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The Role of Economic Growth and FDI in Ecological Footprint and the Load Capacity Factor: Evidence From Türkiye

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Abstract
Proposed sustainable economic development and growth have been among the leading and desired objectives of policymakers. Thus, various investigations have been conducted, considering different social, political, and economic factors to lessen environmental degradation and improve biocapacity. Within this context, Türkiye is one of the most essential cases because of its location and role in the global supply chain, emerging countries' members, and the severity of the environmental situation. Thus, the study employs the Fourier ARDL, FADL co-integration tests, FMOLS estimations with Fourier Terms, and Fourier Toda-Yamamoto analysis to investigate the role of economic growth and FDI in ecological footprint and the load capacity factor along with considering some control variables over the period between 1982 to 2021. As a result of the investigations, it is concluded that the economic growth, the FDI, and the remaining variables do not promote impact the load capacity factor. However, the considered variables pressure the environment when the ecological footprint is regarded as the environmental indicator, and the pollution haven hypothesis holds for Türkiye. To reverse and mitigate the harmful effects of economic activities, efforts, and policies should be made toward environmentally friendly forms of production, trade, FDI, and renewable energy sources.

Keywords
Ecological Footprint, Economic Growth, Energy Economics, FDI, Pollution Haven, Sustainable Development

Introduction

Over the past decades, government initiatives and agendas have been reshaped and oriented toward sustainability and environmentally friendly types. Sustainability policies in Economic, social, and political fields are essential targets for policymakers as global warnings, climate changes, and various environmental degradations such as floods, drought, famine, and erosion are serious threats to humans and the whole planet.

Various agreements, targets, traces, and agendas such as the Kyoto Protocol, the Paris Agreement, and Sustainability Development Goals have been promoted by national and international organizations to mitigate and reverse the effect of environmental degradation, improve the biocapacity of the planet, and achieve the social and economic structure based on the sustainability. Different ecological indicators have been concentrated and employed in sustainability policies within this context. The ecological footprint (EF) introduced by Rees (1992), Wackernagel and Rees (1998) has been replaced as the most used environmental degradation indicator because it discloses comprehensive pressure on air, soil, and marine with the help of its six subcomponents. Although the EF is a pivotal environmental indicator, it ignores the supply side of the environment. However, sustainability means the balance between the supply and demand side, and only mitigating the environmental degradation performs a deficiency in sustainability. Within this scope, the load capacity factor (LCF) proposed by Siche et al. (2010) is employed in the literature and underlined in the targets and policies. The LCF is calculated as biocapacity/ecological footprint, and it discloses the strength of a country, a region, or the world to support the population considering the current lifestyle. If the load capacity is more than 1, the current system is sustainable, but the system is unsustainable if it is less than 1 (Siche et al., 2010; Pata, 2021; Zhao et al., 2022; Torrecillas and Fernández, 2022).

Various social, political, micro, and macroeconomic indicators have been employed to understand the effect of the androgenic activities on the environment and provide robust solutions for mitigating environmental degradations and improving the planet's biocapacity. Economic growth is the leading and most popular variable in the literature because the recent environmental degradations have resulted from the ambition for higher economic development (Apergis and Payne, 2009; Destek et al., 2024; Kuang, 2021; Özbek and Özbek, 2024; Sugözü and Yaşar, 2023).

Foreign Direct Investment (hereafter, FDI) is accepted as one of the blessing factors for the economies, especially developing countries, to overcome financing constraints, insufficient technology, know-how, and weak organizational structure in infrastructure investments. In contrast to other international capital flows, especially short-term capital flows, FDI is a long-term investment type, and developing countries have implemented various policies to attract FDI (Adali et al., 2023).

The driving factors of the FDI inflows to host countries are the abundance of cheap labor, natural resources, and the location of the markets. Although the role of the FDI in the economy has been thought of as generally blessing and desirable, the nexus between FDI and environmental quality is still debatable. Within this context, two different arguments are generated to explain the effect of FDI on environmental quality. The pollution haven hypothesis (hereafter, PHH) is the first argument. The PHH claims that the environmental rules, norms, and regulations in developing countries are mostly not stricter than those in developed countries, and the dirty industries of developed countries flow to the developing countries because of the motives of lowering production costs (Naimoğlu and Özbek, 2024). High energy-intensity and polluted industries degrading air, soil, and water are migrated to developing countries, and the effects of FDI on EF and LCF are expected to be positive and negative, respectively. The Pollution Halo hypothesis (hereafter, P-Halo) has opposite arguments about the role of FDI in environmental quality (Blowers, 1992; McGranahan et al., 2021).

Türkiye is one of the unique and essential examples because of its properties on energy structure, the current situation of industrialization, and the contribution to greenhouse emissions and EF. Türkiye is among the leading emerging countries and ranked among the G-20 countries. Türkiye has been making significant efforts to become one of the top 10 economies in the world. Over four decades, the population of Türkiye increased by 88.4% from 45.2 million in 1980 to 85.2 million in 2022 (OECD data, 2024). Over the exact period, the share of Türkiye's economy, which expanded by an average of 4.65%, rose from 1.18 to 2.05% of the global economy, and environmental degradations such as greenhouse emissions and EF and impaired LCF are accompanied by an increase in economic activities (Yavuz et al., 2023). As seen in Figure 1, the ecological footprint per capita increased by approximately over %101, and the biocapacity shrunk by about 46%. Thus, Turkish economic activities have been operating under the ecological deficit since the 1980s. Figure 2 presents the sustainability of the Turkish economy measured by the load capacity factor. After the middle of the 1980s, the Turkish economy was not sustainable. Figure 3 discloses the trend of greenhouse emissions and CO_2 emissions in Türkiye. The primary reason for the rise in greenhouse emissions and CO_2 emissions over the decades in Türkiye is the need for energy to be fulfilled by nonrenewable energy resources (OECD statistics, 2024).

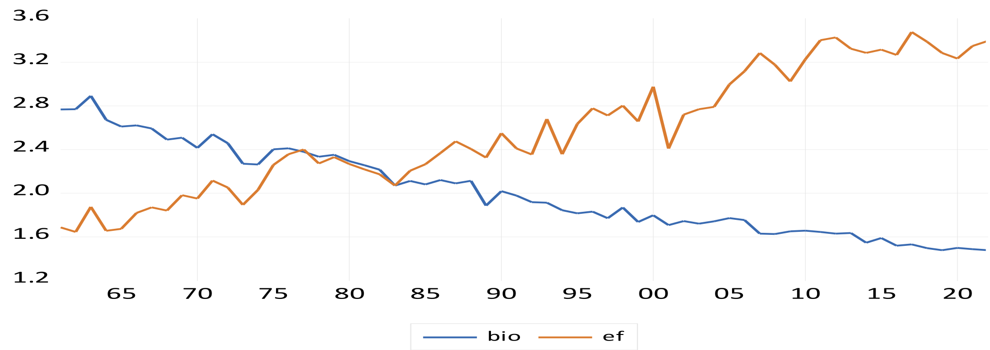

Fig. 1. Ecological footprint and biocapacity

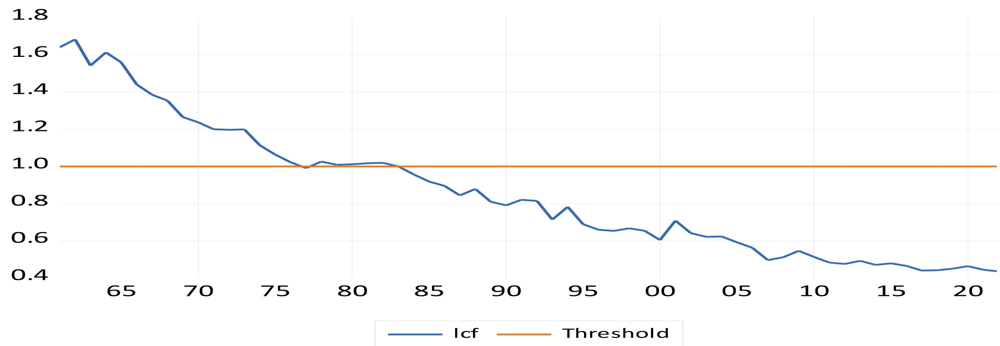

Fig. 2. Load capacity factor

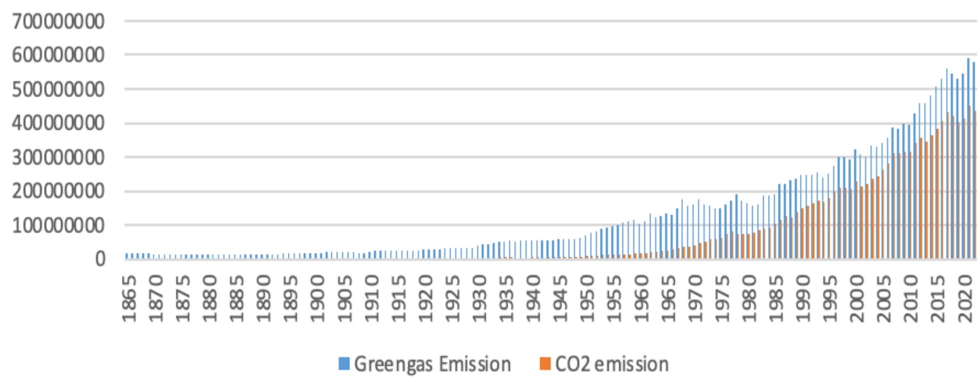

Fig. 3. Greenhouse emissions and CO_2 emissions

Türkiye ranks second in the world after China, whose energy demand has increased the most in the last two decades. About three-quarters of its energy demand is met by imported energy sources. Reliance on imported fossil energy resources also impairs Türkiye's economic resilience because of chronic current account deficits caused by energy and vulnerability to energy supply shocks (Republic of Turkey Ministry of Foreign Affairs, 2024).

This study examines Türkiye as a developing country trying to move to the top league with industrialization moves and needs to develop appropriate policies in this direction. Türkiye will affect development in the future with an industrial move, and evidence-based results will be required when determining FDI and growth policies. The policies to be determined in line with our results will positively impact policymakers and sustainability. Within this targets, the study investigates the effect of economic growth and FDI, considering Total natural resources rents (% of GDP), Trade (% of GDP), Urban population (% total population), Renewables energy per capita, fossil fuels per capita as control variables, on the EF and the LCF over the period between 1982 and 2021. Fourier ARDL, Fourier ADL co-integration tests, and FMOLS estimators expanded with the Fourier Function, and Fourier Toda-Yamamoto causality analysis was performed. This study can contribute to the literature and knowledge of policymakers because the demand and supply side of the environment and time-series methods allow for smooth structural breaks with an unknown type and number.

Literature Review

Previous research on the economic growth and FDI in ecological footprint and the load capacity factor, along with considering some control variables, is covered in this section. This part will contribute to our in-depth comprehension of the relationships among the abovementioned factors. The chosen subjects listed below form the basis of the empirical review:

Numerous proxies have been used in empirical studies on the relationship between environmental degradation and economic growth throughout the years, but the results have been inconsistent and point to the need for more research. Ali et al. (2024) employed a regression-with-Driscoll-Kraay standard error, and the analysis spot shows that EF is upsurged by an expansion in the economic growth in all panels. Performing the ARDL approach, Hassan et al. (2019) economic growth's role in the environment is detected as harmful in the short run. Addai et al. (2022) emphasized that economic growth impairs environmental quality by inducing an increase in EF. Various researchers have highlighted that an increase in economic welfare is managed at the expense of the environment (Ali et al., 2024; Al-Mulali et al., 2016; Huilan et al., 2022; Pata et al., (2023); Usman et al., 2020), while some studies also confirm that an expansion in economic activities is operated in harmony with the environment (Usman et al., 2024). Moreover, the EKC and LCC hypotheses are supported by many researchers (Dong et al., 2018; Fang et al., 2024).

The association between FDI and emissions has attracted less study interest than the relationship between income and emissions. Zafar et al. (2019) indicate that FDI negatively impacts the EF, which approves the P-Halo hypothesis. Ozturk et al. (2023) manage research toward achieving evidence on the nexus between FDI and the EF of South Asia. The second-generation panel methods are executed, and as a result of the analysis, the pollution haven hypothesis is held for South Asian countries. Ali et al. (2024) use the Method of Monent quantile regression, the Ridge regression, the Discroll-Kraay standard error, and the Newey-West standard error estimators to find the role of FDI in the environmental quality of G20 nations. As a result of the estimation, researchers find the validity of the P-Halo hypothesis among G-20 nations. In addition to the abovementioned studies, the pollution haven hypothesis considering the EF is verified by Adebayo et al. (2024) and Majeed and Mazhar (2019), while the P-Halo hypothesis is confirmed by Zafar et al. (2019).

The status of the environment is commonly captured by CO_2 emissions, carbon, and ecological footprints, with the latter being the most thorough. Recently, literature has been directed to evaluate the consequences of urbanization on the environment utilizing the above proxies. Fang et al. (2024) strive to propose evidence of the connection between urbanization and LCF in ASEAN countries. The outcome from the ARDL estimation points out that the environmental quality of the ASEAN countries has deteriorated because of urbanization. The supportive role of urbanization in improving environmental quality has been supported by many studies (Danish et al., 2020; Ragmoun, 2023), whereas Al-Mualali et al. (2016) also proves a controversial finding.

Natural resources have an impact on environmental quality as well. Ecological integrity may be improved while fostering development and growth through sustainable resource management. Ulucak et al. (2020), state that an increase in natural resources accompanies a rise in CO_2 emissions, while the neutrality hypothesis holds for the nexus between natural resource rents and EF. Danish et al. (2020) conducted research for BRICS countries performing the Panel DOLS and FMOLS estimations that natural resource rents promote a positive contribution to environmental quality. Kang et al. (2023) state that mineral rents have an improved effect on the environment by mitigating EF. Usman et al. (2024) try to show the paths concerning China's COP27 targets by focusing on the nexus between natural resource extraction and the LCF. With the help of employing the dynamic ARDL estimation, the researchers demonstrate that the environmental quality is degraded by natural resource extraction. In addition, numerous research reveals evidence proving the cursing effect of natural resource rents on the environment (Adebayo et al., 2024; Yang et al., 2023), while the blessing function of FDI in improving the environmental quality is also detected by Balsalobre-Lorente et al. (2018), Danish et al. (2020), Khan et al. (2021), Ali et al. (2024).

The relationship between trade and emissions of pollution is well documented. Usman et al. (2020) Panel FMOLS, DOLS, FGLS, and AMG estimators are executed, and the outcome of the analysis displays that Trade openness plays an adverse role in the environmental quality of Africa and America. Adebayo et al. (2024) seek to find the effect of foreign trade on the environmental quality measured by CO_2 emissions, the EF, and the LCF in Thailand. The Fourier quantile causality test is applied, and the study's finding proves that export and import promote an impaired effect on environmental quality. Dam and Sarkodie (2023) employ the ARDL approach and the Toda-Yamamoto Granger causality analysis to investigate the influence of trade openness on the inverted LCF of Türkiye. The estimation shows that the role of trade openness changes over time; in the short run, ILCF is positively stimulated by trade openness, but trade openness has a negative influence on ILCF.

Pata et al. (2023) concentrate on the case of Latin American and Caribbean (LAC) countries to investigate the nexus between trade openness and the LCF. According to the analysis, it is concluded that trade openness plays a vital role in improving the environmental quality of LAC countries in the long run. Huilan et al. (2022) use the FMOLS, DOLS, and Frequency domain causality analysis to check the nexus between trade liberalization and Mexico's LCF. The results of the tests claim that trade liberalization plays a supportive role in healing environmental quality. Kartal and Pata (2023) apply quantile-quantile regression, nonparametric causality in quantiles, and quantile regression methods to check the nexus between trade globalization and three environmental indicators consisting of CO_2, the EF, and the LCF in China. The study approves that trade globalization promotes varied influences regarding the types of environmental indicators and quantiles. Al-Mulali et al. (2016) review the evidence to confirm the detrimental impact of trade on the environment, while Uddin et al. (2017) and Caglar et al. (2023) approve the healing effect of trade on the environment.

In addition to this research, the impaired effect of nonrenewable energy resources on the environment has been confirmed by many studies (Kang et al., 2023; Ulucak et al., 2020) and various authors confirm the improved role of renewable energy resources in the environment (Adebayo et al., 2024; Caglar et al., 2023; Danish et al., 2020; Pata et al., 2023; Ulucak et al., 2020; Usman et al., 2020; Usman et al., 2024). However, in contrast to the expected role of renewable energy in the environment, some studies find a neutral and adverse connection between energy resources and environmental quality (Al-Mulali et al., 2016; Dam and Sarkodie, 2023; Huilan et al., 2022).

Data and Methodology

This study is processed to investigate the determinants of the EF and the LCF in Türkiye, focusing on five different models concerning the EF and five other models on the LCF. Annual data from 1982 to 2021 are employed because of the data availability. With the help of FDI and GDP utilized as major variables and the rest of the variables as control variables, the study can provide a reliable outcome on whether the Turkish economic performance is harmonized with environmental sustainability and whether the pollution haven or halo hypothesis is verified. Another reason for the generated different models is related to the employed econometric approaches in the study, and the Fourier ARDL approach and Fourier ADL co-integration analysis allow for three independent variables.

Tab. 1. The details of the variables

Symbol	Detail	Symbol with logarithmic transformation	Data Sources
EF	Ecological Footprint	lnEF	GFN(2024)
LCF	Load Capacity Factor (Biocapacity/Ecological footprint)	lnLCF	GFN(2024)
GDP	GDP Per Capita (constant 2015 US$)	lnGDP	WB(2024a)
FDI	Foreign Direct Investment, net flows(%of GDP)	lnFDI	WB(2024b)
NNR	Total Natural Resources Rents (% of GDP)	lnNNR	WB(2024c)
TRADE	Trade (% of GDP)	lnTRADE	WB(2024d)
URB	Urban Population (%total population)	lnURB	WB(2024e)
REC	Renewables Energy per Capita	lnREC	OWD (2024a)
NONREC	Fossil Fuels Per Capita	lnNONREC	OWD (2024b)

The models considered in the study are documented as follows, and Table 2 documents the details of the variables.

Tab. 2. Models

LCF=f(GDP, FDI, control variables) $nLCFt = \alpha_0 + \delta_1 lnGDPt + \delta_2 lnFDIt + \delta_3 lncontrol\ variablet + \mu_t$	
Model 1	lnlcf=f(lngdp,lnfdi,lnurb)
Model 2	lnlcf=f(lngdp,lnfdi,lnnrr)
Model 3	lnlcf=f(lngdp,lnfdi,lntrade)
Model 4	nlcf=f(lngdp,lnfdi,lnrec)
Model 5	lnlcf=f(lngdp,lnfdi,lnnonrec)
EF=f(GDP, FDI, control variables) $lnEFt = c_0 + \theta_1 lnGDPt + \theta_2 lnFDIt + \theta_3 lncontrol\ variablet + \epsilon t$	
Model 6	lnef=f(lngdp,lnfdi,lnurb)
Model 7	lnef=f(lngdp,lnfdi,lnnrr)
Model 8	lnef=f(lngdp,lnfdi,lntrade)
Model 9	lnef=f(lngdp,lnfdi,lnrec)
Model 10	lnef=f(lngdp,lnfdi,lnnonrec)

Regarding the models, α_0 and c_0 are the constant terms while δ_{1to3} and θ_{1to3} represent the long-term coefficients. However, μ_t and ϵ_t denotes the error terms. As for the models concerning the LCF as dependent variables, if the coefficient of independent variables is found to be positive, it is understood that the considered variables improve the environmental quality and vice versa. Regarding the models for the EF, when the coefficient of the variables is detected as negative, the considered variables mitigate the EF and enhance the environmental quality.

After examining the considering models, the descriptive statistics of the variables are examined, and Table 3 reports the descriptive statistics.

Tab. 3. Descriptive analysis

	LNEF	LNFDI	LNGDP	LNLCF	LNNNR	LNNONREC	LNREC	LNTRADE	LNURB
Mean	1.031209	-0.388362	8.858324	-0.460314	-0.793843	9.381802	7.428360	3.778721	4.167227
Median	1.024093	-0.547146	8.770426	-0.457502	-0.924230	9.374487	7.407862	3.844616	4.184433
Maximum	1.245956	1.287408	9.498639	0.019510	0.259127	9.855503	8.355088	4.260352	4.338192
Minimum	0.727493	-2.595875	8.317860	-0.819521	-1.938487	8.738953	6.553187	3.291417	3.850084
Std. Dev.	0.153215	0.992897	0.339276	0.260697	0.549463	0.327061	0.459725	0.242974	0.128112
Skewness	-0.232250	-0.383548	0.268665	0.210829	0.050635	-0.277306	0.012885	-0.269498	-0.718105
Kurtosis	1.746940	2.390970	1.897554	1.791587	2.317200	1.982581	2.631497	2.167184	2.776536

Jarque-Bera	2.976533	1.598925	2.506855	2.730097	0.794119	2.237894	0.227431	1.640168	3.521056
Probability	0.225764	0.449571	0.285525	0.255368	0.672294	0.326623	0.892512	0.440395	0.171954
Sum	41.24837	-15.53448	354.3330	-18.41257	-31.75373	375.2721	297.1344	151.1488	166.6891
Sum Sq. Dev.	0.915520	38.44793	4.489231	2.650561	11.77445	4.171798	8.242539	2.302426	0.640099
Observations	40	40	40	40	40	40	40	40	40

After examining the considering models, the descriptive statistics of the variables are examined, and Table 3 reports the descriptive statistics. According to Table 3, lnNONREC has the highest means, followed by lnGDP, lnREC, lnURB, and lnTrade, while lnNNR has the lowest means, followed by lnLCF and lnFDI. However, lnFDI possesses the highest standard of deviations, and the Jarque-Bera nominal p-values confirm that all data are normally distributed.

Methodology

The Unit Root Tests

The Augmented Dickey-Fuller (ADF) and the KPSS tests developed by Kwiatkowski et al. (1992) have been some of the best-performing unit root tests to investigate the series containing a unit root and nonstationary. The null hypothesis of the ADF unit root test indicates that the series involves a unit root, while the KPSS unit root test null hypothesis discloses that the series is stationary. They are evaluated as the conventional unit root tests and do not allow for the structural breaks in the series data generations to be considered. When applying the unit root tests ignoring the structural breaks in the presence of the structural breaks, the results of the tests may be inconsistent and unreliable, biasedly rejecting the tests' null hypothesis. However, as the shape, forms, numbers, and unknowns of the structural breaks matter for impacting the test power of the unit root tests, incorporating the Fourier Function proposed by Gallant (1981) with the unit root tests provides more reliable evidence on the stochastic properties of the series. Christopoulos and León-Ledesma (2010) and Enders and Lee (2012) advanced the ADF unit root test into the Fourier ADF unit root tests by adding the Fourier Functions. Christopoulos and León-Ledesma (2010) consider the FADF models as follows:

$$y_t = \delta_0 + \delta_1 sin(2\pi kt/\tau) + \delta_2 cos(2\pi kt/\tau) + v_t$$

Where k, t, and τ mean Fourier frequency, trend, and the number of observations, respectively. The value of k conforms to the frequency at which the residual sum of squares (MinSSR) is minimized. Hence, the frequency value associated with the MinSSR is operated. Assuming the trigonometric terms are significant by determining the competition between F-test statistics and F-test critical values tabulated by Becker et al. (2006), the result of the FADF unit root is applicable for interpretation. However, with the presence of the trigonometric terms' significance, when FADF test statistics in absolute forms exceed the table critical values on the frequency, it is understood that the series is stationary. In order to achieve the FADF test statistics, the above equation is estimated by Ordinary Least Square (OLS) and the obtained OLS residuals are disclosed as follows:

$$\hat{v}_t = y_t - [\hat{\delta}_0 + \hat{\delta}_1 sin(2\pi kt/\tau) + \hat{\delta}_2 cos(2\pi kt/\tau)]$$

However, the residuals are investigated by regression shown as follows:

$$\Delta v_t = a_1 v_{t-1} + \sum_{j=1}^{p} \beta_j \ \Delta v_{t-j} + \mu_t$$

Where μ_t means white-noise error, and the null hypothesis of the unit root test means H_0=$a_1 = 0$ Assuming the trigonometric terms are significant by determining the competition between F-test statistics and F-test critical values tabulated by Becker et al. (2006), the result of the FADF unit root is applicable for interpretation. However, with the presence of the trigonometric terms' significance, when FADF test statistics in absolute forms exceed the table critical values on the frequency, it is understood that the series is stationary.

The Fourier KPSS unit root test was introduced by Becker et al. (2006). Are other employed unit root tests allowing for considering multiple, smooth, and unknown structural changes? The Fourier KPSS unit root test employs the data generation process as follows:

$$c_t = M_t'\beta + B_t' + a_t + \varepsilon_t$$
$$a_t = a_{t-1} + u_t$$

Subsequently, the Fourier KPSS unit root test will be applied in the study. Developed by Becker et al. (2006), this test not only considers sudden shocks but also accounts for gradual changes that occur over time, acknowledging that shocks may not vanish immediately. For this purpose, the data generation process follows the equations below:

$$c_t = M_t'\beta + B_t' + a_t + \varepsilon_t$$
$$a_t = a_{t-1} + u_t$$

Here, ε_t is an error term that does not contain a unit root while u_t represents residuals that are independently distributed with variance unrelated $t_o\, u_t$ $B_t = \left[sin\left(\frac{2\pi kt}{T}\right), cos\,(\frac{2\pi kt}{T})\right]$ is a vector. In this context, t denotes the trend, T represents the time dimension, and k corresponds to the frequency. The unit root test statistic indicates stationarity at the level and trend as follows:

$$c_t = b_0 + \delta_1\, sin\left(\frac{2\pi kt}{T}\right) + \delta_2\, cos\left(\frac{2\pi kt}{T}\right) + e_t$$
$$c_t = b_0 + \beta_t + \delta_1\, sin\left(\frac{2\pi kt}{T}\right) + \delta_2\, cos\left(\frac{2\pi kt}{T}\right) + e_t$$

The model is estimated, residuals are obtained, and the hypothesis is tested. The calculation of the test statistic is as follows:

$$\tau_\mu(k) = \frac{1}{T^2}\frac{\sum_{t=1}^{T}\check{S}_t(k)^2}{\check{\sigma}^2}$$

Here, $\check{S}_t(k) = \sum_{t=1}^{T}\check{e}_j$ If the data generation process does not involve a nonlinear trend, the classical KPSS test is used. Becker et al. (2006) formulated the null hypothesis of no linear trend as follows:

$$F_i(k) = \frac{\frac{SSR_0 - SSR_1}{2}}{\frac{SSR_1}{T-q}}$$

In this equation, SSR_0 and SSR_1 represent the sum of squared residuals, and q denotes the independent variable. The power of the F-test also indicates the significance of variables containing trigonometric functions included in the model. Therefore, if the null hypothesis is not rejected based on F-test results, the KPSS test statistic will be calculated, and the outcomes will be interpreted.

Fourier ARDL Method

The extension of econometric models with Fourier functions provides some advantages over conventional models. One of the most important advantages of these functions is that they consider the assumption that structural breaks occur gradually and slowly rather than abruptly, which is more appropriate for current economic conditions. With these functions, both hard breaks and smooth transitions are considered, and more realistic findings are obtained in econometric analyses.

Traditional co-integration analyses do not take structural breaks into account. In order to solve this problem, Gregory and Hansen (1996), Hatemi (2008), and some other co-integration tests take sharp structural breaks into account, and the number of these breaks is predetermined. In these co-integration tests, dummy variables are used to identify structural breaks but only include time-specific and sharp changes. With Fourier functions, many soft structural breaks of unknown shape, time, and number can be considered. Therefore, the Fourier ARDL (FARDL) approach developed by Solarin (2019) and Pata and Aydın (2020) has taken its place in the literature as a highly effective co-integration method. These researchers developed the FARDL method by adding trigonometric terms to the bootstrap ARDL method proposed by McNown et al. (2018). Indeed, all of these methods are essentially derived from the traditional ARDL approach (Pata et al., 2022). The ARDL bounds test is a test that enables the determination of the relationship between variables integrated in the same degree and variables integrated in different degrees. At the same time, this test can also estimate short and long-run coefficients (Pesaran et al., 2001).

For the FARDL test, the null hypothesis (H_0) is that there is no co-integration relationship between the variables, while the alternative hypothesis (H_1) indicates that there is a co-integration relationship between the variables. FARDL is formulated as follows:

$$\Delta A_t = \beta_0 + \gamma_1 \backslash sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \backslash cos\left(\frac{2\pi kt}{T}\right) + \beta_1 B_{\{t-1\}} + \beta_2 C_{\{t-1\}} + \beta_3 D_{\{t-1\}} + \beta_4 F_{\{t-1\}} + \sum \rho - 1\ \varphi i'\ \Delta At - i\ + \sum \rho - 1\ \delta i'\ \Delta Bt - i \sum \rho - 1\ \emptyset i'\ \Delta Ct - i\ + \sum \rho - 1\ Pi'\ \Delta Dt - i\ + et$$

In this equation, "A, B, C, D, E, F" represent each of the variables used. In addition, the first difference operator is denoted by "Δ", the trend term by "t", the frequency value by "k", the sample size by "T", the appropriate lag length by "p" and the error terms by "e". In addition, the value of "π" corresponds to the number 3.1416.

Fourier ADL Co-integration Method

While the relationship between two series is analyzed by Engle and Granger's (1987) co-integration method, the co-integration relationship between more than two series is tested by Johansen and Juselius (1990). However, neither traditional co-integration method takes structural breaks into account. Therefore, the margin of error in the determined values may be high. In order to overcome the shortcomings of these methods, co-integration tests that incorporate structural breaks have started to be applied as time progresses. Knowing the dates, structures, and number of structural breaks in advance are listed as the main features of the related tests. Banerjee et al. (2017) developed the FADL co-integration method that allows smooth transitions rather than hard structural breaks. In other words, this co-integration test developed by Banerjee et al. (2017) considers multiple smooth transition break patterns and unknown structural breaks. In the study by Banerjee et al. (2017), trigonometric terms are included in the model using Fourier functions. In the FADL model of Banerjee et al. (2017), the deterministic component is added instead of the constant term. The presence of low-frequency components of the Fourier expansion in the model is the most important feature distinguishing this test from traditional methods. The determined t-statistic value is compared with the critical table value of Banerjee et al. (2017), and if it is greater than the table critical value, the existence of a co-integration relationship between the series is proved. After obtaining the optimal frequency, the coefficient "α_3" is applied to determine a long-run co-integration relationship between variables. If $H_1: \alpha_3 = 0$, there is no co-integration relationship between the series, while if, $H_1: \alpha_3 < 0$, there is a co-integration relationship between the series. The model for the FADL co-integration method is formulated below:

$$\Delta y_t = \alpha_0 + \alpha_1 \sin(T2\pi kt) + \alpha_2 \cos(T2\pi kt) + \alpha_3 \Delta y_t - 1 + \alpha_4 \Delta x_t - 1 + j = 1 \sum p \alpha_j \Delta y_t - j + j = 1 \sum q \alpha_j \Delta y_t - j + u_t$$

In this equation, α_0 is the constant term "$\alpha_1\ \alpha_2\ \ \alpha_3\ \alpha_4\ \alpha_5$ and α_6 " are the coefficients, "U_t" is the error term, "k" is a single frequency, "T" is the total number of observations and "t" is the trend. Banerjee et al. (2017) utilize the Akaike information criterion (AIC) for the appropriate lag values "p" and "r".

Fourier Toda-Yamamoto Granger Causality Test

In econometric analyses, causality tests are used to determine the direction of causality between variables. In these tests, the lagged value of a variable should be entered into the equation for another variable. One of the first and frequently used methods for testing the causality relationship between two variables was introduced to the literature by Granger (1969). The Granger (1969) causality method, which is based on the Vector Autoregressive (VAR) model, takes first differences in case the series is nonstationary. However, taking the difference in the series leads to a loss of information when considered in the long run. In order to solve this problem, the Toda-Yamamoto "TY" (1995) Granger causality method was developed. In addition, the standard Granger causality test requires co-integration analysis and the unit root test, provided they have the same degree of stationarity. If the variables in the VAR model are integrated or cointegrated, the Wald test can have a non-standard distribution, and the error term becomes dependent. The TY approach can overcome this problem since the VAR system is robust to unit root and co-integration (Toda and Yamamoto, 1995). The TY (1995) causality test is based on the lagged VAR model, which allows for different degrees of integration or stationarity of variables. The TY approach tests the null hypothesis (H0) using the Wald test statistic. If the test statistic value obtained is greater than the critical value, the null hypothesis of no causality is rejected. The TY (1995) causality test is accepted as a test based on the lagged VAR model, which allows for different degrees of integration or stationarity of variables. However, it is known that Granger (1969), TY, and similar causality tests in the literature ignore possible structural breaks (changes) in the series. Nazlioglu et al. (2016) provided a solution to this problem with the FTY causality test, which includes structural breaks in the modelling and allows the direction of causality between variables to be determined. With this test proposed by Nazlioglu et al. (2016), the constant term assumption is extended by including structural changes in the standard VAR model. In this respect, it was deemed appropriate to add Fourier terms to replace the constant term in the VAR model with the changes that may occur in the dependent variable in this test.Nazlioglu et al. (2016) suggested using the F test statistic instead of the Wald test due to its weakness in the small sample distribution of causality tests. In this test, H_0 is based on the absence of a causality relationship between variables. This hypothesis is based on zero restriction on "p" parameters in the form of "$H_0: a_1 = \cdots\ a_p\ = 0$" (Nazlioglu et al., 2016). The equation for the FTY causality test is as follows:

$$Y_t = \alpha_0 + Y_1 sin(2\pi kt/T) + Y_2 cos(2\pi kt/T) + \beta_1 Y_t - 1 + \cdots + \beta_p + dY_t - (p + d)$$

As can be seen from the equation, the FTY causality test is defined by the VAR $(p + d)$ model by extending it with the assumption that the constant term parameter α does not change over time in order to take into account structural breaks. According to this approach, lag lengths are denoted by "p", and the maximum degree of integration of variables is denoted by "d". For the application of this test, the appropriate lag length and Fourier frequency value are determined, and then the model estimation is performed (Nazlioglu et al., 2016).

FMOLS Method

The ordinary least squares method (OLS) is super-consistent but asymptotically skewness-free and non-normally distributed. While OLS method estimators are consistent and efficient in population regression estimations with large sample sizes and number of observations, in small samples, the t-statistic value will not be asymptotically reliable even if it has a non-normal distribution and gives consistent results. In such a case, the FMOLS method is appropriate and reveals its superiority over other methods. FMOLS method developed by Phillips and Hansen (1990) is used for long-run coefficient estimation. The authors' purpose in developing this method is to obtain optimal estimates of cointegrated regressions. FMOLS aims to eliminate the endogeneity problem by using kernel estimators of the parameter that causes the endogeneity problem. Another objective of FMOLS is to eliminate the problems arising from long-run correlations between co-integration equations and stochastic processes by using the covariance matrix of error terms. Therefore, the FMOLS estimation procedure assumes the existence of a single cointegrated vector, and the way to obtain this estimator is by estimating long-run covariance matrices. In other words, the FMOLS estimator applies a semi-parametric correction method to overcome the estimation problems caused by the long-run correlation between the cointegrated equation and stochastic shocks (Phillips and Hansen, 1990; Hansen, 1992). FMOLS method provides consistent and asymptotically robust results for small sample sizes (Phillips and Hansen, 1990). The FMOLS method also removes second-order biases by taking into account simultaneous relationships between the error terms of the models of the variables. The FMOLS equation is formulated as follows:

$$\theta^\wedge = \begin{bmatrix} \beta^\wedge \\ \gamma^\wedge \end{bmatrix} = (\sum_{t=1}^{T} Z_t Z_t')^{-1} (\sum_{t=1}^{T} Z_t Y_t^{+} - T \begin{bmatrix} \lambda x_{12}^{+'} \\ 0 \end{bmatrix})$$

In summary, FMOLS is used by making some corrections to the ordinary least squares (OLS) method (overfitting of estimates, asymptotically unbiased estimates, asymptotic normal distribution, presentation of the standard deviation of revised criteria allowing for statistical inference).

Results

Checking the series' stochastic properties is the econometric's first step analysis in the study. Within this aim, the conventional unit root tests comprised of ADF and KPSS unit root tests and the Fourier type unit root tests involving FADF and FKPSS unit root tests are performed. Tables 4 and 5 present the results of the unit root tests with constant and constant& trend on the level of the series and the first difference form of the series. The null hypothesis of ADF and FADF unit root test contain the absence of stationary; in other words, when the null hypothesis is accepted, it is found that the series has a unit root. When the value of the test statistics in absolute form is lower than critical values, the null hypothesis is not rejected. However, the null hypothesis of KPSS and FKPSS unit root tests shows that the series is stationary. The null hypothesis is rejected if the test statistic exceeds critical values. Another essential point on the FADF and FKPSS unit root tests is the importance of the trigonometric terms. The trigonometric terms are insignificant when F-statistics is lower than the critical values of the F-test. In the case of this issue, conventional unit root tests are commented on (Table 4).

Tab. 4. Unit root test results

Variables	ADF		KPSS		FADF		FKPSS	
	Constant	Constant and Trend	Constant	Constant and Trend	Constant	Constant and Trend	Constant	Constant and Trend
lnnnr	-2.421493	-2.093051	0.203886*	0.157253	-3.056861	-3.350919	0.198098 [1,15.586]	0.048623 [1,27.500]
lntrade	-1.413816	-3.481900***	0.755793	0.096350*	-1.470607	-2.696340	0.380583 [1,14.2479]	0.106250 [5,4.9304]
lnrec	-1.262154	-3.106277	0.675336	0.107754	-1.670764	-5.247575	0.766808 [2,10.54192]	0.077609 [1,13.97126]
lnef	-1.679700	-4.922603**	0.754039	0.093040	-2.691921	-6.155230	0.372773 [1,30.45361]	0.093806 [2,4.245}
lnlcf	-4.274010*	-1.589805	0.769296	0.130327***	-1.059864	-5.013293	0.395051 [1,29.20472]	0.155575 [2,3.6077]
lnnonrec	-1.593756	-2.820854	0.773297	0.143220	-0.935831	-3.369266	0.397909 [1, 26.56138]	0.178487 [2, 9.354499]

lnurb	-6.255057*	0.168425	0.765319	0.191240	-3.585747	-2.675645	0.404771 [1, 18.47684]	0.069485 [1, 43.08500]
lnfdi	-2.264448	-3.137320	0.669972	0.123902	-3.169670	-4.130839	0.267661 [1, 21.26348]	0.196974 [2, 10.98711]
lngdp	0.312700	-2.215345	0.772519	0.180649	-0.353407	-5.034216	0.405506 [1,25.23003]	0.038413 [1, 19.50132]

Note: *,**, and *** are significance levels at the 10%,5%, and 1%, respectively.

After performing the conventional unit root tests, the study also used the FADF and FKPSS unit root tests because the structural breaks' validity, form, and shape matter the result of the stationary tests. In the case of ignoring structural breaks, the unit root tests will promote misleading results when the data-generating mechanisms involve structural breaks. The trigonometric terms should be significant in evaluating the Fourier unit root tests. When comparing the F-statistics and F-test's critical values, all series' trigonometric terms are found to be significant except the *lnlcf*, whose trigonometric terms are insignificant due to the Ftest with the trend. The lnlcf is also estimated because of the significance of the F-test with constant. The finding of the FADF unit root test with constant presents that all series involve a unit root while *lnnr*, lntrade and lnurb do not have constant mean and mean-reverted patterns regarding the FADF unit root test result with constant & trend. In terms of the findings of the FKPSS unit root test with constant, the null hypothesis is not verified for all series, while the null hypothesis of the FKPSS with constant & trend is approved for *lnnr*, *lnef*. The FADF and FKPSS results show that the series contains a unit root. When all series are converted into the first difference, they become stationary, and the result of the unit root tests for the series at the first difference is presented in Table 5.

Tab.5. Unit root tests results for the series at the first difference

	The First Difference							
Variables	ADF		KPSS		FADF		FKPSS	
	Constant	Constant and Trend	Constant	Constant and Trend	Constant	Constant and Trend	Constant	Constant and Trend
lngdp	-6.491410*	-6.708369*	0.284007	0.067079	-7.146653	-2.723906	0.261471 [3,1.236]	0.244847 [2,1.456]
lntrade	-5.703011*	-5.606374*	0.225430	0.225774	-2.811294	-2.824423	0.500000 [5, 1.519199]	0.500000 [5,1.4771]
lnrec	-7.947230*	-7.816787*	0.115587	0.100530	-9.107013	-9.101507	0.095029 [5,2.6814]	0.092956 [5,2.5771]
lnef	-10.92540*	-10.95591*	0.076326	0.048229	-7.668875	-7.773926	0.060528 [4,0.5906]	0.053046 [4,0.53168]
lnlcf	-6.878936*	-7.077452*	0.219165	0.159066	-8.165140	-6.383923	0.295273 [4,0.906139]	0.266265 [4,0.768426]
lnnonrec	-6.416992*	-6.583644*	0.235992	0.131362	-7.557067	-6.122277	0.242828 [4, 2.709286]	0.374696 [4, 2.304052]
lnurb	-4.197461**	-10.68785*	0.533071	0.166917	0.298851	-6.406768	0.328361 [1, 11.84687]	0.073400 [1, 82.73112]
lnfdi	-7.249658*	-7.316585*	0.500000	0.500000	-5.949276	-2.625734	0.227715 [2, 0.917585]	0.385613 [5, 0.844590]
lngdp	-6.456022*	-6.427908*	0.185874	0.113534	-7.468942	-7.498369	0.151841 [5, 2.620626]	0.107811 [5, 2.382865]

After checking the stochastic properties of the variables, most of the series' data generation mechanism involves structural breaks, and the trigonometric terms are significant. The presence of structural breaks influences the result of unit root tests and the co-integration tests. Considering this issue, co-integration tests considering the structural breaks with an unknown time, structure, and number are performed to determine whether the variables move together in the long run. A recently developed bootstrap Fourier ARDL approach and FADL co-integration analysis introduced by Banerjee et al. (2017) are executed within this objective. The result of the Fourier ARDL approach and FADL co-integration analysis on the models with EF and the LCF as the dependent variables are demonstrated in Table 6. When the value of the t-statistics of the FADL co-integration test in absolute form is greater than critical values, the test's null hypothesis is rejected, and the cointegrated relationship is verified for the defined models. As for the Fourier ARDL approach, the F-stat, t-dep, and F-indep statistics are examined, and if three statistics are significant, it is understood that a long-run relationship holds for the considered models.

Tab. 6. FARDL and FADL co-integration test results

Fourier ARDL Co-integration Test						FADL Co-integration Test			
Model	Frequency	AIC	F_A	t	F_B	Frequency	AIC	t-istatistics	Lag
lnlcf=lngdp,lnfdi,lnurb (model 1)	0.10	-3.993	3.454	-2.693	0.615	3	-3.095	-3.357	2,1,1,1
Criticial values	10%		6.040	-4.362	5.238	10%		-3.79	
	5%		7.284	-4.792	6.525	5%		-4.16	
	1%		10.643	-5.815	9.744	1%		-4.90	
lnlcf=lngdp,lnfdi,lnnnr (model 2)	2.8	-4.127	2.009	-2.754	2.652	4	-3.203	-0.739	3,1,1,1

Criticial values	10%		3.917	-2.944	4.749	10%		-3.65	
	5%		4.886	-3.405	5.876	5%		-4.03	
	1%		7.742	-4.513	9.201	1%		-4.75	
lnlcf=lngdp,lnfdi,lntrade (model 3)	0.7	-3.788	3.931	-3.489	2.898	4	-3.073	-0.942	3,1,1,1
Criticial values	10%		4.910	-3.509	4.010	10%		-3.65	
	5%		5.968	-3.900	5.117	5%		-4.03	
	1%		8.098	-4.767	7.794	1%		-4.75	
lnlcf=lngdp,lnfdi,lnrec (model 4)	0.1	-3.901	1.671	-1.581	0.618	4	-3.153	-0.973	3,1,1,1
Criticial values	10%		5.283	-3.342	4.652	10%		-3.65	
	5%		6.417	-3.808	5.702	5%		-4.03	
	1%		8.751	-4.621	8.359	1%		-4.75	
lnlcf=lngdp,lnfdi,lnnonrec (model 5)	3	-4.279	1.172	-1.949	1.346	4	-3.060	-0.587	3,1,1,1
Criticial values	10%		4.013	-2.988	4.660	10%		-3.65	
	5%		5.208	-3.499	5.879	5%		-4.03	
	1%		7.757	-4.397	9.556	1%		-4.75	
lnef=lngdp,lnfdi,lnurb (model 6)	0.1	-4.183	2.941	-1.665	0.937	3	-3.064	-3.944	2,3,1,1
Criticial values	10%		5.895	-4.174	4.769	10%		-3.79	
	5%		7.026	-4.567	5.833	5%		-4.16	
	1%		9.178	-5.35	8.402	1%		-4.90	
lnef=lngdp,lnfdi,lnnnr (model 7)	3.2	-3.935	4.318	-3.642	4.280	3	-3.012	-4.506	1,1,1,1
Criticial values	10%		4.125	-2.914	3.481	10%		-3.79	
	5%		5.125	-3.369	4.548	5%		-4.16	
	1%		7.229	-4.436	6.807	1%		-4.90	
lnef=lngdp,lnfdi,lntrade (model 8)	0.1	-3.828782	3.724696	-2.396992	1.161860	3	-3.080	-2.083	3,3,1,1
Criticial values	10%		5.943119	-3.611358	3.458215	10%		-3.79	
	5%		7.140563	-4.034374	4.375213	5%		-4.16	
	1%		9.912713	-5.103535	6.585700	1%		-4.90	
lnef=lngdp,lnfdi,lnrec (model 9)	0.1	-3.877	3.723	-2.128	1.161049	1	-3.006	-3.315	2,1,1,1
Criticial values	10%		4.507509	-3.434827	2.776158	10%		-4.17	
	5%		5.484491	-3.779411	3.615776	5%		-4.51	
	1%		7.955107	-4.483185	4.926695	1%		-5.17	
lnef=lngdp,lnfdi,lnnonrec (model 10)	3.1	-4.156	5.569	-4.168	5.875	3	-3.084	-4.878	1,1,1,1
Criticial values	10%		4.060	-3.152	4.844	10%		-3.79	
	5%		4.971	-3.550	6.046	5%		-4.16	
	1%		7.748	-4.504	9.537	1%		-4.90	

According to Table 6, the Fourier ARDL and FADL co-integration test results promote the evidence confirming the null hypothesis for the established models with the LCF as the dependent variable. In other words, the models based on the LCF do not involve cointegrated relations. However, when considering the models for the EF, the cointegrated connection holds for three models. The Fourier ARDL approach confirms the long-run relationship for Models 7 and 10 at a 10 % ten significance level, and the finding of the FADL co-integration analysis rejects the null hypothesis in Models 6, 7, and 10.

The magnitude and direction of the independent variable on the EF are inquired when performing FMOLS estimation extended with Fourier functions for Models 6, 7 and 10. All models, *lngdp* and *lnfdi* are involved in all models. Still, lnurb, lnnnr, and *lnnonrec* are separately engaged in different control variables to determine whether the control variables matter in examining the effect of *lngdp* and lnfdi on the environmental indicators. The results of the FMOLS estimations are presented in Table 6. When checking the finding with Model 6, the effect of *lngdp* is statistically significant, and a 1% increase in *lngdp* corresponds to a 0.97% increase in the EF. In contrast, the coefficient of *lnurb* is not statistically significant, while the coefficient of *lnurb* is statistically significant, and *lnurb* promotes a lessening effect on the EF. Considering the finding of Model 6, the environmental quality is improved by urbanization, but economic activities impair the environmental quality. As a result of the FMOLS estimation on Model 7, it is highlighted that the EF worsens with an increase in *lngdp* and *infdi* while *lnnnr* lessens the EF. Finally, when interpreting the finding of FMOLS on Model 10, it is found that only *lnnonrec* is found to be statistically significant, and a 1% increase in *lnnonrec* induces a 1% increase in the EF, which approves of the detrimental impact of the *lnnonrec* on the environment.

Tab. 7. FMOLS test results

Model : lnef=lngdp, lnfdi, lnurb			
	Coefficient	**Std. Error**	**Prob.**
LNGDP	0.973259	0.164776	0.0000
LNFDI	0.001791	0.013303	0.8937
LNURB	-0.968480	0.437681	0.0339
C	-8.906171	1.898890	0.0000
@SIN	1.328116	0.462793	0.0071
@COS	5.284192	0.999141	0.0000
Model : lnef=lngdp, lnfdi, lnnnr			
	Coefficient	**Std. Error**	**Prob**
LNGDP	0.300399	0.035728	0.0000

LNFDI	0.052604	0.012940	0.0003
LNNNR	-0.028436	0.014630	0.0605
C	-1.635869	0.320279	0.0000
@SIN	0.030253	0.011434	0.0124
@COS	-0.012372	0.010175	0.2326
Model : lnef=lngdp, lnfdi, lnnonrec			
	Coefficient	**Std. Error**	**Prob**
LNGDP	-0.024339	0.086230	0.7795
LNFDI	0.010439	0.012937	0.4255
LNNONREC	0.464565	0.105005	0.0001
C	-3.111516	0.371593	0.0000
@SIN	0.018628	0.009104	0.0488
@COS	-0.002298	0.008252	0.7824

In the study, the Fourier Toda-Yamamoto (FTY) causality analysis introduced by Nazlıoglu et al. (2016) is the final econometric step. The FTY provides many advantages when examining The causality nexus between selected macroeconomic variables and environmental indicators involving the EF and the LCF. First, the FTY is performed on the level of the variables that overcome the long-run information loss. Secondly, the result of the FTY may be accurate and consistent because the structural changes are considered regardless of their time, number, and form. The result of the FTY causality analysis is shown in Table 8. Initially, the result of the causality connection between selected macroeconomic variables and the EF is interpreted, and the bootstrap p-value is considered.

Tab. 8. Fourier Toda-Yamamoto causality analysis

Model	Wald	p-value	Bootstrap p-value
lngdp=>lnef	2931.4310	0.0000000	0.024500000
lnef=>lngdp	7.4173641	0.059720173	0.42290000
lnfdi=>lnef	3248.7752	0.0000000	0.023700000
lnef=>lnfdi	0.23344529	0.97201761	0.96260000
lnrec=>lnef	4187.4942	0.0000000	0.021700000
lnef=>lnrec	0.34612171	0.95113312	0.93910000
lnurb=>lnef	4497.5524	0.0000000	0.019400000
lnef=>lnurb	0.36264510	0.94784629	0.93650000
lntrade=>lnef	8405.6981	0.0000000	0.013000000
lnef=>lntrade	7.0750710	0.069543110	0.43890000
lnnnr=>lnef	2054.8533	0.0000000	0.026200000
lnef=>lnnnr	9.8923417	0.019503791	0.38680000
lnnonrec=>lnef	2288.1387	0.0000000	0.025100000
lnef=>lnnonrec	388.71478	6.1592383e-84	0.062500000
lngdp=>lnlcf	4.9277129	0.17716754	0.50700000
lnlcf=>lngdp	6.3228486	0.096916928	0.45810000
lnfdi=>lnlcf	0.50345918	0.91813079	0.90230000
lnlcf=>lnfdi	114.50919	1.1742214e-24	0.12170000
lnrec=>lnlcf	5.1003601	0.16459407	0.50060000
lnlcf=>lnrec	0.51163695	0.91632749	0.89770000
lnurb=>lnlcf	6.0417412	0.10959699	0.46340000
lnlcf=>lnurb	6.6936704	0.082329688	0.44660000
lntrade=>lnlcf	10.901466	0.012270797	0.36670000
lnlcf=>lntrade	18.856913	0.00029266914	0.28420000
lnnnr=>lnlcf	0.13531399	0.98728632	0.98440000
lnlcf=>lnnnr	7.4157651	0.059762770	0.43290000
lnnonrec=>lnlcf	3.6379473	0.30330659	0.56180000
lnlcf=>lnnonrec	12.698053	0.0053372402	0.34250000

According to the result of the FTY causality analysis, it is indicated that all selected variables induce the EF at a 5% significance level. Moreover, the one-way causality link operating from the EF to the nonrenewable energy consumption is also verified, and this result confirms the mutual causality connection between the EF and the nonrenewable energy consumption. Contrary to the causality evidence, considering the EF, the neutrality causality hypothesis is verified when the causality connection between the selected macroeconomic variables and the LCF is investigated.

Conclusion

Türkiye is ranked Europe's third-highest CO_2 emission economy. In addition to the environmental degradation caused by external fossil energy sources, external fossil energy dependence also drives the current account deficit, which leads to various problems in the Turkish economy. As an emerging country expanding in every sector, energy demand intensified, and Türkiye became more reliant on importing energy supplies, increasing environmental degradation and current account deficits. Therefore, accurate and sufficient environmental-related policies also play a vital role in Türkiye's development projects.

Therefore, this study aims to investigate the pressure of FDI and economic growth on the quality of the environment in Türkiye. As for the environmental quality, one demand-side indicator comprises the EF, and the LCF is employed as the supply side of the environment. Besides, various control variables involving foreign trade, urbanization, renewable and nonrenewable energy resources, natural resources rents, and foreign trade are also considered in the models about the effects of FDI and economic growth on the environmental quality indicators. Within this scope, novelty developed the Fourier ARDL co-integration test and FADL co-integration test, which are executed to determine whether the variables and environmental quality indicators are cointegrated. The limitations of co-integration tests in considering the number of variables used in the model are another reason for constructing different models in the study. After the co-integration analysis, the magnitude and direction of the independent variables on the dependent variables are inquired using FMOLS estimation with the Fourier functions. The Fourier Toda-Yamamoto causality test is the final econometric step to find the causality connections between the macroeconomic variables and environmental quality indicators. A robust result might be achieved with the help of econometric methods because the forms, numbers, unknowns, and types of structural breaks are considered in the models employed.

Initially, the models based on the LCF and macroeconomic variables are examined in the study. The Fourier ARDL and FADL co-integration tests are performed on the five models to understand whether the effect of GDP and FDI on the LCF varies with the considered models. The co-integration findings present that the cointegrated relationship between variables does not hold for the five models. Due to the absence of the cointegrated connection between variables, the magnitude and direction of the independent variables on the LCF are not investigated. Moreover, the causality relationship between selected variables and the LCF is investigated by executing Fourier Toda-Yamamoto Causality Analysis. The outcome of the causality analysis shows that the neutrality causality hypothesis is confirmed for all causality models on the selected macroeconomic variables and LCF. This result implies that the P-Halo or Haven hypothesis and the remaining variables do not matter for sustainability in Türkiye. The study's second objective is to explain whether the selected macroeconomic variables impact the demand side of the environment measured by the EF. The five different models aiming to check the effect of the control variables on the relationship between GDP, FDI, and EF are also established. According to the co-integration analysis, the long-run connection is verified for Models 6, 7, and 10. The FMOLS estimation extended with the Fourier function is executed for the considered models. Regarding the result of Model 6, an increase in GDP impairs the environmental quality while urbanization improves the environmental quality, but the effect of the FDI is not statistically significant. The GDP and FDI promote increasing pressure on the environment, whereas natural resource rent lessens the EF. As for Model 10, the impaired impact of the nonrenewable energy resource on the environment is verified while the EF decreases with the GDP. This evidence shows that the control variables are essential when investigating the nexus between FDI, GDP and EF. The pollution haven hypothesis is approved in Türkiye, and nonrenewable energy resources significantly harm the environment. Moreover, the effort for higher economic income costs the impaired environment quality. Furthermore, the causality analysis verified one-way causality links from the selected macroeconomic variables to the EF and the mutual causality connection between nonrenewable energy consumption and the EF. The study's results are also supported by many studies in the literature (Adebayo et al., 2024; Majeed and Mazhar, 2019; Ozturk et al., 2023).

The evidence presented in the study confirms that the structure and process of the Turkish economy are incompatible with sustainability. As the Turkish economy is documented as one of the top ten nonrenewable energy resources imported to the country, each step aiming to catch up with the advanced economy league in the country increases the need for nonrenewable energy resources and impairs the environmental quality. However, the pressure of economic growth on the environment may result from the lack of per capita resources and efficient technology. Despite the awareness and initiatives about renewable energy projects and environmental quality, higher economic growth is still the country's leading objective. Hence, the objectives and policies of economic growth and FDI have been designed within the scope. To transition to a low-carbon, circular, and sustainable economy, lessening reliance on fossil energy resources is a pivotal initiative in the economy. Within this objective, policymakers could stimulate the sharing of research and development of clean technologies and support the firms offering innovative subsidies. The policymakers establish financial and governance organizations and mechanisms to ease the renewable energy projects and share the risks. For example, tax exemptions and long-term and low-interest credits are essential actions that increase the attractiveness of countries in the eyes of domestic firms and FDI. Though renewable energy sources are a share of total energy consumption, the country is still highly dependent on fossil fuels, and energy consumption has raised human pressure on the environment. In addition to addressing renewable energy, policymakers should focus on sophisticated, skilled, intensive, and knowledge-based products that improve both environmental quality and economic performance because the existing products and economic structure are based on low and medium-tech products and energy efficiency. Environmental quality improves with urbanization in Türkiye, and the improved role of urbanization may be accelerated by employing some policies such as protecting the clean water score and stimulating renewable energy projects comprising shallow geothermal for heating and cooling and solar panels for electricity. Moreover, governments may provide some benefits for firms to use eco-friendly construction materials.

Türkiye should adopt eco-innovation strategies, which ease the shift of the industrial structure from nonrenewable energy resources to sustainable energy. This policy may be vital in lessening environmental degradation and external energy dependence. Reducing external energy dependence is a pivotal step to overcoming the current account deficit, in which Türkiye can allocate domestic savings to invest in high-tech and eco-innovative sectors. By recommending policies, Türkiye will be in a better position regarding EU accession, achieving targets of the SDGs, and having a more resilient economy.

The study has been managed under some limitations, which may be considered and eliminated for further research. For example, the case may be extended to other emerging countries. Energy-imported, energy-exported, and the most polluted countries may be good examples to determine the determinants of environmental quality. Employing different factors such as Globalization, populations, and export diversification may be another contribution to the field. Besides, the investigations have recently been managed regarding the nonlinearity, such as the quantile on a quantile, and hence, future research will be conducted within this context.

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