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Do life expectancy and hydropower consumption affect ecological footprint? Evidence from novel augmented and dynamic ARDL approaches

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ABSTRACT

Human activities threaten the future of the ecosystem by emitting pollution to the air, water, and soil. Considering the increasing ecological footprint (EF), the study focuses on investigating the role of life expectancy and hydropower consumption by controlling also income, trade openness, and globalization on the environment under the environmental Kuznets curve (EKC) hypothesis for Turkey during 1971–2018. In this context, the study performs recently developed augmented autoregressive distributed lag (AARDL) and dynamic ARDL (DARDL) methods. The results show that (i) life expectancy increases the environmental pressure; (ii) hydropower consumption has no effect on the EF; (iii) globalization and trade openness reduce the EF; (iv) the EKC hypothesis is valid, but the estimated turning point lies between USD 19,914 and USD 20,571, which is far from the sample period in Turkey. From the overall results, it can be concluded that Turkey cannot solve environmental problems with insufficient income levels, an increasing elderly population, and ineffective use of hydropower. Hence, Turkey should rely on income much more, use hydropower much more efficiently, and benefit from the spillover effect of technological innovations related to globalization and foreign trade to significantly reduce the EF.

1. Introduction

Climate change has been posing a major threat to humanity [1], which has been causing various environmental problems (e.g., loss of critical water resources, droughts, floods, and ecosystem imbalance) [2]. Human-induced GHG emissions are among the most important causes of climate change and global warming [3]. The amount of CO_2 emissions decreased from 2019 to 2020 due to the COVID-19 pandemic. However, this decrease has not reduced the concern about global warming because the increase in CO_2 emissions is far greater than the decrease envisioned in COVID-19 [4] The inability to stop the rise in CO_2 emissions, which is mainly due to

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Acronyms

Abbreviations

AARDL	Augmented Autoregressive Distributed Lag
BARDL	Bootstrap ARDL
BC	Biocapacity
BP	British Petroleum
CO_2	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
DARDL	Dynamic ARDL Simulations
EC	Energy Consumption
EI	Energy Intensity
EKC	Environmental Kuznets Curve
FADF	Fourier ADF
FDI	Foreign Direct Investment
FF	Fossil Fuel Industry
GFN	Global Footprint Network
GHA	Global Hectares
GHG	Greenhouse Gas
GLS	Generalized Least Squares
HC	Human Capital
IND	Industry
IRENA	International Renewable Energy Agency
LC	Liquefied Petroleum Gas Consumption
NR	Natural Resources Rent
OC	Oil Consumption
PMG	Pooled Mean Group
POP	Population
QARDL	Quantile ARDL
RALS	Residual Augmented Least Squares
REC	Renewable Energy Consumption
TP	Turning Point
URB	Urbanization
USD	United States Dollar
WB	World Bank
WMO	World Meteorological Organization

Dependent Variable

EF	Ecological Footprint

Independent Variables

GDP	Gross Domestic Product
HECP	Hydropower Consumption
TO	Trade Openness
LF	Life Expectancy
KOF	KOF Globalization Index

energy consumption, worries the whole world. However, polluting fossil fuel consumption remains high for more economic growth [5].

There are numerous studies on the relationship between the environment, energy consumption, and economic growth [6–14]. Fossil fuel consumption is a cause of pollution, accounting for about 80% of total global energy consumption [15]. Substitution of fossil fuel energy with renewable energy is of great importance to reduce pollution caused by fossil energy, because renewable sources are obtained from natural resources that do not cause pollution and are constantly renewed [16]. In case of efficient use, renewable sources play a key role in climate change and energy scarcity, and environmental pollution because it provides a decreasing effect [17–19]. Policymakers and scientists have continued to work to accelerate renewable energy use during COVID-19, projecting that global warming can be limited to 1.5 °C by 2050 with the increase in renewable energy consumption [20].

There are various renewable energy sources in nature. One of the renewable energy sources is hydropower, which is derived from flowing water, and is used in many countries [21]. If hydropower has a small share in renewable energy sources, this energy source may not have any decreasing effect on environmental pollution [22,23]. Although hydropower is one of the most important clean energy sources against fossil fuel energy, however, it may pollute the environment. Many scientists have found that hydropower plants change air temperature, damage river ecosystems, and affect biological integrity [24]. Also, some chemical and toxic substances may be mixed with water sources [25]. Therefore, hydropower plants may not only pollute water and the atmosphere, but also disturb the structure of soil, houses, and natural habitat near the dam. This situation may have a negative effect on the environment [26].

Environmental footprints have been frequently used to uncover ecological effects on the environment. One of the most important ecological indicators is the EF, developed by Ref. [27]. Since there are water and soil-related differences in the EF, it is considered an alternative measurement tool to CO_2 emissions [28,29]. The need for natural resources is called EF, while the natural capital is referred to as BC. An ecological deficit occurs if the EF is higher than BC. There has been a global ecological deficit since 1970 and this situation is gradually increasing. Recent studies have found that one of the key reasons for this deficit is population expansion [30]. The basis for this view is the population principle of [31], who state that resources increase arithmetically and population geometrically, famine may occur and humanity would perish if this continues. Accordingly, several authors [e.g., [31–35]] have studied the link between population growth and the environment and concluded that population density leads to a decline in biodiversity. Also, some researchers have used life expectancy as an alternative to population size. Life expectancy, which is considered an indicator of a nation's prosperity [36,37], has been increasing in recent years [15]. One of the crucial factors for life expectancy is the level of wealth, which depends on economic growth [38] because a low level of wealth brings health problems and leads to premature deaths, whereas a high standard of living develops the healthcare system and prevents premature deaths. As living standards and life expectancy increase, societies consume much more energy, which is obtained from environmentally harmful fossil fuels [39].

Although developed countries have relatively stable environmental conditions, this picture is a bit different for emerging countries. So, the study focuses on environmental issues in Turkey a fast-growing country with increasing pollution. At the Conference of Parties meeting in 2021 (COP26), Turkey committed to minimizing forest loss and land degradation by 2030, selling zero-emission vehicles by 2040, reducing aviation-related emissions in line with the 1.5 °C target, and adopting a climate-resilient and sustainable agriculture model [40]. However, Turkey must control its population growth, offset the ecological damage, and effectively use renewable energy sources to achieve these goals. Fig. 1 demonstrates the development of life expectancy.

According to Fig. 1, life expectancy in Turkey has evolved. It was 52.9 years in 1971 and reached 77.4 years in 2018.

Fig. 2 shows hydropower development in Turkey. Hydropower development is not the same as life expectancy. The share of hydropower consumption in the total energy has declined since 1988, falling to 8.9% in 2018. The imbalances and system integration costs incurred by the Turkish economy during 2012–2019 due to hydropower and wind power plants amount to TL 12 billion [41]. For reasons, Turkey has continued to consume energy from fossil fuels, resulting in a burden on the environment.

In Turkey, people have consumed higher energy to increase living standards, but this has caused an increase in pollution. The per capita EF reached 3.35 gha in 2018, whereas it was 1.56 gha in 1961, implying about 115% increase [43]. Fig. 3 presents the comparative progress of the EF and BC as well as ecological balance over time in Turkey.

Based on Fig. 3, an ecological surplus is observed in Turkey in the 1970s, but the ecological deficit continued to increase in the 1980s and later, which indicates that Turkey's environmental problems have increasing continuously. Considering the discussion above, the study aims to provide answers to three research questions: (i) does life expectancy increase environmental degradation? (ii) does hydropower promote environmental sustainability? (iii) is there an inverted U-shaped relationship between income and the EF in Turkey, as suggested by the EKC hypothesis? So, the study investigates Turkey as it has negative environmental progress by focusing on the role of life expectancy and hydropower consumption on the environment by controlling also income, trade openness, and globalization. In doing so, the study uses yearly data for the period 1971–2018 performing both AARDL and DARDL methods. In summary, the study reveals that life expectancy stimulates environmental pressure; hydropower has no effect on the environment; globalization and trade openness curb the EF; and the EKC hypothesis is valid. Based on the results, the study also discusses various implications, such as relying on income much more, using hydropower much more efficiently, and benefiting from the spillover effect of technological innovations related to globalization and foreign trade, for solving environmental problems for Turkey policymakers.

By following up a comprehensive approach, the study contributes to the literature in four ways: (i) this is the first study for Turkey that empirically examines the effects of life expectancy on environmental quality; (ii) the study uses recently developed time series techniques as AARDL and DARDL approaches. As noted by Ref. [44], using only the F-overall test in the traditional ARDL approach can

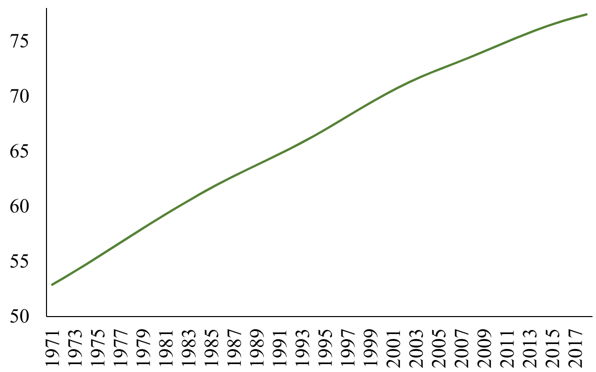

Fig. 1. Life expectancy (years) in Turkey.
Source: [15].

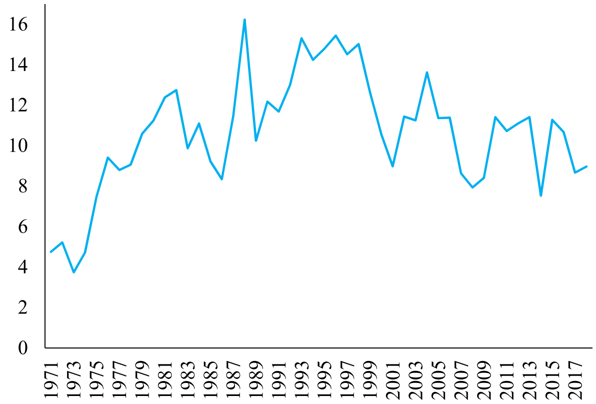

Fig. 2. Hydropower share (%) in Turkey.
Source: [42].

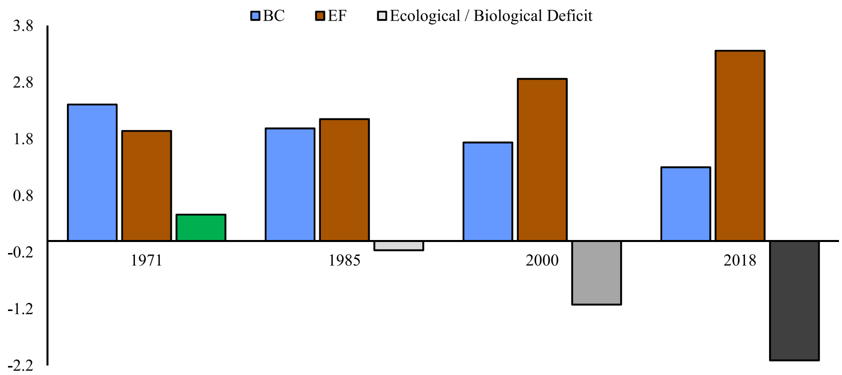

Fig. 3. EF and BC in Turkey (gha).
Source: [43].

lead to biased results in determining cointegration. Moreover, the traditional ARDL approach does not account for the effect of the shock in one variable on the other variable. AARDL and DARDL models can provide more robust findings by eliminating these shortcomings; (iii) Using AARDL and DARDL estimators, the study attempts to identify the turning point, at which income can reduce automatically the EF in Turkey for the first time. To the best knowledge, EKC studies except for [45], which have focused on the EF, have neglected the monetary value of the turning point for Turkey. So, the study may be useful in formulating a better argument for the validity of the EKC hypothesis; (iv) the study examines the effects of the independent variables on the EF in case of counterfactual shocks. Hence, the possible changes in the independent variables and their effects on the EF are examined with a simulation approach.

The study consists of five sections. Section 2 reviews the existing studies in the literature that examine the validity of the EKC hypothesis for Turkey and the effects of life expectancy and hydropower on the environment. Section 3 presents methods. Section 4 discusses the results and Section 5 concludes the study by including policy caveats and future directions as well.

2. Literature review

The pioneering study on the EKC hypothesis is conducted by Ref. [46], who investigate whether there is an inverted U-shaped relationship between income and pollution. Subsequently, the EKC hypothesis has become very popular among researchers [47–51]. In analyzing the EKC hypothesis, researchers have considered the effects of various variables, such as globalization, energy consumption, trade openness, human capital, and research and development investments on environmental degradation in different countries [e.g., [52–59], detailed literature can be found in [60]. Turkey is one of those countries that is often analyzed, and there is no consensus on the validity of the EKC. Many researchers studying Turkey have used the traditional ARDL method. For example [61], analyze the effect of population intensity on sulfur dioxide and particulate matter [62]. investigates the effect of trade openness and energy use on CO_2 emissions [63]. examines only the effect of income on CO_2 emissions without using an extra argument [64]. analyze the effect of oil and coal consumption on CO_2 emissions. These studies have generally focused on CO_2 emissions and reported that the EKC hypothesis is invalid for Turkey.

Another group of studies in the literature e.g., [65–68] has supported the validity of the EKC for Turkey. More recently [45,69], use the Johansen-Juselius cointegration test [70], perform QARDL [71], conducts a conventional ARDL approach, and [72] apply the RALS cointegration test to investigate various factors, such as shadow economy, foreign direct investment, and energy consumption, on the EF. The findings of these researchers also support the validity of the EKC hypothesis for Turkey.

In the EKC studies conducted for Turkey, only [22,72] have investigated the effect of hydropower consumption on CO_2 emissions and the EF, respectively. Apart from these studies, there has been no study that investigates the effect of life expectancy on environmental degradation in Turkey. Life expectancy has two different effects on environmental degradation [73]. First, the increase in environmental quality is directly related to life expectancy, as people, who expect to live longer, want to invest more in the future and green products. Second, in countries, where people's life expectancy increases, there is greater economic growth, and this growth may increase environmentally harmful production and consumption processes, leading to a deterioration in environmental quality. With the increase in life expectancy, a larger population also leads to a larger EF and environmental pressure.

Some studies have determined an increasing effect of life expectancy on environmental degradation [e.g., [30,74–76]]. In contrast [39], find that there is no association between life expectancy and EF. Also [73,77], conclude that an increase in life expectancy reduces EF.

Moreover, there is no consensus on the environmental effect of hydropower in the literature. Five out of ten studies have highlighted the environmental benefits of hydropower [78–82], but other studies have indicated that hydropower consumption does not affect environmental indicators [72,83–85]. Table 1 summarizes the studies that empirically test the effects of life expectancy and hydropower on the environment.

As a result, it can be concluded that (i) no researcher has yet investigated the effects of life expectancy on the EF for Turkey; (ii) [22,72] are the only studies to examine environmental effects of hydropower in Turkey, but they have neglected shocks of variables that are one-to-one; (iii) no study has investigated the environmental effects of these variables for Turkey using recently developed time series techniques (i.e., AARDL and DARDL). Hence, the objective of this study fills the gaps by focusing on the effects of life expectancy and hydropower on the EF for Turkey using novel time series approaches.

3. Methods

3.1. Data

By considering data availability and current literature, this study uses annual data between 1971 and 2018. Data for GDP, GDP^2, trade openness, and life expectancy at birth are collected from Ref. [15]. Data for hydropower energy consumption are gathered from Ref. [21]. Data for the EF are from Ref. [43]. The data for the KOF Globalization Index are derived from the KOF Swiss Economic Institute [87]. A summary of all variables is presented in Table 2.

All data for the variables are transformed into logarithmic form to examine the effects of the independent variables on the EF by

Table 1
Literature on the relationship of life expectancy and hydropower with the environment.

Author	Countries	Data	Variables	Method	Result	EKC
Panel A. Life Expectancy-Environment Relationship						
[30]	15 Asian	1971–2014	EF || LF, KOF, URB, EC	Seemingly unrelated regression	KOF reduces EF LF increases EF	Valid
[39]	8 Asian	1990–2015	EF || GDP, REC, LE, POP	*CS*-ARDL	No relationship between LF and EF.	Valid
[73]	15 MENA	1975–2007	EF || GDP, EC, LF	Pedroni cointegration	LF reduces EF	Valid
[74]	Selected 10	1996–2018	CO_2 || LF, EC, IND, EX, FDI, POP	GLS	LF increases CO_2	–
[75]	N-11	1990–2018	EF || GDP, REC, LF	Panel quantile regression	LF has a positive effect on EF	N-shaped
[76]	10 Newly Industrialized	1990–2018	EF || GDP, IND, URB EC, LF	PMG	LF increases $PM_{2.5}$	–
[77]	Selected 11	1971–2007	EF || GDP, URB, IND, LF, EC	ARDL	LF reduces EF for Paraguay	Invalid
[86]	Algeria	1980–2017	EF || GDP, EC, LF	ARDL	LF increases EF	–
Panel B. Hydropower-Environment Relationship						
[22]	Turkey	1974–2014	CO_2 || GDP, HECP, REC, URB	ARDL	HECP does not affect CO_2	Valid
[72]	Turkey	1970–2017	EF || GDP, HECP, NR	RALS	HECP does not affect the EF	Valid
[78]	Bangladesh	1980–2015	CO_2 || FDI, GDP, HECP, EI, LC, OC	ARDL	HECP reduces EF	Invalid
[79]	Sudan	1990/Q1-2018/Q1	EF || GDP, HECP, URB, NR, IND	Wavelet Coherence	HECP reduces EF	–
[80]	28 European Union	1990–2018	CO_2 || GDP, HECP, URB, FF	Pooled OLS	HECP reduces CO_2	–
[81]	India	1980–2019	CO_2 || GDP, HECP, EI	ARDL	HECP reduces CO_2	–
[82]	China and India	1971/Q1-2017/Q4	EF || HC, HECP, NR, URB, BIO	QARDL	HECP reduces EF in China	–
[83]	China	1965–2016	CO_2 || GDP, HECP	ARDL	HECP does not affect CO_2	Invalid
[84]	Selected 6	1965–2016	EF || GDP, HECP	Fourier ARDL	HECP does not affect the EF	Invalid
[85]	China and India	1980–2016	CO_2 || FDI, HECP	BARDL	HECP has no effect	–

using comparable figures.

3.2. Methodology

Fig. 4 presents the applied methodology in this study.

A total of five-step methodology is used to investigate the effects of life expectancy and hydropower energy on the EF of Turkey as follows.

- First, the dataset is collected from the data providers, which are presented in Table 2.
- Second, preliminary statistics of the variables are investigated. In this context, descriptive statistics and correlation matrix are examined.
- Third, the FADF test is applied to reveal the stationarity of the variables [88,89].
- Fourth, the cointegration is examined using the AARDL test [90]. In addition, the AARDL approach is applied to estimate the short-term and long-term coefficients.
- Fifth, the DARDL approach is conducted [91]. In this context, short-term and long-term coefficients are estimated first. Later, counterfactual shocks are applied to examine the possible effects of the statistically significant variables on the EF for future periods. Also, diagnostic tests are performed for both AARDL and DARDL.

Consistent with the above methodology, the study applies the main empirical model as shown in Eq. (1):

$$lnEF = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln GDP_t^2 + \beta_3 \ln HECP_t + \beta_4 \ln TO_t + \beta_5 \ln KOF_t + \beta_6 \ln LF_t + \varepsilon_t \tag{1}$$

where lnEF, lnGDP, lnGDP^2, lnHECP, lnTO, lnKOF, and lnLF represent the logarithm series of the ecological footprint, GDP, GDP square, hydropower consumption, trade openness, KOF globalization index, and life expectancy at birth, respectively.

Based on the EKC hypothesis, lnEF increases with economic growth at the first stage ($\beta_1 = \frac{\partial lnEF}{\partial lnGDP} > 0$); however, the lnEF decreases with the development of cleaner technologies and the increase of people's environmental awareness while economic growth increases at later stages ($\beta_2 = \frac{\partial lnEF}{\partial lnGDP^2} < 0$). In this way, an inverted U-shaped relationship is obtained and the EKC hypothesis is considered valid.

Besides, an increase in hydropower energy consumption can make a decreasing effect on the EF ($\beta_3 = \frac{\partial lnEF}{\partial lnHECP} < 0$) because it is a type of renewable energy. However, it may not be effective on the lnEF in some countries due to its small share of total energy consumption (Pata, 2018a). Also, hydropower plants installed on stream beds can harm nature and have a negative effect on the EF ($\beta_3 = \frac{\partial lnEF}{\partial lnHECP} > 0$) [92].

Moreover, β_4 ($\frac{\partial lnEF}{\partial lnTO}$) and β_5 ($\frac{\partial lnEF}{\partial lnKOF}$) can have different values. The environmental effect of trade openness and globalization can be varied depending on the technique effect, the composition effect, and the scale effect. In the scale effect stage, trade and globalization have negative effects on the environment. The composition effect states that pollution initially increases and then decreases due to the change in economic structure toward the service sector. The technique effect shows a decrease in pollution with increasing foreign trade and globalization. The intensity of clean technologies applied in the context of trade openness and globalization activities, the increasing level of environmental awareness, and the implementation of strict or flexible environmental regulations can have a negative effect on the lnEF. Many globalization indices have been developed. However, the KOF Globalization Index is the most comprehensive of them. The KOF globalization index, which covers 203 countries and regions [87], is a broad index that includes political, social, and economic relations [93]. Since globalization is a phenomenon that affects human habitats around the world due to these three factors [94], the KOF index is crucial in this study.

Furthermore, β_6 ($\frac{\partial lnEF}{\partial lnLF}$) can have two different situations. In the first, where life expectancy is high, people attach great importance to strict environmental policies to protect both their generation and the next generation. Therefore, people make more environmental investments to live longer. In this case, this variable has a positive effect on the environment ($\beta_6 = \frac{\partial lnEF}{\partial lnLF} < 0$). In the other case, as life expectancy increases, people's desire and speed to accumulate physical and human capital increases. This has a negative effect on the environment ($\beta_6 = \frac{\partial lnEF}{\partial lnLF} > 0$).

3.2.1. FADF unit root test

In [95,96], structural breaks are endogenously specified. However, endogenous determination leads to biased results when the

Table 2
Definition of the variables.

Symbol	Variable	Unit	Source
EF	Ecological footprint	Per capita, gha	[43]
LF	Life expectancy at birth	Years	[15]
HECP	Hydropower consumption	Per capita, tones oil equivalent	[21]
GDP	Gross domestic product	Per capita, constant 2010 USD	[15]
TO	Trade openness	% of GDP	[15]
KOF	KOF globalization index	Basis points between 0 and 100	[87]

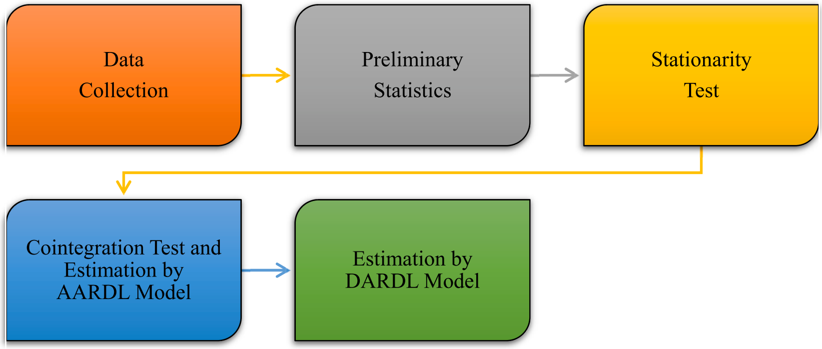

Fig. 4. Empirical methodology.

breaks are more than given and the transitions are smooth. Unit root tests using Fourier functions have been developed to eliminate this problem [88,89]. The basic logic of these tests is to use a low-frequency component in series, where one or more structural breaks occur, by using the Fourier approximation, and obtain structural breaks in this way.

3.2.2. Cointegration and AARDL approach

[97], one of the traditional cointegration tests, examines only the relationship between two variables. The test of [98] gives better results than Engle & Granger (EG) test and allows the analysis of the cointegration relationship between more than two variables. However, in such traditional cointegration tests, the series must be integrated with order one (I(1) to determine the long-term relationship [99]. find that it is not necessary for the variables to be equally integrated to determine the relationship between the variables and developed the ARDL approach, which is based on some basic assumptions: the dependent variable must be I(1), the independent variables must be I(0) or I(1), and there must be no degenerate cases. In the ARDL bounds test, researchers calculate two statistical values (i.e., F and t_{DEP}). The F test analyzes the significance of all variables, while the t_{DEP} test investigates only the significance of the dependent variable. To eliminate the degenerate cases that signify the absence of the cointegration relationship, the dependent variable must be found to be stationary in the first difference I(1) [90].

There are two degenerate cases. Degenerate cases #1 and #2 mean that the lagged values of the independent and dependent variables are insignificant, respectively. Since the F-test is applied to all variables, the significance of the dependent or independent variables is not tested individually. Therefore, the *t*-test should be performed to examine the degenerate cases of the dependent variable [44]. propose the BARDL approach and abandon the assumption that the dependent variable is I(1). In addition to the F and t_{DEP} tests, the BARDL approach offers an additional test (F_{IND}) that can be applied to the independent variables. If the result of the three tests (F, t_{DEP}, and F_{IND}) is significant, a cointegration relationship is inferred. The critical values for the t_{DEP} and F tests can be obtained from Refs. [99,100], respectively. The BARDL approach is implemented with three independent variables [90]. calculate the critical values of the F_{IND} test for more than three variables and referred to this approach as AARDL. In this approach, the cointegration relationship can be tested using Eq. (2).

$$\Delta \ln EF_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1k} \Delta \ln EF_{t-i} + \sum_{i=0}^{l} \alpha_{2k} \Delta \ln GDP_{t-i} + \sum_{i=0}^{m} \alpha_{3k} (\Delta \ln GDP_{t-i})^2 + \sum_{i=0}^{n} \alpha_{4k} \Delta \ln HECP_{t-i} + \sum_{i=0}^{p} \alpha_{5k} \Delta \ln TO_{t-i} + \sum_{i=0}^{r} \alpha_{6k} \Delta \ln KOF_{t-i} + \sum_{i=0}^{s} \alpha_{7k} \Delta \ln LF_{t-i} + \varphi_1 \ln EF_{t-1} + \varphi_2 \ln GDP_{t-1} + \varphi_3 (\ln GDP_{t-1})^2 + \varphi_4 \ln HECP_{t-1} + \varphi_5 \ln TO_{t-1} + \varphi_6 \ln KOF_{t-1} + \varphi_7 \ln LF_{t-1} + e_t \quad (2)$$

The test statistics applied to determine cointegration according to the AARDL model are presented below.

i) F-test applied to all (i.e., dependent and independent) variables

$H_0: \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = \varphi_7 = 0$

ii) *t*-test applied to the dependent variable (t_{DEP})

$H_0: \varphi_1 = 0$

iii) F-test applied to independent variables (F_{IND})

$H_0: \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = \varphi_7 = 0$

If the F and F_{IND} tests are significant, but t_{DEP} is insignificant, degenerate case #1 occurs. When the F and t_{DEP} tests are significant, but F_{IND} is insignificant, degenerate case #2 occurs. Degenerate cases mean that there is no cointegration.

3.2.3. DARDL approach

The ARDL models can be complicated by including series in the analysis at level, first difference, and lagged first difference [91]. develop the DARDL method to eliminate this complexity. In this method, the positive and negative effects of the independent variables on the dependent variable can be examined [101]. The equation of the DARDL model can be given in Eq. (3):

$$\Delta \ln EF_t = \alpha_0 + \lambda_1 \ln EF_{t-1} + \lambda_2 \ln Y_{t-1} + \delta_1 \Delta \ln Y_t + \lambda_3 \ln Y^2{}_{t-1} + \delta_2 \Delta \ln Y^2{}_{t-1} + \lambda_4 \ln HECP_{t-1} \tag{3}$$

$$+\delta_3 \Delta \ln HECP_t + \lambda_5 \ln TO_{t-1} + \delta_4 \Delta \ln TO_t + \lambda_6 \ln LF_{t-1} + \delta_5 \Delta \ln LF_t + \lambda_7 \ln KOF_{t-1} + \delta_6 \Delta \ln KOF_t + u_t$$

In Eq. (3), α_0 is the constant term, λ_{1-7} is the long-term coefficients, and δ_{1-6} is the short-term coefficients.

4. Result

4.1. Preliminary statistics

Table 3 presents descriptive statistics of the variables that include 48 yearly observations.

According to Table 3, the values of lnEF vary from 1.75 to 3.53, lnGDP from 155.4 billion to 1250.5, lnHECP from 4.24 to 6.75, lnTO from 3.22 to 31.2, lnLF from 52.89 to 77.44, and lnKOF from 40.27 to 72.14. Based on statistics and p-values of [102], the null hypothesis of normality can be rejected for lnGDP, lnGDP^2, lnHECP, and lnKOF at the 10% significance level, while lnEF, lnTO, and lnLF are normally distributed. Also, Table 4 presents the correlation matrix for the variables.

According to Table 4, there is a relatively high correlation between the EF and independent variables. All independent variables have an over 80% correlation with the EF. Hence, it can be stated that the independent variables can be used in empirical modeling to estimate the EF.

4.2. Unit root test results

To apply the AARDL and DARDL models, it must be determined that the series are not stationary at the second difference I(2). The FADF is used to examine the stationarity characteristics of the variables and the results are presented in Table 5.

The FADF results show that lnHECP, lnTO, and lnLF are stationary at level. The other four series become stationary at their first difference. Consequently, any series is not I(2) and the dependent variable (i.e., lnEF) is I(1). Therefore, it is appropriate to apply ARDL and its derivative approaches.

4.3. Cointegration results

The AARDL cointegration results are presented in Table 6.

4.4. AARDL and DARDL results

The AARDL of [90] and the DARDL of [91] are used to determine the long- and short-term relationship between the series. The accuracy of the results is strengthened by using two estimators. Table 7 shows both AARDL and DARDL estimation results.

LnGDP is positive and lnGDP^2 is negative in both estimators, implying the validity of the EKC hypothesis. The turning point, at which income begins to reduce lnEF is USD 20,571 in the AARDL and USD 19,914 in the DARDL. Turkey's GDP per capita in 2018 is USD 15,186 and this value is far behind the identified turning points. Only Acar and Asici (2017) analyze the TP, at which EF begins to decline as income increases for Turkey, and they obtain different results for lnEF of consumption and production (see Appendix Table 1A). This study supports the finding of [45] that the TP for lnEF of consumption is outside the sample period.

In addition, lnHECP does not affect pollution in the long run. One possible reason is that the share of hydropower in total energy consumption is small and it is not used effectively. This result is consistent with the findings of [22,72], who also examine Turkey.

Table 3
Descriptive statistics.

Variables	lnEF	lnGDP	lnGDP^2	lnHECP	lnTO	lnLF	lnKOF
Mean	2.58	508.15	349,736.10	5.96	16.96	66.37	56.47
Minimum	1.75	155.41	24,151.81	4.24	3.22	52.89	40.27
Maximum	3.53	1250.49	1,563,713.00	6.75	31.20	77.44	72.14
Std. Dev.	0.49	305.72	404,993.50	0.66	7.70	7.47	11.27
Jarque-Bera	3.29	6.65	25.01	10.72	3.60	3.16	4.64
Probability	0.193	0.036	0.000	0.005	0.166	0.206	0.098
Observations	48	48	48	48	48	48	48

Table 4
Correlation matrix.

	lnEF	lnGDP	lnGDP^2	lnHECP	lnTO	lnLF	lnKOF
EF	1.00						
GDP	0.94	1.00					
GDP^2	0.86	0.97	1.00				
HECP	0.83	0.74	0.61	1.00			
TO	0.82	0.81	0.70	0.83	1.00		
LF	0.94	0.92	0.82	0.89	0.93	1.00	
KOF	0.94	0.91	0.80	0.85	0.92	0.98	1.00

Table 5
FADF unit root test results.

Variable	Level			First Difference		
	Test stat	Frequency (lag)	Min SSR	Test stat	Frequency (lag)	Min SSR
lnEF	1.888	1(2)	0.220	−7.940***	5(1)	0.168
lnGDP	1.372	5(1)	0.061	−7.805***	5(0)	0.059
lnGDP^2	1.590	5(1)	19.604	−7.679***	5(0)	19.213
lnHECP	−3.156**	5(2)	1.952	–	–	–
lnTO	−5.149***	4(8)	1.224	–	–	–
lnLF	−3.245**	3(8)	0.000	–	–	–
lnKOF	−0.669	1(1)	0.015	−5.470***	1(1)	0.015

***and ** denote significance at 1% and 5% levels, respectively.

Table 6
AARDL results.

Model	Tests		Test statistics		Result	
Dependent variable: lnEF AARDL(1,0,0,0,0,0,2)	F		7.433***		Cointegration	
	t_{DEP}		−6.233***			
	F_{IND}		4.799***			
Critical value (k=6)	**1%**		**5%**		**10%**	
	lower	**upper**	**lower**	**upper**	**lower**	**upper**
F stat.	3.54	4.93	2.59	3.77	2.19	3.25
t_{DEP} stat.	−2.88	−3.99	−2.27	−3.28	−1.99	−2.94
F_{IND} stat.	3.35	5.34	2.37	4.02	1.94	3.42

*** denotes significance at the 1% level. K: number of independent variables.
The findings show that F, t_{DEP}, and F_{IND} test statistics are significant at the 1% level, which indicates that there is a cointegration relationship between the series.

Besides, a 1% increase in lnTO and lnKOF reduces environmental pollution by 0.036% and 0.552%, respectively. These empirical results show that trade openness and globalization have a reducing effect on the EF. The technique effect is dominant for Turkey compared to composition and scale. Thanks to globalization and foreign trade, Turkey can transfer environmentally friendly technologies and thus engage in cleaner production. The information transfer network provided by globalization improves environmental awareness and can reduce the EF. In contrast to Ref. [103], the finding of this study on the environmental role of globalization is compatible with Shahbaz et al. (2013).

Moreover, a 1% increase in lnLF increases the lnEF by 0.90–1.34%. The increase in life expectancy is associated with greater environmental pressures and higher population size. A positive and high coefficient on life expectancy indicates that people's desire to accumulate physical capital is increasing and the population is demanding more polluting goods and services. A rise in life expectancy leads to an increase in consumption in the Turkish community. Although there is no study examining the environmental effects of life expectancy in Turkey, the findings of this study are compatible with the outcomes of [30] for 15 Asian countries [74], for 10 selected countries, and [86] for Algeria.

Furthermore, for the inferences based on the ARDL models to be valid, the error terms and the coefficients must satisfy certain assumptions, and these assumptions can be tested with diagnostic tests. The results of the diagnostic tests show that there are no heteroskedasticity, non-normality, and specification problems in the ARDL models. The cumulative sum and cumulative sum of squares tests also show that the coefficients of the AARDL and DARDL models are stable (see Fig. 1A and Table 2A in the Appendix).

In addition to the coefficient estimation by the AARDL model, counterfactual shocks of ±1% are applied to the independent variables that have a statistically significant effect on the EF by exploiting the capabilities of DARDL.

±1% counterfactual shocks are applied to lnGDP. Fig. 5 shows that −1% shock provides approximately a 7% decrease in the lnEF, whereas +1% shock causes approximately a 7% increase in the lnEF.

Table 7
Results of AARDL and DARDL estimators.

Variables	AARDL Coefficient	t-Statistic	Prob.	DARDL Coefficient	t-Statistic	Prob.
Panel A. Short-Run Coefficients						
ΔlnGDP	8.133***	2.840	0.007	6.485	1.38	0.177
$\Delta lnGDP^2$	−0.399***	−2.526	0.016	−0.306	−1.18	0.248
ΔlnHECP	0.015	0.698	0.490	0.008	0.27	0.785
ΔlnTO	−0.030	−1.138	0.262	−0.038	−0.86	0.395
ΔlnKOF	−0.578***	−2.584	0.014	−0.521	−1.39	0.175
ΔlnLF	100.203***	5.146	0.000	102.294***	2.86	0.008
ΔlnLF(-1)	−85.025***	−4.650	0.000	−85.374***	−2.74	0.010
ECT(-1)	−1.202***	−8.648	0.000	−1.220***	−5.24	0.000
Panel B. Long-Run Coefficients						
lnGDP	7.231***	5.259	0.000	8.336**	2.51	0.017
$lnGDP^2$	−0.364***	−5.015	0.000	−0.421**	−2.54	0.020
lnHECP	0.007	0.420	0.677	−0.003	−0.11	0.911
lnTO	−0.036**	−2.369	0.023	−0.051**	−1.99	0.056
lnKOF	−0.552***	−2.822	0.008	−0.665**	−2.15	0.040
lnLF	0.902**	2.060	0.047	1.341**	2.13	0.041
C	−36.177***	−5.860	0.000	−42.604***	−2.89	0.007
Turning point	USD 20,571			USD 19,914		

*** and ** denote significance at 1% and 5% levels, respectively.

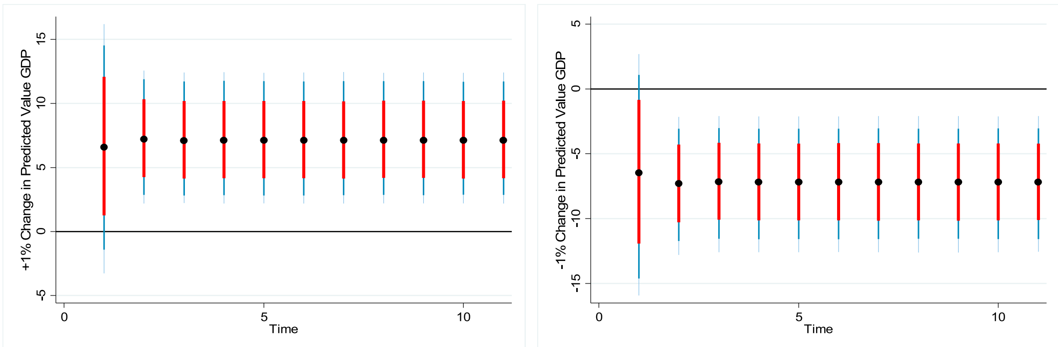

Fig. 5. Effects of ±1% Counterfactual Shocks in lnGDP on the EF.

±1% counterfactual shocks are applied to lnTO. Fig. 6 indicates that −1% shock provides approximately 0.5% decrease in the lnEF, whereas +1% shock causes approximately 0.5% increase in the lnEF.

±1% counterfactual shocks are applied to lnLF. Fig. 7 demonstrates that −1% shock provides approximately 0.5% decrease in the lnEF, whereas +1% shock causes approximately 0.5% increase in the lnEF.

Moreover, ±1% counterfactual shocks are applied to lnKOF. Fig. 8 shows that −1% shock provides approximately a 5% decrease in the lnEF, while +1% shock causes approximately a 5% increase in the lnEF. The overall results of both the AARDL and DARDL models

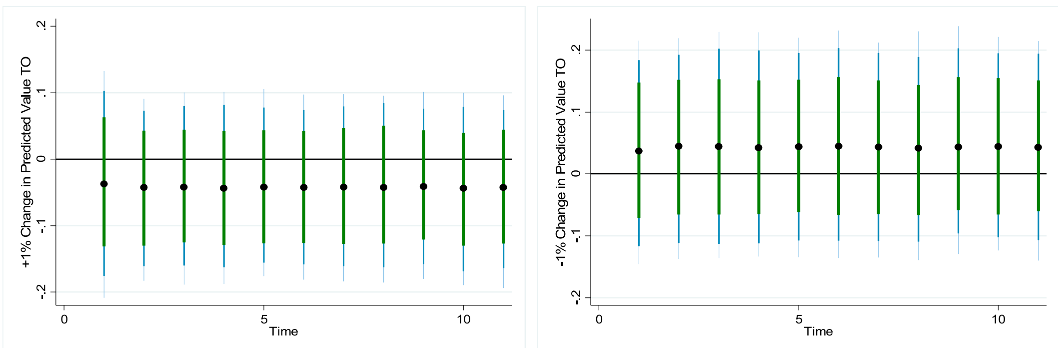

Fig. 6. Effects of ±1% Counterfactual Shocks in lnTO on the EF.

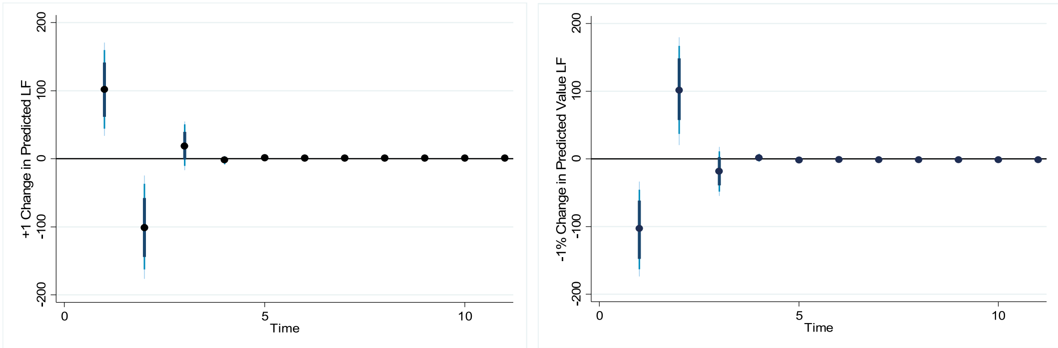

Fig. 7. Effects of ±1% Counterfactual Shocks in lnLF on the EF.

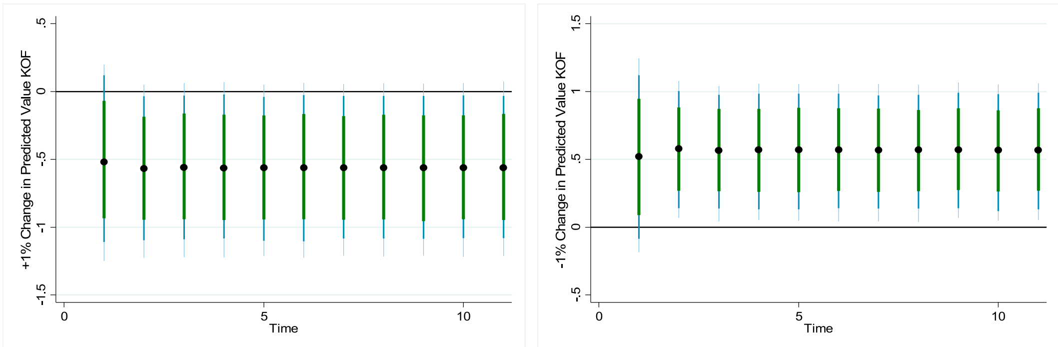

Fig. 8. Effects of ±1% Counterfactual Shocks in lnKOF on the EF.

are summarized in Fig. 9.

5. Conclusion and policies

5.1. Conclusion

Environmental problems have been increasing day by day. This has been affecting societies and people negatively. Accordingly, various studies have focused on the causes (i.e., potential drivers) of such a condition. By differentiating many studies in the literature, the study focuses on investigating the effects of life expectancy and hydropower consumption by controlling also income, globalization, and trade openness on the EF in Turkey under the EKC hypothesis approach. In this context, the study applies both novel AARDL and DARDL methods to research the relationship between the mentioned variables for the period of 1971–2018.

Following up on a comprehensive approach, the study provides significant insights. In summary, the study mainly reveals that life expectancy has an increasing effect on environmental pollution. This result has the same direction as the studies of [30] for 15 Asian countries [74], for 10 selected countries, and [86] for Algeria. Also, the study proves that globalization and trade openness have a curbing effect on environmental pollution, which is consistent with the study of [104]. Besides, economic growth reduces environmental pollution. However, Turkey is far from the required income level to benefit from the income in reducing environmental pollution. This determination is consistent with the study of [45]. Moreover, hydropower does not affect environmental pollution. This finding is consistent with the studies of [22,72], who examine also Turkey. Hence, by considering the results from novel methods (i.e., AARD & DARDL) as well as consistent with the studies, the study provides robust results.

5.2. Policy caveats

By considering the above-summarized robust and consistent results, the study discusses various policy caveats. A 1% increase in life expectancy increases the EF by 1.341%. The main reason for such a result is that life expectancy in Turkey has increased significantly compared to previous years. It reached 77.69 years in 2019, which is higher than the global average [15]. As life expectancy increases, people are engaged in more environmentally damaging production and consumption activities. In addition, increased life expectancy may increase demand for fossil fuels through additional transportation activities, energy use, and production. Turkey should encourage its population to engage in environmentally conscious educational programs, promote energy-saving mechanisms, and ensure the transmission of clean energy between generations to prevent the negative effects of increasing life expectancy.

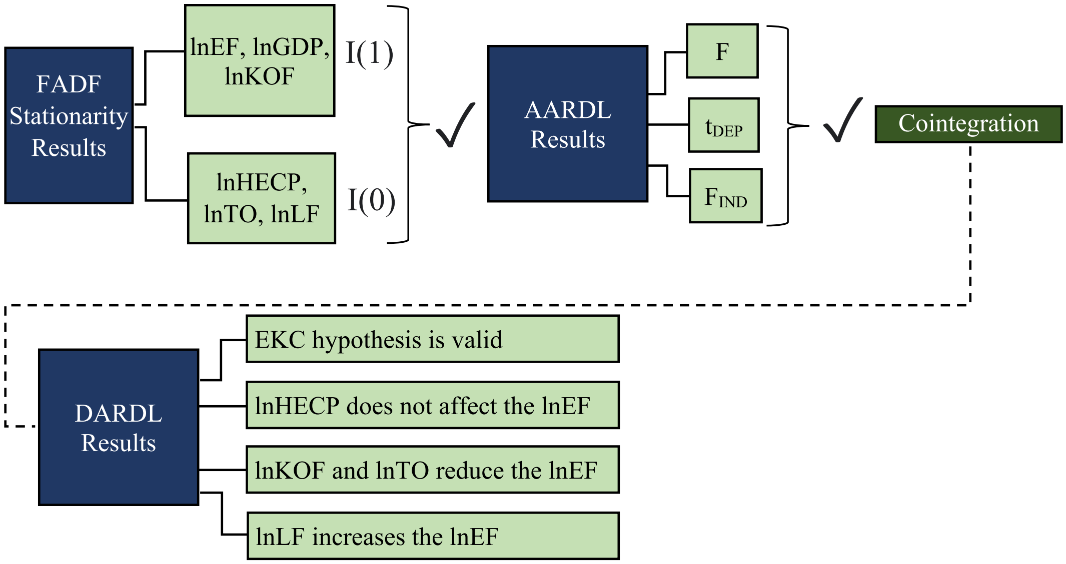

Fig. 9. Summary of the empirical outcomes.

Hydropower does not affect environmental pollution. In Turkey, fossil fuel consumption has a share of 87% of total energy consumption [15]. The effect of renewable energy consumption on pollution is not so powerful. Therefore, reducing fossil fuel and increasing renewable energy has great importance in terms of decreasing environmental pollution, especially carbon footprint. In Turkey, positive activities have been carried out in recent years and the country ranks 9th in the world with 31 GW of installed hydropower capacity. Turkish policymakers have announced that 1036 plants with an installed capacity of 5524 MW will be supported in 2022 [105]. Hydropower plants take place among them. However, it is also very important that the riverbeds and natural habitats of the region should not be damaged while the hydropower plants are built. The authorities must consider these issues. The problem Turkey faces is the low share of renewable energy in total energy and the inefficient use of these resources. Turkey should import and employ high-quality and environmentally friendly technologies that increase efficiency in the use of clean energy. Also, Turkish policymakers should implement measures such as renewable energy incentives and carbon tax to reduce the share of fossil fuels in the total energy and promote renewable energy more efficiently so that the carbon footprint can be reduced.

Moreover, a 1% increase in globalization and trade openness decreases EF by 0.665% and 0.051%, respectively. The meaning of these findings is that environmental pollution has decreased due to the import and transfer of clean energy technologies in the context of globalization activities in Turkey. Based on this point, increasing foreign trade transactions is of great importance for reducing environmental pollution. This is because small enterprises in the trade sector do not have the opportunity to produce and learn clean technologies by themselves. These companies need to acquire technology through international trade. In this way, on the one hand, the volume of international trade is increased and economic growth is stimulated, and on the other hand, production activities are carried out using clean technologies.

Furthermore, empirical results reveal the validation of the EKC hypothesis in Turkey and define the turning point between USD 19,914 and USD 20,571. However, Turkey is far away from such a per capita income so that it can benefit from the positive effect of the EKC hypothesis on sustaining environmental quality by decreasing environmental pollution.

Overall, it is important for sustainability to positively or negatively affect ecological life while economic growth is occurring and life expectancy is increasing. Therefore, Turkey policymakers should give importance to renewable energy policies, use hydropower much more efficiently, improve educational activities, increase income level, and support health spending to develop sustainable environmental factors while supporting the increase in life expectancy. Also, Turkey should rely on benefits from the spillover effect of technological innovations related to globalization and foreign trade to significantly reduce environmental pollution. They should develop strategies and policies in this direction. Technological developments in the world based on clean energy, especially in the fields of health and education, should be followed by Turkey. The necessary budgetary resources should be allocated for the use of these technologies and for the education of the people, who will use them. This will both increase life expectancy as well as create a sustainable environment for future generations.

5.3. Constraints and future research

The study has a comprehensive framework from both theoretical and empirical perspectives. In this way, the study answers the research questions; (i) life expectancy increases environmental degradation; (ii) hydropower consumption does not promote environmental sustainability; (iii) there is an inverted U-shaped relationship between income and the EF in Turkey as suggested by the EKC hypothesis. Hence, the study provides important findings about the effect of life expectancy and hydropower consumption on environmental degradation and provides robust and dependable findings for Turkish policymakers from the both theoretical and empirical sides.

Nevertheless, the study has some constraints. The main constraint is that this study focuses only on Turkey. So, other countries similar to Turkey, which have an ecological deficit, can be examined by following the methodology of this study. Also, the data of this study ended in 2018. Thus, more recent data is needed and new analysis can be applied with the announcement of more recent data. Besides, this study uses two novel time series models, such as AARDL and DARDL. So, other techniques (e.g., machine learning and wavelet multiple local correlation, can be used in new studies to rich the literature in terms of the applied methodology.

Author contribution statement

Ugur Korkut Pata: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, wrote the paper. Suleyman Yurtkuran: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, wrote the paper. Zahoor Ahmed: wrote the paper. Mustafa Tevfik Kartal: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

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Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

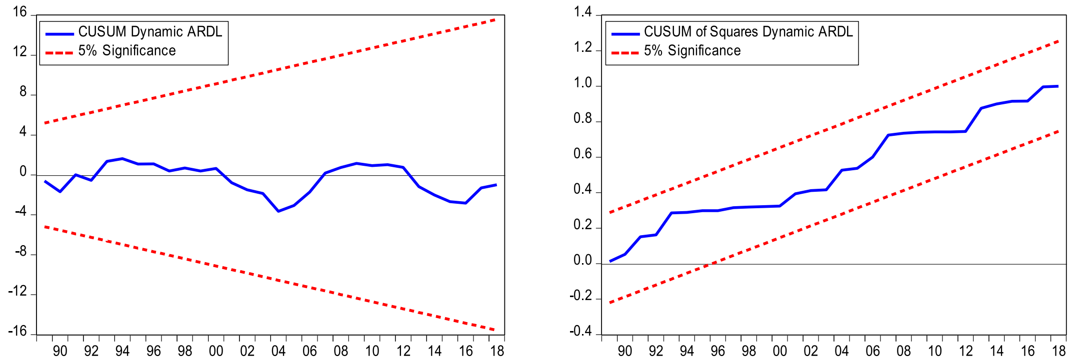

Fig. 1A. CUSUM and CUSUMSQ Results

Table 1A
EKC studies on Turkey and the defined monetary values of the turning point

Author	Dependent Variable	Monetary value of the TP	Highest per capita GDP
[22]	CO_2	USD 13,523-USD 14,077	USD 13,312 in 2014
[45]	EF	TL 1274 for production TL 2934 for consumption	TL 1437 in 2008
[65]	CO_2	USD 9920	TP is outside from the sample period.
[66]	CO_2	USD 16,648	TP is outside from the sample period.
[67]	CO_2	USD 27,748	USD 14,933 in 2014
[106]	CO_2	USD 14,360	USD 13,312 in 2014

Table 2A
Results of Diagnostic Tests

Diagnostic Test	AARDL		DARDL	
	Test statistics	p-value	Test statistics	p-value
BG-LM	0.270	0.765	0.090	0.914
BPG	0.597	0.791	0.729	0.730
White	0.713	0.694	0.594	0.849
ARCH	0.092	0.763	0.717	0.401
Ramsey Reset	1.251	0.219	1.267	0.215
Jarque-Bera	0.114	0.944	0.679	0.712

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