
Kostakis, Lolos, and Sardianou (2017)	1970–2010	Brazil, Singapore	CO_2	ARDL, FMOLS, OLS
Mrabet and Alsamara (2017)	1980–2011	Qatar	CO_2, EF	GH, and H-J tests, ARDL
Liu et al. (2018)	1990–2013	Japan, Korea, and China	EF	VECM
Churchill et al. (2018)	1870–2014	20 OECD Countries	CO_2	Panel data

Bello, Solarin, and Yen (2018)	1971–2016	Malaysia	EF, CF, WF, CO_2	ARDL, GC
Isik, Ongan, and Ozdemir (2019)	2000–2019	10 US states	CO_2	Panel data
Destek and Sarkodie (2019)	1977–2013	11 countries	EF	AMG, Panel causality
Altinbas and Kassouri (2020)	1990–2014	14 EU countries	CO_2, EF	IFE, D-CCE, Panel causality
Miranda et al. (2020)	1990–2016	Canada, Mexico, and U.S.A.	CO_2	Panel data
Ansari (2022)	1991–2016	ASEAN Countries	CO_2, EF	FMOLS, PMG

In the literature, the validity of the EKC hypothesis has also been investigated by using nonparametric methods that provide functional form flexibility and consider the problem of endogeneity arising from simultaneity (Ebru Caglayan Akay & Sinem Guler Kangalli Uyar, 2021). One of them, Muhammad Shahbaz et al. (2017) employed nonparametric cointegration and causality tests for G7 countries over the 1820–2015 period. Their results validate the EKC hypothesis for Canada, France, Germany, Italy, the United Kingdom, and the United States, that is, Japan is the only exception. Churchill et al. (2020) scrutinized the validity of the EKC hypothesis for eight Australian states and territories over the period between 1990 and 2017. The results of the nonparametric panel estimation confirm the existence of the inverted U-shaped hypothesis. Mohammad Younus Bhat et al. (2023) used a nonparametric kernel density and quantile regression approach for 25 OECD countries during the 1990–2014 period. They detected that the EKC hypothesis is only corroborated by relatively lower income countries. Caglayan Akay and Kangalli Uyar (2021) searched the EKC hypothesis for 16 developed and 58 developing countries. They applied a nonparametric pooled regression model for the 1995–2010 sample and concluded that the results do not support the EKC hypothesis for both country groups. Béchir Ben Lahouel et al. (2022) utilized the panel smooth transition regression to search the EKC hypothesis in 15 MENA countries for the 1990–2014 period. Their results reveal the nonexistence of the EKC hypothesis. Recently, Atif Jahanger et al. (2023) applied a nonparametric MMQR approach for the Top 9 thermonuclear energy-producing countries, namely, the United States, France, China, Japan, Russia, South Korea, Canada, the United Kingdom, and Spain, over the 1990–2017 period. They found support for the existence of the EKC hypothesis in the sample. Furthermore, nuclear energy and ICT are found to curb carbon emissions. Similarly, Mustafa Kocaoglu et al. (2023) utilized the panel smooth transition regression (PSTR) approach and concluded that ICT decreases environmental degradation for N-11 countries (i.e., Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, Türkiye, South Korea, Vietnam). Their analysis reveals that economic growth increases CO_2 emissions when human capital is below its threshold value, and human capital has a vital role in curbing environmental pollution.

In brief, there is a growing literature searching for the existence of EKC. Concerning the related literature, some studies investigated the EKC hypothesis for specific countries or country groups with different empirical approaches. The studies achieve different results for the EKC framework. Some confirm the inverted U-shaped nexus while some find the invalidation of the EKC hypothesis. In addition, some studies detect mixed results.

The empirical studies mostly use CO_2 emissions or EF as a measure of environmental degradation. Moreover, it is observed that some studies employ both CO_2 emissions and EF as proxies for environmental pollution. The related literature also investigates various variables that may affect the relationship between economic growth and environmental degradation. These studies also apply different empirical approaches. It seems to be the most used analysis of the parametric approaches. However, it is observed that recent studies consider nonparametric techniques to test the inverted association between economic growth and environmental pollution.

1.2. Related Literature for Türkiye

The link between EF and environmental sustainability is assessed by biocapacity, which is calculated by the total area of biologically productive land and sea. If EF is greater (less) than a country's biocapacity, it refers to an ecological deficit (surplus) that implies a negative (positive) balance sheet of the environmental budget. An ecological deficit (reserve) is interpreted as the environmental unsustainability (sustainability) of an area or country (Bagliani, Bravo, & Dalmazzone, 2008; Khattak Danish et al., 2019). EF generally refers to EFC, and biocapacity is expressed in gha (global hectares). The data released by Global Footprint Network reveals that Türkiye’s EF per person was 1.6 gha in 1961, and it increased roughly by 119% from 1961 to 2017. Türkiye’s EFC per person was 3.51 gha, whereas the biocapacity per person was 1.4 gha in 2017. This indicates that Türkiye’s EF was 2.5 times more than its biocapacity. This means that it does require waiting nearly 2.5 years for the reproduction of natural resources it consumed in one year along with the release of CO_2 emissions into the atmosphere (Arshian Sharif et al., 2020: 102138).

As a measure of environmental degradation, the existing literature on the growth–environment nexus for Türkiye mostly uses CO_2 emissions, whereas limited studies have focused on EF recently. Moreover, the relevant empirical studies consider the different determinant factors of environmental pollution, such as foreign direct investment, financial development, population, urbanization, trade openness, and energy resources. It is conceivable that available local biocapacity affects the relationship between economic growth and EF because biocapacity affects potential ecological resource use (Yong Wang et al., 2013; Asici & Acar, 2016). The significant impact of biocapacity on EF has been reported in the empirical literature (Yong Wang et al., 2013; Asici & Acar, 2016; Shujah-ur-Rahman et al., 2019; Khattak Danish et al., 2019). Regarding human capital, Li Yang, Jianmin Wang, and Jun Shi (2017) detected that high-quality human capital is negatively associated with fossil fuel energy consumption, meaning that environmental quality can enhance through the development of human capital. Likewise, Sadia Bano et al. (2018) evaluated that the promotion of human capital has an important role in the reduction of environmental pollution by improving energy efficiency. Ulucak and Bilgili (2018) depicted that human capital is one of the underlying factors that affects positive environmental quality, so it can be a sufficient tool to deal with environmental threats. Ahmet and Wang (2019) posited that environmental pollution can be mitigated by human capital by promoting an increase in energy efficiency and recycling, the adaption of green technology, and a decrease in deforestation rate. Accordingly, this study that underlined the role of these factors on the environment is expected to fill this gap in the literature for Türkiye.

Tables 4 and 5 offer a summary of the empirical studies for Türkiye. As seen in Table 5, some studies verify the EKC hypothesis, whereas some find invalidation of the EKC hypothesis presented in Table 4. Accordingly, the results on the validity of the EKC hypothesis in Türkiye were inconclusive.

It is observed that the studies presented in Tables 4 and 5 mostly use CO_2 emissions as an indicator of environmental degradation. From these studies, Akbostanci, Turut-Asik, and Tunc (2009) also consider SO_2 (sulfur dioxide) and PM_{10} (particulate matter) emissions along with CO_2 emissions. On the other hand, the studies employing EF as an indicator of environmental degradation are quite limited. More specifically, Acar and Asici (2017); Ozcan, Apergis, and Shahbaz (2018); Arshian Sharif et al. (2020); Bulut (2020); and Koksal, Işik, and Katircioğlu (2020) employed EF as a proxy for environmental degradation. From these studies, Acar and Asici (2017) investigated the validity of the EKC hypothesis considering the components of EF: EFC, EFP, EFM, and export footprints (EFX). They applied the Johansen cointegration test for the 1961–2017 period. They found an inverted U-shaped relationship only between income and the production of footprints. In contrast, their results do not verify the EKC hypothesis when using the consumption, import, and export footprints. In the other study, Ozcan, Apergis, and Shahbaz (2018) utilized the total ecological footprint by employing the Bootstrap Granger causality test to examine the validity of the EKC hypothesis and conclude that EKC is not valid. Arshian Sharif et al. (2020) investigated the relationship between EF, income, and renewable and nonrenewable energy consumption. They employed Quantile Autoregressive Lagged (QARDL) and Granger causality in quantiles over the period from 1965Q1 to 2017Q4. The results of the QARDL corroborate the EKC hypothesis. In addition, the study captures bidirectional causality between EF and other variables used. Bulut (2020) tested the validity of the EKC hypothesis for the 1970–2016 period by considering the role of renewable energy consumption, foreign direct investment, and industrialization on environmental pollution by employing the

ARDL model and DOLS estimator. The results of the analysis validate the presence of the EKC hypothesis. In addition, the study captures the negative effect of renewable energy consumption on EF. Moreover, Koksal, Işik, and Katircioglu (2020) verified the EKC hypothesis via the Johansen cointegration test for the 1961–2014 period. Their results also detect that the shadow economy has a significant positive effect on EF.

The summarized empirical studies use several control variables in their analysis, such as foreign direct investment (Ozturk, Al-Mulali, & Saboori 2016; Kocak & Sarkgunesi, 2018; Bulut, 2020), financial development (Pata, 2018; Karasoy, 2019; Koksal, Işik, & Katircioğlu, 2020; Akca, 2021); population (Akbostanci, Turut-Asik, & Tunc, 2009; Ozatac, Gokmenoglu, & Taspinar, 2017); urbanization (Katircioglu & Katircioglu, 2018; Koksal, Işik, & Katircioğlu, 2020), trade openness (Ozatac, Gokmenoglu, & Taspinar, 2017; Karasoy, 2019; Koksal, Işik, & Katircioğlu, 2020), and energy resources (Karasoy, 2019; Arshian Sharif et al., 2020; Bulut, 2020; Koksal, Işik, & Katircioğlu, 2020).

Table 4. The studies that invalidate the EKC hypothesis.

Author(s)	Period	Environmental Variable(s)	Methodology
Lise (2006)	1980–2013	CO_2	Decomposition analysis
Akbostanci, Turut-Asik, and Tunc (2009)	1963–2003	CO_2	Johansen cointegration test
	1992–2001	SO_2, PM_{10}	Pooled EGLS Panel estimation
Soydas and Sari (2009)	1960–2000	CO_2	Toda–Yamamoto Granger causality, Generalized impulse response analysis
Ozturk and Acaravci (2010)	1968–2005	CO_2	Bound test, ARDL, Granger causality
Kocak (2014)	1960–2010	CO_2	Bound test, ARDL model
Katircioglu and Katircioglu (2018)	1960–2013	CO_2	Maki cointegration test, ARDL
Ozcan, Apergis, and Shahbaz (2018)	1961–2013	EF	Bootstrap time-varying causality
Karasoy (2019)	1965–2015	CO_2	NARDL

Table 5. The studies that confirm the EKC hypothesis.

Author(s)	Period	Environmental Variable(s)	Methodology
Halicioglu (2009)	1960–2005	CO_2	Bound test, ARDL, Granger causality

Muhammad Shahbaz et al. (2013)	1970–2013	CO_2	Bound test, Johansen, and Gregory–Hansen cointegration tests, ARDL, Granger causality
N. Çil Yavuz et al. (2014)	1960–2007	CO_2	Johansen, and Gregory-Hansen cointegration tests, OLS, FMOLS
Boluk and Mert (2015)	1961–2010	CO_2	Bound test, ARDL
Balibey (2015)	1974–2011	CO_2	Johansen cointegration test, Granger causality, VAR
Gokmenoglu and Taspinar (2015)	1974–2010	CO_2	Bound test, ARDL, Toda–Yamamoto causality
Seker, Ertugrul, and Cetin (2015)	1974–2010	CO_2	Bound test, and Hatemi-J' cointegration test, ARDL
Ozturk and Oz (2016)	1974–2011	CO_2	Maki' cointegration test, Granger causality, DOLS
Ozatac, Gokmenoglu, and Taspinar (2017)	1960–2013	CO_2	Bound test, ARDL
Kocak and Sargunesi (2018)	1974–2013	CO_2	Maki' cointegration test, DOLS, Hacker–Hatemi-J bootstrap causality test
Cetin, Ecevit, and Yucel (2018)	1960–2013	CO_2	Bound test, ARDL model, Granger causality
Pata (2018)	1974–2014	CO_2	Bound test, Gregory–Hansen and Hatemi-J cointegration test, ARDL, FMOLS, CCR
Arshian Sharif et al. (2020)	1965Q1–2017Q4	EF	QARDL, Granger causality in quantiles
Bulut (2020)	1970–2016	EF	Bound test, ARDL, DOLS
Koksal, Işik, and Katircioğlu (2020)	1961–2014	EF	Johansen cointegration test
Akca (2021)	1965–2018	CO_2	ARDL, Fourier Toda–Yamamoto test

2. Data and Methodology

The aim of the study is to investigate the validity of the EKC hypothesis in the presence of human capital and biocapacity for Türkiye. Following Khattak Danish et al. (2019), biocapacity and human capital are included in the analysis for explanatory variables. The study uses the annual time-series data covering the period from 1970 to 2017. The period of this study is based on data availability of EF and biocapacity.

The current study identifies the EF[1] as a function of economic growth, the square of economic growth, biocapacity, and human capital. All variables used in the analysis are measured in their natural logarithms. Equation (1) presents the estimated model of this study.

$$LEF_t = \alpha_0 + \beta_1 LY_t + \beta_2 (LY_t)^2 + \beta_3 LBC_t + \beta_4 LHC_t + \varepsilon_t \quad (1)$$

where EF denotes the EF per capita as a proxy for environmental degradation. L, Y, Y^2, BC, and HC signify natural logarithm, real GDP per capita (constant 2010 USD), the square of real GDP per capita, biocapacity per capita, and human capital index, respectively. HC is a comprehensive proxy for human capital based on years of schooling and returns to education. HC is used as a measure of human capital in this study, following Ulucak and Bilgili (2018), Ahmet and Wang (2019), Khattak Danish et al. (2019), Shujah-ur-Rahman et al. (2019), and Mustafa Kocaoglu et al. (2023).

EF and BC are retrieved from the Global Footprint Network. Y is obtained from the World Bank; HC is extracted from the Penn World Table (PWT 10.0). β_1, β_2, β_3, and β_4 are the long-run elasticity of EF with respect to Y, Y^2, BC, and HC, respectively. The sign of the coefficient of income (β_1, $\beta 2$) specifies the shape of the curve (Shujah-Ur-Rahman et al., 2019). If $\beta_1 > 0$, $\beta_2 < 0$, it refers to an inverted U-shaped relationship between economic growth and environmental degradation.

For empirical analysis, the cointegration relationship between variables is investigated by the Bound test developed by M. Hashem Pesaran, Yongcheol Shin, and Richard J. Smith (2001). The Bound test approach has more reliable properties for small sample sizes than other cointegration tests (Paresh Kumar Narayan & Seema Narayan, 2005: 429). For cointegration analysis, the Unrestricted Error Correction Model (UECM) specification is formed in Equation (2).

$$\begin{aligned}\Delta LEF_t = a_0 + a_{1t+} \sum_{i=1}^{m} a_{2i} \Delta LEF_{t-i} + \sum_{i=0}^{m} a_{3i}\, \Delta LY_{t-i} + \sum_{i=0}^{m} a_{4i}\, \Delta LY^2{}_{t-i} + \sum_{i=0}^{m} a_{5i}\, \Delta LBC_{t-i} \\ + \sum_{i=0}^{m} a_{6i}\, \Delta LHC_{t-i} + a_7 LEF_{t-1} + a_8 LY_{t-1} + a_9 LY^2{}_{t-1} \\ + a_{10} LBC_{t-1} + a_{11} LHC_{t-1} + \varepsilon_t \quad (2)\end{aligned}$$

[1]Concerning relevant literature, CO_2 emissions has been widely used as an indicator of environmental degradation, but it only represents a small portion of pollution (Usama Al-Mulali et al., 2015a). Instead, ecological footprint (EF) is considered as the more comprehensive measure of environmental degradation and reveals the direct and indirect effects of goods and services activities on environment quality (Garry W McDonald & Murray G. Patterson, 2004). In this sense, EF is considered to reflect the pressure of human activities on the nature (Khattak Danish et al., 2019)

"m" and "t" in the UECM model in Equation 2 stand for the number of lags and trend variables, respectively. For the Bound test, the null hypothesis of no-cointegration is established as Ho: $\alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11} = 0$ for this study. The null hypothesis is tested by comparing estimated F statistics with the critical values in Pesaran, Shin, and Smith (2001). The null hypothesis is rejected if the calculated F statistics is higher than the upper bound critical value, whereas it is not rejected in case the computed F statistics is lower than the bottom bound critical value (Pesaran, Shin, & Smith, 2001; Seema Narayan & Paresh Kumar Narayan, 2004: 103).

After detecting the cointegration relationship, the study applies the ARDL model to reveal long- and short-run relationships between variables. The ARDL model is used as it has advantages with respect to other conventional methods. For the ARDL model, it is not essential to check the integration order of the variables. In addition, the ARDL approach allows simultaneous analysis of both the short- and the long-run effects of the independent variables on the dependent variables. Moreover, ARDL has properties that are more effective in analyzing small samples than other approaches. Furthermore, with the assumption that all variables are endogenous, the ARDL approach eliminates the endogeneity problems associated with the Engle–Granger model (Usama Al-Mulali, Behnaz Saboori, & Ilhan Ozturk 2015b; Seker, Ertugrul, & Cetin, 2015). Hence, long- and short-run ARDL model specifications are presented in Equation (3) and Equation (4), respectively.

$$LEF_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} LEF_{2t-i} + \sum_{i=0}^{q} \alpha_{2i} LY_{t-i} + \sum_{i=0}^{r} \alpha_{3i} LY^2{}_{t-i} + \sum_{i=0}^{s} \alpha_{4i} LBC_{t-i} + \sum_{i=0}^{s} \alpha_{4i} LHC_{t-i} + \varepsilon_t \qquad (3)$$

$$\Delta LEF_t = \alpha_0 + \alpha_1 ECT_{t-1} + \sum_{i=1}^{m} \alpha_{2i} \Delta LEF_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta LY_{t-i} + \sum_{i=0}^{n} \alpha_{4i} \Delta LY^2{}_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta LBC_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta LBC_{t-i} + \varepsilon_t \qquad (4)$$

ECT in Equation (4) is the error correction term and shows the speed of adjustment of the variables to long-run equilibrium. It is expected that the estimated coefficient of error correction term is negative and statistically significant.

Furthermore, the study employs the Kalman filter methodology to examine the dynamic relationship between EF and the independent variables used. The Kalman filter approach, which is based on state space models, utilizes recursive estimation algorithms for dynamic analysis (Umit Bulut, 2017). Its recursion implying can be used in real-time, which is an attractive characteristic of this technique. Once the Kalman filter algorithm estimates the new state at moment (t), it adds a correction term. This new "corrected" state functions as an initial condition at the following stage (t + 1). In this manner, the prediction of the state variables utilizes all the information available, that is, up to that moment and not only that of the stage before estimation. The Kalman filter enables the identification of the hidden (nonmeasurable) state of a dynamic linear system. In addition, this method also works when the system is exposed to additive white noise (Claudio Urrea & Rayko Agramonte, 2021). Other advantages of the use of this methodology can be stated as follows: The Kalman filter is considered to be superior to the least squares models, especially in the presence of parameter instability. In addition, it is predictive and adaptive, it can be applied with nonstationary data. (R. Inglesi-Lotz, 2011). Moreover, the Kalman filter is better than other algorithms, owing to the small room it needs for storage and its broad array of uses (Urrea & Agramonte, 2021).

A linear state space of the dynamics of an equation is represented as follows:

$$y_t = c_t + Z_t\alpha_t + \varepsilon_t \tag{5}$$

$$\alpha_{t+1} = d_t + T_t\alpha_t + \nu_t \tag{6}$$

where α_t is the mx1 vector of unobserved state variables; c_t, Z_t, d_t, and T_t are adoptable vectors and matrices; and ε_t and ν_t are vectors of mean zero and Gaussian disturbances. As expressed in Equation (6), it is assumed that the unobserved state vector, α_t, changes over time as a first-order vector autoregression.

The Kalman filter specification used in this study is presented in Equation (7) and Equation (8).

$$LEF_t = \alpha_0 + \alpha_{1,t}\, LY_t + \alpha_{2,t}\, LY^2_t + \alpha_{3,t}\, LBC_t + \alpha_{4,t}\, LHC_t \tag{7}$$

$$\alpha_{i,t} = \alpha_{i,t-1} + \nu_{it} \tag{8}$$

where $\alpha_{1,t}$, $\alpha_{2,t}$, $\alpha_{3,t}$ and $\alpha_{4,t}$ are the time-varying parameter estimates for relevant variable elasticity of EF.

4. Empirical Results

4.1. Unit Root Test

The study first tests for the stationary properties of the variables to ensure that none of the variables is integrated in order two (I(2)) and beyond because the Bound test assumes that the variables are either I(0) or I(1) (Joseph Magnus Frimpong, & Eric Fosu Oteng-Abayie, 2006: 9). Hence, the current study employs augmented Dickey–Fuller (ADF) and Ng–Perron tests for stationary analysis. Table 6 presents the results of the unit root tests.

Table 6. Unit Root Test Results

	ADF Test	Ng–Perron Test			
		Mza	MZt	MSB	MPT
LEF	−5.354	−22.354	−3.339	0.149	4.100
LY	−1.735	−7.298	−1.741	0.239	12.774
LY^2	−1.497	−6.126	−1.545	0.252	14.725
LBC	−5.683	−22.647	−3.363	0.148	4.033
LHC	−2.282	−10.700	−2.294	0.214	8.607
ΔLY	−6.532	−22.993	−3.375	0.147	1.118

ΔLY^2	−6.476	−22.989	−3.369	0.146	1.138
ΔLHC	−4.342	−9.804	−2.211	0.225	2.509

ADF Critical Values (Level): 1% = −4.16 5% = −3.51 10%= −3.18
ADF Critical Values (First Difference): 1% = −3.58 5% = −2.92 10%= −2.60
Ng-Peron critical values (Level):
1% significance for MZa, MZt, MSB, and MPT: −23.80, −3.42, 0.14, 4.03, respectively.
5% significance for MZa, MZt, MSB, and MPT: −17.30, −2.91, 0.17, 5.48, respectively.
10% significance for MZa, MZt, MSB, and MPT: −14.20, −2.62, 0,18, 6.67, respectively.
Ng-Peron critical values (First Differences):
1% significance for MZa, MZt, MSB, and MPT: −13.80, −2.58, 0.17, 1.78, respectively.
5% significance for MZa, MZt, MSB, and MPT: −8.10, −1.98, −0.23, 3.17, respectively.
10% significance for MZa, MZt, MSB, and MPT: −5.70, −1.62, 0.27, 4.45, respectively.

Source: Author's calculations.

According to the ADF test, the null hypothesis is that the series is stationary. Table 6 shows that the estimated t-statistics for LEF and LBC are greater than the critical values in their level forms at 1% significant level. For LY, LY^2, and LHC, the calculated t-statistics are less than the critical values in their level forms, and they become stationary at their first difference. Accordingly, ADF test results suggest that LEF and LBC are I(0), whereas the other variables including LY, LY^2, and LHC are I(1).

Regarding the Ng–Perron test, the null hypothesis for MZa and MZt tests is that the series includes unit roots, whereas the null hypothesis for MSB and MPT tests suggests that the series is stationary. In level forms, the estimated t-statistics for LEF and LBC are greater than the critical values at 5% significant level, whereas other variables are less than the critical values, according to the MZa and MZt tests. The results of the MSB and MPT tests reveal that the estimated t-statistics for LEF and LBC are less than the critical values in their level forms at 5% significant level. However, the other variables are greater than the critical values in their level forms.

The estimated t-statistics for LY, LY^2, and LHC for the first difference are greater than the critical values according to the MZa and MZa tests and less than the critical values according to the MSB and MPT tests. Ultimately, Ng–Perron test results support the results of the ADF test.

4.2. Bound Test

The study employs the Bound test after ensuring none of the variables is integrated in two and beyond. Table 7 depicts the results of the Bound test approach.

Table 7. Bound Test Results

k	F-statistics	Significance level	Critical Values	
			Lower Bound	Upper Bound
4	6.725	1%	4.40	5.72
		5%	3.47	4.57

Source: Author's calculations

k is the number of independent variables in Equation (2).
Critical values are obtained from Table CI(v) at Pesaran, Shin, and Smith (2001: 301).

According to Table 7, F-statistics is greater than the upper bound critical values. This result rejects the null hypothesis and shows the presence of a cointegration relationship between EF and the independent variables used.

4.3. ARDL Model

Following cointegration analysis, the long- and short-run static relationships between dependent and independent variables are investigated by employing the ARDL model. Table 8 presents the results of long- and short-run estimates of the ARDL (1,2,0,0,0) model. Optimal lengths are determined via the Akaike Information Criterion (AIC).

Table 8. ARDL (1,2,0,0,0) model results

Long-run Estimation		
Variables	Coefficient	T-statistics
LY	7,527	5,760*
LY^2	−0,370	−5,305*
LBC	0,348	1.941***
LHC	−0,390	−2.386**
C	−36.703	−6.074*
Short-run Estimation		
Variables	Coefficient	T-statistics
D(LY)	6,180	2.154**
D(LY(-1))	−0,31	−2.690**
$D(LY^2)$	−0,285	−1.790**
D(LBC)	0.394	3,232*
D(LHC)	−0,15	−0,383
EC(-1)	−0,89	−6,353*

Diagnostic Tests	
Serial Correlation LM test (Breusch–Godfrey)	0,910 [0.411]
Heteroscedasticity test (Breusch–Pagan–Godfrey)	0.927 [0.497]
Jargue–Bera Normality test	0.730 [0.6947]
Ramsey Reset Test	0.751 [0.457]

Source: Author's calculations

*, **, and *** denotes 1%, 5%, and 10% significant level, respectively.
p values in parentheses.

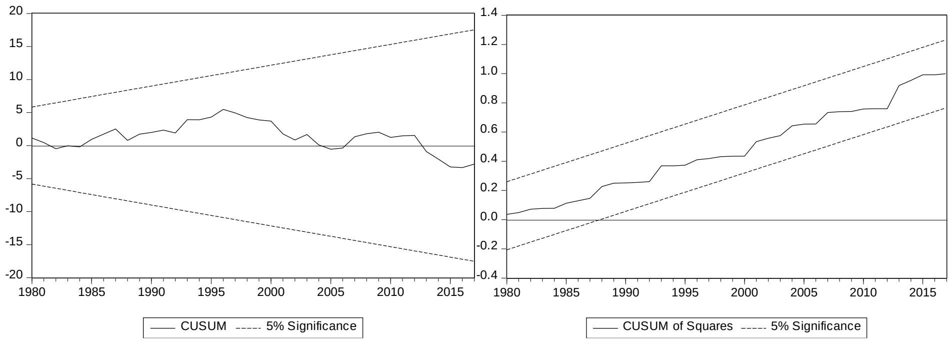
The diagnostic results in Table 8 show that the estimated ARDL model does not suffer from serial correlation, heteroscedasticity, misspecification, and normality problems. The estimated coefficients are also found to be stable according to Figure 1, which presents the results of CUSUM and CUSUM-square tests.

The long-run estimation results show that all estimated coefficients are found to be statistically significant. The coefficient of income infers that a 1% increase in income leads to a 7.527% increase in the level of EF in the long run This result indicates that income has a positively elastic effect on EF. In addition, the estimated coefficient of LY^2 (−0.370) is found to be negative. The positive sign of LY and the negative sign of LY^2 confirm an inverted U-shaped relationship between economic growth and EF for Türkiye in the analyzed period. This result is in line with the results of Arshian Sharif et al. (2020); Bulut (2020); and Koksal, Isık, and Katircioglu (2020) and contradicts with Ozcan, Apergis, and Shahbaz (2018) and Karasoy (2019), which utilizes EF as a proxy for environmental degradation for Türkiye. The coefficient of LBC indicates that a 1% increase in biocapacity will enhance EF by 0.348%. This finding corresponds to the findings of Yong Wang et al. (2013), Shujah-Ur-Rahman et al. (2019), Khattak Danish et al. (2019), and Ulucak and Bilgili (2018). Furthermore, the coefficient of LHC signifies that a 1% increase in human capital improves environmental quality by decreasing EF by 0.39%. This result is consistent with the results of Shujah-ur-Rahman et al. (2019), Sadia Bano et al. (2018), Ulucak and Bilgili (2018), Ahmet and Wang (2019), and Mustafa Kocaoglu et al. (2023).

The short-run ARDL model results also support the EKC hypothesis in the long run, that is, income affects EF positively, whereas the square of income has a negative impact on it. In the short run, biocapacity has a positive effect on environmental degradation. In addition, the coefficient of human capital is found to be insignificant.

The coefficient of error correction term is determined to be negative and statistically significant, as expected. The coefficient of ECT (−0,89) infers that 89% deviations from the long-run equilibrium are eliminated in the current year. This evidence implies that the speed of the adjustment process is quite fast.

Figure 1. CUSUM and CUSUMQ test results.

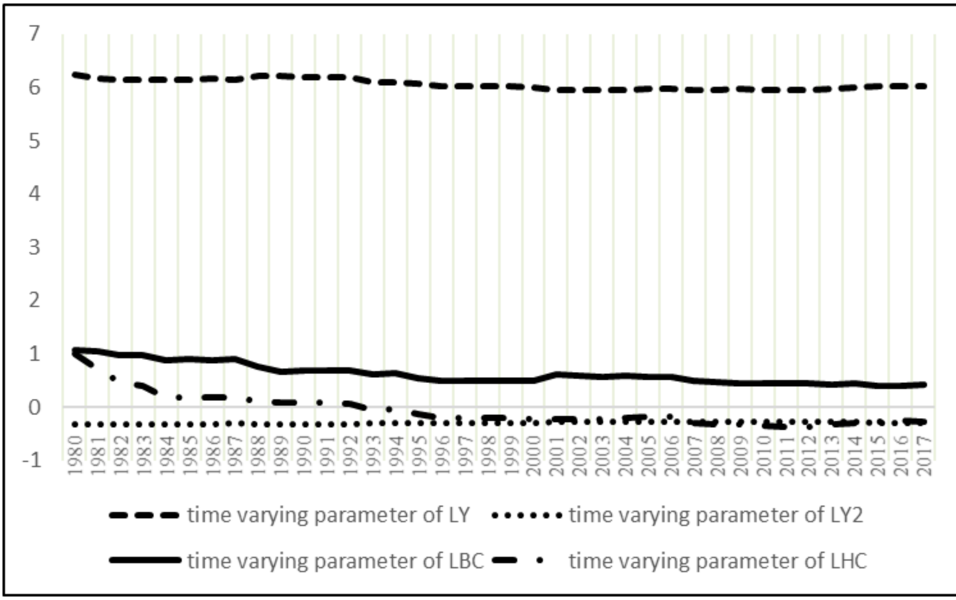


Source: Author's calculations

4.5. Dynamic Approach

Finally, the Kalman filter approach is applied to reveal the dynamic relationship between EF and the independent variables for the 1980–2017 period. Figure 2 presents the time-varying parameter estimates for the Kalman filter approach. The results of the dynamic parameter estimates coincide with the static coefficient obtained from the ARDL model. The coefficients of LY, LY^2, LBC, and LHC in Equation (7) are also statistically significant separately. The results indicate that the estimated coefficient of the income, the square of income, biocapacity, and human capital is found to be positive, negative, positive, and negative, respectively. More specifically, income has a positive effect on EF, and this effect seems to be stable during the sample period. The square of income exhibits a negative impact on environmental degradation for the observed period. Accordingly, the estimated time-varying parameter also verifies the EKC hypothesis for Türkiye. Though the relationship between biocapacity and EF does not give remarkable fluctuations, the effect of biocapacity on EF has a slight tendency to decrease. Furthermore, the estimated coefficient of human capital has become constantly negative after the year of 1993, and the effect of human capital on EF seems to be steady after this year.

Figure 2. Time-varying parameter estimates.



Source: Author's calculations

4. Conclusion

There are quite limited empirical studies that use EF as a proxy for environmental pollution for the EKC framework in Türkiye. The current study differs from the related literature in two aspects. First, this study investigates the validity of the EKC hypothesis for EF by considering the effects of human capital and biocapacity on the environment in Türkiye. Second, the current study employs the Kalman filter technique to detect the time-varying interaction between EF and the independent variables used. To the best of my knowledge, this is the first study that applies a dynamic approach to the EKC framework in the case of Türkiye. To this end, this study seeks to fill this gap in the existing literature.

In the empirical analysis, the study tests the impacts of income, the square of income, biocapacity, and human capital on EF during the 1970–2017 period. After detecting stationary analysis, the Bound test is employed to analyze the cointegration relationship between the variables. The Bound test result shows that there is a cointegration relationship between EF and the other independent variables used. Then, the long- and short-run static relationship is examined by using the ARDL approach. The long-run estimation results obtained from the ARDL model demonstrate that all computed coefficients are statistically significant. Namely, a 1% increase in income enhances EF at 7.527% in the long run. In addition, it is found that the estimated coefficient of the square of income is negative. Regarding control variables, a 1% increase in biocapacity leads to a 0.348% increase in the level of EF. On the other hand, a 1% increase in human capital lessens EF by 0.39%. The short-run ARDL model results confirm the estimated coefficients of income, the square of income, and biocapacity to be significant. However, human capital is found to be insignificant. In the short run, income and biocapacity impact EF positively, whereas the square of the income has a negative effect on EF.

The income and the square of the income are found to be significantly positive and negative, respectively. Hence, the results validate the existence of the EKC hypothesis for Türkiye both in the long and short run. ARDL model results indicate that biocapacity exerts a positively significant impact on EF both in the long and short run. This result implies that biocapacity is one of the main drivers of environmental degradation in Türkiye. On the other hand, the effect of human capital on EF is found to be negative only in the long run. This finding signifies that human capital improves environmental quality by decreasing EF. It is conceivable that the development of human capital is expected to increase awareness of the environment, which in turn decreases environmental pollution.

Finally, the Kalman filter technique is utilized to investigate the dynamic relationship between EF and the other variables used, namely income, the square of income, biocapacity, and human capital. The results of the dynamic approach support the findings obtained from the ARDL model. To be specific, the dynamic parameter estimates for income, the square of income, biocapacity, and human capital are found to be significantly positive, negative, positive, and negative, respectively. Therefore, the results of the time-varying approach also support the existence of the EKC hypothesis in Türkiye. Moreover, the findings from the time-varying effect of human capital on EF indicate that human capital has been promoting environmental quality for nearly two decades now. The time-varying interaction between EF and biocapacity is found to be mostly stable during the analyzed period. The result demonstrates that economic growth drives EF significantly. The most striking finding obtained from the dynamic analysis is that the trend of the relationship between environmental degradation and economic growth does not significantly change over the years. That is to say, there is still quite a strong effect of economic activity on the environment.

These empirical results have some useful recommendations for policymakers in Türkiye. The study reveals that human capital curbs environmental degradation by decreasing EF. There is a need to promote human capital because the more educated people play a vital role in protecting the environment. Indeed, the investment in high-quality human capital, who can have more advantage in adopting environment-friendly technologies, increases awareness of environmental problems, which in turn mitigates environmental threats. Moreover, issues of environmental pollution, recycling, and climate change should be integrated with the formal education system at every education level. On the other hand, there is a need for policy implementations to ensure environmental sustainability by promoting biocapacity without increasing environmental pollution as underlined by Shujah-ur-Rahman et al.

(2019). The empirical findings of this study validate the EKC hypothesis and reveal that economic growth is one of the main drivers of EF in Türkiye. Therefore, policymakers aiming at environmental sustainability should consider mitigating the negative effects of economic growth on environmental quality while promoting economic growth. Therefore, policies should be designed to support the use of eco-friendly technologies so that the initial stage of economic growth does not induce pollution. Furthermore, they should promote more renewable energy sources instead of fossil fuels that are harmful to the environment.

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