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An Empirical Analysis of the Impact of Environmental Taxes, Renewable Energy Consumption, and Economic Growth on Environmental Quality: Evidence from Twelve Selected Countries

Çevre Vergileri, Yenilenebilir Enerji Tüketimi ve Ekonomik Büyümenin Çevre Kalitesi Üzerindeki Etkisinin Ampirik Bir Analizi: Seçilmiş Oniki Ülkeden Kanıtlar

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ABSTRACT

Environmental pollution (EP) and global warming (GW), which emerged with industrialization, have become an increasing global problem in recent years. Greenhouse gases (GHGs) resulting from EP forced countries to introduce carbon tax (CT). This study aims to examine the effect of environmental taxes (ETs), renewable energy consumption (REC), and economic growth (EG) on environmental quality (EQ) in 12 countries with the highest carbon emissions (CEs) over the period 1998-2019. The long-term AMG estimation results showed that ETs and REC reduced EP while EG deteriorates EQ in the countries included in the analysis. Nonetheless, Dumitrescu and Hurlin's (D-H) causality test results indicated that a bilateral causality existed between REC and EG and CEs, whereas a unilateral causality existed from ETs to CEs. Therefore, it is important to implement more effective policies to increase ETs and REC in terms of a sustainable environment in the relevant countries.

Anahtar Kelimeler:
Çevre Vergileri,
Yenilenebilir Enerji Tüketimi,
Çevre Kirliliği,
AMG Tahmincisi
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ÖZET

Sanayileşme ile birlikte ortaya çıkan çevre kirliliği ve küresel ısınma son yıllarda giderek artan küresel bir sorun haline gelmiştir. Çevre kirliliği sonucu ortaya çıkan sera gazları, ülkeleri piyasa temelli bir mali araç olan karbon vergisini uygulamaya geçirmeye zorlamıştır. Bu çalışmanın amacı, 1998-2019 döneminde en fazla karbon emisyonuna neden olan 12 ülkede çevre vergileri, yenilenebilir enerji tüketimi ve ekonomik büyümenin çevre kalitesi üzerindeki etkisinin araştırılmasıdır. Uzun dönem AMG tahmin sonuçları analize dahil edilen ülkelerde çevre vergilerinin ve yenilebilir enerji tüketiminin çevre kirliliğini azalttığını, ekonomik büyümenin ise çevre kalitesini bozduğunu göstermiştir. Diğer yandan Dumitrescu ve Hurlin nedensellik test sonuçlarına göre yenilenebilir tüketimi ve ekonomik büyüme ile karbon emisyonu arasında çift yönlü nedensellik ilişkisi olduğu, çevre vergilerinden karbon emisyonuna doğru tek yönlü nedensellik ilişkisi olduğu bulgusuna ulaşılmıştır. Dolayısıyla ilgili ülkelerde sürdürülebilir çevre açısından çevre vergilerinin ve yenilenebilir enerji tüketiminin artırılmasına yönelik daha etkin politika uygulamaları önem arz etmektedir.

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1. INTRODUCTION

In the international literature, ETs are referred to as environmental taxes, pollution taxes, green taxes, ecological taxes, and CTs. Under the name of Green Tax Reform, the tendency towards ETs has increased for specific purposes for both environmental policies and fiscal, economic, and social policies. A new ET aims to reduce environmental destruction, prevent the loss of biodiversity, reduce GHG emissions, internalize externalities by directing production and consumer preferences in an environmentally sensitive manner, and prevent air and water pollution (Tasdemir & Turgay, 2021; Ozbek, 2023).

In recent years, the increase in the amount of GHGs as a result of increasingly unconscious production and consumption activities has caused EP. The emergence of these negative consequences has necessitated a joint decision at the global level. The Rio Convention in 1992 and the Kyoto Protocol in 1997 were signed to solve problems such as increasing EP and GW, which have become common problems in the world. Signed in 1997, the Kyoto Protocol entered into force on February 16, 2005, with the participation of Russia in 2004. The success of the international decisions taken in the Kyoto Protocol and the Rio Convention is related to the majority of the countries that have ratified these conventions. Because GW and similar environmental problems do not occur within the borders of a single country. Environmental degradation (ED), which affects the whole world, has brought along the measures to be taken by countries. One of these measures used by some countries is CT (Organ & Ciftci, 2013).

A CT is a market-based fiscal instrument. Producers are taxed for the amount of CO2 gas they emit. Therefore, firms, which happen to be taxpayers, provide the state budget with additional revenue and assume social responsibility by incurring social costs (Organ & Ciftci, 2013). CT is based on the “polluter pays” principle. According to this principle, the parties that cause EP should also bear the cost of this pollution. Parties that pollute the environment are obliged to pay for the externalities that cause EP. Therefore, the parties will tend to use the lowest-cost resources that can reduce the level of pollution by paying as much tax as they pollute the environment. Thus, by increasing the prices of fossil-based energy resources (FBER) in countries where CTs are applied, both producers and consumers will avoid the consumption of resources with high carbon intensity and prefer to use less carbon-intensive resources such as hydroelectric, solar, geothermal, wave, and wind energy (Costello, 2019).

This study investigates the effectiveness of ETs in reducing CEs for the 12 countries that generate the highest CEs in the 1998-2019 period by using next-generation panel data analysis. The main motivation for this study is the fact that the effect of ET on EQ has not yet been determined in the country group that generates the highest CEs. It is thought that the study can contribute to the literature in three aspects. i) The impact of ET on EQ is evaluated in terms of countries that cause EP the most. ii) The impact of ET on EQ is analyzed with second-generation panel data techniques. iii) Detection of this effect may guide policymakers in the implementation of effective environmental policies in the relevant countries.

The study first reviews the literature on the subject. Then, the model and data constructed in the study are discussed. Lastly, the study model’s theoretical framework and the results of the analysis are revealed, and conclusions and policy implications are presented.

2. LITERATURE REVIEW

There are many studies in the literature that do not focus on ET and investigate the determinants of CEs. When the literature on EQ is examined, it is seen that the Environmental Kuznet Curve (EKC) hypothesis has been tested in some of the studies published in this field (Baek, 2015; Seker & Cetin, 2015; Cetin et al., 2018; Cetin et al., 2020). In some studies, many variables such as fossil-based energy consumption, renewable energy consumption, financial development, income inequality, agricultural added value, direct investment, trade openness, tourism, political stability, corruption control, rule of law, and natural resource revenues are used as determinants of CEs (Lee & Brahmasrene, 2013; Purcel, 2019; Muhammad & Long, 2021; Altay Topcu, 2022; Cetin et al., 2022; Ozturk et al., 2022).

Studies investigating the association between ET and variables used as EQ indicators (CO2 emissions and ecological footprint (EFP)) have reached various results. In most of the studies, it has been found that ETs increase EQ, thus ETs are an effective policy tool in improving EQ (Nordhaus, 2006; Abrell & Rausch, 2017; Lin & Li, 2011; Liang et al., 2007; Hajek et al., 2019; Liu et al., 2017; Alper, 2017; Allan et al., 2014). In some studies in the literature, it has been found that ETs do not affect EQ (Hatunluoğlu & Tekeli, 2007; Bayar & Şaşmaz, 2016). Some of the studies analyzing this relationship in the literature are presented below.

Pizer (2002) evaluated price and quantity control policies for ETs in mitigating the adverse effects of global climate change and stated that price control policies favoring ETs are more effective than quantity control policies in global climate change policy. The findings showed that the expected welfare gain from the optimal price policy exceeded the expected gain from the optimal quantity policy with fivefold. Morley (2012) investigated the impact of ET on pollution levels and energy consumption (EC) in EU countries and the Norwegian economy for the period 1995-2006. The study concludes that an increase in ETs leads to a decrease in CO2 emissions, but there is no relationship between ETs and EC. Miller & Vela (2013) analyzed the association between ETs, CO2 emissions, REC, and non-REC in 50 developing and developed countries between 1995-2010. The analysis results indicated that an increase in ETs decreased CO2 emissions and fossil-based EC, and encouraged REC.

Bayar & Sasmaz (2016) investigated the relationship between CT and CO2 emissions in Sweden, Denmark, Norway, Finland, and the Netherlands between 1996-2011 conducting panel causality analysis. It is concluded that no causality existed between CT and CO2 emissions. Tekin & Sasmaz (2016) investigated the effect of environmental, energy, and transportation taxes on EP in 25 EU countries between 1995-2012. They found that ETs and transportation taxes had no impact on EP, whereas energy taxes reduced EP. He et al. (2019) examined the association between ETs and EQ in 31 Chinese provinces and 35 OECD countries in the period 2004-2016. They found that ETs reduced CO2 emissions in the short- and long-run in the countries included in the analysis. Aydin (2020) investigated the causality between ETs and EP in OECD countries between 1995-2016 using the Fourier-Granger causality method. The analysis results indicated that there was a unilateral causality from ETs to EFP in Denmark, Sweden, and Germany, and from EFP to ET in Spain and France

Damirova & Yayla (2021) analyzed the impact of ETs on EQ in the UK, Switzerland, Hungary, Slovakia, Italy, Portugal, Malta, Denmark, the Netherlands, and Turkey for the period 1995-2016. Their panel-wide findings showed that ETs did not affect EQ. They also found that ETs increased EP in Denmark and Portugal, whereas they improved EQ in Italy, Switzerland, Hungary, and Turkey. Meireles et al. (2021) examined the relationship between transportation taxes and CO2 emissions in EU countries for the period 2008-2018 and found that a rise in transportation taxes mitigated CO2 emissions. Sümerli Sarıgül & Altay Topcu (2021), in their study for the period 1994-2015 in Turkey, found that ET and REC reduced CO2 emissions in the long-run, whereas EG had a deteriorating impact on EQ.

Wolde-Rufael et al. (2021) found that ET and REC were effective in improving EQ in 18 Latin American and Caribbean (LAC) countries for the period 1994-2018. Wolde-Rufael & Mulat-Weldemeskel (2022) concluded that ETs and REC improved EQ in 18 Latin American and Caribbean countries between 1994-2018. Similarly, Rafique et al. (2022) found that ETs reduced the EFP in 29 OECD countries in the period 1994-2016. Kesbic & Simsek (2022) determined the causality between ET, REC, GDP, and urbanization rate and EFP by performing the D-H (2012) causality test for 9 EU countries and Turkey for the period 1997-2015. They found that there is bilateral causality between ET and REC and EFP, and unilateral causality from GDP and urbanization to EFP.

Ozkaya (2022) found that EG increased CO2 emissions, but no significant association existed between ET revenues and CO2 emissions for 27 EU countries for the period 2000-2017. Causality analysis results indicated that bilateral causality existed between ETs and CO2 emissions, while unilateral causality existed from CO2 emissions to EG. Ozbek (2023) investigated the relationship between ETs, patents on environmental technologies, EC, EG, and CO2 emissions for the period 1994-2021 in Turkey and found that ETs and patents on environmental technologies reduced EP. On the other hand, EC and EG had a deteriorating effect on EQ. Saqib et al. (2023) investigated the effectiveness of ET on EQ in G-10 countries, using the data for the period 1995-2020. As a result of the analysis, it was emphasized that ET is important for sustainable and low-carbon growth in the G-10 countries. O'Ryan et al. (2023) using the Computable General Equilibrium (CGE) model for the Chilean economy, found that carbon taxes are an important tool to reduce CEs and encourage the energy transition to low-carbon sources.

When the literature is evaluated in general, ET can be used as an effective policy tool in improving EQ. Therefore, it is clear that governments should include carbon taxes more effectively in their environmental policies.

3. MODEL AND DATASET

In the study, the impact of ETs on CEs in 12 countries with the highest CO2 emissions (China, USA, Japan, Germany, Brazil, South Africa, Mexico, Turkey, Australia, Italy, Poland, UK)1 over the period 1998-2019 is analyzed. The study is based on the panel data of 12 countries among the 20 countries with the highest CO2 emissions according to the availability of ETs. For this purpose, the effectiveness of ETs on EQ in the relevant countries will be determined. Upon evaluating the literature, it is seen that the said effect is mostly evaluated in terms of EU and OECD countries.

The most important motivating factor for this study is the fact that the related issue has not been evaluated in the literature in terms of the countries that cause the most EP in the world. Thus, the effectiveness of ETs, which have a crucial place in climate change policies, will be evaluated in terms of the relevant countries.

The logarithmic form of the model is given in Equation 1.

$$\ln CO2_{i,t} = \beta_0 + \beta_1 \ln ET_{i,t} + \beta_2 \ln REC_{i,t} + \beta_3 \ln GDP_{i,t} + \varepsilon_{i,t} \quad (1)$$

In the model established to measure the effectiveness of ETs on EQ, REC, and GDP variables are included as control variables.

Table 1 indicates the descriptions of the variables in the model.

Table 1. Descriptions of Variables Used in the Analysis

Variables 1998-2019	Description	Source
lnCO2	CO2 emissions (metric tons per capita)	WB
lnET	Environmental tax (Total, % of GDP)	OECD
lnREC	Renewable energy consumption (% of total final EC	WB
lnGDP	GDP (constant 2015 US$)	WB

4. ECONOMETRIC METHODOLOGY AND ANALYSIS RESULTS

First, descriptive statistics of the panel data for 12 countries are presented. Then, since the time dimension of the panel data set (T=22) is larger than the unit dimension (N=12) (T>N), the cross-section dependence (CSD) of the model is determined by the LM test developed by Breusch and Pagan (1980). In the next phase, the homogeneity of the model was tested with the Δ tests developed by Blomquist and Westerlund (2013). Since CSD and slope heterogeneity (SH) are detected in the model, Peseran's (2007) CIPS test is performed. Before estimating the long-run model, the cointegration relationships among the variables are tested with Westerlund's (2007) cointegration test, which is suitable for second-generation panel data analysis. Afterwards, the AMG estimator developed by Bond & Eberhardt (2013) and Eberhardt & Bond (2009) is used to estimate the long-run model. Lastly, the causalities among the variables are determined by D-H (2012) causality test.

3.1. Descriptive Statistics of Variables and Correlation Results

Descriptive statistics and correlation results of the panel data of the 12 countries that cause the highest CEs with 264 observations over the period 1998-2019 are presented in Table 2.

Table 2. Descriptive Statistics and Correlation Results of Variables

	lnCO2	lnET	lnREC	lnGDP
Mean	1.935	0.010	2.281	28.182
Median	2.043	-0.010	2.317	28.230
Max.	3.018	2.708	3.890	30.623
Min.	0.530	-1.791	-0.162	26.059
Std. dev.	0.616	0.375	0.754	1.143

[1] World Population Review, https://worldpopulationreview.com/country-rankings/co2-emissions-by-country, Date of Access: 04.05.2023.

Skewness	-0.364	2.191	-0.353	0.220
Kurtosis	2.713	26.161	4.578	2.494
Obs.	264	264	264	264
lnCO2	1.000			
lnET	-0.027	1.000		
lnREC	-0.655	-0.007	1.000	
lnGDP	0.324	-0.010	-0.201	1.000

The variable with the highest mean, median, max., and min. values are lnGDP. The variable with the lowest values is lnET. The variable with the highest std. dev. value is lnREC, while the variable with the lowest value is lnET. In addition, descriptive statistics show that the variable with the highest skewness value is lnET and the variable with the lowest skewness value is lnCO2. Lastly, the variable with the highest kurtosis value is lnET and the variable with the lowest kurtosis value is lnGDP. In line with the theoretical expectation, there is a negative correlation between lnET, lnREC, and lnCO2. However, a positive correlation exists between lnCO2 and lnGDP.

3.2. CSD and Homogeneity Analysis

The LM test statistic used to test for CSD is as shown in Equation 2:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{\,2} \qquad (2)$$

Equation 2 $\hat{\rho}ij2$ shows the correlation coefficient of the residuals. Acceptance of the null hypothesis (H_0) in this test indicates that no CSD exists between the series (Breusch & Pagan, 1980; Tatoglu, 2018; Altay Topcu & Dogan, 2022; Kevser et al., 2022; Shahbaz et al., 2023).

According to the test results presented in the table below, H_0 is rejected at the 1% significance level and the alternative hypothesis (H_1) stating that CSD exists between the series is accepted.

Table 3. CSD Test Results

Test	Statistic	P-value
LM	130	0.000
LM adj*	10.93	0.000
LM CD*	5.906	0.000

The HAC version of the homogeneity test is shown in Equation 3:

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{\sqrt{2k}}\right) \qquad (3)$$

When H_0 is rejected and H_1 is accepted in the homogeneity test, the slope coefficients are found to be heterogeneous. Accordingly, the 2nd generation tests should be preferred (Blomquist & Westerlund, 2013; Altay Topcu, 2022). The test results are According to the Δ test results shown in the table below, H_0 expressing the existence of SH is rejected at the 1% significance level. This result shows that the panel data are heterogeneous.

Table 4. SH Test Results

		P-value
$\tilde{\Delta}$	7.487	0.000
$\tilde{\Delta}$**adj**	8.810	0.000

3.3. Panel Unit Root and Cointegration Analysis

The CIPS panel unit root test is preferred due to the CSD test result. The CIPS test yields strong results when T>N. The CIPS test is calculated by averaging the Pesaran (2007) CADF test. This test is formulated as in Equations 4 and 5 (Pesaran, 2007; Keskin & Şimşek, 2020):

$$CIPS(N,T) = t - bar = \frac{1}{N}\sum_{i=1}^{N} t_i\,(N,T) \qquad (4)$$

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \quad (5)$$

CIPS panel unit root test results are given in Table 5. CIPS panel unit root test results for the constant and constant & trend models reveal that all series become stationary in the first difference.

Table 5. CIPS Unit Root Test Results

Variables	**CIPS test statistic for constant**		**CIPS test statistic for constant & trend**	
	I(0)	**I(1)**	**I(0)**	**I(1)**
lnCO2	-1.129	-5.773***	-2.283	-5.880***
lnET	-1.660	-5.371***	-2.129	-5.757***
lnREC	-0.662	-4.353***	-1.769	-4.698***
lnGDP	-1.747	-4.979***	-1.701	-5.206***

Note: *** and ** indicate significance at %1 and %5 levels, respectively.

The cointegration test developed by Westerlund (2007), which takes into account CSD, is used to determine the existence of a cointegration relationship. This test is formulated as in Equation 6 (Zafar et al., 2019; Altay Topcu, 2022):

$$\Delta Y_{it} = \delta_i d_t + \alpha_i Y_{i,t-1} + \gamma_i X_{i,t-1} + \sum_{j=1}^{pi} \alpha_{ij} \Delta Y_{i,t-1} + \sum_{j=-qi}^{pi} \gamma_{ij} \Delta X_{i,t-1} + \varepsilon_{it} \quad (6)$$

Panel cointegration test results are given in Table 6. According to the Gt and Pt test results, H_1 indicating the existence of cointegration is accepted. Therefore, it is determined that a long-run relationship exists between lnET, lnREC and lnGDP, and CO2.

Table 6. Westerlund (2007) ECM Test Results

Statistic	**Value**	**Z-value**	**P-value**
$\boldsymbol{G_t}$	-2.593	-1.322	0.093*
$\boldsymbol{G_a}$	-8.825	1.055	0.854
$\boldsymbol{P_t}$	-9.171	-2.382	0.009***
$\boldsymbol{P_a}$	-8.682	-0.646	0.259

Note: * and *** denote 10% and 1% significance levels, respectively.

3.4. Long-Term Estimation Results

The AMG estimator is used to estimate the long-run elasticity coefficients. The most important feature of this estimation method is that all cross-sectional coefficients are heterogeneous and robust to CSD. The mathematical representation of the AMG estimator is shown in Equation 7 (Topcu & Ozdemir, 2019; Usman et al., 2021; Tekbas, 2022):

$$\widehat{\beta_{AMG}} = N^{-1}\Sigma_{i=1}^{N}\widehat{\beta_t} \quad (7)$$

In Equation 7, $\widehat{\beta_{AMG}}$ denotes the average of the cross-section estimators.

Table 7 reflects the parameter estimates obtained from the AMG estimator.

Table 7. Panel-Wide AMG Estimation Results

Dependent Variable: lnCO2		
	Coefficient	**P-Value**
Constant	-13.795***	0.000
lnET	-0.133**	0.021
lnREC	-0.213***	0.000
lnGDP	0.591***	0.000
Wald χ2	62.24***	
Prob > χ2	0.000	
RMSE	0.024	
Number of Observations	264	
Number of Countries	12	

Note: ***, and ** denote 1% and 5% significance levels, respectively.

As a result of the estimations, a 1% rise in lnET lowers lnCO2 by 0.133% and a 1% rise in lnREC lowers lnCO2 by 0.213%. In other words, ETs and REC improve EQ. Another result obtained from the study is that a 1% increase in lnGDP increases lnCO2 by 0.591%. Therefore, an increase in EG deteriorates EQ.

In the study, the finding that ET improves EQ is consistent with the finding of O'Ryan et al. (2023) for the Chilean. On the other hand, it does not show parallelism with the finding of Tekin and Sasmaz (2016) that ET does not affect environmental pollution (EP) in EU countries.

Another result obtained from the study is related to the positive effect of REC on CEs in the countries included in the analysis. These findings are consistent with the findings of Kesbic and Simsek (2020), Wolde-Rufael et al. (2021), Wolde-Rufael & Mulat-Weldemeskel (2022), and Altay Topcu (2022). On the other hand, the finding in the study that economic growth causes EP is consistent with the findings in studies of Ertugrul et al. (2016) and Sumerli Sarıgul & Altay Topcu (2021).

Panel-specific AMG estimation results are presented in Table 8.

Table 8. Country-Specific AMG Estimation Results

Countries	lnET	lnREC	lnGDP	Constant
China	0.003 (0.834)	-0.604*** (0.000)	0.329** (0.044)	-6.412 (0.217)
The USA	0.902*** (0.001)	-0.271*** (0.000)	0.851*** (0.001)	-22.245*** (0.004)
Japan	-0.351 (0.259)	-0.243 (0.110)	0.773** (0.011)	-19.698** (0.024)
Germany	0.017 (0.830)	-0.079*** (0.002)	0.587* (0.057)	-14.392* (0.103)
Brazil	-0.050*** (0.000)	-1.094*** (0.000)	0.718*** (0.000)	-15.313*** (0.000)
South Africa	-0.268*** (0.001)	-0.132 (0.187)	0.515*** (0.000)	-11.007*** (0.002)
Mexico	-0.001 (0.685)	-0.278*** (0.000)	0.337*** (0.000)	-7.212*** (0.007)
Turkey	-0.107*** (0.005)	-0.362*** (0.000)	0.339*** (0.000)	-6.765*** (0.001)
Australia	-0.021 (0.317)	-0.229*** (0.000)	-0.058 (0.315)	5.005*** (0.002)
Italy	-0.118 (0.238)	-0.165*** 0.000	1.422*** (0.000)	-37.683*** (0.000)
Poland	-0.247 (0.002)	-0.301*** (0.000)	0.456*** (0.000)	-9.181*** (0.000)
The UK	-0.307** (0.101)	-0.101*** (0.000)	0.135 (0.608)	-1.322 (0.864)

Note: ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively.

According to Table 8, ETs have an improving effect on EQ in Turkey, South Africa, Brazil, the UK, and Poland. In the top-four countries (China, USA, Japan, and Germany), which generate the highest CEs, it is noteworthy that this tax is not implemented effectively. In this framework, it can be interpreted that these countries should reconsider their environmental policies. The effect of REC on EQ is observed in all countries except Japan and South Africa in the panel. On the other hand, the impact of EG on EP is positive in all countries except for Australia and the UK.

3.5. Causality Test Results

The D-H (2012) test is developed for heterogeneous panels and gives consistent results when both T>N and N>T. Acceptance of H_1 implies that causality exists between the variables. The mathematical expression of this test is given below (Dumitrescu & Hurlin, 2012; Kesbiç & Şimşek, 2020; Altay Topcu, 2022):

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \beta_{ik}\, y_{i,t-k} + \sum_{k=1}^{K} \gamma_{i,k}\, X_{i,t-k} + \varepsilon_{it} \quad (8)$$

Causality test results are presented in Table 9.

Table 9. D-H Causality Test Results

Causality	W-bar	Z-bar	P-value
lnET→lnCO2	4.7461	4.7563	0.000***
lnCO2→lnET	2.880	1.5256	0.127
lnREC→lnCO2	4.356	4.081	0.000***
lnCO2→lnREC	5.555	6.157	0.000***
lnGDP→lnCO2	5.1270	5.4161	0.000***
lnCO2→lnGDP	4.4057	4.1668	0.000***

Note: *** indicates a 1% significance level.

The directions of the causality are summarized in Figure 1.

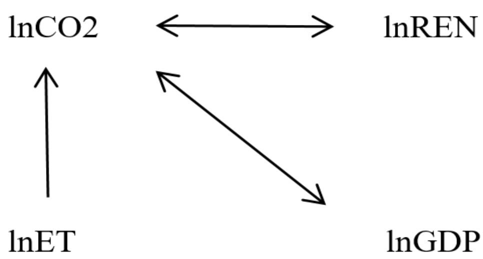

Figure 1. Directions of Causality

Note: → and ↔ indicate the existence of unilateral and bilateral causalities, respectively.

As seen in Figure 1, a bilateral causality exists between lnCO2 and lnREC, and lnGDP, whereas a unilateral causality exists from lnET to lnCO2.

5. CONCLUSION AND POLICY IMPLICATIONS

Today, global problems such as increasing EP and climate change have made environmental regulations important. The importance of EQ has increased to ensure sustainable development in the world. One of the public regulations related to improving EQ is ETs. ETs have been applied in many countries since the 1990s. This tax aims to increase social welfare by reducing negative externalities in production and consumption activities.

In this study, the relationship between ETs, REC, and EG and CO2 emissions in a sample of 12 countries that caused the highest CEs in the 1998-2019 period is investigated with second-generation panel data techniques. AMG estimation concluded that ETs and REC reduce CO2 emissions, but EG increases CO2 emissions. D-H causality test results indicated a bilateral causality between REC and EG and CO2 emissions, while there was a unilateral causality from ETs to CO2 emissions.

The finding that ETs improve EQ is consistent with the studies of Morley (2012), Miller & Vela (2013), He et al. (2019), and Özbek (2023). However, this finding is not consistent with the finding of Damirova &Yayla (2021) and Ozkaya (2022) that ETs do not affect EQ. On the other hand, the finding that REC reduces EP is consistent with the studies of Meireles et al. (2021); Wolde-Rufael, Sumerli Sarıgul & Altay Topcu (2021); Mulat-Weldemeskel (2022). In addition, the finding that EG has a deteriorating effect on EQ is in line with the studies of Ozkaya (2022) and Ozbek (2023).

The pressure of EG on the environment can be perceived as the rise in production and consumption activities of individuals with increasing welfare levels and the fact that these activities are largely carried out with FBER. According to the panel-specific results, the fact that ETs have no or insufficient effect on CO2 emissions in most of the countries that cause the most EP indicates that CT implementation is not used as an efficient policy instrument to enhance EQ in the relevant countries. Therefore, the effectiveness of ETs on EQ depends on increasing the CT burden based on the polluter pays principle and encouraging REC.

The results of the analysis obtained in this study have some policy recommendations. Renewable energy costs can be reduced by increasing R&D investments in 12 selected countries that cause the most carbon emissions. Thus, policies to promote clean energy technologies should be developed and implemented in these countries. In addition, effective environmental tax policies should be established and implemented to improve EQ in the countries included in the analysis. In this context, regulations that encourage investment in sustainable and low-carbon areas such as carbon taxes, additional fees, and/or taxes on carbon emissions where upper and lower limits are determined should be implemented.

In subsequent studies, this effect can be investigated by using independent variables such as globalization, financial development, and technological innovation. In addition, the Environmental Kuznets Curve Hypothesis can be tested by evaluating different country groups.

AUTHORS' DECLARATION

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AUTHORS' CONTRIBUTIONS

All sections are written by the author.

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