Letters in Spatial and Resource Sciences (2023) 16:3
https://doi.org/10.1007/s12076-023-00328-w

ORIGINAL PAPER

The effect of mineral saving and energy on the ecological footprint in an emerging market: evidence from novel Fourier based approaches

Emrah Sofuoğlu[1] · Dervis Kirikkaleli[2]

Received: 13 January 2023 / Accepted: 2 February 2023

Abstract
Environmental degradation has been one of the hot topics discussed since the 1980s. In the literature, CO_2 emissions are generally used to represent environmental degradation. However, in this study, environmental degradation is examined in the context of ecological footprint. The study aims to investigate the effect of economic growth, energy consumption, and mineral saving on the ecological footprint in Turkey for the period of 1975–2017. For this purpose, the bootstrap autoregressive distributed lag model with a Fourier function (FARDL) method is utilized to test the long-term relationship between the variables. The findings indicate a long-term relationship between the variables. In addition, long-run estimation results based on the FARDL model show that economic growth and mineral saving increase the ecological footprint in Turkey. The conclusion discusses these findings and presents long-term policy recommendations for Turkey.

Keywords Ecological footprint · Environmental economics · Fourier ARDL · Sustainable development · Turkey

JEL Classification Q43 · Q53 · Q54 · Q56

✉ Dervis Kirikkaleli
dkirikkaleli@eul.edu.tr

Emrah Sofuoğlu
emrahsofuoglu@gmail.com

[1] Department of Economics, Faculty of Economics and Administrative Sciences, Kirsehir Ahi Evran University, 40100 Kırşehir, Turkey

[2] Department of Banking and Finance, Faculty of Economic and Administrative Sciences, European University of Lefke, 99700 Lefke, Northern Cyprus, Turkey

Published online: 24 February 2023

1 Introduction

Economic growth is one of the most critical targets for governments; however, these efforts have environmental consequences. Energy consumption is the most critical component of the economy and a key input to economic activities. However, the type of energy is essential in terms of environmental quality (Shahzad 2020). Manufacturing, agriculture and energy sectors, which are economic growth triggers, play an active role in increasing emissions (Abid 2015). The increase in fossil fuel-based energy consumption causes emissions (Judkins et al. 1993; Wuebbles and Jain 2001; Martínez-Zarzoso and Maruotti 2011) and ecological footprint (Ibrahiem and Hanafy 2020) to increase and leads to many environmental problems, especially climate change. For this reason, countries are looking for ways to achieve sustainable development, which could help improve their welfare without harming the environment.

Many indicators are used to represent environmental degradation. Generally, CO_2 emissions represent environmental degradation, such as climate change (Alvarado et al. 2019; Destek and Sarkodie 2019; Apergis et al. 2020). However, ecological footprint (EF) considers both production and consumption processes and focuses on different dimensions of environmental degradation (Dogan et al. 2020). EF gives a better idea than many indicators since it offers an inclusive perspective on environmental degradation (Galli et al. 2012; Al-Mulali et al. 2015). Therefore, it has recently been used in many studies examining environmental degradation (Bello et al. 2018; Solarin 2019; Nathaniel et al. 2020a, b; Alola et al. 2021). EF was first introduced by Wackernagel and Rees (1996) and referred to the area required for a sustainable population. For example, built land, forest land, carbon footprint, grazing land, cultivated land, and oceans are included in these calculations. In addition, it includes resource consumption and generated waste (Solarin and Bello 2018). Overall, EF focuses on meeting and replenishing the world's resource demand. Three leading indicators are generally used as determinants of EF in the literature. These are (i) economic growth, (ii) energy consumption, and (iii) globalization (Alper et al. 2022). In addition, many studies consider natural resources while explaining the effect of economic growth on EF (Hassan et al. 2019; Ahmed et al. 2020; Hussain et al. 2021; Nathaniel 2021; Zia et al. 2021; Jahanger et al. 2022).

To calculate EF, the Global Footprint Network (2022) focuses on how much biologically productive space is required to meet individuals' demands. If the computed footprint is less than the biocapacity, this is positive, and there is more than enough bio-space to meet the needs of that country. Conversely, if there is an ecological deficiency, the bio-capacity is insufficient to meet the demands. According to the calculations made by the Global Footprint Network (2018a, b), many countries in the world have an ecological deficit, and more than 85% of the world's population lives in countries with ecological deficits. Therefore, it is clear that EF should be included in the strategies and policies to solve environmental problems.

Turkey is the 8th largest economy among the European Union countries in 2020 (Statista 2020) and is responsible for 1.13% of the world's CO_2 emissions (Global Carbon Budget 2020). Therefore, Turkey's energy demand has increased

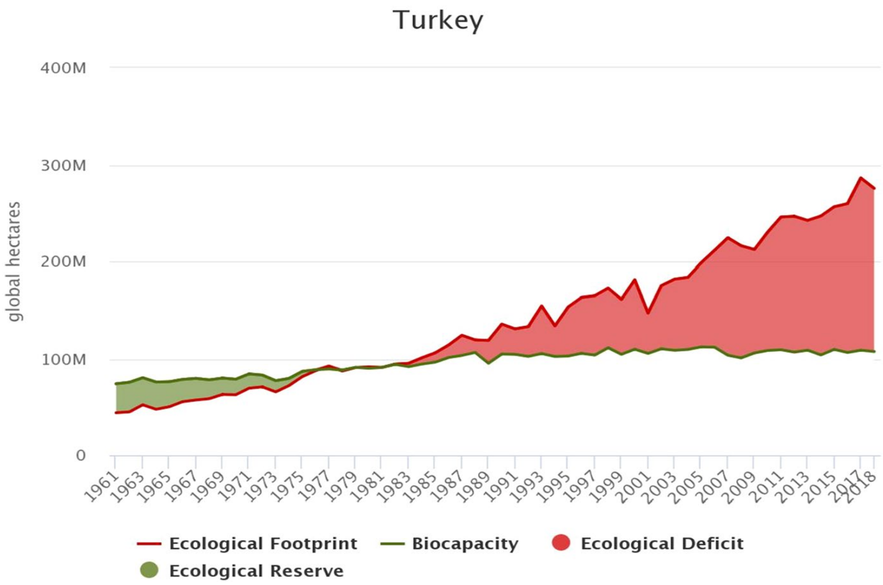

Fig. 1 Ecological footprint versus biocapacity (gha). *Source*: Global Footprint (2018a, b)

significantly as a developing country with an increasing population and rapid urbanization. In this context, the economy-environment interaction is essential in terms of environmental quality and the global climate change problem.

Figure 1 shows the ecological footprint of Turkey. While there was an ecological reserve in Turkey during the 1961–1980 period, there has been an ecological deficit since 1980. Turkey has adopted the open economy and export-based industrialization models since 1980. This structural change in the economy has inevitably

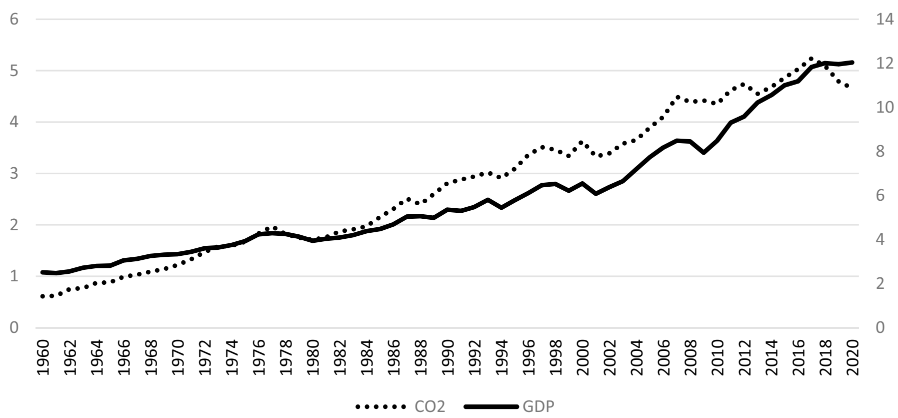

Fig. 2 Decoupling between GDP (per capita) and CO_2 (per capita). *Source*: Our World in Data (2022)

changed the environmental dynamics of the Turkish economy, and an ecological deficit has emerged.

Figure 2 shows the GDP and CO_2 emissions per capita. Accordingly, while GDP per capita has risen in the last few years, CO_2 per capita has decreased. There has been a decoupling between economic growth and CO_2 emissions since 2018. However, we have to see the future emissions to decide whether this divergence is temporary (due to COVID-19) or permanent.

The contribution of this study is to review Turkey's climate change policies in the context of ecological footprint. Reducing CO_2 emissions to combat climate change is not the only solution. In this context, examining the ecological footprint comprehensively will provide new tools to countries for long-term climate strategies. We also apply the FARDL bootstrap approach, which gives robust results for the small samples and considers structural breaks. Finally, to the best of our knowledge, this study is the first to examine the impact of mineral savings on environmental pollution in Turkey. This study suggests significant policy recommendations to Turkish policymakers to combat climate change, achieve net zero-emission targets by 2053 and adapt to European Green Deal.

This study examined the determinants of the ecological footprint in Turkey. For this purpose, we investigate the relationship between economic growth, energy consumption, mineral saving, and EF. The study consists of three parts. The first part introduces EF theoretically and discusses the current situation in Turkey. The second part presents a literature review on the relationship between ecological footprint and economic growth. In the third part, empirical analysis findings are reported. Finally, empirical findings are discussed, and some policy recommendations are suggested to policymakers.

2 Literature

Many studies consider economic growth as the primary trigger for climate change and environmental degradation. For this reason, in this part, studies that focus on the relationship between economic growth and EF are examined through different variables (globalization, energy consumption, human capital, natural resources, etc.).

In this section, the studies examining the relationship between EF and economic growth through different indicators are discussed. First, Ulucak and Bilgili (2018) re-tested the EKC hypothesis for low-middle and high-income countries, using the EF variable instead of CO_2 emissions to represent environmental quality. The results revealed that the EKC hypothesis is valid in all country groups. Danish et al. (2019) examined the relationship between economic growth and EF through human capital and biocapacity. The results reveal that while economic growth and biocapacity increase EF, human capital has a negative impact on it. According to Ahmed et al. (2020), there is a long-run relationship between economic growth, natural resources, urbanization, human capital and EF. In addition, natural resources and urbanization increase the ecological footprint, while human capital reduces environmental degradation. Udemba (2020), on the other hand, found a positive relationship between EF and economic growth and claimed that the scale effect is valid. According to the scale effect, especially developing countries ignore the environment to achieve economic growth in the first stages of economic development, so while economic growth increases, environmental quality decreases. In addition, he found that population is a Granger cause of EF and economic growth. Ahmad (2021) argued that while economic growth and urbanization increase EF, financial globalization and eco-innovative decrease it. In addition, the relationship between EF and economic growth supports the hypothesis of an inverted U-shaped EKC. Similarly, Kongbuamai et al. (2020) found bidirectional causality between economic growth, energy consumption and EF for ASEAN countries. They suggested lowering the EF, pointing to a shift towards renewable energy policies in this context. Ulucak et al. (2020) found that renewable and non-renewable energy, urbanization and natural resources reduce EF. However, economic growth increases EF. Li et al. (2022) investigated whether renewable energy reduces EF despite economic growth. According to empirical results, renewable energy contributes to economic growth and increases environmental quality. Furthermore, urbanization reduces the pressure of energy consumption on environmental quality. According to Khan and Hou (2021), energy consumption promotes economic growth and reduces environmental quality in the long run. However, tourism growth improves environmental quality in the long run. In this context, they suggested developing investment strategies for renewable energy production and consumption for IEA countries. Nathaniel et al. (2020a, b) determined that the relationship between economic growth and EF is different for each country. According to the empirical results, while economic growth reduces environmental degradation in Colombia, South Africa, and Turkey, it increases EF in Egypt, Indonesia, and Vietnam. In addition, it was determined that renewable energy improves environmental quality and trade is not harmful to the environment. Finally, they concluded that non-renewable energy consumption and urbanization are the most important determinants of environmental degradation. Another study by Nathaniel et al. (2020a, b) reached similar results regarding energy and urbanization. However, financial development increases environmental degradation. According to Zeraibi (2021), while higher renewable electricity generation capacity and technological innovations reduce EF, higher financial development and economic growth affect it negatively. However, Ahmed et al. (2021) claimed that financial development anc economic growth increases the ecological footprint in Japan. Ahmed et al. (2022a) also found that decreasing financial risk leads to lower EF in India. Uzar (2021) examined the relationship between economic growth and EF through institutional quality. According to the findings, while institutional quality reduces EF, economic growth and energy consumption increase it. However, Alper et al. (2022) reached the opposite result regarding economic growth and energy consumption. Accordingly, while economic growth and energy consumption decrease EF, economic globalization affects EF negatively. Ahmed et al. (2022b), found that economic growth increases EF. They also determined that democracy and environmental regulations increase ecological sustainability by decreasing EF. Adebayo et al. (2023) support the ecological footprint hypothesis through trade openness in MINT countries (Mexico, Indonesia, Nigeria, and Turkey).

In this section, studies related to Turkey are examined. First of all, Acar and Asıcı (2017) examined EF within the scope of EKC. The results support an inverted

U-shaped EKC hypothesis between production footprint and income. However, the EKC hypothesis is not supported for consumption, import and export footprints. According to Sharif et al. (2020), there is a bidirectional causality relationship between economic growth, renewable energy, non-renewable energy and EF. Koksal et al. (2020), on the other hand, examined EF in the context of the shadow economy, unlike the other studies in the literature. According to the findings, the shadow economy is a long-term determinant of EF in Turkey. Therefore, they emphasized that governments should tackle the shadow economy not only through tax concerns but also through environmental concerns. Gökmenoğlu et al. (2021) compared CO_2 emissions and EF in the context of financial development and military expenditure. They found a unidirectional causality relation from military expenditure to CO_2 and EF. They also support the destruction theory for Turkey. Özdemir and Çevikalp (2021) found a long-term relationship between EF, economic growth and technological change. Unlike the other studies, Gülmez et al. (2020) found a U-shaped causal relationship from energy consumption to ecological footprint which means EF first decreases and then increases due to growing energy consumption. Based on the findings, they claimed that Turkey achieved sustainable growth. For this reason, they suggest that Turkey should consider not only emissions but also ecological footprints in its environmental agenda. Table 1 presents detailed information about the studies examined above.

3 Data and methodology

The study aims to investigate the effect of economic growth, energy consumption, and mineral saving on the ecological footprint in Turkey. Based on this aim, the present study considers the following model:

$$EF_{it} = \beta_1 GDP_{it} + \beta_2 EC_{it} + \beta_3 MS_{it} + \varepsilon_{it} \quad (1)$$

where EF, GDP, EC and MS stand for ecological footprint, economic growth, energy consumption, and mineral saving, respectively. Ecological footprint data was obtained from Global Footprint Network. Energy consumption data was obtained from the BP Statistical World Review of Energy. Finally, GDP and mineral saving data were obtained from the World Bank database. All variables are in the logarithmic term.

Ordinary cointegration tests cannot be used where the variables are integrated to different degrees. Instead, Pesaran et al. (2001) proposed the Autoregressive Delay Distributed (ARDL) cointegration test. This test allows independent variables to be integrated at different degrees if the dependent variable is I(1). The ARDL approach considers the F and t statistics. The cointegration relationship is tested by comparing the test statistics with the lower and upper limits defined as I(0) and I(1). If the test statistic is greater than the critical upper bound values, the basic hypothesis of no cointegration is rejected. Equation (2) show the ARDL model for this study.

Table 1 Literature summary

Study	Sample	Period	Method
Acar and Aşıcı (2017)	Turkey	1961–2008	Johansen cointegration test
Ulucak and Bilgili (2018)	High, middle and low-income countries	1961–2013	Fully modified and continuously updated bias-corrected models
Danish et al. (2019)	Pakistan	1971–2014	ARDL
Udemba (2020)	Nigeria	1981–2018	ARDL & Granger causality
Khan and Hou (2021)	38 IEA countries	1995–2018	FMOLS
Ahmed et al. (2020)	China	1970–2016	Bayer-Hanck cointegration test & bootstrap causality
Kongbuamai et al. (2020)	ASEAN countries	1995–2016	Dumitrescu-Hurlin panel causality test
Ulucak et al (2020)	BRICS	1995–2016	FMOLS, DOLS
Sharif et al. (2020)	Turkey	1965:Q1-2017:Q4	Quantile ARDL
Köksal et al. (2020)	Turkey	1961–2014	Johansen cointegration test
Gökmenoğlu et al. (2021)	Turkey	1960–2014	FMOLS
Gülmez et al. (2020)	Turkey	1961–2016	ARDL
Öcal et al. (2020)	Turkey	1968–2016	ARDL
Nathaniel et al. (2020a, b)	CIVETS (Colombia, Indonesia, Vietnam, Egypt, Turkey, and South Africa)	1990–2014	Johansen Fisher and Pedroni panel cointegration tests
Nathaniel et al. (2020a, b)	The Middle East and North Africa	1990–2016	Johansen Fisher and Pedroni panel cointegration tests
Zeraibi et al. (2021)	Indonesia, Malaysia, the Philippines, Thailand, and Vietnam	1985–2016	CS-ARDL
Uzar (2021)	E-7 countries	1992–2015	AMG and CCEMG
Ahmad (2021)	G7 Countries	1980–2016	CS-ARDL
Özdemir and Çevikalp (2021)	Turkey	1961–2017	Bayer-Hanck combined cointegration approach
Alper et al. (2022)	Canada, China, Germany, Japan, India, Indonesia, Iran, Korea, Saudi Arabia, the USA	1970–2017	Fourier ARDL
Li et al. (2022)	120 countries	1995–2014	Panel threshold regression model

$$\Delta EF_t = \beta_0 + \beta_1 EF_{t-1} + \beta_2 GDP_{t-1} + \beta_3 EC_{t-1} + \beta_4 MS_{t-1} + \sum_{i=1}^{\rho-1} \varphi_i' \Delta EF_{t-i} + \sum_{i=1}^{\rho-1} \delta_i' \Delta GDP_{t-i} + \sum_{i=1}^{\rho-1} \emptyset_i' \Delta EC_{t-i} + \sum_{i=1}^{\rho-1} \vartheta_i' \Delta MS_{t-i} + e_t \quad (2)$$

where Δ is the first difference operator and ρ is the lag length. e_t represents the independent identically distributed disturbance term with zero mean and finite variance. The Akaike Information Criteria (AIC) determines the optimal lag length. According to Pesaran et al. (2001), the following hypotheses should be rejected by using the F test (F_A) and *t*-test (t) for the existence of a cointegration relationship.

$$H_{0A} : \beta_1 = \beta_2 = \beta_3 = 0 \quad (3)$$

$$H_{0B} : \beta_1 = 0 \quad (4)$$

McNon et al. (2018) modified Equation (3) and (4) to develop an additional *F*-test (F_B) that tests the main hypothesis.

$$H_{0C} : \beta_2 = \beta_3 = 0 \quad (5)$$

In order to confirm the cointegration relationship, all three basic hypotheses mentioned above should be rejected. McNon et al. (2018) does not make

Table 2 FADF unit root test results

Variables	k	FADF test statistics	FADF critical values	*F* test
EF	5	25.08[a]	−3.81	−4.91[b]
EC	5	8.46[a]	−2.93	2.82
GDP	5	0.63	−3.27	1.42
EC	2	2.10	−2.97	−2.81
		ADF test stat (level)		ADF test stat (Δ, first difference)
EF		0.35 (0.78)		−8.78[a]
EC		4.17 (1.00)		−2.44[b] (0.02)
GDP		6.73 (1.00)		−2.17[b] (0.03)
MS		−0.57 (0.46)		−5.10[a] (0.00)

ADF critical values (1%, 5%, 10%): −3.61, −2.93, −2.60

[a], [b], [c]Show statistical significany at 1%, 5%, %10, respectively

Table 3 Fourier ARDL test results

		Bootstrap critical values				Bootstrap critical values				Bootstrap critical values		
Optimal frequency	F_A	10%	%5	%1	t	10%	10%	10%	F_B	10%	%5	%1
5	8.85*	3.89	4.94	7.90	−5.69*	−3.20	−3.68	−4.82	3.75***	3.45	4.59	7.02

* and ***show the significance at the 1% and 10% level

any assumptions about the degree of integration of the variables. However, this approach gives more robust results than the standard ARDL approach. In addition, this approach can detect structural changes through Fourier functions (Serener et al. 2022; Addia et al. 2022). In this way, there is no need to apply an additional structural change test. The structural changes in the model can be seen thanks to the Fourier function developed by Yılancı et al. (2020).

$$d(t) = \sum_{k=1}^{n} a_k \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_k \cos\left(\frac{2\pi kt}{T}\right) \tag{6}$$

where n is the number of frequencies, π = 3.1416, k is the number of special frequencies selected, t is the trend, and T is the sample size. A single frequency value suggested by Becker et al. (2006) and Ludlow and Enders (2000) was used in the equation.

$$d(t) = \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) \tag{7}$$

Equation (9) shows the FARDL model for this study.

$$\begin{aligned} \Delta EF_t = {} & \beta_0 + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) \\ & + \beta_1 EF_{t-1} + \beta_2 GDP_{t-1} + \beta_3 EC_{t-1} + \beta_4 MS_{t-1} \\ & + \sum_{i-1}^{\rho-1} \varphi_i' \Delta EF_{t-i} + \sum_{i-1}^{\rho-1} \delta_i' \Delta GDP_{t-i} + \sum_{i-1}^{\rho-1} \emptyset_i' \Delta EC_{t-i} + \sum_{i-1}^{\rho-1} \vartheta_i' \Delta MS_{t-i} + e_t \end{aligned} \tag{8}$$

Yılancı et al. (2020) chose the frequency value that gives the minimum sum of squared residuals by following the studies conducted by Christopoulos and Leon-Ledesma (2011) and Omay (2015). Based on this, they determine the critical values for F_A, F_B, and t-tests using bootstrap simulation.

4 Empirical results

The study aims to capture the effect of economic growth, energy consumption, and mineral saving on the ecological footprint in Turkey. As an initial test to check the integration order of the time series variables, the Fourier ADF and the traditional ADF unit root tests are applied for empirical analysis.

Table 4 Long-run estimation results based on the FARDL model (EF is the dependent variable)

Constant	GDP	EC	MS
1.66	1.31*	− 1.11	0.27***
(0.00)	(0.00)	(0.11)	(0.07)

Numbers in parentheses show the *p*-values

* and **show the significance at the 1%, and 10% level, respectively

Table 2 shows the Fourier ADF and traditional ADF test statistics for the variables. Since the trigonometric terms of the variables (except EF and EC) are not statistically significant according to the Fourier ADF approach, the traditional ADF test is also applied for the unit root test. According to the ADF unit root test results, it is seen that all variables are stationary at the first difference, while they are not at level I(0). After these results, it is possible to examine the existence of a long-term relationship between the variables. For this reason, in the second step, the Fourier ARDL bounds test, which gave successful results in small samples, is performed.

According to the FARDL bounds test results in Table 3, there is a long-term cointegration relationship between the variables. This indicates that the combination of economic growth, energy consumption and mineral saving has a long-run effect on environmental degradation in Turkey. After determining a long-term relationship among the time series variables, the size and significance of the impact of the time series variables on the dependent variables are examined for the long-run. For this purpose, Table 3 depicts the long-term coefficient test results through the FARDL model.

As reported in Table 4, the effect of economic growth on the ecological footprint in Turkey over the period of 1975–2017 is statistically significant and positive. These findings show resemblance with the findings of (Danish et al. 2019; Udemba 2020; Ahmad 2021; Uzar 2021). This is because as well know due to Turkey's growing economy and energy demand. This finding shows that an economic growth path that is not green and sustainable for Turkey. Through economic growth strategies, Turkey should simultaneously improve environmental quality and seize new opportunities without neglecting the environment. Table 4 also depict that the coefficient of energy consumption is not statistically significant in Turkey. However, we would like to find that energy consumption negatively affects environmental quality as a result of many enterprises as well as human activities and human consumption in Turkey. In order to reduce the ecological footprint in Turkey, it will be beneficial to diversify energy sources into renewable sources such as solar, hydro and wind. Finally, we capture the positive effect of mineral saving on the ecological footprint in Turkey based on the FARDL model. The positive impact of mineral saving on ecological footprint was also confirmed by Koç and Gülmez 2021).

5 Conclusion

This study examines environmental degradation in the context of ecological footprint. According to the FARDL test results, there is a long-term relationship between economic growth, energy consumption, mineral saving, and EF. In addition, long-term estimation results based on the FARDL model show that economic growth and mineral saving increase the ecological footprint in Turkey covering the period 1975–2017. Turkey's energy demand is high due to its growing economy. These findings reveal that Turkey should reach a green and sustainable economic growth path. Furthermore, Turkey has achieved a decoupling between economic growth and CO_2 emissions recently. While CO_2 emissions tend to decrease, economic growth has been increasing since 2018. Therefore, Turkey might both increase environmental quality and seize new opportunities by creating economic growth strategies without ignoring the environment. In this context, Turkey should include EF in both environmental and energy policies. Turkey also can implement strict environmental policies to reduce EF without ignoring economic growth. In particular, the competitiveness of wind and solar energy is increasing and offers cost advantages (Öznazik 2022). For this reason, Turkey should encourage more renewable energy sources and increase the incentive for these resources. Turkey plans to achieve net-zero emission target for 2053 (Birpınar 2022) and declared its net-zero targets at COP 27 meeting in Sharm el-Sheikh. However, there is a significant barrier to the 2053 net-zero target since Turkey has stated that emissions will increase until 2038. Reaching the net-zero target in 15 years is unrealistic because as emissions increase, it will become more difficult to achieve the net-zero target. In this sense, revising the peak year backwards will be more advantageous to realize sustainable development goals, adapt to EGD and not miss the opportunity for the green transition in the long run. In this context, more efforts are required to utilize green and climate-resilient investment projects. The number of climate projects should also be increased, especially through the private sector.

The European Union (EU) is Turkey's most important trade partner in terms of foreign trade. In 2021, the EU ranked first in Turkey's exports with 41.3%, and imports with a share of 31.5% (Republic of Turkey Ministery of Trade 2022). In this context, the European Green Deal (EGD) offers both risks and opportunities for Turkey. The EU is pursuing a new growth strategy with EGD. The main objectives of EGD are; (i) zero net greenhouse gas emissions by 2050, (ii) decoupling economic growth from resource use, (iii) including neighbors and trading partners in these policies. The EU also will use financial influence to achieve this goal. In this context, Turkey first submitted its INDCs (Intended Nationally Determined Contribution) to the UNFCCC secretariat in 2015, declaring a greenhouse gas reduction target of approximately 21% for the 2021–2030 period (UNFCCC 2015), then ratified the Paris Climate Agreement in 2021. At the international climate negotiation (COP27) held in Sharm el-Sheikh in 2022, countries agreed to stop negotiating on the implementation of the Paris Agreement and move on to practice (Altomonte and Altomonte 2023).

In addition, Turkey is preparing a new strategy, including seven key policies to combat climate change and plans to update its INDC and set a net zero emission target for 2053 (Birpınar 2022). These steps might be considered preparation for EGD and have created three opportunities for Turkey. First, Turkey can transform its economy into a greener and more climate-resilient structure. Secondly, If Turkey considers EGD from a broad perspective, new trade opportunities may arise in case of a commercial dispute between the EU and other countries. Finally, EGD can contribute to the circular economy by providing a sustainable production and consumption practice. These developments might enable Turkey to lower its EF and contribute to economic growth. Therefore, more efforts are required to benefit from green and climate-resilient investment projects and the number of climate projects should be increased especially through the private sector. Establishing a climate-resilient and sustainable economic infrastructure is an opportunity for Turkey rather than an additional financial burden or threat.

The limitation of this study is to use ecological footprint as an independent variable to show the environmental quality. However, recently load capacity factor has drawn the attention of researchers in environmental studies. The load capacity factor bounces an idea of environmental quality by dividing the biological capacity with the ecological footprint. In this context, we suggest researchers focus on determinants of load capacity factor (energy consumption, economic complexity, trade openness, human capital, globalization etc.) by using time series or panel data analysis.

Funding In addition, we also confirm that this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations

Conflict of interest We have no conflicts of interest to disclose.

References

Abid, M.: The close relationship between informal economic growth and carbon emissions in Tunisia since 1980: the (ir)relevance of structural breaks. Sustain. Cities Soc. **15**, 11–21 (2015)

Acar, S., Aşıcı, A.A.: Nature and economic growth in Turkey: what does ecological footprint imply? Middle East Dev. J. **9**(1), 101–115 (2017)

Addai, K., Ozbay, R.D., Castanho, R.A., Genc, S.Y., Couto, G., Kirikkaleli, D.: Energy productivity and environmental degradation in Germany: evidence from novel Fourier approaches. Sustainability **14**(24), 16911 (2022)

Adebayo, T.S., Sevinç, H., Sevinç, D.E., Ojekemi, O.S., Kirikkaleli, D.: A wavelet-based model of trade openness with ecological footprint in the MINT economies. Energy Environ. (2023). https://doi.org/10.1177/0958305X221150489

Ahmad, M., Jiang, P., Murshed, M., Shehzad, K., Akram, R., Cui, L., Khan, Z.: Modelling the dynamic linkages between eco-innovation, urbanization, economic growth and ecological footprints for G7 countries: does financial globalization matter? Sustain. Cities Soc. **70**, 102881 (2021)

Ahmed, Z., Asghar, M.M., Malik, M.N., Nawaz, K.: Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resour. Policy **67**, 101677 (2020)

Ahmed, Z., Zhang, B., Cary, M.: Linking economic globalization, economic growth, financial development, and ecological footprint: evidence from symmetric and asymmetric ARDL. Ecol. Ind. **121**, 107060 (2021)

Ahmed, Z., Ahmad, M., Alvarado, R., Sinha, A., Shah, M.I., Abbas, S.: Towards environmental sustainability: do financial risk and external conflicts matter? J. Clean. Prod. **371**, 133721 (2022a)

Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O.A., Hussain, N.: Economic growth, renewable energy consumption, and ecological footprint: exploring the role of environmental regulations and democracy in sustainable development. Sustain. Dev. **30**(4), 595–605 (2022b)

Al-Mulali, U., Tang, C.F., Ozturk, I.: Estimating the environment Kuznets curve hypothesis: evidence from Latin America and the Caribbean countries. Renew. Sustain. Energy Rev. **50**, 918–924 (2015)

Alola, A.A., Adebayo, T.S., Onifade, S.T.: Examining the dynamics of ecological footprint in China with spectral Granger causality and quantile-on-quantile approaches. Int. J. Sustain. Dev. World Ecol. **29**, 263–276 (2021)

Alper, A.E., Alper, F.O., Ozayturk, G., Mike, F.: Testing the long-run impact of economic growth, energy consumption, and globalization on ecological footprint: new evidence from Fourier bootstrap ARDL and Fourier bootstrap Toda-Yamamoto test results. Environ. Sci. Pollut. Res. (2022). https://doi.org/10.1007/s11356-022-18610-7

Altomonte, S., Altomonte, C (2023): COP27: a step ahead or a missed opportunity? Buildings & Cities, https://www.buildingsandcities.org/insights/commentaries/cop27-step-ahead-missed-opportunity.html

Alvarado, R., Ponce, P., Alvarado, R., Ponce, K., Huachizaca, V., Toledo, E.: Sustainable and non-sustainable energy and output in Latin America: a cointegration and causality approach with panel data. Energy Strategy Rev. **26**, 100369 (2019)

Apergis, N., Payne, J.E., Rayos-Velazquez, M.: Carbon dioxide emissions intensity convergence: evidence from Central American countries. Front. Energy Res. **7**, 158 (2020)

Becker, R., Enders, W., Lee, J.: A stationarity test in the presence of an unknown number of smooth breaks. J. Time Ser. Anal. **27**(3), 381–409 (2006)

Bello, M.O., Solarin, S.A., Yen, Y.Y.: The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: the role of hydropower in an emerging economy. J. Environ. Manag. **219**, 218–230 (2018)

Birpınar, M.E.: Turkey's strong bid for a boost in climate finance. (2022) https://www.dailysabah.com/opinion/op-ed/turkeys-strong-bid-for-a-boost-in-climate-finance?fbclid=IwAR0oo6aQ-__9RCw1SfcMN7aqMNXUsGaAD7zxrAc22QsfRtzYluay9IphCWw

Christopoulos, D.K., Leon-Ledesma, M.A.: International output convergence, breaks, and asymmetric adjustment. Stud. Nonlinear Dyn. Econom. **15**(3), 1–31 (2011)

Danish, K., Hassan, S.T., Baloch, M.A., Mahmood, N., Zhang, J.: Linking economic growth and ecological footprint through human capital and biocapacity. Sustain. Cities Soc. **47**, 101516 (2019)

Destek, M.A., Sarkodie, S.A.: Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. Sci. Total Environ. **650**, 2483–2489 (2019)

Dogan, E., Ulucak, R., Kocak, E., Isik, C.: The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. Sci. Total Environ. **723**, 138063 (2020)

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., Marchettini, N.: Assessing the global environmental consequences of economic growth through the ecological footprint: a focus on China and India. Ecol. Ind. **17**, 99–107 (2012)

Global Carbon Budget. Data supplement to the Global Carbon Budget 2021. https://www.icos-cp.eu/science-and-impact/global-carbon-budget/2021 (2020)

Global Footprint Neetwork. Country trends. https://data.footprintnetwork.org/#/countryTrends?cn=5001&type=BCtot,EFCtot (2018a)

Global Footprint Neetwork. Ecological footprint vs biocapacity (Turkey). https://data.footprintnetwork.org/#/countryTrends?cn=223&type=BCpc,EFCpc (2018b)

Global Footprint Neetwork. Data and methodology. https://www.footprintnetwork.org/resources/data/ (2022)

Gökmenoğlu, K.K., Taspinar, N., Rahman, M.M.: Military expenditure, financial development and environmental degradation in Turkey: a comparison of CO_2 emissions and ecological footprint. Int. J. Financ. Econ. **26**(1), 986–997 (2021)

Gülmez, A., Altıntaş, N., Kahraman, Ü.O.: A puzzle over ecological footprint, energy consumption and economic growth: the case of Turkey. Environ. Ecol. Stat. **27**(4), 753–768 (2020)

Hassan, S.T., Xia, E., Khan, N.H., Shah, S.M.A.: Economic growth, natural resources, and ecological footprints: evidence from Pakistan. Environ. Sci. Pollut. Res. **26**(3), 2929–2938 (2019)

Hussain, H.I., Haseeb, M., Kamarudin, F., Dacko-Pikiewicz, Z., Szczepańska-Woszczyna, K.: The role of globalization, economic growth and natural resources on the ecological footprint in Thailand: Evidence from nonlinear causal estimations. Processes **9**(7), 1103 (2021)

Ibrahiem, D.M., Hanafy, S.A.: Dynamic linkages amongst ecological footprints, fossil fuel energy consumption and globalization: an empirical analysis. Manag. Environ. Qual. Int. J. **6**, 1549–1568 (2020)

Jahanger, A., Usman, M., Murshed, M., Mahmood, H., Balsalobre-Lorente, D.: The linkages between natural resources, human capital, globalization, economic growth, financial development, and

ecological footprint: the moderating role of technological innovations. Resour. Policy **76**, 102569 (2022)
Judkins, R.R., Fulkerson, W., Sanghvi, M.K.: The dilemma of fossil fuel use and global climate change. Energy Fuels **7**(1), 14–22 (1993)
Khan, I., Hou, F.: The dynamic links among energy consumption, tourism growth, and the ecological footprint: the role of environmental quality in 38 IEA countries. Environ. Sci. Pollut. Res. **28**(5), 5049–5062 (2021)
Koç, P., Gülmez, A.: Analysis of relationships between nanotechnology applications, mineral saving and ecological footprint: evidence from panel Fourier cointegration and causality tests. Resour. Policy **74**, 102373 (2021)
Köksal, C., Işik, M., Katircioğlu, S.: The role of shadow economies in ecological footprint quality: empirical evidence from Turkey. Environ. Sci. Pollut. Res. **27**(12), 13457–13466 (2020)
Kongbuamai, N., Bui, Q., Yousaf, H.M.A.U., Liu, Y.: The impact of tourism and natural resources on the ecological footprint: a case study of ASEAN countries. Environ. Sci. Pollut. Res. **27**(16), 19251–19264 (2020)
Li, R., Wang, X., Wang, Q.: Does renewable energy reduce ecological footprint at the expense of economic growth? An empirical analysis of 120 countries. J. Clean. Prod. **346**, 131207 (2022)
Ludlow, J., Enders, W.: Estimating non-linear ARMA models using Fourier coefficients. Int. J. Forecast. **16**(3), 333–347 (2000)
Martínez-Zarzoso, I., Maruotti, A.: The impact of urbanization on CO_2 emissions: evidence from developing countries. Ecol. Econ. **70**(7), 1344–1353 (2011)
McNown, R., Sam, C.Y., Goh, S.K.: Bootstrapping the autoregressive distributed lag test for cointegration. Appl. Econ. **50**(13), 1509–1521 (2018)
Nathaniel, S.P.: Natural resources, urbanization, economic growth and the ecological footprint in South Africa: the moderating role of human capital. Quaest. Geogr. **40**(2), 63–76 (2021)
Nathaniel, S., Nwodo, O., Sharma, G., Shah, M.: Renewable energy, urbanization, and ecological footprint linkage in CIVETS. Environ. Sci. Pollut. Res. **27**(16), 19616–19629 (2020a)
Nathaniel, S., Anyanwu, O., Shah, M.: Renewable energy, urbanization, and ecological footprint in the Middle East and North Africa region. Environ. Sci. Pollut. Res. **27**, 14601–14613 (2020b)
Öcal, O., Altınöz, B., Aslan, A.: The effects of economic growth and energy consumption on ecological footprint and carbon emissions: evidence from Turkey. Ekon. Polit. Finans Araştırmaları Derg. **5**(3), 667–681 (2020)
Omay, T.: Fractional frequency flexible Fourier form to approximate smooth breaks in unit root testing. Econ. Lett. **134**, 123–126 (2015)
Our World in Data. Turkey: CO_2 country profile. https://ourworldindata.org/co2/country/turkey (2022)
Özdemir, O., Çevikalp, S.: Ecological footprint, economic growth and technological change in Turkey: evidence from Bayer-Hanck combined cointegration approach. Int. J. Green Econ. **15**(2), 127–148 (2021)
Öznazik, H.A.: Türkiye’de Yenilenebilir Enerji Kaynaklarına Dayalı Elektrik Üretimine Verilen Fiyat Desteklerinin İncelenmesi: Karşılaştırmalı Bir Analiz. J. Fiscaoecon. **6**(1), 161–188 (2022)
Pesaran, M.H., Shin, Y., Smith, R.J.: Bounds testing approaches to the analysis of level relationships. J. Appl. Economet. **16**(3), 289–326 (2001)
Republic of Türkiye Ministery of Trade. Foreign trade stratistics. https://www.trade.gov.tr/statistics/foreign-trade-statistics (2022)
Serener, B., Kirikkaleli, D., Addai, K.: Patents on environmental technologies, financial development, and environmental degradation in Sweden: evidence from novel Fourier-based approaches. Sustainability **15**(1), 302 (2022)
Shahzad, U.: Environmental taxes, energy consumption, and environmental quality: theoretical survey with policy implications. Environ. Sci. Pollut. Res. **27**(20), 24848–24862 (2020)
Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., Sinha, A.: Revisiting the role of renewable and non-renewable energy consumption on Turkey’s ecological footprint: evidence from Quantile ARDL approach. Sustain. Cities Soc. **57**, 102138 (2020)
Solarin, S.A.: Convergence in CO_2 emissions, carbon footprint and ecological footprint: evidence from OECD countries. Environ. Sci. Pollut. Res. **26**(6), 6167–6181 (2019)
Solarin, S.A., Bello, M.O.: Persistence of policy shocks to an environmental degradation index: the case of ecological footprint in 128 developed and developing countries. Ecol. Ind. **89**, 35–44 (2018)
Statista. Gross domestic product at current market prices of selected European countries in 2020 (in million euros). https://www.statista.com/statistics/685925/gdp-of-european-countries/ (2020)

Udemba, E.N.: A sustainable study of economic growth and development amidst ecological footprint: new insight from Nigerian perspective. Sci. Total Environ. **732**, 139270 (2020)

Ulucak, R., Bilgili, F.: A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. J. Clean. Prod. **188**, 144–157 (2018)

Ulucak, R., Khan, S.U.D., Baloch, M.A., Li, N.: Mitigation pathways toward sustainable development: is there any trade-off between environmental regulation and carbon emissions reduction? Sustain. Dev. **28**(4), 813–822 (2020)

UNFCCC. Republic Of Turkey intended nationally determined contribution. https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Turkey/1/The_INDC_of_TURKEY_v.15.19.30.pdf (2015)

Uzar, U.: The relationship between institutional quality and ecological footprint: is there a connection? Nat. Resour. Forum **45**(4), 380–396 (2021)

Wuebbles, D.J., Jain, A.K.: Concerns about climate change and the role of fossil fuel use. Fuel Process. Technol. **71**(1–3), 99–119 (2001)

Yilanci, V., Bozoklu, S., Gorus, M.S.: Are BRICS countries pollution havens? Evidence from a bootstrap ARDL bounds testing approach with a Fourier function. Sustain. Cities Soc. **55**, 102035 (2020)

Zeraibi, A., Balsalobre-Lorente, D., Murshed, M.: The influences of renewable electricity generation, technological innovation, financial development, and economic growth on ecological footprints in ASEAN-5 countries. Environ. Sci. Pollut. Res. **28**(37), 51003–51021 (2021)

Zia, S., Noor, M.H., Khan, M.K., Bibi, M., Godil, D.I., Quddoos, M.U., Anser, M.K.: Striving towards environmental sustainability: how natural resources, human capital, financial development, and economic growth interact with ecological footprint in China. Environ. Sci. Pollut. Res. **28**(37), 52499–52513 (2021)

Wackernagel, M., Rees, W.: Ecological footprint: Reducing human impact on the earth. New Society, Gabriola Island, BC, Canada (1996)