



Assessing the environmental sustainability corridor: linking oil consumption, hydro energy consumption, and ecological footprint in Turkey

Tomiwa Sunday Adebayo¹

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Abstract

Climate change has been a topic of significant discourse and debate among scholars and policy makers for several decades. In recent decades, it has become a major problem for the entire human race. Therefore, the present research evaluates the impact of oil consumption, hydro energy use, population density, and economic growth on ecological footprint in Turkey for the period from 1965Q1 to 2018Q4. This paper uses the BDS test to assess the nonlinearity of the variables in the pre-estimation analysis. The results of the test reveal that non-linearity occurs in all of the variables used in this study. As a consequence, using traditional linear methodologies would produce erroneous results. Our research uses the quantile techniques (quantile cointegration, quantile causality, quantile-on-quantile regression), which are recently developed nonlinear estimate methodologies to assess these associations. The results from the study reveal that oil consumption, hydro energy use, population density, and economic growth contribute to environmental degradation in Turkey in majority of the quantiles. The Granger Causality in Quantiles result also gives credence to the results. The study proposes policy recommendation based on these results.

Keywords Ecological Footprint · Hydro energy · Oil consumption · Population density · Economic growth

Abbreviation

| | |
|-----------------|--------------------------------------|
| CO ₂ | Carbon Emissions |
| DOLS | Dynamic ordinary least square |
| ECF | Ecological footprint |
| GDP | Economic growth |
| HYDRO | Hydro energy consumption |
| FMOLS | Fully modified ordinary least square |
| OIL | Oil consumption |
| NREC | Nonrenewable energy |
| POPD | Population density |
| REC | Renewable energy |
| SDGs | Sustainable development goals |
| QQR | Quantile-on-quantile regression |
| QR | Quantile regression |

Introduction

The majority of developing and developed nations around the globe are working hard to achieve and maintain economic growth and development. This may be unattainable unless both natural and intellectual resources are used for consumption and industrialization. Governments, policymakers, and environmentalists have progressively turned their attention to efforts to establish a sustainable environment. The majority of human actions that have harmed the environment's regeneration and absorptive ability can be linked to the consumption and production of products and services, as well as the exhaustion and refinement of natural resources. The ecological footprint (ECF) is a measurement of its regenerative and absorptive potential.

According to Wackernagel and Rees (1997), ECF is expressed as “the total amount of land and water required by players in this economy to generate all of the resources they consume and to absorb all of the wastes they make on a regular basis, employing current technology.” Now that the globe has adopted the SDGs, it is becoming increasingly critical for countries around the world to meet the SDG targets by 2030. As a result, countries are working to rethink

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✉ Tomiwa Sunday Adebayo
twaikline@gmail.com

¹ Department of Economics, Faculty of Economics and Administrative Science, Cyprus International University, Northern Cyprus, 10 Mersin, Turkey

their environmental and energy policies in order to provide a platform for achieving the SDGs by gaining control over the ecological destruction they are causing by means of the ECF. As a result of global efforts to establish a sustainable environment, as defined in various international accords such as the Kyoto Protocol, Paris Accords, and the goals of the 2030 Agenda for Sustainable Development, interest has been drawn to the ecological impact of human activities. As a result, nations are rethinking their strategies for human welfare and environmental sustainability in order to meet the 2030 targets (Gyamfi et al. 2022a). Therefore, scholars are increasingly endeavoring to develop and review the energy-environment connection. Figure 1 presents the ecological situation of Turkey.

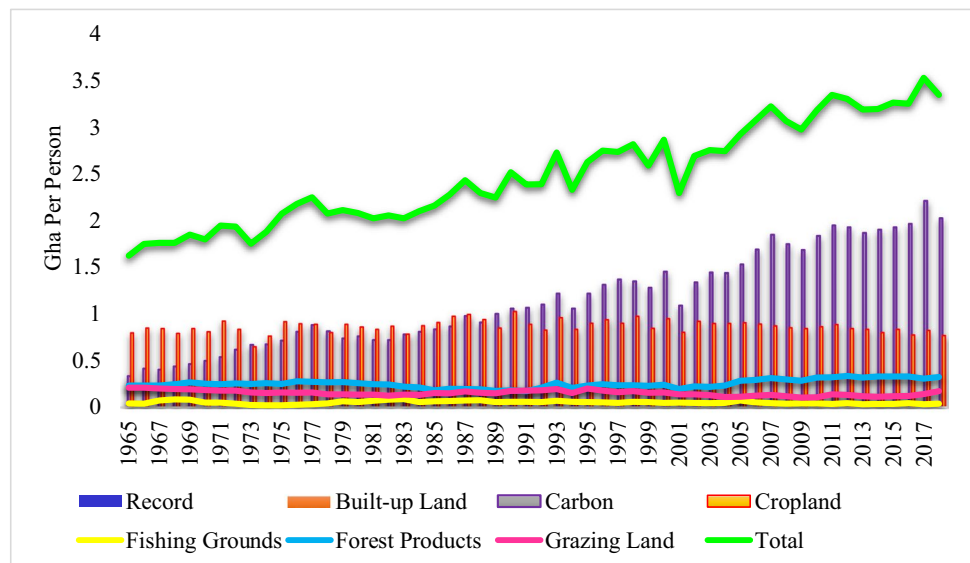
Why Turkey? The recent rapid economic and demographic expansion in Turkey has not only significantly increased energy demand, but also exacerbated reliance on imports. In order to rationalize the expansion of its energy demand, minimize consumer energy costs, and slow the rate of import increase, Turkey has sought a reform of its energy system. Given its significant reliance on oil and gas imports, Turkey has made securing its energy supply a top priority and one of the cornerstones of its energy policy (IEA 2022). The strategy calls for growing domestic oil and gas exploration and production, varying the sources of oil and gas supply and related infrastructure, expanding the output of renewable sources of energy, and enhancing energy efficiency. Through recent LNG terminals, pipelines, and improved storage, Turkey has made considerable headway in enhancing its gas supply alternatives. In the last 10 years, Turkey has significantly diversified its energy mix (IEA 2022). Particularly, renewable energy has shown significant development, with the output of renewable electricity doubling over the previous 10 years. Despite advancements in

the liberalization of energy markets and the diversification of energy sources, the government should make sure that measures taken to increase energy security, such as the expansion of coal-fired power, do not impair the nation’s long-term decarbonization efforts.

Clearly, empirical studies exist on the association between environmental quality and nonrenewable energy at regional, national, and global levels (Ibrahim and Ajide 2021; Zhang et al. 2021). As shown by those investigations, the harmful ecological and welfare consequences of nonrenewable energy (NREC) have stimulated the search for alternatives that do not stifle economic progress. For a sound energy mix, renewables appear to be a preferable alternative. Therefore, renewable energy derived from wind, solar, tidal, biomass, and hydro, among other sources, has been found to have a major effect on ecological sustainability (Abbasi et al. 2021; Acheampong et al. 2019; Adams and Nsiah 2019). Nevertheless, while renewable energy sources may assist in preventing environmental deterioration, nations may find it difficult to exploit them since they can stifle economic progress (Anwar et al. 2021). Also, according to Awosusi et al. (2022), socio-economic variables could obstruct the use of renewable energy, causing renewable energy consumption to fall short of expectations in terms of impacting environmental deterioration. Nations may return to using nonrenewable energy in this situation, despite empirical evidence that it causes environmental destruction.

Based on the above discourse, the current paper evaluates the effect of oil consumption, hydro energy use, population density, and economic growth on the ecological footprint in Turkey. Furthermore, it is also essential to understand that different levels of oil consumption, hydro energy use, population density, and economic growth may not have the same influence on all levels of ECF. At the same time, this relationship must be

Fig. 1 Ecological situation of Turkey from 1965 to 2018



examined in each quantile, as the study's findings will be used to make policy recommendations. In this pursuit, the quantile-on-quantile regression approach by Sim and Zhou (2015) has been employed. In comparison to other approaches, the QQR technique has several benefits. The application of the novel quantile-on-quantile method permits us to the effect of the quantiles of the X on the Y quantiles, thus offering a comprehensive explanation vis-à-vis the association between Y and X variables. This methodological approach supports the policy-level contribution from a policymaking standpoint. Because technological diffusion is an issue in Turkey owing to inadequate R&D, varying forms of oil consumption, hydro energy use, population density, and economic growth are likely to have dissimilar levels of impact on ECF. Thus, the QQR application supplements contextual development, thus adding to the body of knowledge on energy and environmental economics from the methodological viewpoint.

A summary of prior studies is shown in “Literature review”. The econometric approach and data collection are designated in “Data and method”. “Results and discussion” discusses the results, and “Conclusion and policy implications” closes the research.

Literature review

Regarding the nexus between ecological footprint, population density, and disintegrated energy-oil and hydro energy, substantial studies ((Adebayo 2022a, b, c; Adedoyin et al. 2021; Alola et al. 2019; Du et al. 2022; Altarhouni et al. 2021; Ali et al. 2022; Pata and Samour 2022; Baskaya et al. 2022; Qashou et al. 2022; Gyamfi et al. 2022a, b; Mujtaba et al. 2022a; Nathaniel et al. 2021; Pan et al. 2022; Solarin et al. 2021) have been initiated. However, findings vary based on the timeframe, techniques employed, and the country/group of nation's characteristics. For instance, Sadiq-Bamgbopa et al. (2022), using the nonparametric methods, explored the effect of disintegrated energy in India from 1980 to 2018. The result gathered from this investigation shows that growth lessens environmental quality while green energy amplifies it. Likewise, Miao et al. (2022), in their research on the path toward carbon neutrality in BRICS nations using the quantile approach and data covering the 1990 to 2019 period, reported that clean energy and technological innovation lessens environmental damage while real growth and nonrenewable energy amplifies it. Moreover, the research of Oladipupo et al. (2021) in Portugal on the time-frequency analysis between real growth and disintegrated energy using data between 1980 and 2018 revealed that real growth triggers environmental deterioration while clean energy reduces it.

Furthermore, using quarterly data from 1965 to 2017, the study of Sharif et al. (2020) using the quantile method reported the validity of the EKC hypothesis. Besides, renewable and

nonrenewable energy decrease and increase environmental deterioration respectively in Turkey. In addition, the quantile causality shows that all the regressors can forecast ecological footprint. Likewise, the study of Adekoya et al. (2022), using an AMG estimator and dataset between 1990 and 2019, reported that fossil fuel-based energy increases ecological footprint while renewable energy use decreases it. Moreover, Pata (2021) tested the EKC hypothesis with a structural break in the USA using long-run estimators and data between 1980 and 2016. The research findings show the validity of the EKC in the USA. In addition, renewable energy curbs emissions, while globalization and nonrenewable energy trigger emissions.

The research of Mujtaba et al. (2022b) evaluated the asymmetric and symmetric impact of disintegrated energy consumption on ecological dilapidation in the OECD, employing data from 1970 to 2016. The investigators used the NARDL to evaluate this nexus, and the study results show that a 1% upsurge in REC and NREC increased and decreased ecological deterioration in the OECD nations. Unlike the studies of Mujtaba et al. (2022a), Adekoya et al. (2022), and Oladipupo et al. (2021), the study of Akadir et al. (2022) using the quantile approach reported that REC contributes to the damage of the environment in China using the nonparametric techniques. Similarly, the positive connection between REC and ECF is reported by the study of Alola et al. (2021) in China using quantile approach. The study posits that in all quantile distribution of ECF, renewable energy use, as well as fossil fuel and GDP, lessens quality of the ecosystem.

The paper's contribution is imitated in the following ways based on the review of the relevant literature; first, the present research utilizes the novel QQR approach to evaluate the connection between these variables. The study variables were inspired by the United Nations SDGs 7, 11, 12, 13, and 17, which is uncommon in the existing literature. Second, the study explores disintegrated energy (renewable or nonrenewable), economic growth, and economic complexity, which form the progressive pattern of Turkey's ecological quality and situation. Few studies have been dedicated to these associations in the context of Turkey. Third, the QQR approach is employed, which has several benefits in comparison to other approaches. The application of the novel quantile-on-quantile method permits us to assess the effect of the quantiles of the X on the Y quantiles, thus offering a comprehensive explanation vis-à-vis the association between Y and X variables. Lastly, this paper will serve as a framework for Turkey in its pursuit of ecological sustainability.

Data and method

Data

The current paper evaluates the effect of oil consumption, hydro energy consumption, population density, and

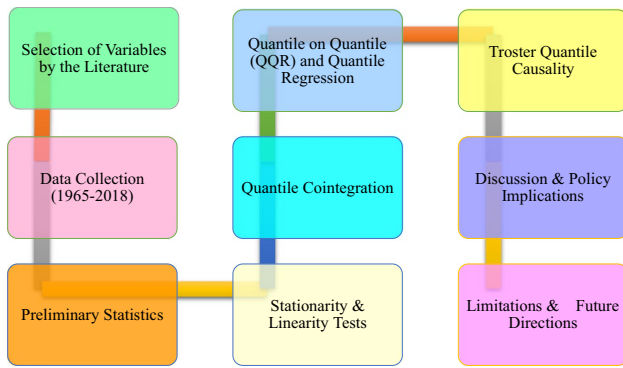


Fig. 2 Flow of analysis

economic growth on ecological footprint in Turkey. The research utilizes the data from 1965Q1 to 2018Q4. The data for oil consumption and hydro energy consumption are gathered from the British Petroleum database. Population density is gathered from the World Bank database, and it is measured as people per sq. km of land area. Furthermore, the data for economic growth is gathered from World Bank, while the ecological footprint data is measured as Gha per Person, and it is obtained from the Global Footprint Network database. Figure 2 shows the flow of the analysis.

Methodology

The QQR is utilized in this empirical analysis. The independent and dependent variables are depicted by *I* and *D*, respectively. The QQR framework for determining the dependent (*D*) variable *q*-quantile as a function of an exogenous variable (*I*) is depicted below:

$$D_t = \alpha^q(I_t) + \epsilon_t^q \tag{1}$$

where the error term with zero *q*-quantile is depicted by ϵ_t^q . To evaluate the structure of dependence between *p*-quantile of *I* and *q*-quantile of *D*, the unrecognized association function $\alpha^q(\cdot)$ is linearized utilizing Taylor expansion first-order as:

$$\alpha^q(I_t) \approx \alpha^q(I^p) + \alpha^q(I)(I_t - I^p) \tag{2}$$

We transformed Eq. 2 into 3 in line with the research of following (Sim and Zhou 2015):

$$\alpha^q(I_t) \approx \alpha^q(q, p) + \alpha^q(q, p)(I_t - I^p) \tag{3}$$

We obtained Eq. 4 by substituting Eq. 2 into Eq. 1 as follows:

$$D_t = \underbrace{\alpha_0 + \alpha_1(I_t - I^q)}_{(*)} + \epsilon_t^q \tag{4}$$

where $\alpha_0 = \alpha_0(q, p)$ and $\alpha_1 = \alpha_1(q, p)$. In Eq. 4, (*) represents the *D* *q*th conditional quantile. By reducing the following equation, the estimated of Eq. 5 is derived:

$$\min_{\alpha_0, \alpha_1} \sum_{i=1}^n [D_t - \alpha_0 - \alpha_1(\hat{I}_t - \hat{I}^p)] \times Q\left(\frac{G_{n(D_t)-p}}{h}\right) \tag{5}$$

The absolute value function \varnothing_q tallies to the *q* conditional quantiles of *D*. Then, using the Gaussian kernel $Q(\cdot)$, the observation is weighted as per the normal probability distribution centered on bandwidth *h*. In line with earlier research, the current paper utilized a bandwidth of 5% (*h* = 0.05).

Results and discussion

Pre-estimation outcomes

Table 1 shows summary of the data and unit root outcomes of the parameters of inquiry. The mean of GDP (5912.3)

Table 1 Data description

| | ECF | GDP | HYDRO | POPD | OIL |
|-------------|-----------|-----------|-----------|-----------|-----------|
| Mean | 2.4353 | 5912.3 | 69.109 | 71.194 | 274.46 |
| Median | 2.3336 | 5367.9 | 66.364 | 71.256 | 275.34 |
| Maximum | 3.3627 | 12180.1 | 180.069 | 106.07 | 584.30 |
| Minimum | 1.3828 | 2683.1 | 5.8169 | 39.885 | 39.073 |
| Std. dev. | 0.5166 | 2368.1 | 48.808 | 19.000 | 130.43 |
| Skewness | 0.2124 | 0.8536 | 0.3132 | 0.0469 | 0.0470 |
| Kurtosis | 1.9322 | 2.7843 | 1.9665 | 1.8224 | 2.3430 |
| Jarque-Bera | 11.665 | 26.157 | 12.900 | 12.326 | 3.8903 |
| Probability | 0.0029 | 0.0000 | 0.0015 | 0.00210 | 0.1429 |
| ΔADF | − 10.697* | − 6.9903* | − 7.9806* | − 9.5271* | − 6.2988* |
| ΔPP | − 11.173* | − 7.0188* | − 8.4996* | − 10.677* | − 6.9980* |

*1% level of significance

the highest, and it ranges from 2683.1 to 12,180.1. This is accompanied by OIL (274.46) which falls between 39.073 and 584.30, POPD (71.194) which ranges from 39.885 to 106.07, and HYDRO (69.109) which ranges between 5.8169 and 180.069 and ECF (2.4353) between 1.3828 and 3.3627. The skewness values revealed that all the parameters are skewed positively. Besides, the values of kurtosis disclosed all the parameters are platykurtic. Moreover, Jarque-Bera outcomes uncovered only OIL comply with normal distribution while GDP, HYDRO, POPD, and ECF do not align with normality. Furthermore, we evaluate the unit root features of the variables, and the results show that the parameters are $I(1)$ variables which implies that variables are stationary at the first difference (see Table 1). To check the consistency of the Jarque-Bera, we used the BDS test to check the linearity attribute of all the parameters with the results suggesting that the variables are nonlinear (see Table 2). Furthermore, we check the correlation between ECF and the exogenous variables, as depicted in Table 3. The results revealed a positive correlation between ECF and the independent variables. These outcomes imply that ECF and the independent variables move in the same direction.

Quantile cointegration outcomes

We proceed to evaluate the cointegration properties of the variables. Furthermore, it is claimed from a cointegration theoretical perspective that the construction of model is only viable when the variables have a long-run association (Chien et al. 2021). Therefore, Table 4 shows the quantile cointegration analysis results, which displays the diverse quantiles of ecological footprint and each independent variable. The findings confirmed cointegration by surpassing critical values at several degrees of statistical significance. Using the same approach, a spaced grid of (0.05–0.95) 19 quantiles was created to evaluate the relationship between ECF and each independent variable. As a result, a comprehensive and plausible regression analysis can be carried out to determine the interrelationship between the ecological footprint and each independent variable (Sharif et al. 2019).

Table 2 BDS test outcomes

| | ECF | GDP | OIL | HYDRO | POPD |
|----|---------|---------|---------|---------|---------|
| M2 | 18.389* | 17.543* | 21.364* | 12.695* | 26.206* |
| M3 | 20.363* | 17.616* | 21.679* | 12.687* | 27.813* |
| M4 | 21.751* | 18.043* | 22.609* | 12.441* | 29.924* |
| M5 | 23.589* | 18.949* | 24.358* | 12.552* | 32.930* |
| M6 | 26.177* | 20.149* | 27.074* | 14.514* | 36.917* |

*1% level of significance

Table 3 Correlation table

| | Coefficient | T-statistics | P-value |
|----------------------|-------------|--------------|---------|
| ECF_t vs GDP_t | 0.8916 | 14.206 | 0.0000* |
| ECF_t vs OIL_t | 0.8808 | 13.418 | 0.0000* |
| ECF_t vs $HYDRO_t$ | 0.5859 | 7.1776 | 0.0000* |
| ECF_t vs $POPD_t$ | 0.8390 | 11.119 | 0.0000* |

*1% level of significance

Outcomes of QQR

This study used the QQR method to identify the association between ECF and the independent variables. Figure 3 a reveals the effect of GDP on ecological footprint in each quantile (0.1–0.95). The outcomes show that the positive effect of GDP on ECF is dominant in the majority of the quantiles, although the effect is weak. These results indicate that Turkey will find it difficult to achieve its SDGs. This scenario is commonly found in most emerging nations where economic progress is favored while minimal attention is paid to the health of the environment. The papers of Xie et al. (2022) testified comparable findings.

Furthermore, the positive effect of oil consumption on ECF is evident as shown in Fig. 3a. In the majority of the quantiles (0.10.95) of both, ECF and oil consumption impact ECF positively. This implies that the use of oil consumption which is a fossil fuel-based energy contributes to ecological damage in Turkey. This outcome corroborates the results of Baloch et al. (2021), Kirikkaleli et al. (2021), and Xu et al. (2022). Moreover, in each quantile (0.1–0.95), we found a weak and positive effect of REC on ECF in Turkey. This result conforms with the papers of Alola et al. (2021) for China and Akadiri et al. (2022) for China who reported a positive association between renewable energy and ECF. However, this outcome refutes the studies of Samour et al. (2022) and Isik et al. (2021), who reported that hydro energy lessens ECF. These findings are unsurprising given that nonrenewable sources accounted for 67% of total electricity production in 2018 in Turkey, while renewable resources accounted for

Table 4 Quantile cointegration test outcomes

| | Coefficient | $Sup_t V_\pi(\tau) $ | CV1 | CV5 | CV10 |
|----------------------|-------------|-----------------------|------|------|------|
| ECF_t vs GDP_t | B | 8718 | 6140 | 4501 | 2329 |
| | γ | 895 | 604 | 484 | 267 |
| ECF_t vs OIL_t | B | 6364 | 4948 | 2791 | 1785 |
| | γ | 593 | 392 | 204 | 137 |
| ECF_t vs $HYDRO_t$ | B | 3885 | 2623 | 1242 | 764 |
| | γ | 283 | 179 | 108 | 67 |
| ECF_t vs $POPD_t$ | B | 4165 | 3038 | 1693 | 1033 |
| | γ | 425 | 301 | 183 | 80 |

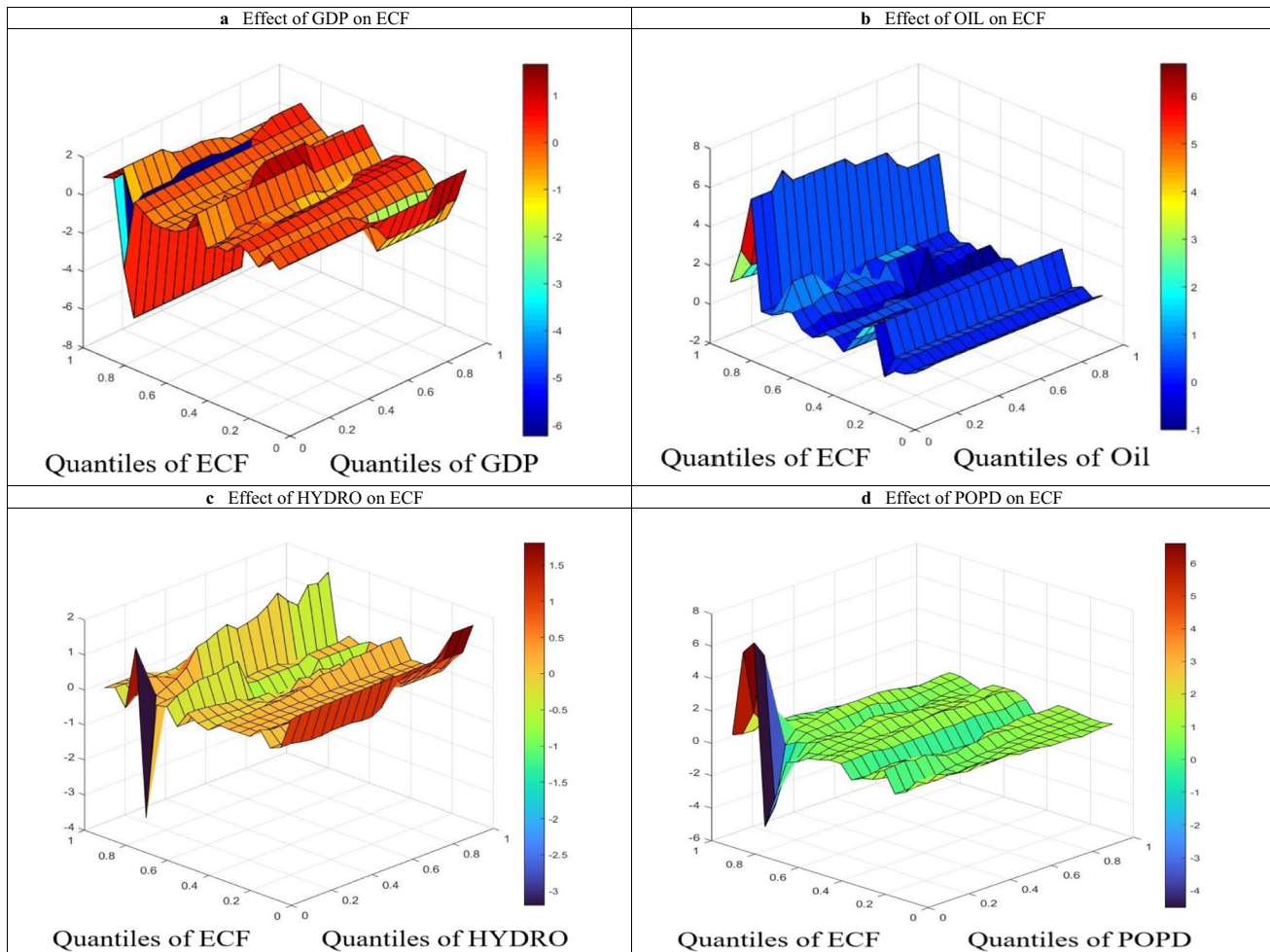


Fig. 3 **a** Effect of GDP on ECF. **b** Effect of OIL on ECF. **c** Effect of HYDRO on ECF. **d** Effect of POPD on ECF

only 31.5%. In 1018, coal accounted for 37.3% of total fossil fuel consumption in Turkey, while renewable energy sources such as wind and solar accounted for only 6.6% and 2.6% of total electricity generation, respectively (Republic of Turkey Ministry of Energy and Natural Resources 2018). Because of the higher prices of renewable energy plants, Turkey's energy output continues to be dominated by fossil fuels. As a result, energy imports account for a larger proportion of Turkey's total imports, given the country's limited and inadequate local fossil energy resources. Other nations provide Turkey with over 75% of its total energy needs (IEA 2022). Because of this reliance on external resources, the nation's economy is constantly running a large current account deficit. CO₂ emissions are rising in tandem with rising energy consumption. In economic, environmental, and social terms, the energy sector in Turkey, as well as around the globe, should be decarbonized in a sustainable way. As a result, renewables, which have shown significant promise, should be employed to eliminate the fossil fuels that Turkey now uses to generate electricity. Using clean energy sources instead of fossil fuels

should reduce the country's energy reliance and provide price stability and energy security.

Lastly, the effect of POPD on ECF is positive in the majority of the quantiles of both ECF and POPD (see Fig. 3d). This demonstrates that POPD contributes to the deterioration of the ecosystem in Turkey. The findings comply with the studies by Gyamfi et al. (2022b), Menz and Welsch (2010), Mujtaba et al. (2022b), where population increase is found to have an escalating connection with CO₂ emissions, and Pang et al. (2022) and Yu et al. (2022), where population density contributes to the deterioration of the environment. The number of people living below the poverty line rises as population density rises, placing strain on natural resources and causing environmental deterioration via overuse of those resources.

Robustness check

As a stoutness check, we used the QR which results shown in Fig. 4a–d. Figure 4 presents the comparison of QQR

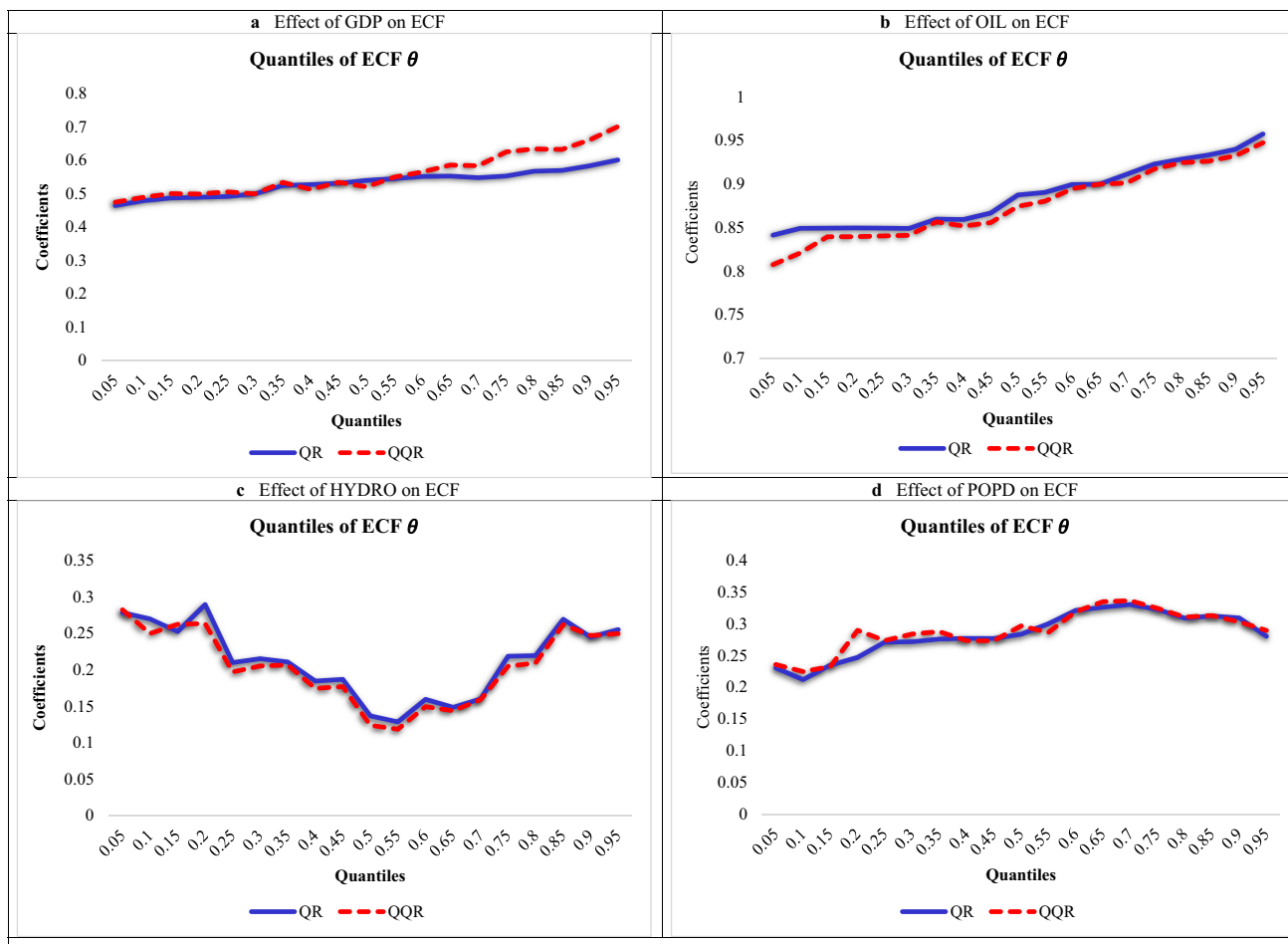


Fig. 4 Comparison between QQR and QR estimates. **a** Effect of GDP on ECF. **b** Effect of OIL on ECF. **c** Effect of HYDRO on ECF. **d** Effect of POPD on ECF

and QR coefficients. The positive effect of economic growth on ecological footprint is more pronounced, which is in accordance with the QQR results in all quantiles (0.1–0.95). In each tail (0.1–0.95), evidence of a positive connection between OIL and ECF surfaced, which corroborates the QQR outcomes (see Fig. 3b). Moreover, the positive effect of HYDRO on ECF is positive and weak in each quantile (0.1–0.95) which is in accordance with the QQR results (see Fig. 4c). Lastly, Fig. 4d compares the slope coefficients of both QQR and QR of the effect of POPD on ECF. In each tail (0.1–0.95), evidence of a positive connection between POPD and ECF surfaced, which corroborates the QQR outcomes.

Granger causality in quantiles results

The study applied the Granger causality in quantiles to evaluate the causality between ecological footprint and the regressors (HYDRO, OIL, GDP, and POPD). The results of Granger causality in quantiles are presented in Table 5. It

includes the DT test for log series significance value. Over a comparable grid of 19 quantiles, we employ the test DT (0.05–0.95). The results show that fluctuation in oil Granger-cause ecological footprints at the significance level of 5% in lower (i.e., 0.05–0.30) and higher (0.75–0.95). On the flip side, the outcomes show that fluctuation in ecological footprint Granger-causes oil at the significance level of 5%. These results support feedback causality between oil and ecological footprint. Furthermore, GDP Granger-cause ecological footprint at the significance level of 5% in lower tails (i.e., 0.05–0.30) and higher (0.75–0.90). On the other hand, ecological footprint Granger-cause GDP at the significance level of 5% in a majority of the quantiles. The results affirm the causal feedback linkage between GDP and ecological footprint.

We observed that hydro Granger causes ecological footprints at the significance level of 5% in the lower (i.e., 0.05–0.30) and higher (0.75–0.95) quantiles. On the flip side, the outcomes show that fluctuation in ecological footprint Granger causes hydro at the significance level of 5%.

Table 5 Troster (2018) quantile causality

| | All | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 |
|-------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| GDP → ECF | 0.120 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.156 | 0.629 | 0.120 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.365 |
| ECF → GDP | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.784 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| OIL → ECF | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.473 | 0.126 | 0.623 | 0.305 | 0.096 | 0.144 | 0.012 | 0.006 | 0.006 | 0.006 | 0.317 | 0.581 |
| ECF → OIL | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.802 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| HYDRO → ECF | 0.006 | 0.018 | 0.006 | 0.006 | 0.006 | 0.006 | 0.012 | 0.006 | 0.186 | 0.491 | 0.120 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.012 | 0.365 |
| ECF → HYDRO | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.904 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| POPD → ECF | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.784 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| ECF → POPD | 0.210 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.329 | 0.078 | 0.012 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.635 |

This table depicts the DT test subsampling p-values. The dependent variable is ECF (ecological footprint while the independent variables are Oil consumption (OIL), Hydro energy consumption (HYDRO), Population density (POPD) and economic growth (GDP). The bold values depict the rejection of the null hypothesis of "no Grangercausality"

These results support feedback causality between hydro and ecological footprint. Furthermore, population density Granger causes ecological footprint at the significance level of 5% in the majority of the quantiles. On the other hand, ecological footprint Granger causes population density at the significance level of 5% in majority of the quantiles. The results affirm the causal feedback linkage between population density and ecological footprint.

Conclusion and policy implications

Conclusion

Unlike past research, this study employed newly developed econometric approaches to evaluate the associations between ecological footprint (ECF) and energy (oil and hydro), economic growth, and population density utilizing data from 1965 to 2018 in Turkey. The application of the novel quantile-on-quantile method permitted us to evaluate what effect the quantiles of the independent variables have on the dependent variable’s quantiles, thus offering a comprehensive explanation vis-à-vis the interdependency between ECF and the independent variables. This study used the BDS test to assess the linearity of the variables in the pre-estimation analysis. The test results revealed that non-linearity occurs in all of the variables used in this study. As a result, using traditional linear methodologies would produce erroneous results. The research employed quantile causality, quantile-on-quantile regression (QQR) and quantile regression (QR) methodologies, based on the findings of the BDS test. The QQR findings revealed that all the regressors (OIL, GDP, HYDRO, and POPD) worsen ecological quality in Turkey. Moreover, the findings of the QR method also corroborate the QQR results. Based on the results, a multi-pronged policy agenda has been developed to help Turkey achieve the key SDGs.

Policy recommendations

Based on the above findings, various policy ramifications for sustainable development are suggested. Since the quality of the environment tends to deteriorate as income levels increase, it is reasonable to conclude that Turkey’s present economic growth path is not sustainable. The utilization of fossil fuel-based energy is one of the key reasons for this, as evidenced by the empirical results. On the flip side, the low penetration of renewable energy (hydro energy) has a positive impact on ECF, demonstrating policy deficiencies in disseminating renewable energy alternatives. A simple solution would be to substitute fossil fuel-based alternatives with renewable energy alternatives; however, this alternative may not be feasible because it may have a detrimental effect

on economic progress patterns. As a result, a policy-level remedy may be established based on the various quantile levels, and the remedy can be constructed phase-wise. These processes will be discussed.

Renewable energy alternatives should be encouraged in Turkey. This can be accomplished by assisting REC in reaching its full potential and increasing the degree of acceptance of renewable energy in households and industry by involving residents, the public sector, and the commercial sector in raising environmental awareness. In doing so, the government can offer clean and sustainable energy solutions at a pro-rata rate to households with an interest rate exemption for a duration of time. This move can help to increase household acceptance of renewable energy options over time. To support this policy, the government can change school curricula to emphasize the environmental advantages of renewable energy alternatives. This mix of measures may assist the government in attracting more people to conduct research and development of alternative energy solutions, and Turkey may see an increase in the generation of renewable energy generation enterprises. This could assist Turkey in achieving SGD 4 by steadily improving academic outcomes in research. Nevertheless, there would be some economic losses in the first stage, which may be indicated in the fiscal deficit. However, such losses could be recouped in the second stage.

The industries will be prioritized at this stage since the economic expansion path is more vulnerable to environmental deterioration at this point. Industries may be given one of two alternatives: (i) take advantage of the government's renewable energy solutions at a higher interest rate than the average household and (ii) offer a higher interest rate on loans for projects that are powered by fossil fuels. As a result, businesses will be progressively deterred from adopting fossil fuel-based alternatives, and they will shift to renewable energy alternatives. At this time, the current facilities for renewable energy generation may not be adequate to meet the growing demand for renewable energy solutions. In this case, firms will have to depend on green energy generation companies that were established during the policy's initial stage of execution. This will increase local competitiveness in the clean energy generation industry, potentially leading to an increase in R&D in this area, and therefore progressing towards achieving SDG 9. In the last phase, appropriate regulations and rules to regulate market competition, steadily taxing fossil fuel alternatives, slowly enhancing educational curricula to institutionalize awareness about the environment via technological discoveries, and incentivizing firms to enter the renewable energy market should be facilitated by the government. The implementation of such measures will eventually reduce the degradation of water and land along with ambient air emissions, and the SDG 13, 14, and 15 objectives will be met. As a result, Turkey

will make progress toward achieving the SDGs, where it currently lags behind.

Author contribution Tomiwa Sunday Adebayo wrote the whole manuscript.

Data availability Data is readily available at the request of the corresponding author.

Declarations

Ethics approval This research complies with internationally accepted standards for research practice and reporting

Consent to participate Not applicable

Consent for publication Not applicable

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