Journal of Cleaner Production 413 (2023) 137517

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Is ecological footprint related to foreign trade? Evidence from the top ten fastest developing countries in the global economy

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ARTICLE INFO

Handling Editor: Giovanni Baiocchi

Keywords:
Ecological footprint
Economic growth
Foreign trade
Renewable energy

ABSTRACT

An ecological footprint (EF) refers to the resources that are used by the people or production companies in an area for commerce, which includes the production of food, water resources, and housing; however, it also includes foreign trade of the products produced. The present study aims to examine how foreign trade affects EF and recommend specific new policies or revisions to policies to reduce EF. EF is used as an environmental indicator in the present study. The top 10 fastest developing countries (Argentina, Brazil, China, India, Indonesia, Mexico, Poland, South Africa, South Korea, and Turkey) comprised the study sample. The analyses were conducted using annual data for the period of 1990–2018; export and import data were taken as foreign trade variables, and their relationship with EF was tested through two different models. Renewable energy consumption (REC) and national income were modeled as control variables, and second-generation panel data analysis techniques were used. When the Durbin-Hausman cointegration test was applied, the data indicated a strong correlation between foreign trade and EF. According to the Common Correlated Effects (CCE) coefficient estimator, there was an inverse relationship between exports and REC and EF and a positive relationship with economic growth. When the Augmented Mean Group (AMG) coefficient estimator was applied, an inverse correlation was indicated among exports, imports, REC, and EF. Based on the findings of the analyses, it can be argued that policymakers and market players should manage foreign trade and environmental policies in a harmonized manner, and long-term planning should be shaped around these test results.

1. Introduction

Stable growth, which is based on an increase in production, is very important in the globalized world. Production is realized through the development of the manufacturing industry and international trade. At this point, the importance of energy, which is accepted as the basis of social welfare and the development of the economy, cannot be denied (Anwar et al., 2021). The energy required for an increase in production is dependent on using fossil fuels, which has a deep effect on natural resources. While the consumption of natural resources helps the growth of nations, this consumption model distorts the environmental quality of these nations (Sharif et al., 2020). Therefore, economic growth and trade openness can damage ecological balance if economies do not make necessary improvements in the long and medium term. This damage is especially sensed in developed economies because many environmental problems arise when the quality of life and consumption habits change. Some of the environmental problems can be caused by increases in CO_2 emissions, which contributes to harmful effects on the ozone layer and possibly climate changes. In addition, natural resources, such as forests, in production areas become limited or even depleted. This also leads to a decrease in biodiversity and desertification. Although global warming and the melting of polar ice caps remain controversial, these environmental problems could lead to such effects.

To prevent environmental pollution resulting from economic growth and trade openness, the participating countries must adopt cleaner ways to make products. Open foreign trade gives countries not only more power to influence their national income but also to provide input into efforts to introduce cleaner technologies and environmental policies. Developed countries try to implement environmentally sensitive production systems to minimize environmental problems. Consumer preferences in these countries, because of the high per capita income, lean toward recyclable products that do not harm the environment. This

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https://doi.org/10.1016/j.jclepro.2023.137517
Received 11 February 2023; Received in revised form 4 May 2023; Accepted 16 May 2023
Available online 17 May 2023

leads to a decrease in damage to the environment and minimizes pollution. However, in developing countries, these systems cannot be implemented due to high costs. Although many developed countries have stricter environmental standards, this is not the case in developing countries. In these countries, having non-existent or flexible environmental standards greatly endangers the natural resources of that country. Unfortunately, stricter environmental standards for production often come with higher production costs; therefore, some developed countries have moved their operations to countries in which the standards are flexible or non-existent.

Rapid urbanization together with technology that is not eco-friendly is the main factor that increases environmental problems. Scientists conducting solution-oriented studies on this field have used various methods to calculate the amount and productivity of environmental problems. Wackernagel and Rees (1996) defined ecological footprint (EF) as the amount and increase in environmental problems. This calculation tool measures how much of the area's natural resources are being consumed and what is necessary to help eliminate waste (Wackernagel and Rees, 1996). Variables such as CO_2, water pollution rate, and SO_2 are part of the EF effects and used as environmental indicators. Saqib and Benhmad (2021), Udemba (2021), Dogan et al. (2020), Ansari et al. (2020), Destek and Sarkodie (2019), Al-Mulali et al. (2015), and Hervieux and Darné (2015) have used EF as a comprehensive environmental indicator that includes the effects on grassland, fishing, agricultural land, forests, built-up areas, and carbon load; therefore, EF was used in the present study as a comprehensive environmental indicator.

Between 1960 and 2008, EF gradually increased (Fig. 1). If the population increases and current consumption habits continue, the biological capacity ("biocapacity") for two worlds will be needed by 2030 and three worlds by 2050. To date, humans have used biocapacity equivalent to one and a half worlds on average (Global Footprint Network, 2022).

The market conditions fail to explain the effect of economic activities on the environment. The EF is a tool for balancing biocapacity and consumption. Consumption of goods and services within one country is not the only indicator affecting EF because resources from other countries can also be used, especially in international trade (Ghita et al., 2018: 3); therefore, EF from goods and services consumed extends beyond one country's borders. For example, when products made using domestic resources are exported, EF is exported, and vice versa for products imported. In other words, foreign trade can indicate whether countries are exporters or importers of an EF, and this affects EF differently in different countries depending on the production and consumption of resources. The EF indicator reveals how biophysical production capacity is used. Since the environment and foreign trade constantly affect each other, it is aimed to create a conscious and sustainable environment with global prosperity and economy. These policies are easily implemented depending on the level of knowledge and well-being in developed countries. For developing countries, this situation is very substantial regarding their share and acceptance in the global economy. By adapting to developed countries, they have a more reliable position in foreign trade by attaching importance to environmental standards.

The influence of foreign trade on EF can be expressed with four effects: allocation, income, rich country illusion, and trade distortion (Andersson and Lindroth, 2001: 119–121).

The allocation effect refers to foreign trade specializing in low-cost production but high productivity. This high productivity reduces EF as long as consumption does not increase; however, a country in need of foreign exchange may export a product produced with lower efficiency. In this case, the EF will increase even if consumption remains constant. In general, it can be said that EF decreases resulting from the allocation effect.

The income effect provides additional income to the participating country, which in turn, tends to increase consumption in that country as the per-capita income increases and provides more buying power to the population. In addition, import demand and consumption of countries whose income levels rise also increase. As import demand and consumption increase, it can be presumed that EF at both national and global levels also increases.

When developed countries increase expenditures so as to ensure that their own ecological resources are protected, they often import resources to use from countries that are less developed. This rich-country illusion effect diminishes the ecological resources of poor countries.

Trade distortion effect refers to the risk of inflation being high in developed countries as the general level of wages is high and the full employment process is experienced. Therefore, aggregate demand needs to be reduced regularly for ecological balance in developed countries.

It can be argued that environmental policies affect foreign trade in three ways. If a country has a strict environmental policy, its production costs will be higher than those of countries adopting flexible environmental policies. This causes countries with strict policies to shift production to countries with lower costs. Contrarily, if strict environmental policies reduce production costs, countries with strict regulations will be able to produce at lower costs. While countries that produce at lower costs gain a financial advantage, they boost their profits and shares in

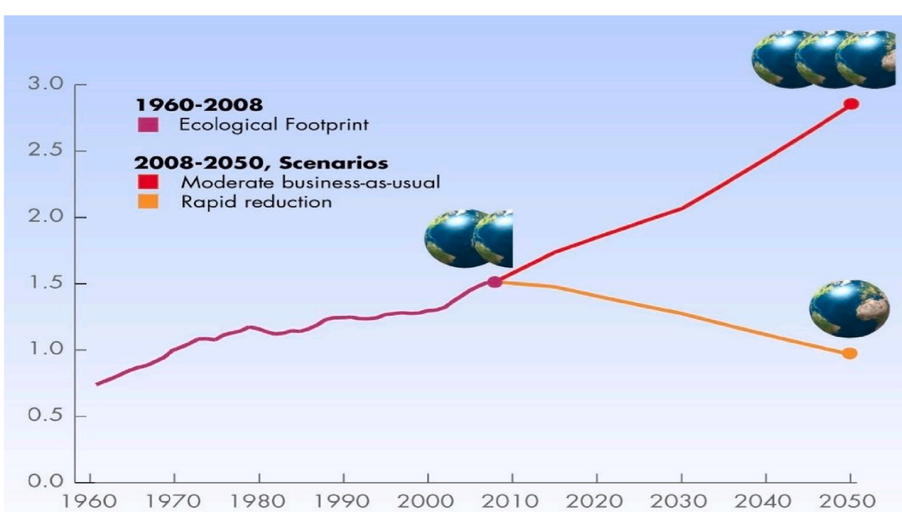

Fig. 1. Global footprint.
Source*:* Global Footprint Network, 2022.

the market. Third, if a country develops green technologies, it can affect foreign trade by facilitating the export of products (Kahn, 1998: 148).

Developing and underdeveloped countries need raw materials, machinery, and technology to carry out foreign trade activities for their development. Countries, on the other hand, can meet these needs only by importing. The release of fossil fuel emission into the air due to transportation at the entrance and exit of goods to the country causes environmental problems for reasons such as waste generated during production. However, because the aim of developing and underdeveloped countries is only growth and profit, they ignore the environmental problems that arise (Deger and Pata, 2017).

As seen, the relationship between foreign trade and EF is influenced by many factors. A literature review shows that studies have mostly examined the relationship between economic growth and the environment. However, few studies have addressed the correlation between foreign trade and the environment. This study empirically examines how the EF, which is determined as an environmental indicator, affects foreign trade using the data of the top 10 fastest developing countries in the global economy. This study will introduce an innovation to the literature in terms of the country sample selected. Within this context, the present study has assessed the correlation among EF, economic growth, exports, imports, and renewable energy consumption (REC) over the long term of the sampled countries using two models, export and import variables, based on annual data for 1990–2018. The objective of the present study was to analyse how foreign trade and EF are correlated and use that information to recommend new resource-saving policies. The World Bank data report that the foreign trade share of the countries selected as the sample in the hypothesis tests of the study, which was around 10% in 1990, increased to approximately 30% in 2021. China's share of world output was 1.6% in 1990, while in 2021 it increased significantly to 18.4%. In other words, China produces nearly one out of five world products, which was significant for the selection of the countries to use as the study sample. As mentioned, the policies in place in the various countries have a direct effect on the environment and the solutions to harmful effect depend on the policies that these countries implement. The countries selected for the present study were the biggest participants in global trade. Using the study sample, we hereby present both the theoretical and conceptual frameworks, the literature that was reviewed in the related fields, and its contribution to the literature. The results of the present study provide econometric analyses of the correlation between foreign trade and EF. The findings are discussed, and recommendations for policy revisions are provided. In the general planning of the study, first, after the theoretical and conceptual framework is created, literature research related to the relevant field is given, and the contribution of the study to the literature is discussed. Afterward, econometric analyses that focus on the relationship between foreign trade and ecological footprint are carried out, and the results are interpreted based on the findings. At the end of the study, the findings of the analyses are discussed, and policy recommendations are made.

The main problem statements of the research were stated as follows: "Is there a relationship between foreign trade and environmental pollution? What are the effects of exports and imports on the environment?" The main limitations of the study under the identified problems are.

- ✓ Conducting analyses on the 10 fastest developing countries,
- ✓ Due to the data constraints, the analyses cover the years of 1990–2018 only,
- ✓ Performing analyses with ecological footprint as an environmental indicator; economic growth, export, and import as economic variables; renewable energy consumption variables as control variables. Other indicators that are included in the literature and affect ecological footprint are not included in the model.

2. Literature review

The literature reviewed for the present study included research that examined the correlation between the environment and the economy. These studies have mainly tested the Environmental Kuznets Curve (EKC) hypothesis. There were few studies that tested the correlation between foreign trade and the environment. The studies we reviewed were within the scope of EKC, the pollution refuge, and the pollution haven hypotheses. In addition, CO_2 emissions were generally used as an environmental variable. There were few studies in which EF was used in their analyses as an environmental indicator and there were none that analysed the correlation between EF and foreign trade, especially from the sampled countries. Those references reviewed for the present study are outlined below.

Yilanci et al. (2022) examined the relationship between trade openness and EF in G-7 countries using annual data for the period of 1990–2017. The authors used dynamic symmetric and asymmetric panel causality tests and found a correlation between the degree of open trade and the environmental pollution indicators in G7 countries, as well as relationships between negative and positive shocks. Rehman et al. (2021), using data from 1974 through 2017, studied globalization, energy consumption, and foreign trade to assess their effects on EF in Pakistan. Using the augmented autoregressive distributed lag (ARDL) bounds test, the researchers found a correlation among the variables identified, foreign trade, and EF over the long and short terms. Usman et al. (2020) have examined the causal relationship in 33 developing countries in Africa, Europe, and North and South America among EF and economic growth, foreign direct investment, renewable energy, and trade openness. They used the Dumitrescu and Hurlin Causality Test, Fully Modified Least Squares, Dynamic Ordinary Least Squares (DOLS), Feasible Generalized Least Squares, and Augmented Mean Group (AMG) coefficient estimators and found a negative correlation between trade openness and EF. Moreover, there was a unidirectional causality from trade openness to EF in Africa, Asia, and the Americas. From 1971 to 2017, Tran (2020) had used the Generalized Method of Moments (GMM) to assess 66 developing countries. The results of the analyses showed that CO_2 emissions increased where openness increased. Dumrul and Kilicarslan (2020) analysed the effect of ecological footprint on international trade in Turkey between 1961 and 2014 according to the Johansen co-integration test and VECM. Accordingly, it was concluded that there is a causal relationship between international trade and ecological footprint. Liu et al. (2018) have assessed the correlation between EF and export product diversification in China using data for 1990–2013. The researcher analysed the results using Johansen cointegration and determined that EF increased in case of increased export product diversification. Uddin et al. (2017) used the DOLS estimation method and data from 27 countries with the highest CO2 emissions for the period of 1991–2012. Based on the study results, they found a positive correlation between EF and real income; however, trade openness had a negative effect on EF. Charfeddine (2017) conducted a study using the data of the Qatari economy for 1970–2015 and found an inverse relationship between trade openness and EF. Dam et al. (2017) analysed the impact of ecological footprint on international trade in 32 countries between 1966 and 2012 with the panel data method. Accordingly, it was concluded that high-income countries are importers in ecological footprint, while less developed countries are exporters, and high-income countries have stricter environmental policies. Gao and ve Tian (2016) used data from China from 1978 through 2010 and analysed the impact of foreign trade on EF. Their results indicated that China is a net importer of raw materials and have recommended that it revise its policies on importing raw material and exporting products and increase its investments in products of high value. Le et al. (2016) examined the relationship between trade openness, environmental pollution, and per capita income using data from 98 countries for the period of 1980–2013. Their study results indicated a long-term relationship between particulate matter emissions, trade openness, and economic growth. Al-Mulali et al. (2015) have examined the impact of gross domestic product (GDP), urbanization, energy consumption, trade openness, and financial development on EF using the panel data analysis method and data from 93 countries from 1980 through 2008. Their results indicated that energy consumption, urbanization, and trade openness increase EF over all income groups in several countries. Based on the results obtained, they stated the expectation that if consumption increased, the EF would also increase. Farhani et al. (2013) used data from 11 Middle East and North Africa countries from 1980 through 2009 and concluded that an increase in trade openness increases CO_2 emissions. Fotros and Maaboudi (2010) examined the effect that trade openness and economic growth have on CO_2 emissions in Iran. Their results indicated that although economic growth had a negative impact on CO_2 emissions from 1971 through 2005, trade openness had a positive effect. Using data from 150 countries, Moran et al. (2013) examined the size of EF of their trading partners using the Product Terrain Matrix and EF to measure the biophysical value of foreign trade. The results of their study within the framework of EF indicated that countries of high and middle-income trade predominantly with countries of the same economic status and much less with countries of low-income status; therefore, it can be presumed that EF determines which countries trade with each other. Jorgenson and Rice (2005) used a different approach for examining the impacts of foreign trade on EF. Using data from 2000 and Ordinary Least Squares (OLS) analysis, the results of their study indicated a negative correlation between exports and EF.

Our review of the relevant studies generally displays a negative correlation between foreign trade and EF. The studies basically differ from one another in terms of the environmental indicator used. Because EF is more inclusive, it is more frequently used; however, CO_2 emissions remains the preferred indicator in several studies. In addition to the environmental indicator being different in different studies, there were differences in the study methods, countries used in the samples, and control variables. In contrast to those, the present study used EF as an environmental indicator and followed a different methodological analysis. The present study tested the correlation between foreign trade and EF using two separate models for exports and imports, filling an important gap found in the literature. Moreover, in the study, conducting the analyses using the data of the top 10 fastest developing countries in the global economy for 1990–2018 and developing policy recommendations based on the findings of the analysis would also make important contributions to the literature.

3. Econometric methods

Using data from 10 countries as the sample group, the long-term correlation between EF and foreign trade was studied. Foreign trade comprises total exports and imports; therefore, our data were evaluated within the scope of the two following models: export EF and import EF. Data from 1990 through 2018 were analysed with panel data analysis techniques. The hypothesis of the study was constructed as “there is a long-run relationship between EF and foreign trade.” Our dataset and models for analysis and the theoretical explanation of which variables were used are presented, after which the results of the analyses are discussed.

3.1. Dataset and model

Because some variable data were missing, the analyses were conducted using annual data from 1990 through 2018. In addition, Poland was not included among the top 10 fastest developing countries used as the study sample because of common data problems. The countries were selected because they are among the largest participators in global trade and their policies on global production to be implemented are of great importance in resolving environmental problems.

Two models were used to test the hypothesis. Basic information on the variables used in the models, which were determined based on the literature, is provided in Table 1. The most commonly used and most comprehensive environmental indicator used in the literature is EF, which is the dependent variable. Exports and imports, the two components of foreign trade, were the independent variables used in the models. In addition, REC and GDP that affect EF were also included in the models as controls.

All variables used in the model, as can be seen in the literature, are the most preferred variables and they do not have common data problems. The evaluation of these variables shows that, consistent with several studies, GDP was the most preferred control, especially when analysing the EKC hypothesis. The REC variable, selected as another control because of its impact on EF, is also preferred in many studies in the literature and is an important source of alternative to the environmental problems caused by fossil fuels.

In the present study, the equations for the models for the specific data range were created within the scope of the stated hypothesis.

$$\text{Model 1: } EF_{it} = \beta_0 + \beta_1 EXP_{it} + \beta_2 REC_{it} + \beta_3 GDP_{it} + \varepsilon_{it}.$$
$$\text{Model 2: } EF_{it} = \beta_0 + \beta_1 IMP_{it} + \beta_2 REC_{it} + \beta_3 GDP_{it} + \varepsilon_{it}.$$

In the models, $i = 1, 2, 3, \ldots$ N denotes horizontal cross-section data, $t = 1, 2, 3, \ldots$T denotes the time dimension, and ϵ denotes the error term. Because all the variables in the models are proportions or indices, they are included in the analysis without taking their logarithms.

Descriptive statistical changes and graphical changes of all variables used in the model should be interpreted before econometric analyses. Thus, the changes in variables over the years, cyclical changes, fluctuations, and statistical changes are determined. Countries are listed from 1 to 9 in the figures given below. These are Mexico, Brazil, Argentina, South Africa, Turkey, India, Indonesia, China, and South Korea, respectively. Poland was not included in the analysis due to lack of data, and its graphical interpretation was not performed.

When Fig. 2 was examined, there were no serious fluctuations in the ecological footprint of the first three countries. According to the figure, the country with the maximum fluctuation is South Africa, while the minimum fluctuation is observed in South Korea. The highest difference between fluctuations is in China, which is the eighth country. When the change in the exports of goods and services belonging to the countries is examined, an unstable and continuous fluctuation is observed. The countries least affected by the change in national income of goods and services exports were Brazil, South Africa, and Turkey. In addition, Indonesia and South Korea reached the maximum level, while India was the least affected country. When we look at the changes in the national income of nine countries, there were generally waves in the same periods. However, the national income fluctuation margin observed in Indonesia is much higher than in other countries. Finally, this graph showing the change in renewable energy is different from the fluctuations in other changes. Although the difference among countries is not stable, the largest fluctuation difference is in India and then in Brazil. The least change was seen in Argentina. While Turkey has reached the maximum point in the change in renewable energy, South Korea has become the minimum point in the change.

In Table 2, whether the series is normally distributed or not is examined according to skewness, kurtosis and Jarque-Bera statistics. According to the skewness and kurtosis values, it is seen that the EF and

Table 1
Data set and sources.

Variables	Description of the variables	Source
EF	Ecological Footprint	Global Footprint Network
EXP	Exports of goods and services (% of GDP)	World Bank
IMP	Imports of goods and services (% of GDP)	World Bank
GDP	Growth (annual %)	World Bank
REC	Renewable energy consumption (% of total final energy consumption)	World Bank

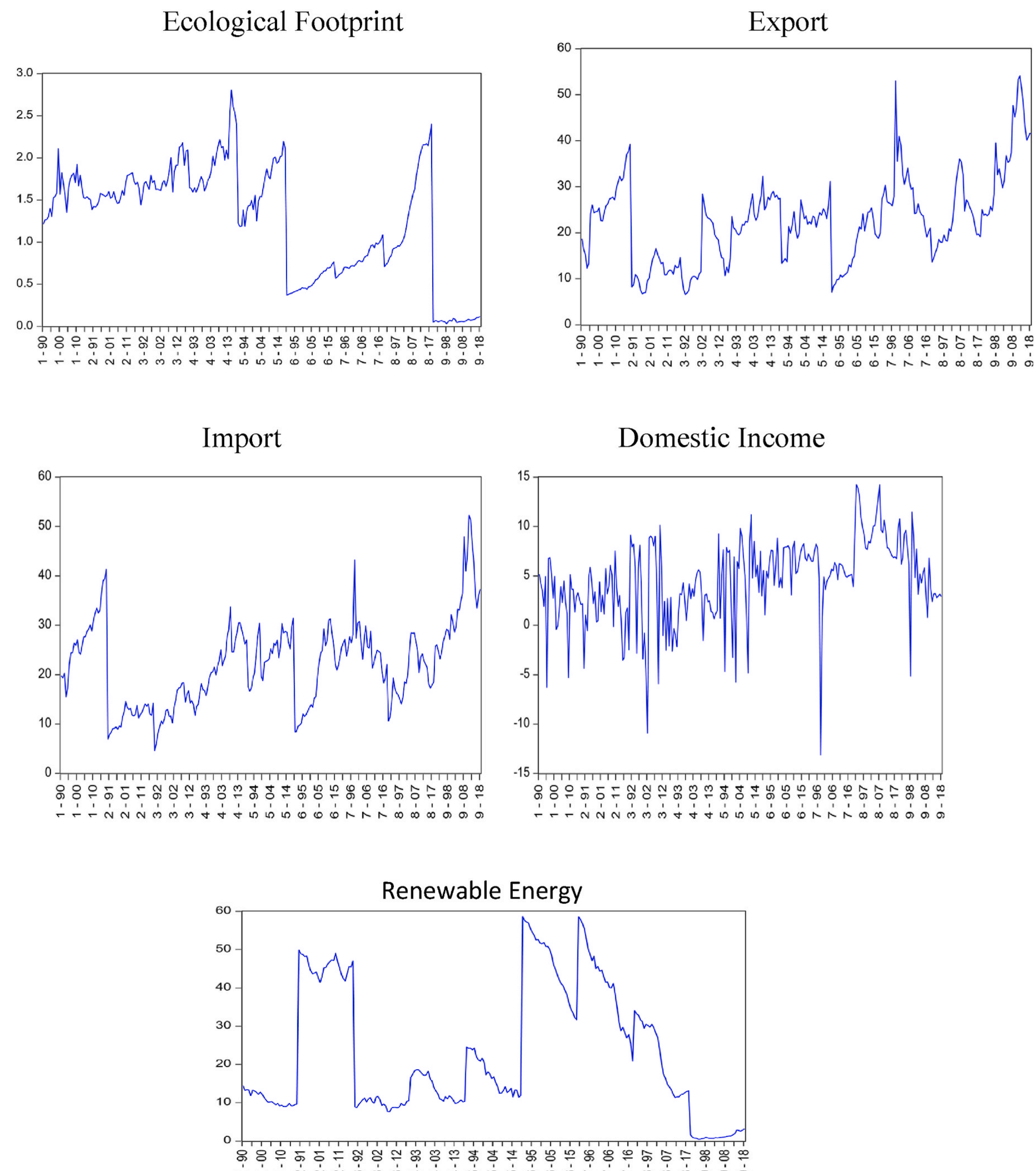

Fig. 2. Graphical analyses of variables.

Table 2
Descriptive statistics of variables.

	Observation	Mean	Maximum	Minimum	Standart Deviation	Skewness	Kurtosis	Jarque-Bera
EF	261	1.264600	2.802549	0.032254	0.665919	−0.361987	3.755712	14.15023 (0.0008)
EXP	261	22.65532	54.09405	6.598187	9.412274	0.670954	2.118505	25.79354 (0.0000)
GDP	261	4.528032	14.23086	−1.312.673	4.110000	−0.787353	4.625076	55.68621 (0.0000)
IMP	261	22.18270	52.22858	4.631322	8.643200	0.520837	3.452918	14.03113 (0.0008)
REC	261	23.12510	58.65286	0.441575	17.07680	0.548170	1.903510	26.14622 (0.0000)

Note: The values in parentheses indicate the probability values.

GDP variables are pointed to the right (in a negative direction), and the IMP variable is pointed to the left (in a positive direction). The variables EXP and REC, on the other hand, can be interpreted as being flattened to the left (in a positive direction). According to the JB test, all variables are significant at the level of 1% and are not normally distributed.

3.2. Econometric method

The methodological sequence applied in the study examining the long-run relationship between EF and foreign trade in the sampled countries of the global economy is as follows.

- The existence of horizontal cross-section dependence of the variables in the model was investigated using the LMadj test developed by Pesaran et al. (2008).
- For the unit root analysis of the variables, the panel analysis of the constancy of residuals and common factors (PANIC) unit root test developed by Bai and Ng 2004, 2010was utilized.
- The Delta test (Pesaran and Yamagata, 2008) was conducted to determine variance in the slope coefficients across units.
- The Durbin-Hausman cointegration test (Westerlund, 2008) was conducted to determine the existence of cointegration relationship between variables.
- For the cointegration coefficients of the variables, the CCE estimator (Pesaran, 2006) and the AMG estimator (Eberhartd and Bond, 2009) were used.

3.2.1. Cross-sectional dependence test

It is necessary to determine the existence of a horizontal cross-sectional relationship between variables before hypothesis testing in studies conducted using panel data analyses. Due to the constant globalization of the world, the interdependence of countries increases. Therefore, positive or negative shocks occurring in a country may affect other countries due to this interdependence. For these reasons, in econometric studies, it is necessary to detect the cross-sectional dependence of variables caused by a common factor problem.

The tests used to detect horizontal cross-sectional dependence can be shown as follows.

- When the time dimension is larger than the cross-sectional dimension (T > N), Breusch-Pagan (1980) CD_{lm1} test
- When the time dimension is equal to the cross-sectional dimension (T = N), Pesaran (2004) CD_{lm2} test
- When the time dimension is smaller than the cross-sectional dimension (T < N), Pesaran (2004) CD_{lm} test
- When the time dimension is both smaller (T < N) and larger (T > N) than the cross-sectional dimension, Pesaran et al. (2008)'s (LM_{adj}) test.

There are 9 countries included in the analysis; therefore, the cross-sectional dimension was 9 (N = 9). The time dimension for the periods studied was 29 (T = 29) for 1990–2018, which was larger than the observation dimension. Because of this difference, (T > N), the Breusch-Pagan's (1980) Cross-Sectional Dependence (CD_{lm1}) test and Pesaran et al.'s (2008) Lagrange Multiplier (LM_{adj}) tests were used.

According to Table 3, which shows the cross-sectional dependence test results, there is a horizontal cross-section dependence in all variables significant at the 1% level. This is in line with today's global world, and is within expectations; in other words, a shock to one of the countries included in the sample may also have an impact on other countries. Therefore, leaders of the countries should make plans by considering this before making decisions.

Table 3
Cross-sectional dependence test results.

Variables	CD tests	CD_{lm1} (Breusch-Pagan, 1980)	CD_{lm2} (Pesaran, 2004)	CD (Pesaran, 2004)	LM_{adj} (Pesaran et al., 2008)
EF	T statistics	559.6807	61.71636	22.10375	61.55564
	Probability value	0.0000*	0.0000*	0.0000*	0.0000*
EXP	T statistics	312.3982	32.57384	13.30004	32.41313
	Probability value	0.0000*	0.0000*	0.0000*	0.0000*
IMP	T statistics	419.1048	45.14934	15.51369	44.98862
	Probability value	0.0000*	0.0000*	0.0000*	0.0000*
REC	T statistics	495.1215	54.10798	11.42826	53.94727
	Probability value	0.0000*	0.0000*	0.0000*	0.0000*
GDP	T statistics	81.14535	5.320431	5.793672	5.159717
	Probability value	0.0000*	0.0000*	0.0000*	0.0000*

Note. *, **, and *** indicate that the coefficients are significant at 1%, 5%, and 10% levels, respectively.

3.2.2. Results of panel unit root test

Given that stationarity tests are required for econometric analyses to resolve any spurious regression issues and that a unit root in the series of variables cause any results to be false (Granger and Newbold, 1974), the overlying issue in the panel data analyses was whether the sample countries were independent of each other. Tests of panel data analyses are first- and second-generation unit root tests. First-generation unit root tests account for cross-sectional dependence; second-generation tests are conducted based on cross-sectional dependence. Because we observed cross-sectional dependence among the variables used in the present study models, the PANIC unit root test (Bai and Ng, 2004, 2010), a second-generation test, was used for all the variables.

PANIC examines the stationarity in the residuals and factors separately. The data-generating process for variable X is as follows:

$$X_{it} = D_{it} + \lambda_i' F_t + e_{it}$$

The X_{it} variable is the sum of the common factor and residuals. The F_t variable is used to eliminate the cross-sectional dependence problem. Factor estimates were obtained by applying the principal components method to the first differenced data. Consistent estimation of factors does not require the condition that the residuals are constant regardless of whether or not the residuals are constant. The advantage of PANIC is that it examines the unit root in the residuals after the unit root is rejected.

The PANIC test, which is one of the second-generation panel unit root tests, is among the most up-to-date tests today. This test analyses whether the series contains a unit root without considering the stationarity of the error terms of the cross-section dependence and does not give information about the stationarity in the differences of the series. The PANIC unit root test is calculated as follows:

$$PMSB = \frac{\sqrt{N}\left(tr\left(\frac{1}{NT^2}\hat{e}'\,\hat{e}\right) - \hat{\omega}_\varepsilon^2/2\right.}{\sqrt{\hat{\varnothing}_\varepsilon^4/3}}$$

$$PMSB = \frac{\sqrt{N}\left(tr\left(\frac{1}{NT^2}\hat{e}'\,\hat{e}\right) - \hat{\omega}_\varepsilon^2/6\right.}{\sqrt{\hat{\varnothing}_\varepsilon^4/45}}$$

For the stationarity of the residuals, PANIC test statistics P_a and P_b are used. The Augmented Dickey-Fuller (ADF) test statistics examining the individual stationarity of e_{it} are constructed from p-values. P_a denotes the results of the ADF test with a constant and P_b denotes the results of the ADF test with constant and trend. In addition, Stock (1990) developed the panel version of the modified Sargan and Bhargava (1983) (PMSB) test when e_{it} is autocorrelated. If any of the Pa, Pb, and PMSB statistics are unit rooted, it is concluded that the variable is unit rooted.

In the PANIC unit root test results (see Table 4), all three probability values Pa, Pb, and PSMB should be statistically significant. In the event that one of the statistical values is insignificant, it is interpreted that the variable has a unit root. Within this context, it is observed that all the

Table 4
PANIC unit root test results.

Variables	Statistical values	Constant			Constant and trend		
		Pa	Pb	PSMB	Pa	Pb	PSMB
EF	Test statistics	1.869	2.481	1.859	−3.411	−2.267	−1.325
	Probability value	0.9692	0.9934	0.9685	0.0003*	0.0117**	0.0926***
ΔEF	Test statistics	−32.961	−8.643	−1.739	−10.978	−5.487	−1.755
	Probability value	0.0000*	0.0000*	0.041**	0.0000*	0.0000*	0.0396**
EXP	Test statistics	0.75	0.65	−0.383	−1.224	−1.04	−0,804
	Probability value	0.5298	0,526	0.3508	0.1106	0.1491	0.2108
ΔEXP	Test statistics	−24,257	−7,371	−1,969	−11,751	−5,986	−2.83
	Probability value	0.0000*	0.0000*	0.0245**	0.0000*	0.0000*	0.0186**
IMP	Test statistics	−0.454	−0.363	−0.686	−0.57	−0.524	−0.442
	Probability value	0.325	0.3583	0.2464	0.2843	0.3003	0.3291
ΔIMP	Test statistics	−28.887	−8.316	−2.106	−13.398	−6.701	−2.306
	Probability value	0.0000*	0.0000*	0.0176**	0.0000*	0.0000*	0.0106**
REC	Test statistics	−1.707	−1.221	−0.91	−0.16	−0.155	−0.143
	Probability value	0.0436**	0.1111	0.1813	0.4363	0.4383	0,443
ΔREC	Test statistics	−15.693	−5.462	−1.854	−10.993	−5.588	−1.942
	Probability value	0.0000*	0.0000*	0.0319**	0.0000*	0.0000*	0.0261**
GDP	Test statistics	−7.163	−3.517	−1.586	−6.17	−3.601	−1.658
	Probability value	0.0000*	0.0002*	0.0564***	0.0000*	0.0002*	0.0486**
ΔGDP	Test statistics	−21.019	−6.586	−1.899	−24.885	−8.784	−2.296
	Probability value	0.0000*	0.0000*	0.0288**	0.0000*	0.0000*	0.0108**

Note. *, **, and *** indicate that the coefficients are significant at 1%, 5%, and 10% levels, respectively.

variables included in the model except GDP are unit rooted, and when these are differenced, the variables become constant. In addition, the degree of stationarity of GDP strengthens when its difference is taken. Considering the EF variable, the series is constant in the constant and trend model while it has unit root at level values in the constant model. When the difference is taken, the series becomes constant in the constant model and the degree of stationarity of the series strengthens in the constant and trend models.

This result can be interpreted as the fact that the shock to one of the countries included in the model causes permanent results and does not lose its effect immediately. Moreover, finding nonstationarity in the series provides the necessary precondition to conduct cointegration tests. When the same test is repeated using the first-order difference of all series for the stationarity of the series, it is concluded that the variables become constant at the I(I) level.

In the Durbin-Hausman cointegration test, which will be used in the next section of the study, the dependent variable being I(I) indicates that the sufficient condition for the analysis is met.

3.2.3. Homogeneity test

When detecting a long-term correlation in the econometric analyses, it is necessary to examine whether the coefficients are homogeneous. This examination will give results about whether the change in one of the countries affects the other countries to the same level. In these analyses, coefficients in the models should be heterogeneous for countries with varying economic structures but homogenous for countries with similar economic structures. In this study, the Slope Homogeneity Test (Delta test) developed by Pesaran et al. (2008) was used to test homogeneity. The Delta test is calculated in two ways:

$$\widetilde{\Delta} = \sqrt{N}\ \frac{N^{-1}\check{S} - k}{\sqrt{2k}}$$

$$\widetilde{\Delta}_{adj} = \sqrt{N}\ \frac{N^{-1}\check{S} - k}{\sqrt{Var(t,k)}}$$

$\widetilde{\Delta}$: gives the delta test statistic for small samples, while $\widetilde{\Delta}$ *adj*: gives the corrected delta test statistic for large samples. *N* in the equation shows the number of observations, $\check{S}$ is the Swamy test statistic, k is the number of explanatory variables, and the value $\sqrt{Vat}\ (t, k)$ shows the standard error (variance).

In the present study, homogeneity analysis was conducted using the Delta test (Pesaran and Yamagata, 2008), which is valid for large samples; Delta $_{adj}$ test is valid for small samples. For the homogeneity test, the null hypothesis (H_0) was interpreted as “slope coefficients are homogeneous” and the alternative hypothesis (H_1) was interpreted as “slope coefficients are heterogeneous.”

The results of the homogeneity test of the model variables are presented in Table 5.

In the study, the Delta homogeneity test was used to analyse the coefficients of EF and exports (EF-EXP) in Model 1 and EF and imports (EF-IMP) in Model 2. Because the probability value of both test statistics was <0.05, the slope coefficients changed between units in the long term. In other words, it was concluded that the variables were heterogeneous.

3.2.4. Durbin-Hausman cointegration test results

In panel data analyses, the existence of a long-term relationship is most frequently examined using a cointegration test. Pedroni (1999), Westerlund (2008), and Westerlund and Edgerton (2007) estimated this using different techniques; however, horizontal cross-sectional dependence must absolutely be considered in these analyses. If not, problems, such as the existence of a false cointegration relationship, may be encountered. To avoid this, the Durbin-Hausman analysis, which estimates the long-term relationship by accounting for horizontal cross-sectional dependence (Westerlund, 2008), was used in the present study.

The reasons that the Durbin-Hausman test was used in this study are as follows: the main strength of the test that makes it prominent is that it takes into consideration cross-sectional dependence and that it is a second-generation test. In addition, if the dependent variable is I(I), it is not important at which level the independent variables are stationary.

Table 5
Homogeneity test results.

Models	Test statistics	Test statistics	Probability value
Model 1	Delta_tilde	12.485	0.0000*
	Delta_tilde_adj	13.677	0.0000*
Model 2	Delta_tilde	13.266	0.0000*
	Delta_tilde_adj	14.532	0.0000*

Note. *, **, and *** indicate that the panel coefficients are heterogeneous at 1%, 5%, and 10% significance levels, respectively.

This allows testing the long-term relationship among stationary variables and allows for homogeneous and heterogeneous parameters. If the parameters are homogeneous, Durbin-Hausman panel test statistics should be taken into account; however, if they are heterogeneous, Durbin-Hausman group test statistics should be considered. In this study, Durbin-Hausman group statistics were considered because it was decided that the coefficients were heterogeneous based on the Delta test results of the study.

In order to apply the Durbin-Hausman cointegration test, the dependent variable must contain a unit root. Test calculation is in the form of Durbin-Hausman group and Durbin-Hausman panel statistics. The first of these is the Durbin-Hausman group mean statistic (*DHg*), which assumes that the autoregressive parameters are heterogeneous. This test statistic is calculated as follows:

$$DH_g = \sum_{i=1}^{n} \widetilde{S}_i(\widetilde{\varphi}_i - \widehat{\varphi}_i)^2 \sum_{t=2}^{T} \widehat{e}_{it-1}^2$$

The second is the Durbin-Hausman panel statistic (*DHp*), which assumes that the autoregressive parameters are homogeneous. This test statistic is calculated as follows:

$$DH_p = \widehat{S}_n(\widetilde{\varphi} - \widehat{\varphi})^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \widehat{e}_{it-1}^2$$

Using the Durbin-Hausman test, the cointegration relationship can be assessed separately in both panel and group dimensions. The group test allows the autoregressive parameter to vary across cross sections. According to this test, rejection of the H_0 hypothesis implies the existence of a cointegration relationship in some cross sections. Accordingly, the autoregressive parameter is presumed to be the same in all cross sections and a cointegration relationship for all cross sections is accepted when the H_0 hypothesis is rejected (Di Iorio and Fachin, 2007).

Within the scope of this test, the relationship between foreign trade and EF was analysed using Models 1 and 2.

The results of Durbin-Hausman cointegration test, a second-generation econometric test, was used to determine the long-term correlation between EF and EXP in Model 1 and between EF and IMP in Model 2, where the slope coefficients varied, and the variables were heterogeneous (Table 6). When the results obtained from the homogeneity test were analysed, the results of the Durbin-H group statistics were considered since it was determined that it would be more appropriate to use group statistics. When the probability values of the Durbin-Hausman panel statistics were analysed, a long-term correlation was observed among EF and export/import variables ($P < 0.05$).

The long-run relationship between exports and imports, which are the two components of foreign trade, and EF shows that all decisions in countries' foreign trade and environmental policies should be sensitively and carefully made. It is understood that the liberalization of foreign trade, supports to be applied in the sector, protectionist policies to be implemented, and environmental policies should be compatible because policies to be implemented regarding both EF and foreign trade will have an impact on markets and ecological balance.

The fact that a long-run relationship between the variables was detected indicates that the prerequisite for coefficient estimation was met. Once the cointegration relationship between the two variables is identified, the Common Correlated Effects (CCE) estimators developed by Pesaran (2006) and the AMG estimator developed by Eberhardt and Teal (2011) were used to estimate the cointegration coefficients.

The Monte Carlo study by Pesaran (2006) shows that cross-sectional dependence should be tested in panel data models, and methods that take this into account, if any, should be used. The CCE estimators consider the dependence between the cross-sections that make up the panel. The CCE long-run coefficient estimators assume that the independent variables and unobserved common effects are constant and exogenous. They are also consistent when the independent variables and unobserved common effects are constant (I (0)), first-order integrated (I (1)) and/or cointegrated.

Eberhartd and Bond (2009), Eberhartd and Teal (2011), and Eberhardt (2012) developed the AMG method that takes into account cross-sectional dependence. The AMG estimator considers the differences in observable and unobservable factors between panel groups as well as time series characteristics. Eberhartd and Bond (2009) and Eberhardt (2012) developed an estimator that can calculate cointegration coefficients for the countries that make up the panel and the overall panel with the AMG test. This method takes into account the common factors in the series and is also used when the endogeneity problem, which indicates that there is correlation between explanatory variables and error terms, emerges (Eberhartd and Bond, 2009). AMG estimators with cross-sectional group specification are calculated by averaging the coefficients of each country in the panel. This test is also much stronger than other coefficient estimation methods as it estimates the coefficients by weighting the arithmetic mean of the cointegration coefficients. The results of AMG and CCE tests are shown in Table 7 and Table 8.

According to CCE estimator, all variables are significant, and the coefficient signs are consistent with the theory. The increase in exports and REC decreases the EF. In other words, there is an inverse relationship between exports and REC, and EF. An increase in economic growth increases the EF. That is, there is a direct positive correlation between economic growth and EF. According to the AMG estimator, variables (except for GDP) are statistically significant and the coefficient signs are consistent with the theory.

According to the CCE coefficient estimation results, except for imports, all variables are statistically significant, and the coefficient signs are consistent with the theory. In addition, the increase in REC reduces the EF. An increase in economic growth increases the EF. Based on the AMG estimator results, except for GDP, the other variables are statistically significant, and the coefficient signs are consistent with the theory. It was concluded that the increase in imports and REC reduces the EF. Therefore, there is an inverse relationship between import-REC and EF.

The results obtained from the CCE and AMG coefficient estimator analyses are generally consistent with the theory. As seen in Tables 6 and 7, the increase in exports indicates that ecological problems are also exported. Therefore, the fact that the coefficient of the export variable is negative is consistent with the theory. REC has a positive effect on EF because it reduces the environmental problems caused by fossil fuels. GDP, on the other hand, is expected to increase the EF when it is considered with the production dimension in general. Similar results have been obtained in many studies in the literature.

4. Discussion

The impact of foreign trade on the environment began to increase with the industrial revolution. Along with the trade liberalization imposed by globalization, the areas of production and consumption have diverged. Production and consumption activities carried out with the aim of cost minimization and benefit maximization have differentiated the environmental impacts caused by foreign trade. In other words, environmental problems are not only consumption-oriented. The realization of production outside the borders of the country and the geographical differences in the supply chain can also cause environmental problems. Thus, the environmental problems created by

Table 6
Durbin-hausman cointegration test results.

Models	Test statistics	T statistics	Probability value
Model 1	Durbin-H group statistics	14.152*	0.000
	Durbin-H panel statistics	2.875*	0.002
Model 2	Durbin-H group statistics	17.971*	0.000
	Durbin-H panel statistics	3.633*	0.000

Note. *, **, and *** indicate that the coefficients are significant at 1, 5, and 10% levels, respectively.

Table 7
Panel cointegration coefficients estimation results (model 1).

Independent variables	CCE estimator			AMG estimator		
	Coefficient	Standard error	Probability	Coefficient	Standard error	Probability
EXP	−0.0067	0.0030	0.029**	−0.0054	0.0024	0.026**
REC	−0.022	0.0135	0.100***	−0.0199	0.0083	0.017**
GDP	0.0069	0.0028	0.014**	0.0020	0.0024	0.396

Note. *, **, and *** indicate that the coefficients are significant at 1%, 5%, and 10% levels, respectively.

Table 8
Panel cointegration coefficients estimation results (model 2).

Independent variables	CCE estimator			AMG estimator		
	Coefficient	Standard error	Probability	Coefficient	Standard error	Probability
IMP	−0.0050	0.0041	0.230	−0.0051	0.0021	0,014**
REC	−0.0200	0.0097	0.040**	−0.0193	0.0082	0.019**
GDP	0.0051	0.0012	0,000**	0.0031	0.0023	0.180

Note. *, **, and *** indicate that the coefficients are significant at 1%, 5%, and 10% levels, respectively.

production and consumption through foreign trade, which is the main indicator of openness to foreign trade, have gone beyond the borders of the country. Another contribution of trade liberalization is that it allows countries to import cleaner technologies to adapt to global competition and to raise environmental standards.

The present study discussed the long-term correlation between foreign trade and EF using data on the top 10 fastest developing countries in the global economy and examined the cross-sectional dependence among the variables used in the study models. According to the results of the LM_{adj} test, a cross-sectional dependence was identified among the participating countries. For the stationarity analysis of the variables, the PANIC unit root test, one of the second-generation unit root tests, was performed; and considering the results obtained, the variables were made constant at the I(I) level. According to the Delta test, the variables used in the two models were heterogeneous. The results of the Durbin-Hausman test analysis showed that there was a long-term relationship between EF and export and import variables. Finally, after the long-run relationship between the variables was determined, the analysis was finalized with the CCE and AMG coefficient estimators. The CCE coefficient estimator indicated that in Model 1, there was an inverse relationship between exports and REC, and EF, and a positive relationship with economic growth. The AMG coefficient estimator showed that the increase in exports and REC decreased the EF. According to CCE, when the coefficient estimators for Model 2 were examined, there was a negative correlation between REC and EF but a positive correlation between economic growth and EF. According to AMG, the increase in imports and REC decreased the EF. Therefore, there is an inverse relationship between import-REC and EF.

The existence of a long-run relationship between the two components of foreign trade —exports and imports— and EF suggested that countries should manage their foreign trade and environmental policies more carefully. This result will make great contributions to the literature and to policies of the sample countries. In addition, another novelty that the study has brought to the literature is that it analyses the impact of foreign trade on the environment by modelling it separately through exports and imports. As an environmental variable, CO2 emissions is mostly used in the literature. The use of EF, which is a more inclusive variable in the environmental sense, is also considered to bring a different perspective to the literature. The literature review for the present study showed that the countries used as our sample were not used in other studies to assess the correlation between the environment and foreign trade. Considering the effectiveness of both global trade and environmental policies in the global world, the effectiveness of this country group is very important.

The results obtained from the analysis of the relationship between foreign trade and EF using the top 10 fastest developing countries are generally similar to the limited studies in the literature. The results of the present study are generally consistent with those of Yilanci et al. (2022), Rehman et al. (2021), Usman et al. (2020), Tran (2020), Liu et al. (2018), Uddin et al. (2017), Charfeddine (2017), Le et al. (2016), Al-Mulali et al. (2015), Farhani et al. (2013), and Jorgenson and Rica (2005) but contradictory with that of Fotros and Maaboudi (2010). It can be argued that in the studies in the literature, the variables used, the countries selected, and the data ranges are different. In addition, the PANIC unit root test and Durbin-Hausman cointegration tests used in the study have not been frequently used in the literature, so the present study is methodologically different.

5. Conclusions

Several suggestions can be presented to policymakers, companies, and researchers based on our findings of the correlation between foreign trade and EF. Suggestions for policymakers are as follows: If the country's economy is strengthened and foreign dependency is reduced, environmentally friendly products are produced with high technology and conscious production, the ecological balance is positively affected. Companies that harm the environment should be informed and encouraged and, if necessary, sanctions should be imposed. Administrators of countries should take into account the EF impacts of these activities in the policies to be established through foreign trade. Especially when applying incentives, tax exemptions, and subsidies, sectors and firms that do not cause environmental problems can be prioritized. Suggestions for firms based on the findings of the analyses are as follows: Investments should be made in sectors that will not cause environmental damage in goods subject to foreign trade. Energy sources used in production should be created from renewable energy sources. Manufacturing companies should develop efficient production policies in the use of raw materials and in every step of production, thus preventing waste and consumption of resources. Manufacturing companies should minimize environmental damage by using advanced technology. It is very important for countries and companies to develop policies by considering the EF of the countries they trade with the most. New research which will deal with the related issue should focus on the impact of trade openness on the environment using different environmental indicators. New researchers can achieve different results using data of different income groups by analysing different countries. Finally, new researchers should carry out analyses using different statistical and econometric methods. Panel data analysis techniques were used in the study since a country group was taken as the sample. New researchers can interpret the results in a country and develop policy recommendations by using time series analysis with new generation tests.

Availability of data and materials

The data will be provided upon a reasonable request to the corresponding author.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Ethics approval

No animal or human data were used in this study.

Consent to participate

The authors have agreed to the authorship of this manuscript and have read and approved its content and given consent to submit it for review.

Consent for publication

The authors have given their consent for subsequent publication of this manuscript.

CRediT authorship contribution statement

Ibrahim Cutcu contributed to the literature review, econometric analysis, and issues related to international economics within the study. **Asiye Beyaz** contributed to the planning, literature review, data collection, and writing of the findings and discussion, and conclusion parts within the study. **Selcuk Gokhan Gerlikhan** contributed to the planning, literature review and issues related to political science and public administration within the study. **Yunus Kilic** contributed to the planning, literature review, methodology and writing of the findings.

Declaration of competing interest

As the corresponding author, on behalf of all authors I declare that **there is not any conflict of interest to be declared** and **there is not any** funding **institution for the research**.

Data availability

Data will be made available on request.

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