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Charting Sustainable Future on Energy Security, Financial Development, Natural Resources and Economic Output for Turkey

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ABSTRACT

The achievement of 16 out of the 123 sustainable development goals (SDGs) indicates the vast task ahead for Turkey. Addressing the aspects of ecological sustainability via the trend of the ratio of biocapacity to ecological footprint, this study seeks to examine whether energy security, financial development, natural resources and economic expansion drive Turkey's load capacity factor. By implementing quantile-on-quantile and its Granger causality dimension, the results largely affirm the statistically significant effect of energy security on the load capacity factor in all quantiles. Although this impact is weak, it is significantly positive, thus indicating that the country's energy security profile is advancing its ecological sustainability. Similarly, globalization positively impacts the load capacity factor by a strong dimension. Conversely, financial development and economic growth exert a significant but negative effect on the load capacity factor in most quantiles, which reflects the undesirability of these indicators on the country's environmental sustainability drive. Specifically, the negative effects of financial development and economic output on the load capacity factor are mainly in the middle to higher quantiles (0.4–0.95) and lowest quantiles (0.05–0.3), respectively. The results of this study can guide the development of intuitive and robust energy efficiency and energy security-related policies.

1 | Introduction

Threats from climate change to human development and survival include food scarcity, mass extinctions and harsh weather. The primary source of global warming is thought to be carbon dioxide (CO_2) emissions, which make up 58% of all greenhouse gas emissions. As CO_2 emissions may linger in the Earth's atmosphere for thousands of years, they are the most harmful and common pollutants. Changes in the global population, industrialization, economic performance and standards of living continue to make environmental degradation a problem for many nations. As an essential asset, energy has historically been a fundamental component of economic progress and a means of guaranteeing both social and economic development. Consequently, energy security (ES) has consistently been one of the most crucial goals for nations seeking to achieve sustained economic growth (Kanwal et al. 2022). The International Energy Agency (IEA) defines 'energy security' as

the availability of energy sources at reasonable rates and without interruption (IEA 2014b). It indicates less susceptibility to temporary or permanent interruptions of imports. It also refers to the availability of domestic and foreign resources to supply rising energy demands both gradually and affordably. This is why the four elements of ES, as defined by the Asia Pacific Energy Research Centre (APERC 2007), are acceptability, affordability, accessibility and availability. Within these four As, 'availability' ensures the continuous attainability of commodities, 'affordability' refers to how inexpensive the resources are; 'acceptability' relates to how they should not harm the environment, and 'accessibility' refers to how easily they can be acquired (Tufail, Ibrahim, and Melan 2018).

In the case of Turkey, one of the emerging nations with the fastest structural transformation, the increasing pace of industrialization and urbanization has not come without a significant increase in energy consumption and greenhouse gas emissions (Ozkan, Khan, and Ahmed 2023). According to the IEA, Turkey's energy-related CO_2 emissions increased by 138.3% between 1990 and 2012 (IEA 2014a; Rjoub et al. 2021). Given that Turkey's economic growth is primarily dependent on fossil fuel-based options, its current trajectory of economic development is not environmentally sustainable. Consequently, Turkey is facing challenges in reorganizing its current policies to fulfil the objectives of climate action (Adebayo et al. 2022). Turkey ranks 50th out of 61 countries on the Climate Change Performance Index (2016), indicating the country's poor performance in protecting the environment. Turkey's unsatisfactory environmental record is primarily attributable to the absence of an adequate, long-term policy meant to reduce the nation's emissions (Alola and Donve 2021). With the ecological footprint surpassing biocapacity since the early 1980s according to Global Footprint Network (GFN 2024), Turkey's biocapacity deficit has now declined by 120%. Currently, Turkey has insufficient natural resources (NR) to satisfy its environmental demands. Turkey's ES risk, or energy insecurity, was consistently high between 1980 and 2018, according to a report by the Global Energy Institute (GEI 2021). The multipronged indicator of Turkey's energy insecurity, the energy security risk index (ENSRI), has consistently been significantly higher than the average of the Organization for Economic Co-operation and Development (OECD). In this regard, Turkey's primary goals are to decrease energy imports and the associated economic pressures while achieving increased energy independence and security (Wilson 2017; Erat et al. 2021).

For energy-importing economies (i.e., Turkey), the fast-moving process of globalization could not have a minimal impact on the country given the social, political and economic effects of globalization since the early 1990s (Gozgor et al. 2020). As with most other nations, Turkey adopted a liberal economic system on 24 January 1980, and globalization has accelerated ever since (Yurtkuran 2021). The influence and contribution of globalization to almost every aspect have been the subject of debate, especially in energy and environmental aspects (Etokakpan et al. 2020). In particular, in the globalized era, developing and emerging countries integrate trade, transfer of technology and financial transactions to improve their own economic structure. However, the expansion of worldwide economic activity may result in increased energy consumption and greenhouse gas emissions (Adebayo and Kirikkaleli 2021; Olowu, Odugbesan, and Sunday 2021; Xia et al. 2022; Xu et al. 2022). Besides globalization and related aspects including social, financial and economic aspects, rents from NR are vital to a nation's growth, especially in developing and emerging economies. These emerging countries mostly depend on using their NR to significantly increase their national gross domestic product (GDP) (Hassan et al. 2019; Gao and Tian 2016; Xue et al. 2021; Aladejare 2022). On the other hand, higher NR rents can also further environmental degradation due to primarily being the consequence of rising NR output, which increases environmental pressure and subsequently accelerates environmental degradation (Akadiri et al. 2022). Countries such as Bangladesh, South Korea, Nigeria, Indonesia and Turkey, whose NR are decreasing and impacting environmental quality, must adopt sustainable techniques in their resource exploration (Nathaniel 2021).

In essence, this research seeks to analyse the influence of ES, financial development (FD), NR rent, globalization and economic progress on Turkey's load capacity factor (LCF). The LCF illustrates a nation or region's ability to sustain its population's way of life and can be computed through the biocapacity/ecological footprint formula. A load capacity (LC) of less than one denotes an unsustainable state of the environment, while a number higher than one means that the infrastructure is sustainable (Siche et al. 2010; Pata 2021). Given that only Deng et al. (2024) examined the connection between LCF and ES in the top 10 polluting nations, this study offers significant contributions to the literature. One of the study's most significant contributions is that the link between these two factors has never been examined in Turkey previously. Additionally, the study's use of the newly modified quantile-on-quantile (QQ) Granger Causality (Adebayo and Özkan 2024) approach is another significant addition. The QQ method is an additional technique used in the investigation. The research was conducted using data from 1985 to 2021, thereby offering another contribution in the form of its extensive timeframe. The research verifies the existence of a complete model by examining the impact of factors such as financial growth, globalization, economic advancement and NR on LCF, in addition to ES. This highlights yet another one of the significant achievements of the study.

The remainder of the study is structured as follows: Section 2 provides a review of the literature; Section 3 describes the methodologies and data; Section 4 details the primary conclusions; and, finally, Section 5 provides our results' policy ramifications and a succinct conclusion.

2 | Literature Review

The literature review section is categorized into subsections based on the relationship between the independent variables and the dependent variable used in the research.

2.1 | Energy Security–LCF Nexus

There is a lack of research analysing the link between ES and LCF, as shown in this relationship. Several studies have examined the connection between environmental sustainability or

other environmental degradation indicators and ES (Huang, Chung, and Wu 2021; Wang et al. 2024; Fu et al. 2021; Doğan et al. 2023; Ainou, Ali, and Sadiq 2023; Chu et al. 2023). Aside from Deng et al. (2024), who studied the effect of ES on LCF in the 10 most polluted countries in the world, our study is the first to examine the connection between LCF and ES. Deng et al. (2024) used the panel data techniques PMG-ARDL (pooled mean group autoregressive distributed lag) and cross-sectional-ARDL (CS-ARDL), together with data from 1998 to 2018, to reach their empirical results. The CS-ARDL findings demonstrated that ES improves environmental quality in the examined areas.

2.2 | Financial Development–LCF Nexus

Considering research examining the connection between LCF and FD, Latif and Faridi (2023) examined the effects of FD on the environmental LCF in 3 distinct methods for 48 Asian countries. To evaluate the data, spanning 1996 through 2020, they used the two-step System GMM approach. According to their findings, there are statistically significant long-run co-integrating correlations between FD and LCF in the countries under study. This research showed how environmental degradation in 48 Asian nations results from FD. Similarly, Okezie et al. (2023) also examined the connection between Nigeria's ecological LCF and FD. They used the autoregressive distributed lag (ARDL) approach using yearly data from 1970 to 2021 and found that, over time, a negative correlation emerges between the ecological LCF and FD. Using a second-generation methodology, Yang et al. (2023) evaluated the impact of FD on the LCF, a proxy for ecological quality, focusing on the BRICS countries (the data which spanned from 1990 to 2018). The study concluded that ecological quality declines as a consequence of FD. In their research, Kartal et al. (2023a) evaluated how FD affected LCF in Japan. The authors employed Fourier-based time series models and used data from 1974 to 2018. The research discovered that environmental deterioration is exacerbated by FD. Additionally, the work of Awosusi et al. (2023) assessed the impact of FD on LCF in Japan from 1980 to 2017 using dynamic ARDL techniques. According to empirical evidence, they found FD to negatively influence LCF. Meanwhile, Özkan, Saleem, and Sharif (2023) studied the dynamic impact of FD—which considers either the supply and demand aspects of environmental problems—on environmental degradation in India via the LCF. This was accomplished through their use of yearly time series data covering 1980–2020 and the newly developed dynamic ARDL approach. They found that FD has a dynamically negative effect on the LCF.

2.3 | Globalization–LCF Nexus

According to a review of the literature, research on how globalization affects LCF appears scarce. The link between globalization and LCF in South Africa was examined by Awosusi et al. (2022). Using the ARDL approach, and data from 1980 to 2017, the authors found that South Africa's environmental quality has improved due to globalization. Moreover, the frequency-domain causality test showed that globalization predicted the long-term LCF. Globalization's influence on LAC nations was investigated by Pata, Kartal, et al. (2023) using the PMG-ARDL technique on yearly data from 1990 to 2018. The findings demonstrate that, over time, globalization has a deteriorating effect on the LCF. Li et al. (2023) examined the connection between LCF and globalization in Next-11 nations. The authors used the CS-ARDL approach with data from 1990 to 2018. Long-term results show that LCF falls with increasing globalization. The factors affecting the LCF in the top-performing sustainable development goals countries were examined by Jahanger et al. (2024). From 1994 to 2018, the study used the method of moments quantile regression (MMQR) to quantify each variable's effect at various quantiles. The results demonstrated that globalization negatively and considerably impacted LCF within the nations.

2.4 | Natural Resource Rent–LCF Nexus

This section discusses studies that have examined the connection between LCF and NR rent. Akadiri et al. (2022) used the unique dual adjustment technique and time–frequency domain causality approaches to investigate the effect of NR rent on LCF in India, using data from 1970 to 2017. The authors found that the short-term impact of NR rent is negligible. NR rent has a long-term beneficial impact on the LCF. The impact of NR rent on LCF across 96 countries was examined by Wang et al. (2024). The threshold model approach was used in the investigation, which employed data from 2000 to 2018. It was discovered that increasing ecological quality via trade openness is positively impacted by greater NR rents. Pata and Isik (2021) studied the factors influencing LCF in China between 1981 and 2017 using a newly created dynamic ARDL simulation model. Their findings showed that a rise in NR rent causes the LCF to decrease. The connection between LCF and NR rents was further analysed by Li et al. (2023). The research used data from 1990 to 2018, employed the CS-ARDL approach, and found that reliance on NR rent reduced LCF. Pata and Ertugrul (2023) examined how India's LCF was affected by NR rent. By considering a dummy variable representing the impacts of the Kyoto Protocol from 1988 to 2018, the research used the ARDL technique and found that NR rents encourage the enhancement of environmental quality. Using the CS-ARDL technique, Ni, Yang, and Razzaq (2022) examined the effect of NR rent on LCF for highly resource-consuming countries from 1965 to 2018. The results showed that, in high-resource-consuming countries, NR rent reduces LCF. In their thorough environmental study of 26 OECD nations, Guloglu, Caglar, and Pata (2023) studied how NR rent affected LCF between 1980 and 2018. They used the newly developed quantile common correlated effects mean group (QMG) estimator and found that NR rent can improve LCF.

2.5 | Economic Progress LCF Nexus

Much research in the literature has examined the relationship between LCF and economic progress. The link between LCF and per capita income in China was examined by Pata and Isik (2021), using a freshly-developed ARDL simulation model for data spanning 1981–2017. Their findings showed that, over time, a rise in revenue is accompanied by a decrease in the LCF. Furthermore, the EKC theory holds for China since its short-run income elasticity is lower than its long-run elasticity. Jin

et al. (2024) used data from 1995 to 2022 and the MMQR approach to study the influence of economic development on LCF in the G7 nations. They discovered that GDP reduces LCF in the G7 nations. The link between LCF and economic development in the US was researched by Pata et al. (2024), who used data from 1961 to 2018 and employed the Fourier causality test using the wavelet-decomposed series. The findings show that the relationship between economic development and the LCF is bidirectionally causal. Agila et al. (2022) assessed how South Korea's LCF was affected by economic progress by examining data from 1970 to 2018 using the QQR methodology. The results showed that the impact of economic expansion attenuates the LCF in most quantiles. Between 1980 and 2018, the influence of economic development on Malaysia's LCF was evaluated by Altıntaş et al. (2024) through the ARDL bound test methodology. The results indicated that LCF is lowered over the long and short terms by economic advancement. Pata and Balsalobre-Lorente (2021) used new dynamic ARDL simulations (for 1965–2017) to study the impact of economic progress on LCF in Turkey. The findings showed that economic expansion negatively impacts the LCF over the long term. Investigation of the connection between economic progress and LCF in 26 OECD nations between 1980 and 2018, Guloglu, Caglar, and Pata (2023) used the QMG estimator and found a U-shaped relationship between LCF and economic advancement. The link between LCF and economic progress in APEC nations was studied by Caglar et al. (2023). The CUP-BC and CUP-FM techniques were used for the years 1992 through 2018. The empirical results showed that economic progress lowers the LCF in APEC nations. Huilan et al. (2022) studied how economic development affected LCF between 1970 and 2017 in Mexico. Using the dual adjustment technique, they discovered indications of a long-run cointegration nexus between the series. According to the research, LCF is negatively impacted by economic expansion.

2.6 | Gaps in the Literature

A review of the relevant literature reveals a number of significant gaps. The first is that the connection between ES and LCF has rarely been analysed—indeed, only Deng et al. (2024) appear to have done so. Second, there is sparse prior research that has been conducted on the connection between ES and LCF in Turkey. Turkey has a significant risk of ES, meaning that it would be vital to determine how ES affects LCF. Third, it is expected that using novel techniques to perform the analysis would fill a significant gap in the literature. The research used the Quantile-on-Quantile Granger Causality (QQGC) technique, a new modification of QQ by Adebayo and Özkan (2024), to assess the conditional distribution of independent and dependent variables. Notably, compared with the current quantile-based Granger causality approaches, the QQGC allows for a more complex analysis by examining causality from the quantiles of an independent variable to those of a dependent variable. Fourth, the study's thorough analysis is expected to address a significant gap in the literature. Its goal is to determine how Turkey's LCF is affected by ES, as well as by globalization, FD, economic progress and NR rent. Fifth, the study's dataset spans the years 1985 through 2021. It is anticipated that this data range's comprehensiveness would enable the creation of more accurate policy suggestions regarding Turkey's energy and environmental policies. Finally, the policy suggestions presented in this study are also deemed significant since no prior research has examined the connection between ES and LCF in Turkey. These policy recommendations have great importance for a nation confronted with significant environmental hazards and energy insecurity.

3 | Materials and Methods

3.1 | Data

Through this research, we aim to provide a path for Turkey's sustainable future by investigating the effect of ES, FD, globalization, economic progress and NR on the LCF. Within this objective, the annual time series data from 1985 to 2021 were used due to the availability of annual data. While we endeavoured to obtain the most extended period for the variables, FD dictates the beginning of the sample period, and the KOF globalization index dictates its end. The annual frequency data were then converted into the quarterly frequency to achieve adequate observations for the empirical analysis performing the quadratic-match approach, following the research of Olasehinde-Williams, Olanipekun, et al. (2023) and Olasehinde-Williams, Özkan, et al. (2023). This method provides a local quadratic polynomial for each observation in the low-frequency series. Then, the polynomial serves the observations in the high-frequency series for a particular duration (Lee, Olasehinde-Williams, and Özkan 2023; Olanipekun, Ozkan, and Olasehinde-Williams 2023).

The LCF was the dependent variable used as a proxy for sustainability measuring biocapacity/ecological footprint. LCF was obtained from the Global Footprint Network (GFN 2023). Primary energy production/primary energy consumption was employed to measure ES which was obtained from the IEA. The FD index was considered (Ozkan, Sharif, et al. 2023), with the data obtained from the International Monetary Fund (IMF 2023). The KOF globalization index was used for globalization (GL), as per Pata, Erdogan, and Ozkan (2023), and GL was gathered from the KOF Swiss Economic Institute (KOF 2023). However, GDP per capita (constant 2015 US$) was used as an economic indicator (Olasehinde-Williams and Özkan 2023) while total NR rent (% of GDP) was performed for NR, as in Özkan, Alola, and Adebayo (2023) and Özkan, Obekpa, and Alola (2023). EP and NR were obtained from the World Bank's data stream (WB 2023). All definitions, abbreviations, references and sources of the data are presented in Table 1. Finally, the logarithm of the series was taken to diminish the size difference between the indices and address the heteroscedasticity issue, and the series in logarithmic forms were converted into the first difference values for stationarity.

3.2 | Methods

The empirical approach steps followed in the study are displayed in Figure 1.

Following the data collection and transformation process, the descriptive statistics were checked twice to investigate the properties of the series. We altered these variables into quarterly frequencies using the quadratic-match-sum approach to overcome

TABLE 1 | Data description (name, metric and source).

Variable	Definition	Source
Load capacity factor (LCF)	Biocapacity/ ecological footprint	GFN (2023)
Energy security (ES)	Primary energy production/primary energy consumption	IEA
Financial development (FD)	Financial development index	IMF (2023)
Globalization (GL)	KOF globalization index	KOF (2023)
Economic progress (EP)	GDP per capita (constant 2015 US$)	WB (2023)
Natural resources (NR)	Total NR rent (% of GDP)	WB (2023)

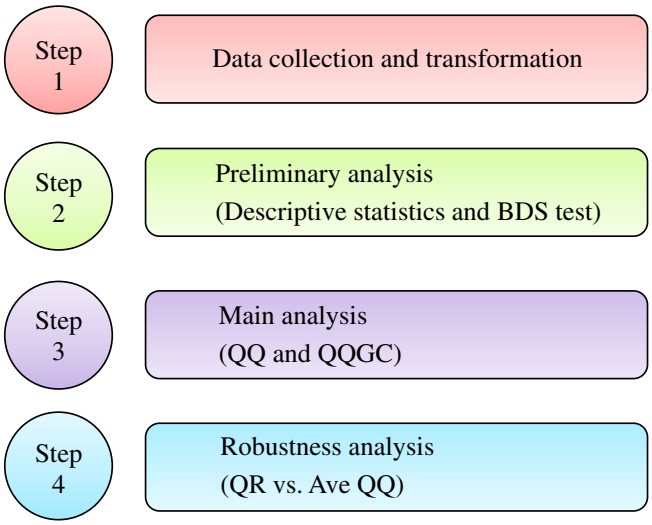

FIGURE 1 | Steps of empirical analysis.

the issues resulting from small observations (Fareed et al. 2021). We favoured this approach over other interpolation techniques because it considers seasonality by minimizing data variations while switching from low to high frequency. All these annual frequency data were transformed into logarithmic values to help remove nonlinear functional forms and stabilize variances, as suggested by Pata, Erdogan, and Ozkan (2023) and Balcilar, Usman, and Özkan (2023). In the second step, the Jarque–Bera, Skewness, and Kurtosis values, which provide insight into whether the series possesses distributional asymmetry and different distributional and non-normality distributed characteristics, were considered to determine whether the series was normally distributed, and the result of the stationary analysis was examined. Another pivotal test in the second step was exploring the BDS test, introduced by Broock et al. (1996) to determine the nonlinearity properties for each series. In the third step, the QQ (Sim and Zhou 2015) and the QQGC (Adebayo and Özkan 2024) were performed to assess the interrelationship between LC and ES, FD, GL, EP, and NR. In the final step, the QR approach was executed to check the robustness of the QQ findings (Koenker 2005).

We performed QQ and QQGC as the variables considered were not normally distributed and possessed nonlinear properties. The QQ provides a more robust result concerning the effect of independent variables on the dependent variables for each quantile, with the help of allowing for the heterogeneity of the nexus among variables and completed dependence compared with other nonlinearity-based regression models. As for the nonlinearity causality analysis, the QQGC is preferred over the quantile-based Granger causality method because it allows one to evaluate the conditional distribution of both the dependent and independent variables and causality from independent variables to dependent variables for each quantile. Finally, we sought to achieve more comprehensive evidence by considering each quantile of the variables to provide more reliable policies on sustainability.

3.2.1 | QQ Regression

The quantile regression (QR) approach introduced by Koenker and Bassett (1978) is widely considered to be the superior version of the traditional linear regression model. The QR approach allows for examining the relationship between variables on different quantiles by considering median values and means. Moreover, the QR approach provides more robust results than ordinary regressions due to considering the heterogeneity of connections among variables. The modelling form of the QR approach is presented in Equation (1):

$$Q_{B_t}\left(\tau IA_t\right) = f\left(A_t, \gamma(\tau)\right) = A_t\,\gamma(\tau), t = 1, 2, \ \ldots\ , n \tag{1}$$

In the Equation (1), $\gamma(\tau)$ symbolizes the regression coefficient, while A_t contains the explonarity variables. Moreover, $Q_{B_t}\left(\tau IA_t\right)$ represents the τ-th quantiles of the dependent variables. The connection between variables representing A and B is investigated for each quantile. Equation (2) shows the estimation process:

$$\widehat{Q}_{B_t}\left(\tau IA_t\right) = A_t\widehat{\gamma}(\tau) \tag{2}$$

where $\widehat{\gamma}(\tau)$ displays the measured coefficients in the relevant quantile. Although the QR approach provides more robust results compared with conventional linear regressions, it does not consider complete dependence. Therefore, Sim and Zhou (2015) introduced the QQ method to overcome this deficiency. The QQ method allows for full dependence on variables in different quantiles and provides the investigation of the influence of independent variables on the values of the dependent variables in various quantiles. In our study, the dependent variable is LCF and the independent variables are symbolized as D (ES, FD, GL, EP and EP). The model of the QQ method is displayed in Equation (3):

$$\mathrm{LC}_{2t} = \gamma^{\vartheta}\left(D_t\right) + \epsilon_t^{\theta} \tag{3}$$

where $\gamma^{\vartheta}(\varsigma)$ is assumed to be an unknown factor and D donates the LCF–D relationship at the ϑth quantile. However, ϵ_t^{θ} represent

the quantile error time. When linearizing γ^{ϑ}, Equation (4) is achieved:

$$\gamma^{\theta}(D_t) \approx \gamma^{\theta} D^{\tau} + \gamma^{\theta t}(D^{\tau})(D_t - D^{\tau}) \tag{4}$$

where $\gamma^{\vartheta t}$ means the responsive impact. The last step in the QQ method is that the unknown factor and measured coefficient in Equation (4) are revised as $\gamma_o(\theta, \tau)$ and $\gamma_1(\theta, \tau)$. Once done, Equation (5) can be calculated:

$$\mathrm{LC}_{2t} = \gamma_o(\theta, \tau) + \gamma_1(\theta, \tau)\left(D_t - D^{\tau}\right) + \epsilon_t^{\theta} \tag{5}$$

if $\gamma_o(\theta, \tau) + \gamma_1(\theta, \tau)\left(D_t - D^{\tau}\right)$ is symbolized as α. In Equation (5), α demonstrates the θth conditional quantile of the variables (the θth of LCF and the τ − th quantile of D) (Kartal et al. 2023b).

3.2.2 | Quantile-on-Quantile Granger Causality

As existing quantile-based Granger causality methods have been performed under the limitation that there is only the conditional distribution of the dependent variable (see, e.g., Balcilar, Gupta, and Pierdzioch 2016; Jeong, Härdle, and Song 2012; Troster 2018), the modified approach by Adebayo and Özkan (2024) evaluates the conditional distribution of both the dependent and independent variables. Notably, the QQGC explores causality from an independent variable's quantiles to a dependent variable's, thus permitting a more complicated causality analysis than the existing quantile-based Granger causality methods.

By closely following Li, Li, and Tsai (2015) and Adebayo and Özkan (2024) denoted QB_{τ} as τth conditional quantile of B (i.e., dependent variable), QA_{θ} as θth conditional quantile of A (i.e., independent variable), $QB_{\tau}(A)$ as τth quantile of B conditional on A, and $QA_{\theta}(B)$ as θth quantile of A conditional on B. Moreover, $QB_{\tau}(A)$ independent of A and $QA_{\theta}(B)$ independent of B, that is, $QB_{\tau}(A) = QB_{\tau}$ and $QX_{\theta}(B) = QA_{\theta}$ with probability 1, if and only if A, B, $I\left(B - QB_{\tau} > 0\right)$, and $I\left(A - QA_{\theta} > 0\right)$ independent. Here, $I(\bullet)$ stands for the indicator function. Accordingly, the QQGC can be specified by Equation (6):

$$QB_{\tau,t} = \delta_{\tau,\theta,0} + \sum_{i=1}^{p} \vartheta_i QB_{\tau,t-i} + \sum_{i=1}^{p} \theta_i QA_{\theta,t-i} + \varepsilon_{\tau,\theta,t} \tag{6}$$

where $0 < \tau$ and $\theta < 1$. Furthermore, $\delta_{\tau,\theta,0}$ represents the constant term at quantile τ and θ, ϑ_i denotes the coefficients of the lagged values of the τth conditional quantile of B, B_{t-i} donates the lagged values of τth conditional quantile of B at different time periods $(t-1, t-2, \ldots, t-p)$, θ_i represents the coefficients of the lagged values of the θth conditional quantile of A, A_{t-i} means the lagged values of the θth conditional quantile of A at different time periods $(t-1, t-2, \ldots, t-p)$, and $\varepsilon_{\tau,\theta,t}$ shows the error term at the time t, quantile τ, and θ.

4 | Empirical Analysis

The study assessed the role of globalization, economic progress (EP), NR, ES and FD in sustainability in Turkey from 1985 to 2021. Within this aim, we followed the steps involving preliminary analysis, QQ, QQGC and robustness checks.

4.1 | Preliminary Analysis

The descriptive properties of the series are vital for determining which time series method is more appropriate for being employed as an econometric approach within the objective of the research. The descriptive statistics are documented in Table 1. According to Table 1, NR has the highest standard deviations, followed by FD, LC, ES, EP and GL. Moreover, NR has the highest maximum and lowest minimum values. The Jarque–Bera statistics and probability value confirm that all series are not normally distributed at a 99% confidence level. Furthermore, the Skewness and Kurtosis values are vital in determining time series methods. Skewness values provide insights into the distributional asymmetry, and the difference in distributional characteristics is depicted with the help of the Kurtosis values. The Skewness and Kurtosis values approve of the distributional asymmetry and different distributional characteristics.

Regarding the Skewness and Kurtosis values, the nonlinear econometric approach is more applicable to the series because linear-based approaches provide misleading results. Moreover, the stochastic properties of the series at the first difference are depicted by employing the ADF and PP unit root tests, the results of which are also reported in Table 2. The findings of the unit root tests confirmed the stationarity of all series.

Despite the importance of the normality tests, the outcome of the BDS analysis introduced by Broock et al. (1996) should be applied so as to understand whether the series is based on a nonlinear nature (Alola, Özkan, and Obekpa 2023; Alola, Özkan, and Usman 2023; Balcilar, Usman, and Özkan 2023; Khan, Saleem, and Ozkan 2023). Table 3 reports the results of the BDS tests. According to the findings, the null hypothesis of linearity for all series can be rejected, implying the nonlinearity of the series. Regarding the result of the descriptive statistics and BDS test, the QQ and QQGC methods were found to be accurate and suitable in parallel with the study's objective as they provided robustness for non-normal, nonlinear and skewed series. Therefore, the QQ and QQGC served as the main methods for reflecting the asymmetric distribution of non-normally distributed series, and the QR method was centralized for robustness.

4.2 | QQ-Based Results

After confirming the nonlinear features of the series, the primary empirical results of the QQ regression on the impact of ES, FD, GL, EP and NR on LCF in Turkey are here displayed. The findings are depicted in Figure 2a–e. In the figures, the quantiles on the left side represent the dependent variables, while those on the right represent the independent variables.

Figure 2a presents the impact of ES on LC in all quantiles (0.05–0.95) of the combination of ES and LCF. According to Figure 2a, ES has a weak and positive impact on LCF, whereas

TABLE 2 | Descriptive statistics.

	LC	ES	FD	GL	EP	NR
Mean	−0.001	−0.001	0.003	0.001	0.002	0.000
Med	−0.001	−0.001	0.001	0.001	0.002	−0.002
Max	0.029	0.016	0.041	0.008	0.012	0.151
Min	−0.022	−0.025	−0.030	−0.007	−0.014	−0.122
SD	0.006	0.005	0.010	0.002	0.004	0.032
Ske	0.708	−0.478	1.376	0.028	−1.043	0.276
Kur	11.837	7.130	7.238	7.704	7.423	8.146
J&B-t	490.563***	110.096***	156.418***	135.549***	146.488***	164.041***
J&B-p	0.000	0.000	0.000	0.000	0.000	0.000
AD&F-t	−4.837***	−3.111**	−5.768***	−2.891**	−3.253**	−3.232**
AD&F-p	0.000	0.028	0.000	0.049	0.019	0.020
P&P-t	−8.338***	−5.928***	−5.149***	−6.026***	−5.293***	−5.550***
P&P-p	0.000	0.000	0.000	0.000	0.000	0.000
N	147.000	147.000	147.000	147.000	147.000	147.000

Note: ***, ** and * denotes significance at 1%, 5% and 10%, respectively.

TABLE 3 | BDS test.

	LC	ES	FD	GL	EP	NR
2nd D-z	4.672***	7.115***	8.034***	12.148***	8.223***	6.335***
2nd D-p	0.000	0.000	0.000	0.000	0.000	0.000
3rd D-z	2.819***	5.763***	7.779***	10.698***	6.791***	4.141***
3rd D-p	0.005	0.000	0.000	0.000	0.000	0.000
4th D-z	1.784*	5.132***	7.629***	9.302***	5.717***	2.272**
4th D-p	0.074	0.000	0.000	0.000	0.000	0.023
5th D-z	2.608***	7.273***	9.483***	10.912***	7.652***	2.765***
5th D-p	0.009	0.000	0.000	0.000	0.000	0.006
6th D-z	2.823***	9.233***	11.273***	12.253***	9.206***	2.917***
6th D-p	0.005	0.000	0.000	0.000	0.000	0.003

Note: D means the dimensions, and z donates the z-stats of the Brock-Dechert-Scheinkman (1996). For example, 2nd D-z represents the second dimension of the z-stats of the Brock-Dechert-Scheinkman (1996). D-p shows the dimension of *p* values. ***, ** and * denotes significance at 1%, 5% and 10%, respectively.

the impact is more visible in all quantiles (0.05–0.95) of ES and the lower quantiles (0.05–0.3) of LCF. Figure 2b shows the effect of FD on LCF in all quantiles, with LCF being negatively and weakly impacted by FD—an impact predominantly observed in the middle and higher quantiles of LCF (0.4–0.95). However, the negative impact of FD in all quantiles of FD on LCF in the lower quantiles (0.05–0.3) becomes more compound. The GL impact on LCF is presented in Figure 2c. When all quantiles of the combination of GL and lower quantiles (0.05–0.2) of the combination of LCF are considered, GL strongly positively impacts LC; however, when regarding other quantiles of the combination of LCF, the effect of GL on LCF is weak and positive. The influence of EP on LC is depicted in Figure 2d, where the effect of EP in quantiles (0.05–0.7) on LCF in lower quantiles is not statistically significant, while the EP in the highest quantiles (0.8–0.95) promotes a strong negative impact on LCF in the lowest quantiles. Considering the influence of EP on LCF in the remaining quantile combinations, the effect of EP on LCF is significantly harmful. Figure 2e shows the influence of NR on LCF in a quantile combination of NR and LCF. Figure 2e underlines that the effect of NR on LCF is negative in all quantiles of NR and quantiles (0.3–0.8) of LCF, whereas NR in all quantiles does not affect LCF in its lowest quantile (0.05), and the ineffectiveness of NR is also verified in the middle and higher quantiles (0.6–0.95) of NR and the highest quantiles of LCF (0.95).

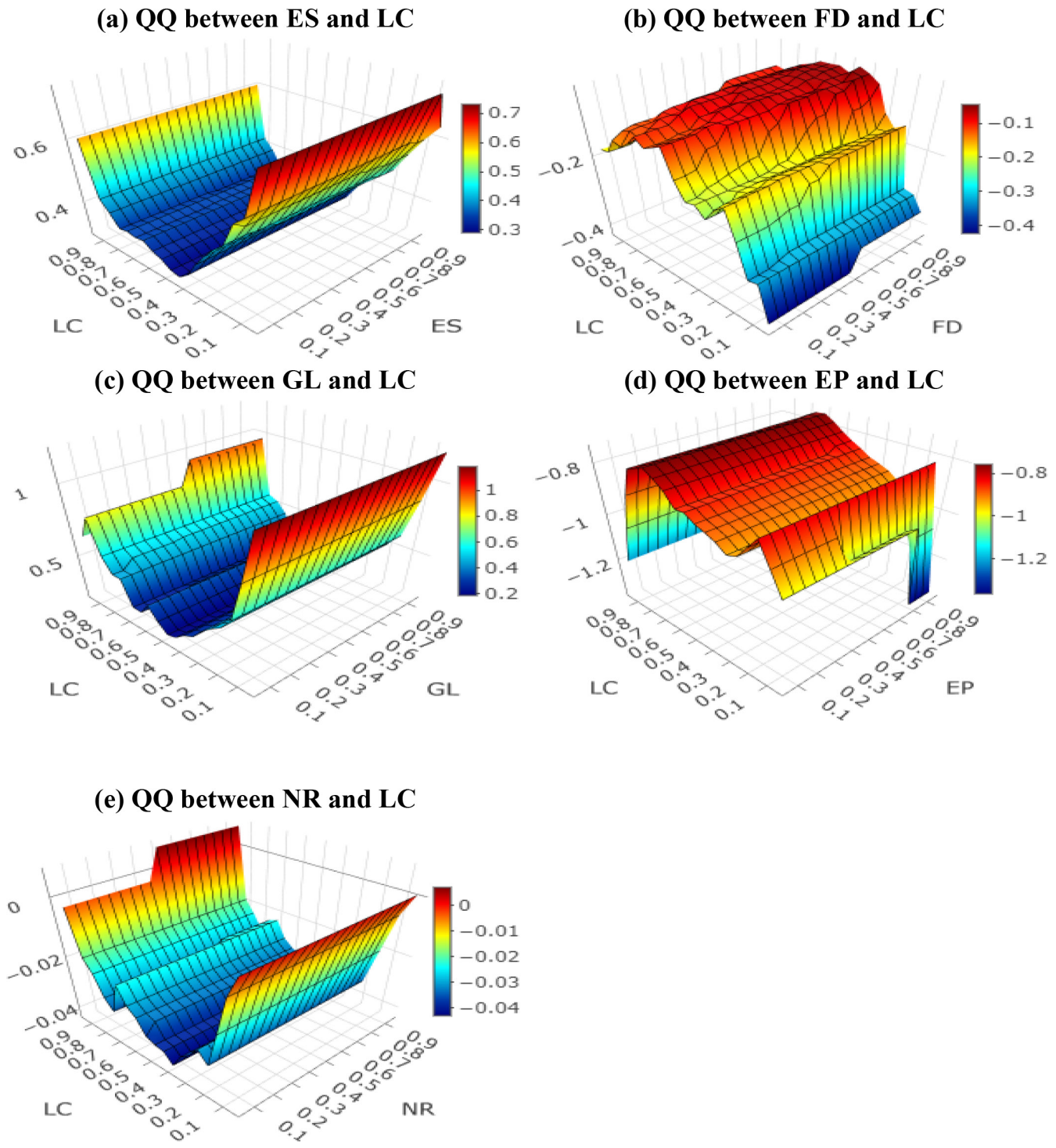

FIGURE 2 | Quantile-on-quantile regression plots.

After checking the slope coefficient of independent variables on LCF in all quantile combinations, the QQGC was performed to determine the causality connection between independent variables and LCF in all quantiles. The QQGC result is depicted in Figure 3a–e. The horizontal and vertical axes in Figure 3a–e represent the quantiles of LCF and independent variables, respectively. Figure 3a depicts the finding of the QQGC relationship between ES and LCF. The null hypothesis of the QQGC analysis can be mainly accepted in ES's intermediate and highest quantiles (0.7–0.95) and from 0.2 to 0.7 of LCF at the 5% significance level. However, regarding the quantiles ranging from 0.05 to 0.65 of ES and the quantile from 0.25 to 0.65, the null hypothesis of QQGC is mostly rejected. The QQGC is especially more complex in the lowest quantile (0.05–0.10) of ES and quantiles (0.65–0.95) of LCF. Figure 3b displays the results of the QQGC between FD and LCF, confirming that all of FD's quantiles (0.05–0.95) cause the lowest and middle quantiles (0.05–0.55) of LCF, and also the highest quantiles (0.90–0.95)

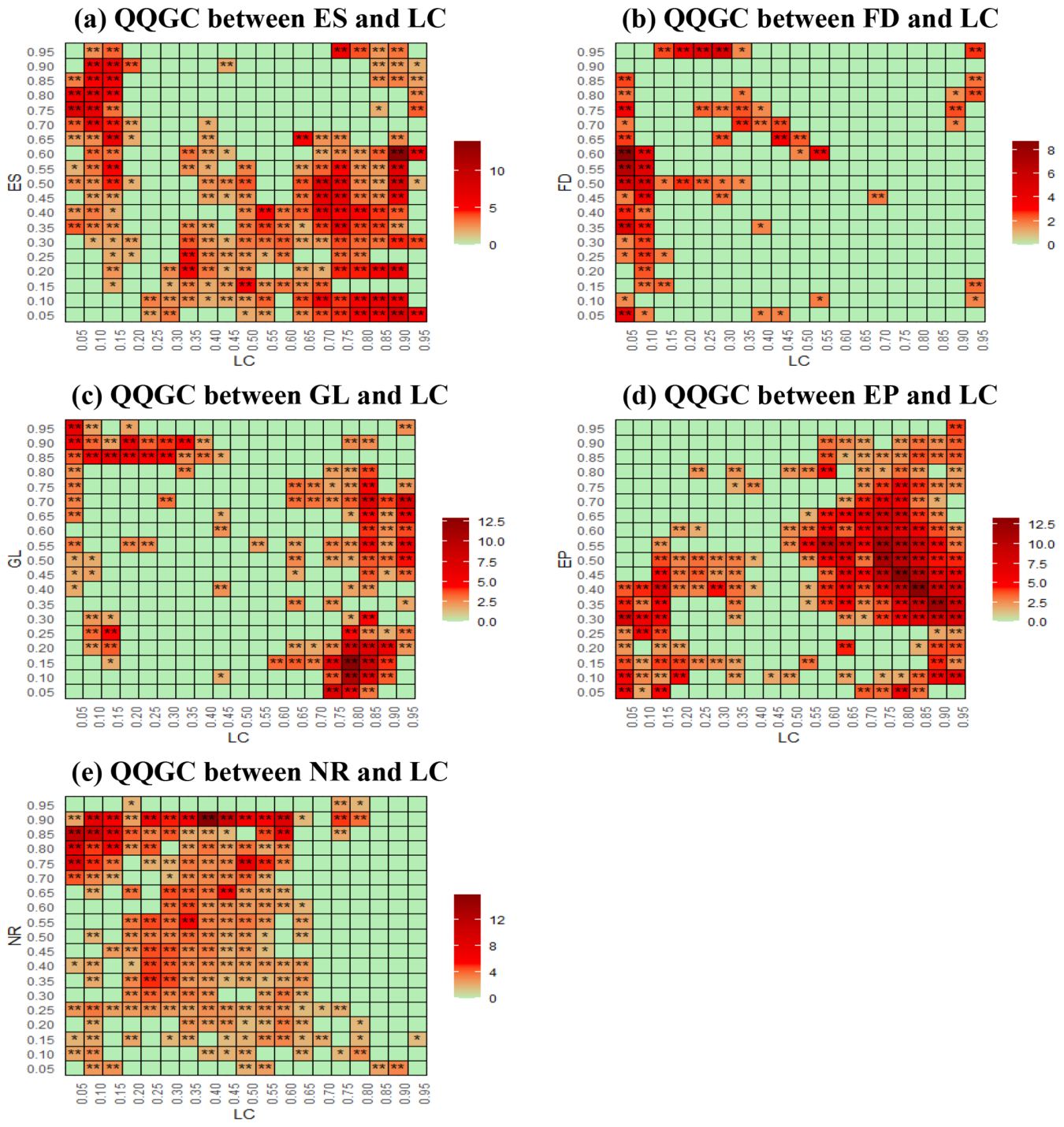

FIGURE 3 | Quantile-on-quantile Granger causality estimates. ** and * denote significance at 5% and 10%, respectively.

of LCF. However, the presence of QQGC on the remaining combination quantiles of FD and LCF is not highly observed. Figure 3c donates the QQGC findings between GL and LCF, finding that the null hypothesis is rejected in extremely high quantiles of GL and LCF quantiles (0.05–0.35). A similar result is also verified in nearly all quantiles of GL and extremely high quantiles of LCF. The outcome of QQGC between EP and LCF is depicted in Figure 3d. The null hypothesis regarding EP and LCF's lowest and middle quantiles is rejected. However, the QQGC connection between EP and LCF highly holds for nearly all EP and LCF quantiles (0.55–0.95). Figure 3e shows the outcome of the QQGC between NR and LCF, with the analysis being approximately verified in all quantile combinations of NR and LCF, except the highest quantiles of LCF.

4.3 | Robustness Check

The robustness check was the final econometric step of the study, and conventional QR (Koenker and Bassett 1978) and averaged QQ were compared within this context. Figure 4 shows the consistency between QR and averaged QQ.

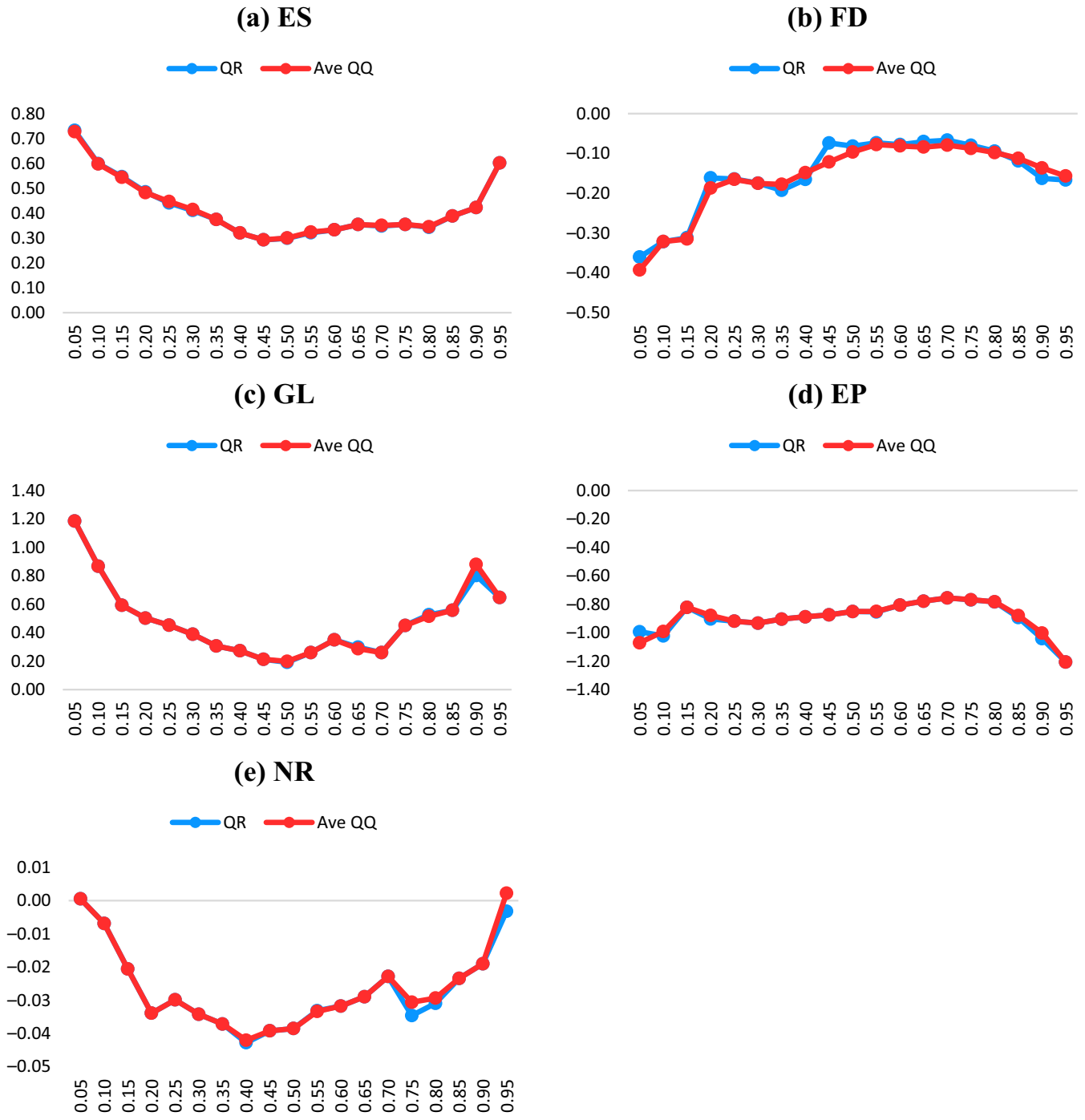

FIGURE 4 | Averaged QQ versus QR.

The graphs in Figure 4a–e show that irrespective of the quantile selected, the averaged QQ estimates of the coefficient slope are equivalent to the QR estimates. Figure 4a depicts the comparison between QR and averaged QQ on ES and LCF, and confirms the positive impact of ES on LCF, which is compatible with the QQ regression outcomes. Figure 4b indicates that the outcome of the QR complies with those of the QQ, thus demonstrating that FD negatively impacts LCF. Figure 4c shows that GL enhances LCF, and the QR outcomes support those of the QQ. Moreover, the outcomes of the QR between EP and LCF are depicted in Figure 4d, with the former detrimentally impacting the latter, which verifies the outcomes of QQ. Finally, Figure 4e reveals the QR outcomes on the effect of NR on LCF, showing the negative effect of the former on the latter on all quantiles, except the lowest and highest quantiles, where NR is insignificant.

These results also show a clear justification for the QQ approach. According to Figure 4, a robust and high correlation is verified between averaged QQ and QR. This result shows that the QQ findings are compatible with the QR outcomes, displaying robustness. According to the robustness tests, the results of this study are robust and applicable to providing different policy options.

4.4 | Discussion

This study has sought to provide vital guidelines for charting Turkey's sustainability. To achieve this aim, we assessed the relationship between selected variables (ES, EP, GL, NR and FD) and LCF. QQ and QQGC methods were performed, and then, QR and averaged QQ were compared for the robustness check. The analysis outcomes are described as follows: the influence of ES on LCF is positive in all quantiles, while the favourable impact is less complex in the intermediate and high quantiles. The QQGC analysis also demonstrated that ES contributes to LCF in most quantiles. Comparing the QR and QQ results confirmed the findings on the nexus between ES and LCF, thus implying that primary energy production is mainly sourced from hydro-power and biomass in Turkey, whose techniques and technology enhance environmental quality. Besides, Turkey has made significant efforts to capitalize upon renewable energy sources and lessen the share of non-renewable in total energy production. Regarding these results, increasing renewable energy projects positively impacts sustainability—a finding supported by Deng et al. (2024). Moreover, GL was found to have a positive influence on LCF, which was more complex in all GL quantiles. The lowest LCF quantile and the robustness check support the findings of the QQ analysis, as did the QQGC in different quantiles. As for the outcome of the role of globalization, Turkey should be in a better position to build a sustainable economic structure harmonized with sustainability via transferring green technology, improving energy efficiency, and focusing on foreign trade with advanced technology. As for GL, our findings parallel those of Awosusi et al. (2022). However, the QQ and robustness check found that FD impairs LCF in all quantiles, while the validity of QQ causality between LCF and FD is minimal. Within this scope, the financial structure is not harmonized with sustainability. Turkey's financial sector should provide more funds with long-term and low interests for firms with greener technologies and investing in renewable energy projects. In addition, various studies have also confirmed the detrimental effect of FD (Latif and Faridi 2023; Okezie et al. 2023; Yang et al. 2023; Özkan, Saleem, and Sharif 2023).

Moreover, the QQ and robustness check found that higher achieved EP is not the solution for sustainability, which highlights the existing financial structure in which Turkey is one of the leading importers of fossil fuels and emitters of greenhouse gases. QQGC methods also show that the causality connection between EP and LCF is concentrated on the highest quantiles of the latter. In addition, the study presents that NR is irrelevant to LCF in the lowest and highest quantiles, but unfavourable in the remaining quantiles. This finding means that NR extraction and utilization are incompatible with environmentally friendly management. NR and EP have been managed under energy intensity, dominated by non-renewable energy resources and low-technology structure. Reliance on non-renewable energy resources and un-environmental technologies should be transformed into a pro-environmental one to reverse the effect of economic activities on sustainability. This study's findings echo those of various studies in the literature. For example, Pata and Balsalobre-Lorente (2021), Caglar et al. (2023) and Jin et al. (2024) documented a negative influence of EP on LCF, while Pata and Isik (2021) and Ni, Yang, and Razzaq (2022) found the harmful effects of NR on LCF.

5 | Conclusions and Policy Recommendations

Having achieved 16 of the 123 SDG targets (OECD 2023), Turkey (as a leading developing state) is burdened with how to further advance its nationally determined SDG targets. In terms of environmental aspects, this study examined whether ES, FD, NR and economic expansion drive Turkey's LCF. By implementing a combination of QR-related approaches, the observed results were largely similar. For instance, a statistically significant effect of ES on LCF was observed in all quantiles (0.05–0.95) of the combination of ES and LCF. However, the influence of ES on LCF was found to be weak and positive, whereas the impact was more visible in all quantiles (0.05–0.95) of ES and the lower quantiles (0.05–0.3) of LCF. For the FD–LCF nexus, FD exerted a significant effect on LC in all quantiles, and LCF was negatively and weakly impacted by FD. However, the negatively weak effect of FD on LCF was mainly observed in the middle and higher quantiles of LCF (0.4–0.95). GL was found to positively impact LCF by a strong dimension; however, regarding other quantiles of the combination of LCF, GL's effect was weak and positive. The influence of EP in quantiles (0.05–0.7) on lower quantiles of LCF was not statistically significant, while the EP in the highest quantiles (0.8–0.95) promoted a strong negative impact on LC in the lowest quantiles. Considering the influence of EP on LCF in remaining quantile combinations, its effect on LFC could be said to be enormously harmful. Moreover, the effect of NR on LCF was negative in all quantiles of NR and quantiles (0.3–0.8) of LCF. However, the NR in all quantiles did not affect LCF in its lowest quantile (0.05) and the validity of the ineffectiveness of NR was also verified in its middle and higher quantiles (0.6–0.95), as well as the highest quantiles of LCF (0.95).

However, the link between ES and LCF has seldom been studied within the literature. Accordingly, we would recommend that future research examine the connection between LCF and ES for other countries while also comparing the results to achieve a reliable policy framework. This is important to establish the link between these factors for nations with different levels of development. Furthermore, research on the factors influencing LCF could be conducted in nations where the load factor is vulnerable. Against the time span of the variables included in this analysis, a broader and updated data range could offer a more valuable outcome. Moreover, this study is also limited to aggregate energy sources, however, future endeavours can rely on ES as per different sources of conventional and nonconventional energy.

5.1 | Policy Recommendations

Although Turkey has continued to show commitment in its approach to ES and diversification, a concerted policy drive could further complement the country's increase in renewable electricity generation and its first nuclear power facility (IEA 2021). For instance, opening up the domestic upstream sector to more privately owned energy corporations could advance the discovery and exploration of oil and natural gas, thus improving the country's energy. Since ES largely improves environmental sustainability, according to the results of this investigation, public–private partnerships in research and development should be improved to advance energy transition aspects, such as energy

efficiency technologies in construction and other sectors of the economy. Moreover, the undesirable effect of FD on a sustainable ecosystem can be overturned through improved technology adoption and penetration in the service delivery of financial activities across economic sectors. Additionally, the negative influence of economic prosperity on sustainable ecosystems, as uncovered in this study, could be mitigated through stricter commitment and strategic implementation of circular economy practices. Adopting these practices could both directly and indirectly improve the influence of NR on the country's ecological components.

Author Contributions

Mustafa Necati Coban: writing – review and editing, writing – original draft, investigation, resources. **Zafer Adali:** writing – review and editing, writing – original draft, methodology, investigation. **Oktay Ozkan:** writing – review and editing, writing – original draft, supervision, conceptualization, formal analysis, software, data curation, visualization. **Andrew Adewale Alola:** writing – review and editing, writing – original draft, corresponding.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/gj.5063.

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