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Assessing the Environmental Impacts of Natural Resource Rents and Trade Openness in Countries with the Highest Carbon Emissions



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Abstract

The factor that contributes the most to environmental pollution is greenhouse gas emissions. CO₂ emission, one of the main indicators of environmental degradation, has the highest volume among greenhouse gases. Therefore, the greenhouse gas that causes the most pollution to the environment among the total greenhouse gas emissions is carbon dioxide. The emission of carbon dioxide and other harmful gases threatens living life by causing problems such as global warming. For this reason, it is necessary to protect the environment, and in order to protect the environment, policies to reduce carbon dioxide emissions should be determined and implemented. There are many factors affecting carbon dioxide emissions. The primary factors are various activities carried out for economic purposes. In this study, the factors affecting environmental pollution were examined using the indicators of energy, foreign trade and income. For this purpose, the relationships of the total energy resource rents, trade openness and GDP variables with carbon dioxide emissions were investigated. In the study, panel data analysis was used with 1990-2020 data from the 14 countries with the highest carbon dioxide emissions. In the analyses, the CIPS panel unit root test, one of the second-generation unit root tests, was applied. Then, the second-generation co-integration test was applied, and as a result of this test, it was determined that there was a long-run relationship between the variables. The PDOLSMG test was applied to estimate the long-run coefficients. The results showed that natural resource rents and economic growth had a positive impact on carbon emissions. Finally, the Dumitrescu-Hurlin panel causality test was applied to investigate whether there were causality relationships between the variables. As a result of the causality test, it was determined that there were bidirectional causal relationships between natural resource rents and carbon dioxide emissions, unidirectional causal relationships from GDP to carbon dioxide emissions and from trade openness to GDP.

Keywords

CO₂ · Trade Openness · Total Resource Rents · GDP · Co-integration and Causality Analysis

JEL Classification

O13 · F18 · F43 · C23



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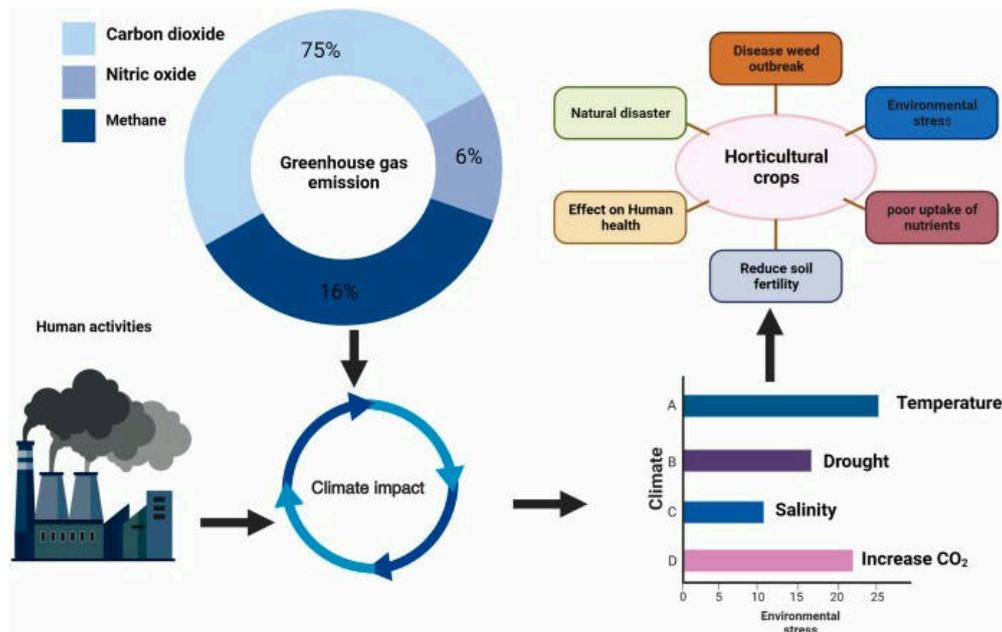
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Assessing the Environmental Impacts of Natural Resource Rents and Trade Openness in Countries with the Highest Carbon Emissions

The factor that causes environmental pollution at the highest level is greenhouse gas emissions. CO₂ is the gas with the largest share of greenhouse gas emissions. For this reason, among the total greenhouse gas emissions, the greenhouse gas that causes the most pollution to the environment is CO₂ (Coşkuner et al., 2020).

Figure 1
Greenhouse gases and the impact of climate change



Source: Shah et al., 2024

Countries must protect the environment for sustainable economic growth and development. Policies to reduce CO₂ emissions must first be determined and implemented to protect the environment (Sun et al., 2023). Protecting the environment is very important for people to survive and protect their health in this day and the future. Because, as shown in Figure 1, the gases that emerge as a result of human activities and cause environmental pollution directly threaten the lives of all living things. Countries that are aware of this are turning to economic policies to ensure environmentally friendly green growth (Kaftan et al., 2023). It becomes important to first determine the factors affecting CO₂ emissions in policies aimed at reducing CO₂ emissions to reduce environmental pollution. With the studies performed to do this, economic, social, and political factors affecting CO₂ emissions have been investigated (Dutta et al., 2021).

Countries increase their national income and foreign trade volumes and cause environmental destruction because of greater industrialisation. In our present day, industrialisation activities performed for economic growth constitute one of the most important causes of environmental destruction. The use of fossil resources is quite common in almost every aspect of life (e.g., as energy raw material in industry, as fuel for vehicles in social life, or as a heating source in households). Greenhouse gases emerge because of reasons such as the intensive use of fossil resources (especially in industrial activities) as well as ignoring environmental damage in production activities and individuals not being sensitive enough to environmental issues. These gases accumulate in the atmosphere and cause climate change. For this reason, environmental

degradation is accelerating in connection with the economic development of countries, and air, soil, and water resources are polluted and the quality of life of people decreases. Although trying to increase the welfare level of individuals by producing and consuming more, becoming more industrialised, using more natural resources, and performing more agricultural activities economically increases the income level of countries and individuals, it also condemns individuals to poor conditions in terms of quality of life and health indicators.

Economic growth is among the main determinants of increased environmental pollution (Islam, 2021). However, an important theory on this subject has been proposed as the Environmental Kuznets Curve (EKC). According to this theory, there is a relationship between environmental destruction and economic growth, which follows an inverted U-shaped course (Grossman and Krueger, 1995). Panayotou (1992, 1995, 1997) focused on environmental pollution and economic growth. In this way, he made great contributions to the Environmental Kuznets Curve (EKC) hypothesis. According to this hypothesis, in the initial stages of economic growth and development, environmental problems are ignored while economic growth is of more interest. In this way, environmental degradation accelerates due to the increasing production activities. However, when the income level reaches a certain point in the later stages, the objectives associated with economic growth have been largely achieved and more importance is attached to environmental problems. At this stage, environmental pollution decreases with the use of clean resources and increased environmental awareness. Aye and Edoja (2017) reported in their study that there was an inverted U-shaped relationship between environmental pollution and DGP. CO₂ emission, which is used as an indicator of environmental degradation, is closely associated with issues such as trade openness, financial development, industrialisation, agricultural production, and energy consumption, as well as GDP in economic terms (Mughal et al., 2024:65). One of the determining factors in the relationship between the economy and the environment is the development level of countries. Developed countries can prevent environmental destruction because they can invest more in clean resources and environmentally friendly technologies. The cost of environmentally friendly resources and technologies cannot be covered in developing countries; instead, policymakers primarily work to increase income levels. In such a condition, environmental pollution is put in the background. For these reasons, the relationship between GDP and CO₂ might be positive in some countries and negative in others.

In addition to increasing GDP and ensuring economic growth, another issue that is important for economies is foreign trade, which consists of export and import activities, and shows the outward-looking face of a country in commercial terms. There are increases in foreign trade volumes, especially with the decisions and practices aimed at liberalising trade among countries. Countries also try to increase their trade volumes by concluding bilateral or multi-trade agreements because foreign trade provides foreign currency inflow to the country through exports, and countries can make the investments they need more easily with this foreign currency. However, many countries can obtain the raw materials, strategically important medicines, weapons, etc. that they need with imports. It increases social welfare by obtaining products from foreign countries. In addition, the foreign exchange resources provided by exports to the country not only provide resources for domestic investments but also the financing of imports. However, such important export and import activities create invisible connections among countries and bring them closer and even connect them politically as well as economically.

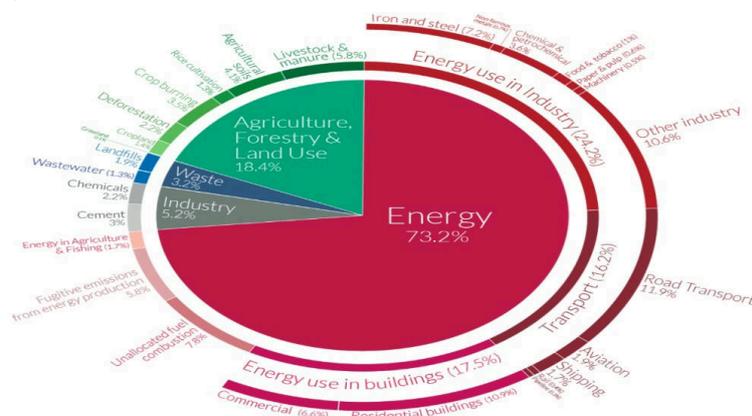
In addition to increased commercial activities, factors such as population growth, industrialisation, and the increase in the urban population rate also have positive impacts on CO₂ (Amin and Murshed, 2017). The rapid increase in population necessitates a faster increase in production. For this reason, industrialisation activities are also accelerating and the urban population rate is increasing as the population migrates from rural areas to cities close to industrial areas. There are significant increases in the production volume in various branches of industry with increasing production resources. These production increases also increase

the export supply. Right at this point, one must examine the relations of these economic activities with the environment. Industrialisation, increased urban population, and increased production volume by using more natural resources are among the most basic factors that negatively affect the environment. Foreign trade activities, which depend on producing, selling, and purchasing to/from foreign countries, are also becoming closely associated with the environment. Not providing production from clean sources, not using environmentally friendly technologies, and not using areas such as forests and lakes for economic activities have negative impacts on the environment. The fact that production in export sectors is mostly obtained as a result of such polluting activities or the transfer of products that cause environmental pollution to countries with imports can be counted among the negative impacts of foreign trade on the environment. Also, foreign trade requires intensive transportation activities. Transportation activities release harmful gases into the environment through the burning of fossil fuels used in vehicles, negatively affecting the environment and human health. For these reasons, the higher the trade openness of a country, the higher the access of individuals to goods and services, but the higher the environmental destruction might be.

Increasing trade volume, and for this reason, trade openness causes increased production and consumption and expansion in markets, which also causes increased CO₂ levels. Increased trade volumes of countries with their trading partners also have positive effects on their economic activities. As a result, trade-oriented economic growth occurs, but in this process, the increase in trade volume and economic growth also causes an increase in CO₂ (Tian et al., 2022). However, commercial openness loses its negative effect on CO₂ in countries that have adopted advanced production techniques and production structures that take environmental regulations into account (Cole, 2004). As a result, increases or decreases in CO₂ levels might change depending on how and from which sources the increase in GDP and foreign trade volume are achieved. Also, all this information shows that the effects of trade openness on CO₂ are associated with efforts to increase GDP. In addition to activities aimed at economic growth, the stages and magnitude of economic growth also affect the relationship between trade openness and CO₂.

The effects of trade openness on the environment might occur in three ways. The first is the scale effect, which refers to increased production, the second is the technology effect and production techniques, and the third is the composition effect, which refers to the characteristics of the goods produced and traded. In other words, increasing the production and trade volume, using traditional polluting technologies in production, and trading in products that create more pollution have positive effects on CO₂ (Chhabra et al., 2023:50987).

Figure 2
Emissions by Sector



Source: Conserve, 2024

The distribution of environmentally harmful gases is shown in [Figure 2](#) by sector in 2021. When the shares of electricity production in industry, transportation, and buildings are added up, the energy sector makes up the most important sector causing greenhouse gas and CO₂ emissions. However, the industrial sector accounts for the highest share among all sectors, followed by the agriculture and forestry sectors, which makes natural resources an important factor affecting CO₂ emissions. For this reason, natural resource rents constitute an important part of this study. Natural resource revenues (rent) are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents. The ratio of this variable to the gross domestic product was used in the analysis. Considering that natural resource rents are associated with economic growth and for this reason CO₂ emissions, they were included in the scope of the study.

Natural resource rents are among the factors affecting CO₂ emissions (Chien et al., 2023). Habitats are damaged and pollution occurs because of the extraction and use of natural resources and the reduction of forests. All of these have negative effects on the environment (Brautigam and Lintner, 2013). This is considered a blessing because the fact that countries have natural resources indicates that they have an important input for production (Naseer et al., 2020; Dorfleitner and Grebler, 2022). However, the search and extraction processes of natural resources lead to CO₂ emissions because they involve energy consumption. These extracted natural resources constitute the basic input for production, and CO₂ emissions occur during production (Hussain et al., 2023). Although natural resources encourage economic growth, they create various negative effects because of environmental pollution and natural resource dependence and reduce economic activities (Shahbaz et al., 2019). In the literature, some studies state that, contrary to these negativities, natural resource rents can indirectly promote human capital and technological development and thus reduce CO₂ emissions (Rahim et al., 2021).

This study aims to investigate the effects of natural resource rents and trade openness on the environment in 14 countries with the highest carbon emissions. The purpose of considering the countries with the highest carbon emissions is to better determine the effects of the variables. Moreover, due to the study on a specific panel of countries, second-generation panel data analysis methods that consider the interactions between countries are used. Although the effects of natural resource rents or trade openness on the environment have been frequently included in the literature, studies examining the combined effects of natural resource rents and trade openness on the environment are less common. Therefore, this study expands on the studies in the literature and addresses environmental sustainability in terms of natural resources and foreign trade. It is expected that the preparation of a study specific to the countries with the highest carbon emissions within the scope of these explanatory variables and the use of second-generation panel data analysis methods will also contribute to the literature. In addition, the analysis results are evaluated for each country and a more detailed study is presented by obtaining country-specific coefficients. In this context, the study seeks to answer the questions of whether natural resource rents and trade openness impact carbon emissions and in what direction.

Literature Review

The relationship between energy resources, foreign trade, and environmental pollution is the subject of academic research because of their social and economic effects. Factors causing environmental pollution are investigated according to some variables. Also, these studies are conducted by using different methods for different countries or country groups in different periods. By doing so, the issue of environmental pollution is dealt with more comprehensively. The factors affecting environmental pollution were investigated using energy, foreign trade, and income indicators. To do this, the relationships among the total energy resource rents, trade openness, and GDP variables with CO₂ were investigated. Examples of previous studies on this subject are given below as a literature review.

Ulucak and Khans (2020), Rahiml et al. (2021), and Nathaniel et al. (2021) reported that natural resource rents reduce CO₂ emissions, but Wang et al. (2022) reported that natural resource rents increase CO₂ emissions. In addition, Huang et al. (2019), Kuik and Gerlagh (2003), Ozturk and Acaravci (2013), and Yasmeen et al. (2018) reported that foreign trade had positive effects on CO₂ emissions, but Ling et al. (2015) and Bernard and Mandal (2016) reported that foreign trade had negative effects on CO₂ emissions. Meng et al. (2022) reported that natural resource rents negatively affected economic growth in countries with low income levels and Lv and Xu (2008) reported that trade openness reduced CO₂ emissions in the short term, increasing them in the long term. Sun et al. (2019) reported that the effects of foreign trade on CO₂ varied by country and had positive effects in some countries and negative effects in others. When these literature studies were investigated, it was seen that trade openness, GDP, and natural resource rents were effective on CO₂ emissions, but the magnitude and direction of these effects varied from country to country or the period analysed. For this reason, the effects of these variables on CO₂ were investigated in more detail with some other literature examples below.

Shuayb (2024) investigated the effects of economic growth, natural resource rents, and energy consumption on environmental pollution using data from 1990 to 2021 for 10 natural resource-rich countries. In the study in which the panel data method was used, various results were obtained with AMG and CCEMG estimation methods showing that economic growth, natural resource rents, and energy intensity increase environmental CO₂ emissions (Yu (2024)). The study also investigated the effects of economic factors on CO₂ emissions in China with quarterly data for 2000Q1-2020Q4. In the study conducted using the ARDL, the analysis results showed that GDP and natural resource rents increase CO₂ emissions. Luo et al. (2023) investigated the effects of natural resource rents and GDP on the environment in Asian countries. Long-term predictions were made with the MG test using the data for 1990-2018. Because of the study, different findings were reported depending on the development levels of the countries. It was found that natural resource rents increased CO₂ emissions in low-income countries, increased CO₂ emissions of GDP in middle- and middle-low-income countries, and reduced CO₂ emissions and GDP in high-income countries. Li et al. (2023) investigated the effects of natural resource rents and energy consumption on CO₂ emissions and the carbon footprint. In the study that covered 152 countries from 2002 to 2018, analyses were performed using the moment QR method. As a result of the study, it was reported that natural resource rents and energy consumption both affect economic growth and cause negative effects on the environment. Tabash et al. (2022) used panel data analysis for 24 African countries in the scope of data for 1995-2017 to investigate the relationships among trade openness, natural resource rents, and GDP. Because of the GMM Test, it was found that natural resource rents negatively affected economic growth.

The results from these studies reveal that natural resource rents, increased economic activity and energy consumption generally have positive effects on CO₂ emissions. However, the findings from the studies of Luo et al. (2023) and Li et al. (2023) reveal that this effect is negative in high-income countries. In addition, because of the studies of Shang et al. (2025) and Deka (2024), it was determined that the emission release decreases if the consumed natural resources are renewable. Similarly, Alvi and Mudassar (2025) argue that the use of renewable resources protects the environment and natural resources and reduces the pressure on natural resource rents. However, Olaniyi and Odhiambo (2025) state that as a result of their studies, inefficient bureaucratic processes and corruption disrupt the management of natural resource rents and the transition to renewable energy and the reduction of environmental negativities; therefore, institutions are important in natural resources and environmental policies. As a result of their studies, Ehigiamusoe et al. (2024) emphasise that technological innovation should be encouraged to reduce the negative environmental impacts of economic activities such as natural resource rents and foreign trade.

Rahman et al. (2020) investigated the relationship between economic growth, trade openness, and CO₂ emissions in South Asia. Co-integration and causality tests were used with the data for 1990-2017. Because of the study, it was found that CO₂ emissions had positive effects on economic growth, but trade openness had negative effects on economic growth. In addition, mutual causality relationships were determined among economic growth and CO₂, and trade openness and CO₂. Mahmood (2023), who investigated the effects of trade openness and oil and natural gas rents on carbon efficiency, conducted a study on GCC countries. Analyses were made with the spatial Durbin Model by using the data for 1980-2021. The findings showed that carbon efficiency was spreading among neighbouring countries in GCC countries. It was also found that oil rents reduced carbon efficiency, but natural gas rents and trade openness increased carbon efficiency. Wang et al. (2024) found that opening countries to trade led to more production in polluting industries. Because of the study conducted on 114 countries from 2002 to 2015, it was found that trade openness increased economic growth but limited the increase in CO₂ emissions. Balounejad Nouri (2023) investigated the relationships among economic growth, trade openness, and natural resource rents in Iran using causality analysis. Because of the study that was conducted with the data for 2006-2021, a bidirectional causality relationship was found among natural resource rents, economic growth, and trade openness. In the study conducted by Xiaoman et al., (2021) for MENA countries in 1980-2018, the effects of trade openness, economic growth, and natural resource abundance on environmental quality were investigated. The findings obtained showed that trade openness and economic growth reduced the environmental quality, but the abundance of natural resources increased the environmental quality. Doğan and Türkekul (2016) discussed the relationships among GDP, trade openness, energy consumption, and CO₂ emissions with the data for the 1960-2010 period for the USA. Co-integration and causality tests were used, and the cointegration test results showed that energy consumption had positive effects on CO₂ and trade openness had negative effects. The causality test results showed that there were bidirectional causal relationships among CO₂ and GDP, CO₂ and energy consumption, and GDP and trade openness, but no causal relationship was found between CO₂ and trade openness. Sebri and Ben-Salha (2014) investigated the relationships among trade openness, GDP, and CO₂ in BRIC countries with a dataset for 1971-2010 by using the VARDL Test, and a long-term positive relationship was found between GDP and CO₂ in Brazil and India. It was also found that there was a long-term positive relationship between CO₂ and trade openness in Brazil and a negative relationship in India.

The literature shows that the effects of trade openness on carbon dioxide emissions can be positive or negative, one-sided or two-sided interactions. When the effects of trade openness are examined, especially with the GDP variable, it is determined that the environmental impacts of economic activities decrease in high-income countries. As İçen (2020) and Polat and Çil (2024) stated in their studies, when countries reach a high level of economic development, the negative effects of natural resources, energy consumption, foreign trade and basic economic activities on the environment decrease and even positive effects begin to emerge.

Econometric Methodology

Globalisation, foreign trade, and various agreements among countries affect economic indicators directly and connect or bring countries closer through invisible ties. This panel data analysis can show cross-sectional dependency in studies that were conducted on a group of countries. A shock that occurred in a country that had established close relations with each other and had close economic relations could affect other countries as well. For this reason, in studies in which panel data analysis is used, cross-sectional dependence should be investigated as a pre-test and other tests should be decided in line with the findings obtained as a result of this test.

To thoroughly explore the connection between CO₂, trade, GDP and TNRR, it is imperative to examine the cross-sectional dependency and homogeneity status of the observations. When performing panel data

analysis on country groups, it is necessary to consider the effects of close relations/integrations between countries. For this purpose, the Peseran (2004) CD test was applied to investigate the cross-section dependence and the Pesaran and Yamagata (2008) Delta test was applied to investigate the homogeneity.

Similar to the time series analysis, in the panel data analysis, one must examine the stationarity of the variables. One commonly used method for determining the stationarity of variables is the application of unit root tests. However, before performing the unit root analysis, one must examine the cross-sectional dependence and homogeneity. In this study, the Pesaran (204) CD test was used to investigate the cross-sectional dependence. The null hypothesis of this test shows that there was no cross-sectional dependence. The statistics for the Pesaran (2004) CD test are included in Equation 1.

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \rho_{ij} \tag{1}$$

$$\rho_{ij} = \rho_{ji} = \left(\sum_{t=1}^T e_{it}e_{jt} \right) / \left(\left(\sum_{t=1}^T e_{it}^2 \right)^{1/2} \left(\sum_{t=1}^T e_{jt}^2 \right)^{1/2} \right)$$

where ρ_{ij} indicates the correlation among the errors.

In cases in which it is determined that the series contains cross-sectional dependence, second-generation unit root analysis is used. For the continuation of the analysis, if the panel contains cross-sectional dependence, the second type of panel cointegration and causality tests must also be used. However, to decide on the tests to be used, the homogeneity of the series must also be determined. Homogeneity tests of the slope coefficients were investigated with the Delta Test developed by Pesaran and Yamagata (2008) and calculated as follows. The statistics for the Delta Test are included in Equation 2. The null hypothesis for the delta test is expressed as “slope coefficients are homogeneous.”

$$\Delta = \sqrt{N} \frac{N^{-1}S - K}{\sqrt{2k}} \tag{2}$$

The corrected delta test statistic is given in Equation 3.

$$\Delta_{adj} = \sqrt{N} \frac{N^{-1}S - E(Z_{it})}{\sqrt{Var(Z_{it})}} \tag{3}$$

The unit root tests are decided by examining the cross-sectional dependencies and homogeneity of the series. In this study, as the series contains cross-sectional dependency and the slope coefficients are heterogeneous, it was decided to apply second-generation unit root tests that take these situations into account. The horizontal section extended Im, Peseran, and Shin (CIPS) panel unit root test with these features was used in the study. In the Pesaran (2007) panel unit root test, the lagged cross-sectional averages of the Extended Dickey-Fuller (ADF) regression are considered. For this reason, the simple CADF regression based on the lagged cross-sectional averages is expressed as in Equation 4.

$$\Delta Y_{it} = a_i + p_{it-1}^* + d_0 Y_{t-1}^- + d_1 \Delta Y_t^- + \varepsilon_{it} \tag{4}$$

After estimating the CADF regression in Equation 4, the averages of the t statistics of the lagged variables in the equation are calculated with the formula in Equation 5 to obtain the CIPS statistic.

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i \tag{5}$$

The stationarity levels of the series are determined by the unit root test, which helps determine which methods will be used in the next part of the analysis. The co-integration analysis can be performed with a series stationary at the same level and with the least difference, but co-integration tests cannot be used

with series that are stationary at the level. To do this, first, the stationarity of the series is investigated, and then analyses such as cointegration, regression analysis, and ARDL are used. In this study, co-integration analysis was used to determine that the series was I (1). The Pedroni panel cointegration test, developed by Pedroni (1999, 2004) and which gives results that are resistant to cross-sectional dependence, was used in the cointegration analysis showing that there is a long-term relationship among the series.

Pedroni (1999, 2004) developed 7 test statistics using the error terms obtained from the regression model. Four of these (v, rho, t, and adf) consist of intra-group statistics, and 3 (rho, t, adf) consist of inter-group statistics. Intra-group statistics are used for homogeneous panels, and among-group statistics are used for heterogeneous panels. The main hypothesis of the test shows that there is no co-integration for all units of the panel. If a long-term relationship is detected among the series considered, panel co-integration estimators are used to determine the direction and degree of this relationship. The Mean Group Dynamic Least Squares (DOLSMG) Estimator, introduced to the literature by Pedroni (2001), was used in the study. In the DOLSMG estimator, the model in Equation 6 is used.

$$Y_{i,t} = \mu_i + \beta_i X_{i,t} + u_{it} \tag{6}$$

Equation 6. Dynamic Least Squares (DOLS) estimation is made by adding the leading values and lags for each unit. For this reason, T is desired to be medium or large. The results are then combined for the entire panel with the Pesaran and Smith MG Approach, as given in Equation 7.

$$\hat{\beta}(\text{DOLSMG}) = N^{-1} \left(\sum_{i=1}^N \left(\sum_{t=1}^T (Z_{i,t} Z'_{i,t})^{-1} \right) \right) \left(\sum_{t=1}^T (Z_{i,t} Y_{i,t}) \right) \tag{7}$$

The DOLSMG Estimator is obtained by taking the average of the DOLS Estimators obtained for each unit *i*, as stated in Equation 8. The *t* statistics are obtained in Equations 9 and 10 (Yerdelen Tatoğlu, 2017).

$$\hat{\beta}(\text{DOLSMG}) = N^{-1} \sum_{i=1}^N \hat{\beta}_{\text{DOLS},i} \tag{8}$$

$$t_{\hat{\beta}_{\text{DOLSMG}}} = N^{-1} \sum_{i=1}^N \hat{\beta}_{\text{DOLS},i} \tag{9}$$

$$t_{\hat{\beta}_{\text{DOLS},i}} = \left(\hat{\beta}_{\text{DOLS},i} - \beta \right) \left(\sigma_i^{-2} \sum_{t=1}^T (X_{i,t} - X_i)^2 \right)^{1/2} \tag{10}$$

Dumitrescu-Hurlin (2012) extended the Granger causality test for heterogeneous panels. In this panel causality test, when *T* represents two stationary processes observed for *X*, *Y*, and *N* units during *T* periods, the linear heterogeneous model in equation 11 is considered for each unit (*i*) at time *t*.

$$Y_{it} = a_1 + \theta_i t + \beta_i X_{it} \varepsilon_{it} \tag{11}$$

In this test, where the Null Hypothesis states that there is no X-Y causality for the entire panel, the model in which stationary Y-X values are defined is as given in equation 12 (Dumitrescu and Hurlin, 2012:1457).

$$Y_{i,t} = a_i + \sum_{k=1}^k Y_i^{(k)} Y_{i,t-k} + \sum_{k=1}^k \beta_i^{(k)} X_{i,t-k} + e_{i,t} \tag{12}$$

The $Y_{i,t}$ and $X_{i,t}$ in Equation 12 represent the dependent and independent stationary variables. The index “*i*” means that the coefficients are allowed to differ among the units. Also, the “*k*” delay degree is the same for all units (Lopez and Weber, 2017: 3).

$$W_{N,T}^{Hnc} = \frac{1}{N} \sum_{i=1}^N W_{i,T} \tag{13}$$

$$Z_{N,T}^{Hnc} = \sqrt{\frac{N}{2K}} (W_{N,T}^{Hnc} - K) \tag{14}$$

$$Z_{N,T}^{Hnc} = \frac{\sqrt{N} (W_{N,T}^{Hnc} - N^{-1} \sum_{i=1}^N E(W_{i,T}))}{\sqrt{N^{-1} \sum_{i=1}^N \text{Var}(W_{i,t})}}, \tag{15}$$

The null hypothesis is tested using the statistics in Equations 13, 14, and 15 in the Dumitrescu-Hurlin Causality Test. According to the test, if the null hypothesis stating that there is no causality relationship among the variables is rejected, it is shown that there is a causality relationship in at least one unit.

This test is preferred because of its advantages such as being able to give effective results in unbalanced panel datasets, being able to be used in N>T and T>N cases and also considering cross-sectional dependency (Dumitrescu and Hurlin, 2012:1457).

Data and Descriptive Statistics

The data utilised in this research spans the time frame from 1990 to 2020, encompassing 31 years of annual data and 14 countries (Australia, Canada, United States, Luxembourg, Korea Rep., Czechia, Japan, Netherlands, Belgium, Germany, Ireland, Norway, Austria, Finland). The first 14 countries with the highest carbon emissions in 2020, for which GDP, TNRR and TRADE data were available, were included in the analysis. The list of countries with the highest carbon emissions in 2020 is given in Table A 1 in the Appendix section. The data were sourced from the World Bank’s World Development Indicator (WDI) Database. The dependent variable is carbon dioxide emission (metric ton) and independent variables examined include trade, GDP and total resource rent. Table 1 provides the variable description and data sources.

Table 1
Variable Description and Data Sources

Variable name	Symbol	Description	Source
CO2 emissions	CO2	CO2 emissions (metric tons (mt) per capita)	World Bank (2024) (World Development Indicators)
Trade	TRADE	Trade (% of GDP)	
Economic growth	GDP	GDP (constant 2015 US\$)	
Total natural resource rents	TNRR	Total natural resource rents (% of GDP)	

The econometric model created to investigate the relationships among CO₂ emissions, economic growth, total resource rents, and trade openness for the 14 countries that had the highest CO₂ emissions in 2020 is included in Equation 16.

$$\text{LNCO2}_{it} = \beta_0 + \beta_1 \text{LNGDP}_{it} + \beta_2 \text{LNTNRR}_{it} + \beta_3 \text{LNTRADE}_{it} + e_{it} \tag{16}$$

Here, *i* refers to the countries, GDP, TNRR, and TRADE are the independent variables, CO₂ is the dependent variable, LN is the natural logarithm, β₁, β₂, and β₃ are the parameter coefficients, and *e* is the error term in Equation 16. The explanations of the dependent and independent variables are given in Table 1.

Given the diverse range of variables, all were transformed into a logarithmic form for analysis. Table 2 provides the descriptive statistics and correlations for the variables.

Table 2
Descriptive statistics and correlation matrix of the variables

Descriptive Statistics	CO2	TRADE	GDP	TNRR
Observations	434	434	434	434
Mean	11.97	96.27	1.98e+12	1.23
Max	30.37	382.34	1.99e+13	12.61



Descriptive Statistics	CO2	TRADE	GDP	TNRR
Min	5.77	15.72	2.52e+10	0.006
SD	4.42	68.22	3.86e+12	2.28
Correlation Matrix	LNCO2	LNTRADE	LNGDP	LNTNRR
LNCO2	1.0000			
LNTRADE	-0.06	1.0000		
LNGDP	0.05	-0.76	1.0000	
LNTNRR	0.14	-0.28	0.12	1.0000

The summary of the descriptive statistics in Table 2 reveals that the average CO2 emission in the country panel is 11.97 metric tons, trade openness is 96% on average and natural resource rents are 1.23% of GDP on average. It is also seen that the average GDP in the country panel is \$1.98 trillion. It was also determined that the highest CO2 emissions occurred in Luxembourg in 1991 and the highest TRADE value occurred in Luxembourg in 2019. The highest GDP value was reached in the United States in 2019, and the highest TNRR value was reached in Norway in 2008.

Empirical Results and Findings

Before the estimation results of the relationships among the series, the results of the cross-section dependence and homogeneity tests are included. These tests are important as they allow the determination of other tests to be used in the analyses. The results of the cross-section dependence test are given in Table 3.

Table 3

Results of the Cross-Sectional Dependence Test (Pesaran (2004) CD test)

Variable	CD-test	P-value		
LNCO2	23.62*	0.000	LNTRADE	35.38*
0.000	LNGDP	51.98*	0.000	LNTNRR
18.89*	0.000			

* indicates significance at the 1% level. The null hypothesis has no cross-sectional dependence.

When the data in Table 3 are evaluated, it is seen that all series contain cross-section dependence. This shows that other countries will also be affected by a shock that might occur in a country in the panel.

Table 4

Slope homogeneity test results

	Δ	Δ_{adj}
t-ist	17.950*	19.600*
P-value	0.000	0.000

* indicates significance at the 1% level. The null hypothesis is slope homogeneity (no heterogeneity)

Table 4 gives the results of the Delta Test used to test the homogeneity of the slope coefficients. When the information in the table is evaluated, it is seen that the null hypothesis that the slope coefficients are homogeneous is rejected at the 1% significance level, which shows that the slope coefficients are heterogeneous. In the panel, the countries have different economic growth rates, etc. and their presence leads to the heterogeneity of the slope coefficients.

Table 5*Panel Unit Root Test Results*

Variables	Level		First Difference		Decisions
	CIPS Statistic	Critical Value	CIPS Statistic	Critical Value	
LNCO2	-2.73***	-2.66	-5.314*	-2.96	I(1)
LNTRADE	-2.53	-2.66	-4.38*	-2.96	I(1)
LNGDP	-2.58	-2.66	-4.46*	-2.96	I(1)
LNTNRR	-2.64	-2.66	-5.53*	-2.96	I(1)

* and *** indicate significance at the 1% and 10% level. The null hypothesis is non-stationarity. N,T=(14,31)

The results of the unit root test with constant and trend models are shown in Table 5. According to the empirical findings, not all series are stationary at level values. However, test statistics and relevant p values show that all series become stationary at the first difference at the 1% significance level.

The fact that all variables are stationary at their first difference suggests that there might be a long-term relationship among these variables because the series become stationary after taking their first differences, which is a prerequisite for cointegration analysis. For this reason, the analysis continues with the investigation of co-integration relationships. However, considering the cross-sectional dependence and heterogeneity, Pedroni's (1999, 2004) panel co-integration test was used, which takes these situations into account.

It is possible to make the variables resistant to cross-sectional dependence in the Pedroni Co-integration Test by taking their differences from the averages (performing the demeaning process). It is also possible to work with large time sizes and medium size unit sizes in this test. The main hypothesis of this test, which shows separate results for homogeneous and heterogeneous panels, states that there is no co-integration for all units of the panel (Yerdelen Tatođlu, 2017:195).

Table 6*Pedroni (1999, 2004) Panel Co-integration Test Results*

Test Statistics	Panel	Group
v	-0.43	
Rho	0.03	0.69
T	-1.65	-1.965
adf	-1.77	-2.631

T table values are 1.960 at the 0.05 significance level. The null hypothesis is no co-integration.

The homogeneity of the model is considered when interpreting the Pedroni Cointegration Test results because if the model is homogeneous, the decision is made based on panel statistics, and if it is heterogeneous, the decision is made based on group statistics. For this reason, as it has been determined that the model is heterogeneous, the results of the group statistics are interpreted. When the test results in Table 6 are evaluated, it is seen that the *t* and *adf* statistics results of the group statistics are greater in absolute value than the critical value of the table, 1.96. These results show that the variables are co-integrated.

Once the co-integration relationship among the variables was determined, the mean group dynamic least squares (DOLSMG) estimator was used to estimate the long-term relationship. The data obtained because of the DOLSMG estimator are given in Table 7.

Table 7*Long-term coefficient estimation results*

	LNTRADE	LNGDP	LNTNRR
Countries	Beta (T statistic)	Beta (T statistic)	Beta (T statistic)
Australia	0.50 (1.79)	0.90* (2.63)	0.08 (1.23)
Austria	0.87* (6.85)	-0.33* (-7.27)	-0.09 (-1.51)
Belgium	-1.77* (-5.75)	2.89* (13.94)	0.001 (0.08)
Canada	0.21* (3.58)	-3.13* (-5.52)	-0.11* (-4.20)
Czechia	-0.94* (-9.78)	1.19* (7.7)	-0.14* (-5.37)
Germany	0.26* (0.99)	0.48 (1.54)	-0.21* (-7.26)
Finland	-0.40 (-0.36)	35431 (1.65)	-0.02 (-0.36)
Ireland	0.06 (0.28)	0.05 (0.60)	0.06* (2.78)
Japan	0.32* (3.7)	0.036* (4.29)	-0.11* (-5.47)
Korea	0.02 (0.18)	1.12* (8.91)	0.02 (0.52)
Luxembourg	-3.19 (0.18)	3.16* (6.32)	-0.09* (-3.04)
Netherlands	0.56* (7.68)	0.34* (4.34)	0.03 (1.08)
Norway	-0.39* (-6.50)	1.19* (5.50)	-0.15* (-8.84)
United States	0.97* (4.12)	-2.65 (-1.20)	0.23* (3.09)
Panel	-0.20 (-0.05)	0.54* (11.62)	-0.03* (-7.29)

* T table value is 1.960 at the statistical significance level of 0.05. The lag length was determined to be 2 by using the AIC information criteria.

Estimations were made in the co-integration model, where the parameters are heterogeneous according to the units, with the DOLS estimator for the units and the DOLSMG estimator for the entire panel. When the results were evaluated, it was found that the test statistics of the LNGDP and LNTNRR variables for the panel were greater than the t table value of 1.96 in absolute value, which shows that both variables have a significant effect on the LNCO2 variable in the long term. Looking at the directions of these effects, it was

determined that a 1% increase in the LNGDP variable increased LNCO2 by 0.54%, while a 1% increase in the LNTNRR variable decreased LNCO2 by 0.03%.

Also, based on the results obtained for the countries, it was determined that the LNTRADE variable was effective on LNCO2 in Austria, Belgium, Canada, Czech Rep., Germany, Japan, Netherlands, Norway, and the USA. LNGDP was found to be effective on the LNCO2 variable in Australia, Austria, Belgium, Canada, Czech Rep., Japan, Korea, Luxembourg, Netherlands, and Norway, and LNTNRR was found to be effective on LNCO2 in Canada, Czech Rep., Germany, Ireland, Japan, Luxembourg, Norway, and the USA.

Causality relationships were also investigated after the co-integration analysis for the country panel considered in the study. To do this, Dumitrescu & Hurlin's (2012) Panel Granger non-causality test with a bootstrap procedure was used in the study. The findings from the causality test are given in Table 8.

Table 8

Results of Dumitrescu and Hurlin's (2012) Panel Non-Causality Test

Hypothesis	W-bar	Z-bar	Z-bar tilde	p-value
LNTRADE does not cause LNCO2	3.10	5.57	4.67	0.11
LNCO2 does not cause LNTRADE	2.36	3.60	2.95	0.21
LNGDP does not cause LNCO2*	5.14	10.97	9.37*	0.02
LNCO2 does not cause LNGDP	2.03	2.73	2.19	0.19
LNTNRR does not cause LNCO2*	3.87	7.61	6.45*	0.003
LNCO2 does not cause LNTNRR*	3.45	6.49	5.47*	0.01
LNGDP does not cause LNTRADE	3.23	5.90	4.96	0.22
LNTRADE does not cause LNGP*	4.36	8.89	7.56*	0.02
LNTNRR does not cause LNTRADE	1.20	0.54	0.29	0.72
LNTRADE does not cause LNTNRR	1.89	2.35	1.86	0.34
LNGDP does not cause LNTNRR	2.68	4.46	3.70	0.17
LNTNRR does not cause LNGDP	1.85	2.25	1.78	0.12

* Indicate Significance at the 1% Level. Optimal Number of Lags (Aic):1, Bootstrap Replications (1000)

The causality results given in Table 8 are compatible with the results obtained in the co-integration test for the country panel. Because of the test, causal relationships were determined from LNGDP to LNCO2 and from LNTNRR to LNCO2, which are similar to the results obtained from the long-term coefficient estimation. Because of the causality test, causal relationships were also detected from LNCO2 to LNTNRR and from LNTRADE to LNGDP.

Conclusion and Policy Recommendations

This study investigated the relationships among CO₂ emissions, total natural resource rents (TNRR), trade openness (TRADE), and economic growth (GDP). The data from the 14 countries with the highest CO₂ emissions for 1990-2020 were used in the study. In country selection, countries with the highest CO₂ emissions in 2020, where TNRR, TRADE, and GDP data could be obtained, were included in (Australia, Canada, the USA, Luxembourg, the Korean Republic, Czech Republic, Japan, Netherlands, Belgium, Poland, Germany, Ireland, Norway, Austria, and Finland).

First, cross-sectional dependence and heterogeneity tests were used in the analysis part of the study. These tests constitute preliminary tests. The types of other tests to be used were decided in line with the findings obtained from these tests. Because of the tests, because of the presence of cross-sectional dependence among the series, second-generation unit root, cointegration, and long-term coefficient estimation

tests were used. Also, it was found that the slope coefficients were heterogeneous. Because of the CIPS unit root test, it was found that all series were stationary at the first difference. Then, the analysis continued with the co-integration test. Because of the Pedroni panel co-integration test, it was determined that the series were in a long-term relationship. The PDOLSMG estimator was used to estimate the long-term coefficients. This test is important as it considers the cross-sectional dependence and heterogeneity. Because of the test, the results for the panel show that the TNRR and GDP variables had effects on CO₂ emissions in the long term. Finally, the Dumitrescu and Hurlin Panel Causality Test was used to examine the causality relationships among the variables. The results obtained showed bidirectional causality relationships among LNCO₂ and LNTNRR, unidirectional causality relationships from LNGDP to LNCO₂ and LNTRADE to LNGDP.

The findings from the PDOLSMG estimator are as follows:

- It was found that LNTNRR had negative effects on LNCO₂, but LNGDP had positive effects on LNCO₂.
- LNTRADE had positive effects on LNCO₂ in Austria, Canada, Germany, Japan, Netherlands, and the USA, but negative effects in Belgium and Czech Republic.
- LNGDP had positive effects on LNCO₂ in Australia, Belgium, the Czech Republic, Japan, Korea, Luxembourg, the Netherlands, and Norway, but it had negative effects in Austria and Canada.
- LNTNRR had positive effects on LNCO₂ in Germany, Ireland, and the USA, but it had negative effects in Canada, the Czech Republic, Luxembourg, and Norway.

The positive effects of LNTRADE on CO₂ are similar to the studies of Mahmood et al. (2019) and Matascu (2018). This effect can be attributed to three reasons. First, the high export volumes of countries indicate that the production volume in the country is high. However, this also shows that production is done from unclean sources and with traditional production tools that create pollution. Second, it shows that most imported products are products causing environmental pollution. Third, it is associated with the fact that foreign trade activities intensely include transportation activities. The vehicles used in these transportation activities use fuels based on fossil resources. Therefore, it causes environmental pollution. The negative effects of LNTRADE on CO₂ can be explained by the fact that production is based on renewable resources in export sectors, innovative technologies are used in production, and the products that are produced and sold and the products imported from foreign countries are environmentally friendly and non-polluting. In addition, the preference of countries for products that do not cause CO₂ emissions in foreign trade might push states to provide more incentives for the production of these products. Such activities also have an impact on CO₂ emissions.

The positive effect of LNGDP on CO₂ is consistent with the studies of Ghoshray and Lorusso (2025) and Fakrullah et al. (2025). This positive effect is related to the concentration of production in the polluting industries. Also, factors such as the fact that the energy sources that make up input for production consist of non-renewable resources, production techniques are not environmentally friendly, and producers and employees are not conscious enough about environmental pollution can also explain these positive effects. Because of their studies, Polat and Çil (2024) concluded that economic development reduces the negative impacts on the environment. The fact that LNGDP has negative effects on CO₂ is associated with the fact that countries invest in development and sustainability issues with their increasing income as their income level increases. Countries that increase their income levels and provide economic growth can focus on the production of products that create less pollution. In addition, these countries are turning to renewable resources and innovative technologies instead of traditional energy sources and production techniques that create pollution. However, increased GDP in a country shows that people's incomes also increase. Individuals with rising income levels have access to higher education opportunities and become more conscious about the environment. In addition, individuals with rising income levels can purchase relatively expensive

products with more modern and innovative technologies that consume less energy (e.g., electric cars, etc.), and CO₂ emissions decrease.

The positive effects of LNTNRR on CO₂ emissions provide similar results to the studies of Chen et al. (2023), Agboola et al. (2021), and Cai et al. (2023). This positive effect shows that non-renewable resources that cause environmental damage predominate among the natural resources in these countries. It can also be stated that energy consumption is high during the extraction of natural resources and CO₂ emissions increase when these resources are used in production. However, the excessive use of natural resources such as forests and lakes also has positive effects on CO₂ emissions (e.g., reducing the oxygen content and damaging the habitat). The fact that LNTNRR has negative impacts on CO₂ shows that renewable resources are at the forefront in these countries.

These results show that sustainability occurs when the natural resource wealth consists of renewable resources. However, the results also show that if the natural resource wealth consists of non-renewable resources, CO₂ emissions increase despite supporting economic growth and foreign trade. Ensuring economic growth and foreign trade from clean, renewable resources and using technologies that support clean production also reduce harm to the environment. As a result, it can be argued that the most important factors that increase CO₂ emissions are human and production activities because the use of natural resources, foreign trade, and ensuring economic growth in the country depend on the realisation of production activities. Necessary measures must be taken to reduce CO₂ emissions and minimise the environmental damage of production activities. Policymakers should determine priority policy areas in order of importance by determining each factor that causes CO₂ emissions according to the degree of severity. Raising the levels of awareness of people about the environment by increasing education levels can be one of these policies. The state should also provide various incentives to non-polluting sectors and support the production of products that require less resource use. Also, it is important to provide R&D support for production methods and technologies that ensure efficient use of resources minimise the environmental damage of production, and direct producers to renewable resources and non-polluting industries.

Other studies to be conducted on this subject may investigate how CO₂ emissions are affected by economic activities in general, as well as each energy source and the production of each product. However, foreign trade activities affecting CO₂ can be detailed and the effects of separate export and import activities and the effects of bilateral trade among countries can be determined. Investigating the factors affecting CO₂ emissions, as well as the areas affected by CO₂ emissions and potential risks, will contribute to the literature by making the issue more detailed.



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Appendix | Ek

Table A 1

Results of Dumitrescu and Hurlin's (2012) Panel Non-Causality Test

Place	Countries	CO2 (mt)	Place	Countries	CO2 (mt)	Place	Countries	CO2 (mt)
1.	Qatar	31,73	13.	Kazakhstan	11,3	28.	Malaysia	7,38
2.	Bahrain	21,98	14.	Russian Federation	11,23	29.	Poland	7,37
3.	Brunei Darussalam	21,71	15.	Korea, Rep.	10,99	30.	Germany	7,26
4.	Kuwait	21,17	16.	Turkmenistan	10,18	31.	Iran, Islamic Rep.	7,06
5.	United Arab Emirates	20,25	17.	Trinidad and Tobago	10,16	32.	Ireland	6,77
6.	Oman	15,64	18.	Palau	8,8	33.	Norway	6,73
7.	Australia	14,78	22.	Czechia	8,3	34.	Serbia	6,71
8.	Saudi Arabia	14,27	23.	Japan	8,03	35.	South Africa	6,69
9.	Canada	13,6	24.	China	7,76	36.	Libya	6,68
10.	North America	13,09	25.	Singapore	7,69	37.	Austria	6,63
11.	United States	13,03	26.	Netherlands	7,47	38.	Finland	6,57
12.	Luxembourg	12,46	27.	Belgium	7,4	39.	Mongolia	6,43

Source: World Bank