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RESEARCH ARTICLE

Environmental sustainability statement of economic regimes with energy intensity and urbanization in Turkey: a threshold regression approach

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Abstract
In recent time, the investigation of the state of environmental quality has largely been conducted with less attention on the situation of environment sustainability especially in different economic regimes (expansion and recession). In the current context, the role of income per capita, energy intensity, and urbanization in driving the ecological footprint of Turkey is examined in the framework of Environmental Kuznets Curve (EKC) hypothesis over the period of 1990–2015. Considering the potential evidence of regime switching, we employed the Threshold Autoregressive Model (TAR) method with a regime change threshold of 14.43505 per hectare per capita and found that the EKC hypothesis is valid for all the 4 models. Moreover, eight observations are below the threshold value in the first regime while fifteen observations are equal or higher than the threshold value in the second regime. With a threshold per capita income of 9340.1326 USD, the study found that Turkey begin to experience a decline in environmental degradation resulting from income growth in 2015. However, this desirable outcome was short-lived in 2018 because the per capita income slightly decreases to 9340.1326 USD. In addition, increases in energy intensity and urbanization level hamper environmental sustainability drive of the country. The frequency domain causality test further supports the nexus evidence among the implied variables. By virtue of observation, this study offers that the government should work toward achieving a sustainable growth in order to attain the country's environmental sustainability agenda.

Keywords Environmental sustainability; · Ecological footprint; · Energy intensity; · Urban population; · EKC hypothesis; · Threshold regression

JEL classification C32 · C33 · Q43 · Q58

Highlights • State of environmental quality is examined at different economic regimes in Turkey.
• Threshold Autoregressive Model (TAR) found a 14.43505 per hectare threshold of ecological footprint.
• Environmental quality start to improve when per capita income attain 9340.1326 USD
• Turkey exceeded the income per capita threshold in 2015 but declined to 9340.1326 USD per capita in 2018.
• Energy intensity and urbanization are both detrimental to environmental sustainability.

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Introduction

The adverse effects of environmental degradations due to global warming have increased rapidly in recent years. According to the Global Climate Change data of the National Aeronautics and Space Administration (NASA), global warming has increased by about 0.9 °*C* degrees since the 19th century to present (National Aeronautics and Space Administration 2020). In addition, the report from the data further informed that the temperatures reached the highest levels since 2010 due to the environmental effects caused by the interaction of human activities with the environment. Another effect of global warming has being the melting of glaciers, rises in sea level and increases in the temperatures of the oceans. During the period of 1993–2016, 413 tons of glaciers melted in Greenland and Antarctica. The temperature in the oceans increased by 0.4°*C* degrees (National Centers for Environmental Information 2020). Global warming and climate change affect the lives of all people in the world because of their impact on water, food production, health and the environment. These severities in the global environmental effects of global warming and climate change could trigger an increase in human deaths resulting from hunger, water shortage, health problems, conflict, and other causative factors (Stern 2006).

In addition to global warming, other human activities and natural disasters associated with the air, water, and soil are increasingly being linked with severe environmental degradation (Adedoyin et al. 2020a; Ahmad et al. 2020; Alola et al. 2020; Khan et al. 2020). Importantly, air pollution caused by greenhouse gas emissions has remained the most important causative factor of global warming. This situation has been the subject of many studies. Studies on environmental degradation and economic growth have increased rapidly in the last decades. Foremost, Kuznets (1955) forwarded the Kuznets Curve (KC). In a subsequent study, the KC was later developed into Environmental Kuznets Curve (EKC) (Grossman and Krueger 1991; Shafik and Bandyopadhyay 1992; Panayotou 1993; Arrow et al. 1995; Holtz-Eakin and Selden 1995). The EKC hypothesis describe environmental degradation will decrease as economic growth increases due to structural and technological developments. Although carbon dioxide (CO_2) emission has been largely used to proxy environmental degradation, ecological footprint has also been increasingly employed in recent studies such as Charfeddine (2017), Ulucak and Bilgili (2018), Aydın et al. (2019), Xun and Hu (2019), Destek and Sinha (2020), and Saint Akadiri et al. (2020).

Energy utilization, especially the use of non-renewable energy source in all levels of economic activities has remained a major source of environmental degradation (Adedoyin et al. 2020b). According to World Bank Data, energy use per capita in Turkey has increased by an approximate rate of 44% from 1971 to 2014 (World Bank Development Indicator, WDI 2020). The share of fossil fuels in total of energy use was put at 44.2% in 1960 and 86.6% in 2016. In addition, in 1960 the CO_2 emission per capita in Turkey is 3.1 metric tons, this later increased to 5.0 in the 2016 (World Bank Development 2020). This evidence suggest that the increased in CO_2 emission and fossil fuel consumption is not unrelated with the economic growth in Turkey. In other words, economic growth makes environmental pollution inevitable to a threshold level.

Given this motivation, this study analyzes the relationship between economic growth, energy intensity, urban population growth, and environmental degradation in Turkey for different regimes of economic growth in the context of the EKC hypothesis. In this case, we utilized the *Stochastic Impact by Regression on Population, Affluence and Technology* (STIRPAT) approach to model the environmental degradation function in the context of ecological footprint as described in previous studies (Charfeddine 2017; Ulucak and Bilgili 2018; Bello et al. 2018; Destek 2018; Xun and Hu 2019; Aydın et al. 2019; Destek and Sinha 2020; Adedoyin et al. 2021). The ecological footprint is employed as the environmental degradation variable since it covers the footprint as regard to the built-up land, carbon footprint, cropland, fishing grounds and forest areas.

The current study is distinct from other related previous investigation for several reasons. Importantly, we employed the regime switching methodology that allows different linear regressions for different regimes in phases of the economy such as expansion and depression. The essence of implementing the threshold regression is to underpin the recent years of peculiar economic fluctuations in Turkey and its environmental implication. The peculiarity of the Turkey's economic fluctuations especially in response to the volatility of the country's country cannot be overlooked in the study of environmental quality. In addition, as a unique option, this study offers a time-frequency Granger causality approach of Breitung and Candelon (2006). The importance of the approach is to provide causality insight in term of frequency in addition to the time inference. As an important contribution to the EKC hypothesis literature, the empirical procedures offer a useful insight for the nexus of energy intensity, urbanization, economic expansion, and ecological footprint. Above all, the current study also provides a summary of the studies on the EKC hypothesis that employed the CO_2 emission and ecological footprint as dependent variables, and the highlights of existing studies with the STIRPAT approach.

The remaining of the paper is as follows. A highlighted review of the existing literature especially in the framework of the EKC hypothesis is presented in the "Literature review" section. The "Data, model, and empirical methodology" section accommodates the data description and the illustration of the regime switching methodology that offers asymmetries in the EKC hypothesis approach. Section 4 offers the discussion of the results while the study is summarized in the “Empirical results and discussion” section.

Literature review

There are many studies in the literature regarding the Environmental Kuznets Curve (EKC) Hypothesis. Since the pioneer work of Kuznets and Simon (1955), the Kuznets Curve was adapted in 1970s to explain environmental disturbances thus becoming the subject of many studies in the economic literature. In the economic literature, several studies have utilized the income and CO_2 emission to investigate the validity of the EKC hypothesis for several cases (Grossman and Krueger 1991; Al-Mulali et al. 2016; Akadırı et al. 2021). Consequently, the Table 1 shows the compilation of the studies on the EKC hypothesis for the nexus of income and CO_2 while the study of EKC hypothesis from the nexus of income and ecological footprint is compiled in Table 2

Several other studies have used the ecological footprint in studying environmental degradation: Jorgenson and Burns (2007) for the developed countries, Liobikiene and Dagiliute (2016) and Alola et al. (2019) for a panel of the European Union member countries, Szigeti et al. 2017for 131 countries, Markaki et al. (2017) for the case of Greece, Yue et al. (2019) for a panel of 55 countries, Saint Akadırı et al (2021) for South Africa, Solarin et al. (2019) in a panel of 92 countries, Danish and Wang (2019) for the Next-11 countries, Zafar et al. (2019), Usman et al. 2020and Hao et al. (2021) for the US, Ozcan et al. (2020) for the Organization for Economic Cooperation and Development (OECD) countries. In addition, Table 3 shows the EKC hypothesis studies from the framework of the STIRPAT Model.

Data, model, and empirical methodology

Data

In the study, the analysis has been conducted by using the annual data of the period 1990–2015. As mentioned earlier, we employed the ecological footprint as the environmental and dependent variable in lieu of CO_2 emission, because the carbon dioxide emission cannot entirely represent environmental sustainability. While the ecological footprint is included as a dependent variable in the model, real gross domestic product per capita, urbanization level and energy intensity are included as an explanatory variables. The variable of gross product per capita in the model represents economic growth. Energy intensity represents the level of technological development. Accordingly, the amount of energy used to produce one unit of GDP is the energy intensity. Table 4 contains the variables used in this study and the respective descriptive statistics for these variables.

Model

The first study in the literature that draws attention to the effect of human in environmental degradation is the POET (P: Population, O: Organization, E: Environment, T: Technology) model that was developed by Duncan (1961). According to this model, there is a complex relationship between population, social organization, technology and environment (Gezdim 2017). However, the structure of the POET model has not been used frequently in the literature because it is complex and difficult to interpret with statistical analysis methods. Later, the IPAT (Environmental Impact by Population, Affluence and Technology) model developed by (Ehrlich and Holdren 1971) started to be used in the literature. The basic equation of this model is as follows:

$$I = P \times A \times T \tag{1}$$

while I indicates the environmental degradation variable, P refers to population size, A per capita consumption of goods and services, and T refers to the technology used for the production of consumed goods and services. However, IPAT model has been criticized because all factors causing environmental degradation have no equal effects and model does not contain an error term. Subsequently, Dietz and Rosa (1994) later reformulated the IPAT model. This new model, which is the STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology), allows both the use of new statistical methods and the testing of hypothesis test. This model equation is as follows:

$$\mathrm{I_t} = \alpha \mathrm{P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3}} \varepsilon_t \tag{2}$$

In the equation above, (2) represents environmental degradation, (P) is the population, (A) is the welfare level, and (T) technology level. While “α” denotes the constant term, "β_1", "β_2", "β_3" indicate the coefficients of environmental degradation, population, welfare level and technology level, respectively. ε_t in the model shows the error term. When logarithm of variables in equation 2 is taken, the econometric model is as follows:

$$\mathrm{lnI_t} = \mathrm{a} + \beta_1 \mathrm{lnP_t} + \beta_2 \mathrm{lnA_t} + \beta_3 \mathrm{lnT_t} + \varepsilon_t \tag{3}$$

The STIRPAT model has been used in many basic studies (Dietz and Rosa 1994; York et al. 2002, 2003; Shı 2003; Fan et al. 2006; Alam et al. 2007; Madu 2009). Apart from these studies using the STIRPAT model, several studies have also examined the EKC hypothesis within framework of the STIRPAT model approach (Bello et al. 2018; Destek 2018; Alola, 2019a & b). In this paper, EKC hypothesis was tested

Table 1 Summary literature review of EKC using CO_2 emission

Author(s)	Period	Countries	Methodology	Environment Variables	Results (EKC Hypothesis)
Holtz-Eakin and Selden (1995)	1951–1986	130 countries	Panel Data Analysis	CO_2	No
Lindmark (2002)	1870–1997	Sweden	STRM	CO_2	Yes
Cole (2004)	1980–1997	21 countries	Panel Data Analysis	CO_2	Yes
Azomahou et al. (2006)	1960–1996	100 countries	Regression Analysis	CO_2	No
Lee et al. (2009)	1960–2000	89 countries	Dynamic Panel Data Analysis	CO_2	No "N" shaped
Halıcıoglu (2009)	1960–2005	Turkey	ARDL	CO_2	Yes
Choi et al. (2010)	1971–2006	China, Korea Japan	OLS	CO_2	Yes (Korea, Japan) "U" shaped (China)
Lean and Smyth (2010)	1980–2006	ASEAN	VECM Causality	CO_2	Yes
Pao and Tsai (2011)	1980–2007	BRICS	VECM Causality	CO_2	Yes
Wang (2012)	1971–2007	98 countries	FMOLS	CO_2	Yes
Mert and Bozdag (2013)	1992–2009	Bosnia-Herzegovina	Regression Analysis	CO_2	No (Inverted "N" shaped)
Sahli and Rejeb (2015)	1996–2013	MENA	Dynamic Panel Data Analysis	CO_2	Yes
Apergis and Öztürk (2015)	1990–2011	14 ASEAN Countries	FMOLS, DOLS	CO_2	Yes
Öztürk and Al-Mulali et al. (2015)	1996–2012	Cambodia	GMM	CO_2	No
Zhao et al. (2016)	1980–2013	China (Yangtze River Delta)	Dynamic CCD Model	CO_2	Yes
Lebe (2016)	1960–2010	Turkey	ARDL, Granger Causality	CO_2	Yes, between GDP and Environment degradation "Feedback Hypothesis"
Beşer and Beşer et al. (2017)	1960–2015	Turkey	ARDL	CO_2	Yes
Beşer et al. (2017)	1990–2013	190 countries	Panel Regression	CO_2	Yes
Güney (2018)	1960–2016	Turkey	ARDL, ECM	CO_2 CO_2	Yes
Ravanoglu et al. (2018)	1990–2013	Kyrgyzstan	ARDL	CO_2	Yes
Danish et al. (2019)	1970–2012	Pakistan	ARDL,FMOLS DOLS,CCR, VECM Causality	CO_2	Yes, GDP => CO_2(+), RNW=>CO_2, NRNW=>CO_2

Note: EKC (Environmental Kuznets Curve), CO_2 (carbondioxide emissions), ARDL (auto regressive distributive model), GMM (Generalized Moment Model), FMOLS (fully modified ordinary least squares), DOLS (dynamic ordinary least squares), OLS (ordinary least squares), ECM (error correction model), CCR (canonical cointegrating regression), VECM (vector error correction model), EU (European union), ASEAN (Association of Southeast Asian Nations), MENA (the Middle East and North Africa region), BRICS (Brazil, Russia, India, China, South Africa), STRM (Smooth Transition Regression Model)

using the ecological footprint within the framework of STIRPAT model following the work of Bello et al. (2018) and Destek (2018). The equation for this model is follows:

$$\ln EF_t = a + \beta_1 \ln pcGDP_t + \beta_2 \ln pcGDP^2{}_t + \beta_3 \ln URB_t + \beta_4 \ln ED_t + \varepsilon_t \quad (4)$$

In the above model, the population variable is excluded from the equation as all variables are used in a per capita form. The EF is the per capita ecological footprint variable that represents environmental degradation. GDP, GDP^2, URB and ED represent real gross domestic product per capita, urbanization level and energy intensity, respectively. While the URB (urbanization level) included in the model internalizes the impact of human on environmental degradation. The ecological footprint represents a wide environmental degradation such as built-up land, carbon footprint, cropland, fishing grounds, forest products and grazing lands increases the power of the model. If the gross domestic product of coefficient ($\beta_1 > 0$) is positive and the square of the gross domestic

Table 2 Summary literature review of EKC using ecological footprint

Author(s)	Period	Countries	Methodology	Environment Variables	Results (EKC Hypothesis)
Caviglia-Harris et al. (2009)	1961–2000	146 countries	Panel GMM	EF	No
Al-Mulali et al. (2015)	1980–2018	93 countries	Panel GMM	EF	Yes (upper middle and high income) No (lower middle income)
Aşıcı and Acar (2016)	2004–2008	116 countries	Panel Fixed Effects Model	EF	Yes
Charfeddine and Mrabet (2017)	1995–2007	15 MENA	FMOLS, DOLS	EF	Yes
Charfeddine (2017)	1970–2015	Qatar	Markov Switching Model	EF,CF	Yes
Aşıcı and Acar (2018)	2004–2010	87 countries	Panel Fixed Effects Model	EF	Yes
Ulucak and Bilgili (2018)	1961–2013	Lower, Middle Upper İncome	CUP-FM, CUP-BC	EF	Yes
Aydın et al. (2019)	1990–2013	26 EU	PSTR	EF	No
Destek and Sarkodie (2019)	1977–2013	11 Newly industrialized countries	AMG, Panel Causality	EF	EKC (Mexico, Singapure, S. Africa Philippines) U shaped (China, India, S. Korea, Thailand, Turkey)
Xun and Hu (2019)	2010–2015	China (17 city)	Panel Data Analysis	EF	Yes
Destek and Sinha (2020)	1980–2014	24 OECD	FMOLS,DOLS	EF	Yes

Note: AMG (augmenting mean group), OECD (organization for economic co-operation and development), PSTR (Panel Smooth Transition Regression Model), CUP-FM (continuously updated fully modified), CUP-BC (continuously updated bias-corrected), EF (ecological footprint), CF (carbon footprint), WF (water footprint)

product of coefficient($\beta_2 < 0$) is negative, the EKC hypothesis is valid.

Empirical methodology

As the recession and expansion periods are experienced in the economy (in this case the Turkish economy), asymmetric fluctuations are observed in the conjuncture. In this case, the estimations made with a linear model are not sufficient to represent the variables with an asymmetric structure. For this reason, since the economy assume that there are more than one linear model in different regime changes, more realistic predictions are made with regime switching models. However, most regime switching models can be quite difficult to predict (Enders 2003). Some of these threshold models are known as: Threshold Autoregressive Model (TAR), Self-Exciting Threshold Autoregressive Model (SETAR), Smooth Transition Autoregressive Model (STAR), and the Markov Switching Model.

In this study, we employed the Threshold Autoregressive (TAR) model developed byTsay (1989). The Threshold models follow a linear approach in different regime periods of a nonlinear model. In other words, the linear model is created for each of regime period. The TAR model equation, which was first discovered by Tong (1983), was later modified as follows:

$$Y_t = a_0^{(i)} + a_1^{(i)} Y_{t-1} + a_{pi}^{(i)} Y_{t-pi} + \varepsilon_{it} \quad (5)$$

$\gamma_{i-1} < S_{t-d} < \gamma_i$ $i = 1,2,...,k$whereas k is the number of regime, threshold variable is denoted as S_{t-d}, the threshold value is denoted as γ in the equation, and d shows the delay length of S_{t-d} (5). The expressions in the superscript of the parameters refer to regimes where the variables are located. The TAR models are expressed with various names such as TAR, TARMA, SETAR, and SETARMA according to the method following the determination of the threshold variable S_{t-d}. If the threshold variable among these models is a variable outside the model, it is expressed as the TAR model. If the threshold variable consists of the lagged values of the dependent variable, it is named as the Self Exciting Threshold Autoregressive (SETAR) model. The two-regime threshold model representation is as follows:

$$Y_t = \begin{cases} a_1^{(1)} y_{t-1} + a_p^{(1)} Y_{t-p} \Big) I[Y_{t-d} \leq \gamma] + \varepsilon_t, \\ a_1^{(2)} y_{t-1} + a_p^{(2)} Y_{t-p} \Big) I[Y_{t-d} > \gamma] + \varepsilon_t, \end{cases} \quad (6)$$

Table 3 The extant studies of the EKC Hypothesis with the STIRPAT model

Author(s)	Period	Countries	Methodology	Environment Variable	Results (EKC Hypothesis)
Acaracvı and Öztürk (2010)	1960-2005	19 EU	ARDL	CO_2	Yes, (Denmark and Italy)
Zhao (2010)	1980-2007	China (Gannan Pasturing Area)	OLS	EF	Yes
Shafiei and Salim (2014)	1980-2011	OECD	AMG, Granger Causality	CO_2	Yes
Liddle (2015)	1990-2006	OECD (26) Non-OECD (54)	OLS, FMOLS, DOLS	CO_2	No
Liu et al. (2015)	1990-2012	China (30 Area)	OLS	CO_2	No
Shahbaz et al. (2015)	1970Q1-2011Q4	Malaysia	ARDL, VECM Granger Causality	CO_2	Yes
Xu and Lin (2015)	1990-2011	China	Nonparametric additive regression	CO_2	Yes
Wang et al. (2016a)	1995-2011	China	Sys-GMM	CO_2	No, "N" Shaped
Xu et al. (2016)	2001-2012	China (Three area)	Panel Fixed Effect	CO_2	Yes
Cao et al. (2016)	2005-2013	China	Pooled OLS	Total cement consumption	Yes
Wang et al. (2016b)	1990-2012	China	Semi-parametric regression	SO_2	Yes
Abdallh and Abugamos (2017)	1980-2014	MENA	Semi-parametric regression	CO_2	Yes
Zhang et al. (2017)	1961-2011	141 countries	Robust Regression	CO_2	Yes
Wang et al. (2017)	2000-2013	China	Panel Fixed Effects Regression	CO_2	Yes
Bello et al. (2018)	1971-2016	Malaysia	ARDL,VECM Granger Causality	EF, CF, WF	Yes, GDP ⇔ EF, GDP ⇔ CF, GDP ⇔ WF
Destek (2018)	1990-2014	Turkey	ARDL,VECM Granger Causality	EF	Yes, GDP ⇒ EF, URB ⇒ EF, ED ⇒ EF

The ⇔ is the bidirectional relationship and ⇒ is the unidirectional relationship between the variables

The step-by-step procedure of the threshold model is as follows: (i) p is a temporary AR process and possible threshold variables that are determined. (ii) It is tested whether it is linear for each of threshold variable. (iii) According to the findings obtained in the second step, appropriate threshold variable (Y_{t-d}) is selected. (iv) The threshold values are determined by scatter plots for p and d values. (v) The model is estimated using the Least Squares method (Cao and Tsay 1992).

As a robustness investigation, the short-run and long-run Granger causality developed by Breitung and Candelon (2006) was employed but without providing the step-by-step procedure for reason of space constraint.

Empirical results and discussion

In this study, the first approach is to investigate whether the series is stationary or not by testing for the presence of unit. Traditional unit root tests do not take into account structural breaking. For this reason, the stationarity test by Zivot and Andrews (2002) which takes into account structural breaks while investigating unit root is considered. According to the structural break unit root test results in Table 5, if absolute value of the test statistics is greater than the absolute value of critical value, it is concluded that series does not contain unit root. The results show that lnGDP, lnpcGDP^2, lnURB and lnED series of contain unit root when examined by considering structural breaks. However, it was determined that lnEF series that represents environmental degradation does not contain unit root. In other words, it is concluded that the lnEF series is stationary considering the structural breaks, while the other series are not stationary.

After the stationary test, we investigated whether the series are linear or not. Three different tests such as Tsay Test, BDS Test, and Ramsey Reset were used to determine linearity. The results are shown as in detail in the Table 6. According to the results in Table 6, it was determined that lnEF and lnED series are not linear in BDS test. According to the results of the Ramsey RESET test, it was concluded that the lnURB series is not linear. Tsay test results do not verify non-linearity because R^2 and F-statistic probability value are not significant at level 5% for all variables. Although these results are weak, some of the variables in the model show evidence of non linearity. It is thought that the analysis made with non-linear series will not give realistic results.

Table 4 Variables and descriptive statistics

Variable	Definition	Source	Obs.	Mean	Max.	Min.	St. Dev.
lnEF	Logarithmic Ecological Footprint, gha per person	Global Footprint Network	26	14.38	14.53	13.36	0.290
lnpcGDP	Logarithmic Gross Domestic Product per capita, constant 2010 US$	World Data Bank	26	3.95	4.14	3.82	0.096
lnpcGDP²	Logarithmic Gross Domestic Product per capita, constant 2010 US$ square	World Data Bank	26	7.91	8.28	7.65	0.193
lnURB	Logarithmic Urbanization Level, the ratio of urban population to total population	World Data Bank	26	-0.17	-0.13	-0.22	0.028
lnED	Logarithmic Energy Density, GDP per unit of energy use constant 2011 PPP $ per kg of oil equivalent	World Data Bank	26	1.09	1.15	1.06	0.026

For this reason, the threshold regression method was analyzed through different linear models in different regimes.

Table 7 shows the results of the analysis made with different threshold regression models. By determining the threshold value or threshold values with the TAR model, different linear regressions are estimated for diferent regimes. In addition, Table 7 shows the change in ecological footprint at different threshold values with eight different models. According to the situation where the ecological footprint variable is below or above the threshold value, a non-linear structure is formed. In other words, the threshold value shows the breaking point of the ecological footprint in two different regimes. This threshold value showing regime change is 14.43505 per hectare per capita of ecological footprint for Model 1. With this threshold value, complex probabilistic systems are analyzed by decomposing into smaller sub-systems.

In Model 1, the ecological footprint (EF) is a dependent variable, while the gross domestic product per capita (pc) GDP, the square of the per capita gross domestic product ($pcGDP^2$), energy density (ED) and urbanization level (URB) are the explanatory variables. In the first regime, there are eight observations that are below the threshold value. In the second regime, there are fifteen observations equal to or higher than the threshold value. In the first regime where is EF(-3) < 14.43505, pcGDP and $pcGDP^2$ threshold variables are statistically significant at 1% level. According to the results of Model 1 in Table 7, the coefficients of the threshold variables are statistically significant in both regimes. As per the EKC hypothesis, the result found the validity of the EKC hypothesis because the coefficient of the per capita GDP ($\beta_1 > 0$) is positive and the coefficient of the $pcGDP^2$ ($\beta_2 < 0$) is negative. In addition, when we look at the other components of the STIRPAT model, it was concluded that %1 increase in of ED and URB increased environmental degradation by approximately 0.95% and 0.79%, respectively.

Overall, according to the results shown in the Model 1, Model 2, Model 3, and Model 4 of the study, an irrespective of economic fluctuations, the EKC hypothesis is shown to be valid in Turkey for all the models. This relationship suggests that environmental degradation increases to a certain level when economic growth increased in Turkey. However, it further indicates that environmental degradation will decrease later. That is, when it reaches a certain economic growth, then environmental degradation follows a negative trend. Although the EKC hypothesis is investigated for the first time in the framework of threshold regression, the evidence in the current study affirms the validity of EKC hypothesis in the extant studies of Ozturk et al. (2016) for 144 countries, Zhang et al. (2017) for 141 countries, Wang et al. (2017) and Xun and Hu (2019) for China, Bello et al. (2018) for Malaysia, Destek (2018) and Ozatac et al. (2017) for Turkey .

When we look at the STIRPAT model, the increase in energy density and urbanization level in the Model 1 and Model 4 increases environmental degradation. The first regime in the Model 3, environmental degradation increases due to the decrease in energy efficiency as the amount of energy (energy density) used to produce one unit of gross domestic product also increases. Thus, the current evidence supports the results from the existing literature that both urban population growth and energy intensity are detrimental to environmental quality (Farhani and Ozturk 2015; Pata 2018). In the second regime, although not statistically significant, the result opined that the increase in energy density reduces environmental degradation.

Moreover, the results of the frequency domain Granger causality by Breitung and Candelon (2006) are illustrated in Figure 2 and Table 8 of the appendix. Importantly, by complimenting the visual evidence of the relationship between the examined variables in Fig. 1, the pairwise frequency causality for both low and high occurrences among the variables are amplified in Figure 2.

Table 5 Results of Zivot-Andrews unit root test

Variables	Model	*t*-Statistic	%1	%5	%10	Prob.	Break Date
lnEF	C	-6.289322	-5.57	-5.08	-4.82	0.094316***	2003
lnpcGDP	A	-3.575444	-5.34	-4.93	-4.58	0.012020**	1999
lnpcGDP^2	A	-3.575444	-5.34	-4.93	-4.58	0.012020**	1999
lnURB	B	-2.255597	-4.80	-4.42	-4.11	0.003249*	2010
lnED	C	-2.889105	-5.57	-5.08	-4.82	0.024817**	2009

Note: Probability values are calculated from a standard t-distribution and do not take into account the breakpoint selection process. *,**,*** are statistically significant at the level of 1%, 5%, 10%, respectively. Model A: Variable has a unit root with a structural break in the intercept. Model B: Variable has a unit root with a structural break in the trend. Model C: Variable has a unit root with a structural break in both the intercept and trend

Conclusion and policy implications

In this study, the EKC hypothesis in Turkey has been examined within the framework of STIRPAT model for the period of 1990 to 2015. In this case, the study employed the ecological footprint, per capita real gross domestic product, square of per capita real gross domestic product, the amount of energy used to produce a unit of gross domestic product (energy intensity) and the level of urbanization. The preliminary test includes the investigation of whether the series are stationary or not. For that reason, we employed the Zivot-Andrews structural break unit root test. Thereafter, we investigated whether the variables are linear or not. Due to the non-linearity of the ecological footprint and energy density, the EKC hypothesis was tested in different regimes by using the TAR method.

According to the findings from the different models employed, the result established the validity of the EKC hypothesis in Turkey in the long run, thus affirming that economic regimes in Turkey does not invalidate the EKC hypothesis. This result translate that the inverse U relationship between economic growth and environmental degradation is exist. Consequently, the turning point (decline in the ecological footprint) exist when the level of per capita real gross domestic product exceeds 9340.1326 USD in Turkey. The per capita real gross domestic product in the year 2018 in Turkey is $ 9370,176. According to the data for 2015, per capita real gross domestic product is $ 10948, 7246 USD. This situation shows that Turkey has reached a turning point in the period and followed by a negative trend of environmental degradation. These results indicate that environmental degradation has reached the reduced level of prosperity in Turkey. However, in 2018, real income per capita decreased slightly below the turning point per capita income level of 9340.1326 USD. Therefore, the stability of the per capita real gross domestic product in Turkey is very important for environmental degradation. In addition, the positive correlation between the amount of energy used to produce a unit gross product and the ecological footprint indicates that environmental degradation also will increased if energy efficiency decreases. Similarly, increase in the density of urban population because of migration from rural areas to urban areas is another factor that significantly deters environmental quality.

For policy observation, the results here indicate that sustainable economic growth policy in Turkey is important in order to achieve the desired environmental sustainability goal. Therefore, in order to reach the level of welfare, where environmental

Table 6 Linearity tests of series

Variables	Tsay Test		BDS Test				Ramsey Reset Test	
	F-statistic (Prob.)	R^2	Dimension	2	3	4	F-statistic (t-statistic)	Likelihood ratio
lnEF	0.557	0.118	Normal prob. Boostrap prob.	0.617 0.530	0.474 0.460	0.372 0.417	1.000 (1.000)	-
lnpcGDP	0.590	0.120	Normal prob. Boostrap prob.	0.000 0.000	0.000 0.000	0.000 0.000	0.665 (0.665)	0.620
lnpcGDP^2	0.590	0.120	Normal prob. Boostrap prob.	0.000 0.000	0.000 0.000	0.000 0.000	0.665 (0.665)	0.620
lnURB	0.119	0.299	Normal prob. Boostrap prob.	0.000 0.000	0.000 0.000	0.000 0.000	0.070 (0.070)	0.038
lnED	0.970	0.015	Normal prob. Boostrap prob.	0.000 0.017	0.235 0.275	0.020 0.156	0.768 (0.768)	0.736

Table 7 Results of threshold regression models

	Model 1	Model 2	Model 3	Model 4	Model 5
Threshold Variable	EF(-3)	EF	URB	EF(-1)	EF(-2)
Dependent Variable	EF	EF	EF	EF	EF
c	-486.371*	-18.306	-334.29***	-634.029	7.978
pcGDP	256.590*	36.163*	185.985**	332.142*	0.996
	246.964*	15.133***	168.600***	319.696*	
$pcGDP^2$	-32.921*	-7.181*	-25.066**	-43.081*	
	-30.493*	-1.701***	-20.56***	-39.947*	
ED	0.953	-0.937***	1.403	9.402***	
URB	0.789	-3.204*	-11.980	9.035	
EF(-1)					1.094
					-0.117
EF(-2)					-0.986*
					0.288
Threshold Values	EF(-3) < 14.435 (8)	EF < 14.387 (3)	URB < -0.1994 (7)	EF(-1) < 14.464 (14)	EF(-2)< 14.387 (3)
	14.435 <=EF(-3) (15)	14.387 <=EF (23)	-0.199 <= URB (19)	14.465 <= EF(-1) (11)	14.388<=EF(-2) (21)
R^2	0.707	0.994	0.499	0.5897	0.525
(F-sta. Prob.)	(0.0013)	(0.0000)	(0.0254)	(0.0072)	(0.013)

Note: *, **, *** are significant at the level of 1%, 5%, and 10%, respectively. Values in parentheses represent the number of observations in that range. PcGDP, $pcGDP^2$, EF(-1) and EF(-2) is threshold variable. ED and URB is non-threshold variable. The constant term c is the estimation intercept

degradation will begin to decrease, technological innovations should be deliberately encouraged especially in the development of efficient energy sources as well as policies to sustain the increase in the country's per capita income level. According to the energy identity certificate application that was commenced in 2020, the implementation of the guideline for mitigation of greenhouse gas emissions should be carried out for each house, factory and other buildings. In addition, the development of renewable energy sources should be encouraged to drastically increase the share of renewable energy consumption that is currently at 13.4% in total of energy consumption. With the decision taken in 2011, the amount of energy used to produce unit of output is targeted at reducing GHG emissions by 20% by 2023. While more than 3.5 unit of energy were consumed in

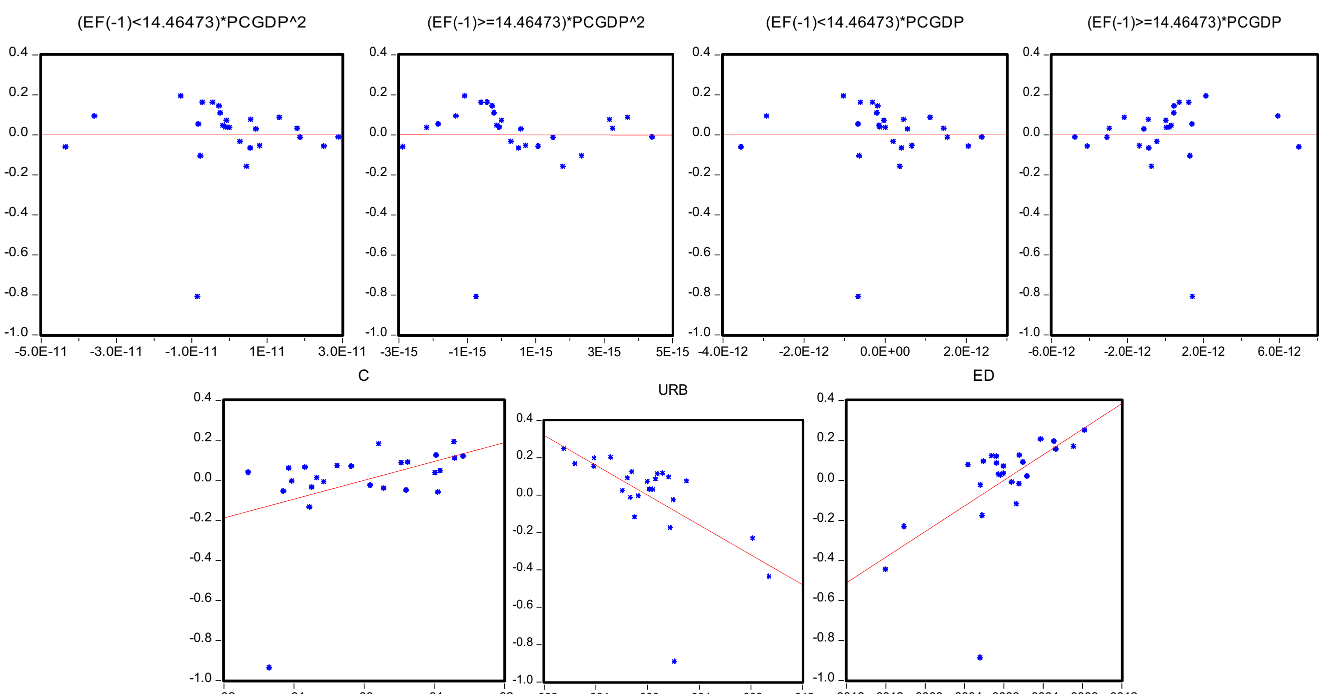

Fig. 1 Graphical representation of Model 4

2012 to produce unit of output, in 2015 this ratio decreased to 3 units of energy use for the production of one unit of output. However, after in 2015, energy efficiency decreased, thus increasing energy density again to 3 units in 2017. Considering this development, the government should be more consistent as it re-examine the implementation of energy efficiency policy in order to attain the country's environmental sustainability agenda.

Author contribution Andrew Adewale Alola: formal analysis, ınvestigation, methodology, and corresponding.

Tuğba Koyuncu: writing—original draft and data curation.

Mustafa Kemal Beşer: writing and **c**onceptualization.

Data availability Not applicable

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

Appendix

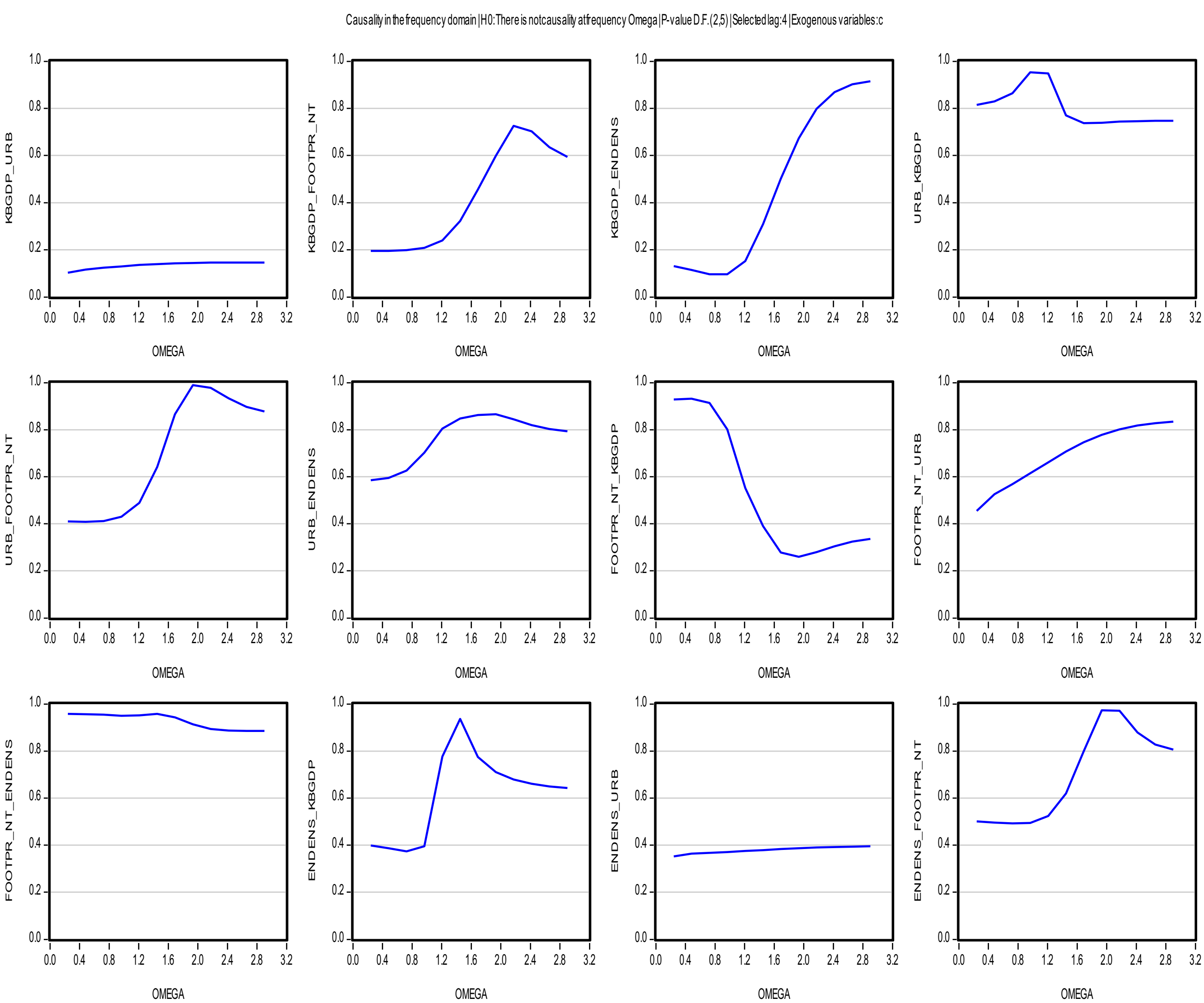

Figure 2 Frequency Domain Causality Breitung and Candelon (2006)

Table 8 Statistical Result of the Frequency Domain Causality Breitung and Candelon (2006)

Direction of Causality	Long Term		Middle Term		Short Term	
	w:0.1	*w:0.5*	*w:1.0*	*w:1.5*	*w:2.0*	*w:2.5*
KBGDP→URB						
KBGDP→FOOTPRINT						
KBGDP→ENDENS						
URB→KBGDP						
URB→FOOTPRINT						
URB→ENDENS						
FOOTPRINT→KBGDP						
FOOTPRINT→URB						
FOOTPRINT→ENDENS						
ENDENS→KBGDP						
ENDENS→URB						
ENDENS→FOOTPRINT						
Angular frequency	URB No Granger-cause pcGDP		EF No Granger-cause pcGDP			
0.241661	0.103410		0.195636			
0.483322	0.116944		0.195715			
0.724983	0.123891		0.197915			
0.966644	0.129982		0.207729			
1.208305	0.135369		0.239729			
1.449966	0.139627		0.321537			
1.691627	0.142572		0.454716			
1.933288	0.144347		0.599657			
2.174949	0.145264		0.726388			
2.416610	0.145648		0.702189			
2.658271	0.145754		0.634853			
2.899932	0.145755		0.594696			
ED No Granger-cause pcGDP	pcGDP No Granger-cause URB		EF No Granger-cause URB			
0.130405	0.814933		0.409247			
0.114855	0.828761		0.408892			
0.097113	0.864319		0.412203			
0.095774	0.953293		0.429679			
0.151763	0.947859		0.489144			
0.308093	0.770973		0.641088			
0.501738	0.737436		0.865773			
0.672656	0.739271		0.988989			
0.798957	0.743329		0.978331			
0.869056	0.745783		0.933003			
0.901335	0.747121		0.897280			
0.914384	0.747790		0.876403			
ED No Granger-cause URB	pcGDP No Granger-cause EF		URB No Granger-cause FB			
0.584831	0.928057		0.454890			
0.594893	0.930773		0.524860			
0.625799	0.913527		0.569034			
0.702933	0.801717		0.614353			
0.804864	0.552414		0.661618			
0.846793	0.390993		0.706880			
0.862084	0.278492		0.746280			
0.864724	0.259211		0.777795			

Table 8 (continued)

Direction of Causality	Long Term		Middle Term		Short Term	
	w:0.1	*w:0.5*	*w:1.0*	*w:1.5*	*w:2.0*	*w:2.5*
0.844131	0.279690		0.801281			
0.820088	0.304995		0.817692			
0.802799	0.324579		0.828297			
0.793042	0.336335		0.834190			
ED No Granger-cause EF	pcGDP No Granger-cause ED	URB No Granger-cause ED	EF No Granger-cause ED			
0.957427	0.397994	0.352732	0.500257			
0.956992	0.387745	0.363457	0.496432			
0.954756	0.373811	0.367614	0.492299			
0.950392	0.395666	0.371277	0.494790			
0.951448	0.775971	0.375257	0.523795			
0.957182	0.937133	0.379435	0.619136			
0.943197	0.774649	0.383477	0.798721			
0.912616	0.709949	0.387088	0.973382			
0.893387	0.679142	0.390092	0.971887			
0.886752	0.660736	0.392416	0.878652			
0.885287	0.649534	0.394053	0.827538			
0.885253	0.643464	0.395022	0.806325			

References

Abdallh AA, Abugamos H (2017) A semi-parametric panel data analysis on the urbanisation-carbon emissions nexus for the MENA countries. Renew Sust Energ Rev 78:1350–1356

Acaracvı A, Öztürk İ (2010) On the relationship between energy consumption, CO2 emissions and economic growth in Europe. Energy 35(12):5412–5420

Adedoyin FF, Alola AA, Bekun FV (2020a) The nexus of environmental sustainability and agro-economic performance of Sub-Saharan African countries. Heliyon 6(9):e04878

Adedoyin FF, Bekun FV, Alola AA (2020b) Growth impact of transition from non-renewable to renewable energy in the EU: the role of research and development expenditure. Renew Energy 159:1139–1145

Adedoyin FF, Nathaniel S, Adeleye N (2021) An investigation into the anthropogenic nexus among consumption of energy, tourism, and economic growth: do economic policy uncertainties matter? Environ Sci Pollut Res 28(3):2835–2847

Ahmad M, Jiang P, Majeed A, Umar M, Khan Z, Muhammad S (2020) The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: an advanced panel data estimation. Res Policy 69:101817

Akadırı SS, Alola AA, & Usman O (2021). Energy mix outlook and the EKC hypothesis in BRICS countries: a perspective of economic freedom vs. economic growth. Environ Sci Pollut Res Int

Alam S, Fatima A, Butt MS (2007) Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation. J Asian Econ 18:825–837

Al-Mulali U, Weing-Wai C, Sheau-Ting I, Mohammed AH (2015) Investigating the environmental Kuznets Curve (EKC) hypothesis by utilizing the ecological foootprint as an indicator of environmental degradation. Ecol Indic 48:315–323

Al-Mulali U, Solarin SA, Ozturk I (2016) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat Hazards 80(3):1729–1747

Alola AA (2019a) The trilemma of trade, monetary and immigration policies in the United States: accounting for environmental sustainability. Sci Total Environ 658:260–267

Alola AA (2019b) Carbon emissions and the trilemma of trade policy, migration policy and health care in the US. Carbon Manag 10(2): 209–218

Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ 685:702–709

Alola AA, Akadiri SS, & Usman O (2020). Domestic material consumption and greenhouse gas emissions in the EU-28 countries: Implications for environmental sustainability targets. Sustain Dev

Apergis N, Öztürk İ (2015) Testing environmental kuznets hypothesis in Asian countries. Ecol Indic 52:16–22

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., ... Pimentel, D. (1995). Economic growth, carrying capacity, and the environment. Ecol Econ 15:91-95.

Aşıcı AA, Acar S (2016) Does income growth relocate ecological footprint? Ecol Indic 61:707–714

Aşıcı AA, Acar S (2018) How does environmental regulation affect production location of non-carbon ecological footprint? J Clean Prod 178:927–936

Aydın C, Esen Ö, Aydın R (2019) Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach. Ecol Indic 98:543–555

Azomahou T, Laisney F, Van PN (2006) Economic development and CO2 emissions: A nonparametric panel approach. J Public Econ 90(6-7):1347–1363

Bello MO, Solarin SA, Yen YY (2018) The impact of electricity consumption on CO2 emission, carbon footprint, water footprint and

ecological footprint: The role of hydropower in an emerging economy. J Environ Manag 219:218–230
Beşer MK, Acaroğlu H, Güllü M (2017) Environmental Kuznets Curve Hypothesıs: Does Human Development Index Matter? Pamukkale Univ J Soc Sci Instit 31:189–201
Breitung J, Candelon B (2006) Testing for short-and long-run causality: A frequency-domain approach. J Econ 132(2):363–378
Cao C, Tsay RS (1992) Nonlinear time-series analysis of stock volatilities. J Appl Econ 7(September):165–185
Cao Z, Shen L, Liu L, Zhong S (2016) Analysis on major drivers of cement consumption during the urbanization process in China. J Clean Prod 133:304–313
Caviglia-Harris JL, Chambers D, Kahn JR (2009) Taking the "U" out of Kuznets:A comprehensive analysis of the EKC and environmental degradation. Ecol Econ 68:1149–1159
Charfeddine L (2017) The impact of energy consumption and economic development on Ecological Footprint and CO2 emissions: Evidence from a Markov Switching Equilibrium Correction Model. Energy Econ 65:355–374
Charfeddine L, Mrabet Z (2017) The ımpact of economic development and social political factors on ecological footprint: a panel data analysis for 15 MENA countries. Renew Sustain Energy 76:138–154
Choi E, Heshmati A, Cho Y (2010) An Empirical Study of the Relationships between CO2 Emissions, Economic Growth and Openness. IZA Discuss Pap 5304(5304):2–27
Cole M (2004) Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. Ecol Econ 48(1):71–81
Danish, Wang Z (2019) Investigation of the ecological footprint's driving factors: What we learn from the experience of the emerging economies. Sustain Cities Soc 49:101626
Danish, Hassan ST, Baloch MA, Mahmood N, Zhang JW (2019) Linking economic growth and ecological footprint through human capital and biocapacity. Sustain Cities Soc 47:101516
Destek MA (2018) Investigation Of Environmental Kuznets Curve Hypothesis In Turkey: Evidence From Stirpat Model. Cumhuriyet University. J Econ Adm Sci 19(2):268–283
Destek MA, Sarkodie SA (2019) Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. Sci Total Environ 650:2483–2489
Destek MA, Sinha A (2020) Renewable, non-Renewable energy consumption, economic growth, trade opennes and ecological footprint: Evidence from organisation for economic Co-operation and development countries. J Clean Prod 240(118537):1–13
Dietz T, Rosa EA (1994) Rethinking the Environmental Impacts of Population,Affluence and Technology'. Hum Ecol Rev 1:277–300
Duncan OD (1961) From social system to ecosystem. Sociol Inq 31:140–149
Ehrlich PR, Holdren JP (1971) Impact of population growth. Science 171(3977):1212–1217
Enders W (2003). Applied Econometric Time Series.
Fan Y, Liu LC, Wu G, Wei YM (2006) Analyzing Impact Factors of CO2 Emissions Using The STIRPAT Model. Environ Impcat Assess Rev 26:377–395
Farhani S, Ozturk I (2015) Causal relationship between CO 2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22(20): 15663–15676
Gezdim SB (2017) Analysis of Determinants of Global CO2 Emission: Dynamic Panel Quantile Regression Model. Uludağ University Institute of Social Sciences, Bursa
Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. Nat Bureau o Economic 3914:1–57
Güney A (2018) A Reassessment of the extended envıronmental kuznets curve for turkey. Atatürk Univ J Econ Adm Sci 32(13):745–761
Halıcıoglu F (2009) An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. Energy Policy 37(3):1156–1164
Hao LN, Umar M, Khan Z, Ali W (2021) Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? Sci Total Environ 752:141853
Holtz-Eakin D, Selden T (1995) Stoking the fires? CO2 emissions and economic growth. J Public Econ 57(1):85–101
Jorgenson AK, Burns TJ (2007) The political economic causes of change in the ecological footprints of nations 1991-2001: A Quantitative Investigation. Soc Sci Res 36:834–853
Khan Z, Ali S, Umar M, Kirikkaleli D, Jiao Z (2020) Consumption-based carbon emissions and international trade in G7 countries: the role of environmental innovation and renewable energy. Sci Total Environ 730:138945
Kuznets S (1955) Economic growth and income inequality. The American Economic Review 45(1):1–28
Kuznets P, Simon P (1955) Economic Growth And Income Inequality. Am Econ Rev 45:1–28
Lean HH, Smyth R (2010) CO2 Emissions, Electricity Consumption and Output in ASEAN. Appl Energy 87(6):1858–1864
Lebe F (2016) The envıronmental kuznets curve hypothesıs: coıntegratıon and causalıty analysıs for Turkey. J Doğuş Univ 17(2):177–194
Lee CC, Chiu YB, Sun CH (2009) Does one size fit all?An reexamination on the Environmetal Kuznets Curve usning to Dynamic Panel Data approach. Rev Agric Econ 31(4):751–778
Liddle B (2015) What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. Glob Environ Chang 31:62–73
Lindmark M (2002) An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997. Ecol Econ 42(1-2):333–347
Liobikiene G, Dagiliute R (2016) The relationship between economic growth and carbon footprint changes in EU: The achievements of the EU sustainable consumption and production policy implementation. Environ Sci Pol 61:204–211
Liu Y, Zhou Y, Wu W (2015) Assessing the impact of population, income and technology on energy consumption and industrial pollutant emissions in China. Appl Energy 155:904–917
Madu IA (2009) The impacts of anthropogenic factors on the environment in Nigeria. J Environ Manag 90:1422–1426
Markaki M, Roboli AB, Sarafidis Y, Mirasgedis S (2017) The carbon footprint of Greek households (1995-2012). Energy Policy 100: 206–215
Mert M, & Bozdag H (2013) Envıronmental kuznets curve for carbon emıssıons ın bosnıa & herzegovına. Dumlupınar Univ J Soc Sci special issue, 79-84
National Aeronautics and Space Administration (2020) Climate Change: Global Temperature. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature. Accessed 25 February 2021
National Centers for Environmental Information (2019) Global climate report - annual 2019. https://www.ncdc.noaa.gov/sotc/global/201913. Accessed 20 December 2020
Ozatac N, Gokmenoglu KK, Taspinar N (2017) Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey. Environ Sci Pollut Res 24(20): 16690–16701
Ozcan B, Tzeremes PG, Tzeremes NG (2020) Energy consumption, economic growth and environmental degradation in OECD countries. Econ Model 84:203–213
Ozturk I, Al-Mulali U, Saboori B (2016) Investigating the environmental Kuznets curve hypothesis: the role of tourism and ecological footprint. Environ Sci Pollut Res 23(2):1916–1928

Panayotou T (1993) Empirical tests and policy analysis of environmental degradation at different stages of economic development. World Employ Program Res 39338:1–42

Pao TH, Tsai CM (2011) Multivariate Granger Causality between CO2 emissions, energy consumption, FDI (Foreign direct investment) and GDP (Gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India and China) countries. Energy 36:685–693

Pata UK (2018) Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: testing EKC hypothesis with structural breaks. J Clean Prod 187:770–779

Ravanoglu GA, Bostan A, Yılmaz A (2018) Valıdıty of envıronmental kuznets curve hypothesıs for kyrgyzstan economy: ardl bound test approach. Manas J Soc Stud 7(2):127–142

Sahli I, Rejeb JB (2015) The Environmental Kuznets Curve and Corruption in the Mena Region. Procedia Soc Behav Sci 195: 1648–1657

Saint Akadiri S, Alola AA, Alola UV, Nwambe CS (2020) The role of ecological footprint and the changes in degree days on environmental sustainability in the USA. Environ Sci Pollut Res 27(20):24929–24938

Saint Akadırı S, Alola AA, Usman O (2021) Energy mix outlook and the EKC hypothesis in BRICS countries: a perspective of economic freedom vs. economic growth. Environ Sci Pollut Res 1–5

Shafiei S, Salim RA (2014) Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis. Energy Policy 66:547–556

Shafik N, & Bandyopadhyay S (1992). Economic Growth and Environmental Quality: Time-Series and Cross-Country Evidence. Backgr Pap World Dev Rep 1-50.

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K, Jabran MA (2015) How Urbanization Affects CO2 Emissions in Malaysia? The Application of STIRPAT Model. Munich Personal RePEc Archive (MPRA) 68422:1–40

Shı A (2003) The Impact of Population Pressure on Global CarbonDioxide Emissions, 1975-1996: Evidence from Pooled Cross-Country Data. Ecol Econ 44:29–42

Solarin SA, Tiwari AK, Bello MO (2019) A Multi-country convergence analysis of ecological footprint and its components. Sustain Cities Soc 46:101422

Stern NH (2006) The Economics of Climate Change: The Stern Review. Cambribge University Press, Cambribge

Szigeti, C., Toth, G., & Szabo, D. R. (2017). Decoupling-shifts in ecological footprint intensity of nations in the last decade. Ecological Indicators(72), 111-117.

Tong H (1983) Threshold Models in Nonlinear Time Series Analysis. Springer-Verlag, New York

Tsay RS (1989) Testing and Modeling Threshold Autoregressive Processes. J Am Stat Assoc 84:231–241

Ulucak R, Bilgili F (2018) A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. J Clean Prod 118:144–157

Usman O, Alola AA, Sarkodie SA (2020) Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: Evidence from the US. Renew Energy 150:266–277

Wang KM (2012) Modelling the non linear relationship between CO2 emissions from oil and economic growth. Econ Model 29:1537–1547

Wang S, Fang C, Wang Y (2016a) Spatiotemporal variations of energy-related CO2 emissions in China and its influencing factors: An empirical analysis based on provincial panel data. Renew Sust Energ Rev 55:505–515

Wang Y, Han R, Kubota J (2016b) Is there an Environmental Kuznets Curve for SO2 emissions? A semi-parametric panel data analysis for China. Renew Sust Energ Rev 54:1182–1188

Wang Y, Zhang C, Lu A, Li L, He Y, ToJo J, Zhu X (2017) A disaggregated analysis of the environmental Kuznets curve for industrial CO2 emissions in China. Appl Energy 190:172–180

World Bank Development (2020) https://data.worldbank.org/indicator. Accessed 20 Dec 2020

World Bank Development Indicator, WDI (2020). https://data.worldbank.org/indicator. (Accessed 03 December 2020).

Xu B, Lin B (2015) How industrialization and urbanization process impacts on CO2 emissions in China: Evidence from nonparametric additive regression models. Energy Econ 48:188–202

Xu B, Luo L, Lin B (2016) A dynamic analysis of air pollution emissions in China: Evidence fromnonparametric additive regression model. Ecol Indic 66:346–358

Xun F, Hu Y (2019) Evaluation of ecological sustainability based on a revised three-dimensional ecological footprint model in Shandong Province, China. Sci Total Environ 649:582–591

York R, Rosa EA, Dietz T (2002) Bridging Environmental Science with Environmental Policy: Plasticity of Population, Affluence, and Technology. Soc Sci Q 83(1):17–33

York R, Rosa EA, Dietz T (2003) STIRPAT, IPAT and ImPACT: Analytic Tools For Unpacking The Driving Forces of Environmental Impacts. Ecol Econ 43:351–365

Yue S, Shen Y, Yuan J (2019) Sustainable total factor productivity growth for 55 states: An application of the new malmquist index considering ecological footprint and human development index. Resour Conserv Recycl 146:475–483

Zafar MW, Zaidi SA, Khan NR, Mirza FM, Hou F, Kirmani SA (2019) The impact of the natural resources, human capital and foreign direct investment on the ecological footprint: The case of the United States. Res Policy 63:101428

Zhang N, Yu K, Chen Z (2017) How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Policy 107:678–687

Zhao XY (2010) Impacts of human activity on environment in the high-cold pasturing area: A case of Gannan pasturing area. Acta Ecol Sin 30:141–149

Zhao Y, Wang S, Zhou C (2016) Understanding the relation between urbanization and the eco-environment in China's Yangtze River Delta using an improved EKC model and coupling analysis. Sci Total Environ 572:862–875

Zivot E, Andrews DWK (2002) Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. J Bus Econ Stat 20(1): 25–44