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Examining the Nexus of Energy Prices, Fossil Use, Efficiency, Technology export, and Environmental Quality: A Novel Analysis of the Top 10 Economies with the Highest Annual Increase in Energy Prices (1990-2021)

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Abstract
This study investigates environmental quality for the top 10 economies with the highest average annual increase in energy prices over the period 1990-2021. For this purpose, the interdependence between energy prices, energy efficiency, fossil fuel consumption, medium-high technology exports, and CO_2 emissions is investigated with annual data in the period 1990-2021. Slope heterogeneity and cross-section dependence were taken into account in the empirical analysis. Durbin-Hausman cointegration test and CCEMG estimator were used as methods. The findings showed that for the top 10 economies, higher energy prices and fossil fuel consumption increased environmental damage. Energy efficiency and more technology exports increase environmental quality. The study findings are new as this specific combination of variables for these top 10 countries has not been studied before.

Keywords
Energy prices, energy efficiency, fossil use, technology export, environmental quality.

Introduction

Sustainability is a concept that aims to manage economic, social, and environmental factors in a balanced way to meet the needs of future generations (Kalender and Vayvay, 2016). Achieving sustainability in national economies is among the most important goals. Ensuring sustainable development, particularly in developing countries, is considered essential. The notion of sustainable development (SD) was initially introduced in the report "Our Common Future," which was compiled by the United Nations World Commission on Environment and Development in 1987 (Meadowcroft, 2000, 370). Termed as the Brundtland Report, Sustainable Development (SD) is characterized by meeting the current needs without jeopardizing the capacity of future generations to fulfill their own requirements (WCED, 1987, 43). Despite being widely used by policymakers and experts worldwide, the concept of SD is still relatively new and lacks a single interpretation. It continues evolving, constantly revising, and expanding (Soubbotina, 2004; Aslan and Özcan, 2008). With the onset of the Industrial Revolution around the 1760s, significant changes occurred in energy production, transformation, storage, transportation, transfer, and utilization. The energy equation initially relied heavily on coal as it was the basis for many sectors when steam engines were introduced. These machines heavily depended on coal usage. Subsequently, humanity entered the era of oil, and petroleum became a fundamental commodity. In the following period, natural gas became part of the energy equation for many countries. These three hydrocarbon trades have served humanity in many ways; however, they have caused harm to the ecosystems of all living species on Earth, including humans (Dinçer, 2020; Dinçer, 2023). Fossil-based fuels have been widely used in the last two centuries due to highly developed and cost-effective production technologies, but the 1973 Oil Crisis created the first atmosphere of insecurity about energy resources. This atmosphere of insecurity led to a significant interest in renewable sources worldwide, and despite the decrease in oil prices in the mid-1980s, petroleum-based energy usage was considered risky. While increasing energy consumption (fossil fuels, non-renewable resources, etc.) is considered a driving force for economic development, it also poses significant environmental challenges for developed, developing, and emerging economies (Bashir et al., 2020). The rising CO_2 emissions seriously threaten environmental sustainability in the global atmosphere, a consequence of globalization (Farooq et al., 2022). Additionally, the increasing prices of petroleum and natural gas and the necessity of ensuring "energy security" have made "energy diversification" an indispensable element of energy policies. These reasons have contributed to including renewable energy sources in the energy portfolio (Çağlar, 2010). Another factor contributing to this situation is increased environmental awareness in the 1990s. This growing consciousness has highlighted the direct adverse effects of conventional energy production and consumption on the environment and natural resources, both locally and globally. As a result, emission-free renewable energy sources have gained support as "clean energies" due to their non-polluting nature and their potential to mitigate atmospheric pollution.

The Copenhagen Accord (UNFCCC, 2010a) holds great importance within the framework of sustainable development goals. In this accord, low-emission development strategies have been highlighted. Developed countries are emphasized to develop low-carbon development strategies (UNFCCC, 2010b). The economic impact of a low-carbon plan encompasses various effects, including fostering economic growth known as the "green economy" and achieving savings from reduced energy import bills (Dowling and Russ, 2012). Particularly, economies heavily reliant on energy imports and experiencing significant increases in energy prices hold special importance. In these countries, the rise in energy prices may lead to challenges such as increased external dependency and a high current account deficit. The issues of energy efficiency and effectiveness gain prominence in response to escalating energy prices. Analyzing the price variable that influences energy efficiency from the demand side, it is evident that the surge in prices, especially for energy derived from fossil fuels, escalates production costs. This situation not only contributes to environmental pollution but also encourages the transition to eco-friendly renewable energy sources. However, achieving this transition may not be equally feasible for every country. This situation is due to differences in countries' income, technology, and geographical location (Naimoğlu and Akal, 2021). Therefore, energy efficiency becomes a critical issue in countries that are energy-dependent or experiencing significant price increases in energy.

In scholarly works, " high-tech " refers to the high-technology sector and knowledge-intensive service industry. The notion of high technology encompasses aspects related to the economy and workforce, as well as advancements in science, technology, and innovation. The capacity of a nation to engage in exports is defined as its international competitiveness (Trabold, 1995). The concept of macroeconomic competition pertains to a nation's engagement in international trade. The progression of macroeconomic competition is influenced by a country's receptiveness to global market dynamics, the efficiency of its labor force, technology diffusion, and the acquisition of novel knowledge (Meral, 2019). Since the 1970s, the ongoing global integration has significantly impacted various areas. Globalization has led to an increase in the volume of international trade. In recent years, the composition and technological levels of traded goods have become increasingly important, surpassing the growth of trade volumes. This shift is due to the high value-added nature of exports in medium and high-tech products, playing a significant role in enriching nations and maintaining their existing levels of development. Developed countries focus on preserving their share of the global economy while developing countries emphasize technology exports to increase their share and achieve sustainable development goals.

This study investigates the determinants of environmental quality for the top 10 economies with the highest annual average growth rate during the sample period of 1990-2021. Among these countries (Brazil, Türkiye, Romania, Argentina, Peru, Egypt, Indonesia, Pakistan, Colombia, Mexico), there are three countries referred to as the "Fragile Five" by James Lord from Morgan Stanley in August 2013 (Wu et al., 2022). These three countries (Brazil, Türkiye, and India) are among the fragile economies due to characteristics such as a high ratio of current account deficit to GDP, low performance in growth rates, increasing need for external financing in subsequent periods, and potential risks in non-economic areas (e.g., internal political conditions) (Çeviş and Ceylan, 2015). These situations are generally applicable to other countries included in the analysis as well. Moreover, many of the analyzed countries are notable for their high energy imports. The significance of environmental quality sensitivity has markedly risen due to global climate change, especially in European countries. In response, these nations are actively pursuing the goal of achieving carbon neutrality by 2050. The use of renewable energy is recognized as an effective approach to improving environmental quality. Nevertheless, the impact of energy prices on environmental quality is still not clear. Thus, the primary objective of this study is to bridge this research gap in the existing literature. Therefore, identifying the factors that influence environmental quality in the ten countries is of utmost importance. The study utilizes CO_2 emissions as the environmental quality variable and draws on data for explanatory variables such as energy prices, energy efficiency, fossil fuel consumption, and medium-high technology exports. The empirical method utilized in this study involves the application of the Durbin-Hausman (D-H) panel cointegration test, accounting for cross-sectional dependence. The coefficient estimation is carried out using the CCEMG estimator. The anticipated contribution of this research lies in its examination of a distinct country group, sample period, and empirical approach, thereby enriching the existing literature in the field. Analyzing the top 10 countries with the highest average increase in energy prices during the relevant period, the study findings are believed to reveal important results for these countries.

The following section of the study will include a review of previous research related to the subject. Subsequently, the data set and methodology will be introduced, and empirical analysis findings will be presented. Finally, evaluations and policy recommendations will be outlined.

Literature Review

In recent years, there has been an increasing interest in the determinants of environmental quality or environmental degradation. The relationship between CO_2 and various variables has been investigated in this context. A few of these variables encompass oil prices, population growth, foreign trade, urbanization, non-renewable energy consumption, industrialization and economic growth (Apergis et al., 2010; Zafeiriou et al., 2014; Akhmat et al., 2014; Li and Lin, 2015; Bento and Moutinho, 2016; Ahmed et al., 2017; Ouyang and Lin, 2017; Bilan et al., 2019; Sarkodie and Ozturk, 2020; Naseem and Guang, 2020; Alola et al., 2021; Akadiri and Adebayo, 2021; Khan et al., 2021; Sikder et al., 2022; Raihan, 2023; Ongab et al., 2023; Mitić et al., 2023). The mentioned studies have utilized various time series and panel data methods. These techniques include the ARDL model, panel ARDL, Granger causality, VAR, GMM, FMOLS, Johansen cointegration, DOLS, Driscoll-Kraay regression, augmented mean group (AMG), fixed effects, random effects, spatial error model (SEM), OLS, robust regression estimator (RREG), Pedroni panel cointegration, and VEC.

In their study, Belaid and Youssef (2017) investigated the factors influencing CO_2 emissions in the Algerian economy from 1980 to 2012. The model includes carbon emissions, variables for energy resources, and economic growth. Empirical findings have shown a positive relationship between electricity consumption and CO_2 emissions. The study also found that renewable electricity did not significantly contribute to reducing CO_2 emissions. Following a similar research question, Khan et al. (2019) examined the period of 1972-2017 for the Pakistani economy. The authors conducted a time series analysis using the ARDL and VECM approaches. The results of their studies demonstrated a positive correlation between urbanization, financial development, and CO2 emissions. Additionally, the existence of a bidirectional relationship between trade openness and carbon emissions was obtained. Focusing on the Malaysian economy, Chin et al. (2018) examined the sample period of 1997-2014 and used the ARDL model. The findings suggested that CO_2 emissions were significantly driven by economic growth. Additionally, an increase in CO_2 emissions was considered to be partly influenced by China's direct foreign investments in Malaysia. The study emphasizes the importance of achieving economic gains without negatively affecting environmental quality. In the study conducted by Mamun et al. (2014), which investigates the contribution of countries to CO_2 emissions based on their level of development, it was found that high-income economies contribute more to CO_2 emissions compared to middle and low-income economies. The main reason behind this finding is the growing service sector in middle-income economies, which is effective in reducing CO_2 emissions. Similarly, Shen et al. (2018) conducted a similar study comparing low-population industries with middle and high-population industries, and they found that population growth is positively associated with CO_2 emissions. This relationship was attributed to the lack of high technology intensity in production in high-population industries. Apergis and Payne (2015) examined the factors influencing CO_2 emissions in 11 South American countries during the period 1980-2010, employing the ARDL method. Their findings indicated a positive and statistically significant long-term association between real GDP per capita, oil prices, and CO_2 emissions. In a similar vein, Azad et al. (2015) addressed a comparable research question in the Australian economy utilizing panel data analysis. The findings of their study demonstrated that renewable energy sources contribute to the reduction of CO_2 emissions, whereas non-renewable energy sources lead to an increase in CO_2 emissions. The authors emphasized the significance of investing in clean energy. Bhattacharya et al. (2017) conducted a comprehensive study on a large data set consisting of socio-economic variables. To analyze these associations, the researchers utilized the two-step system GMM and FMOLS methods for their empirical analysis. The empirical results suggested a positive influence of renewable energy on GDP, coupled with a negative correlation with CO_2 emissions. In a related study, Zafeiriou et al. (2014) put forward the proposition that the rise in crude oil prices serves as a motivating factor for individuals to explore alternative available options. They also suggested that a decrease in ethanol prices would incentivize the reduction of oil and gasoline dependency. Moreover, the authors emphasized that a rise in oil prices would lead to a decline in oil demand, thereby contributing to reduced air pollution. Rasheed et al. (2022) conducted a research endeavor to examine the correlation between energy consumption, encompassing both renewable and non-renewable sources, oil prices, and CO_2 emissions across 30 European countries spanning the period 1997-2017. To scrutinize these relationships, the researchers employed FMOLS, the cointegration method proposed by Westerlund (2007), and Driscoll-Kraay regression tests. Consistent findings concerning energy consumption in Europe were observed in both the individual sample and full sample analyses. The study's results confirmed the existence of a long-term relationship among the variables. More precisely, it has been found that the use of non-renewable energy resources has a positive relationship with carbon emissions. Additionally, it was concluded that carbon emissions and clean energy resource consumption have a negative relationship. Additionally, the findings indicated that as oil prices increase, individuals tend to shift towards alternative energy sources that contribute to a reduction in CO_2 emissions. Oğul (2023) researched environmental areas in the Turkish economy for the period 1980-2017. FMOLS and CCR estimators were used in the study using the ARDL bounds test. It was concluded that the FMOLS and CCR results were similar. The study concluded that a rise in economic growth leads to an expansion of the ecological footprint, whereas an increase in globalization results in a reduction of the ecological footprint.

Empirical Analysis

Data

The information regarding the top 10 countries with the highest average annual increase in energy prices during the period 1990-2021 is presented in Table 1.

Table 1: Top 10 Economies with the Highest Annual Average Energy Price Increase in the 1990-2021 Period

id	Countries	Annual average growth rates for energy prices (%)
1	Brazil	51.86
2	Türkiye	32.97
3	Romania	30.32
4	Argentina	20.89
5	Peru	12.17
6	Egypt	9.53
7	Indonesia	8.57
8	Pakistan	8.45
9	Colombia	8.43
10	Mexico	8.31

Information about the variables used in the empirical analysis and their data sources are presented in Table 2.

Table 2: Summary Information of the Variable

Variable	Definition	Source
CO_2	Log (Carbon dioxide emissions per capita (metric tons))	IEA
PRC	Log (Real energy prices index (constant 2015 USD))	BP, WDI
EE	Log (Primary energy consumption per capita (kWh)/ Population)/ GDP (constant 2015 US$)	Our World in Data/WDI
FOS	Log (Fossil fuels per capita (kWh))	Our World in Data
MHEXP	Log (Medium and high-tech exports (% manufactured exports))	WDI

Methodology

The detection and handling of cross-sectional dependence (CSD) in panel data are crucial considerations before conducting empirical estimations. Ignoring CSD may lead to significant consequences (Sarafidis and Wansbeek, 2012). CSD arises due to increased interconnections in social and economic networks and previously unnoticed common shocks, which can cause traditional panel estimators to yield inconclusive results. Therefore, in this study, three distinct tests for CSD, namely the Breusch-Pagan LM test, the Pesaran CD test, and the Pesaran LM test, are employed to assess the presence of CSD in the panel data. The test statistic used in the Breusch and Pagan (1980) study for testing CSD is expressed as follows (Pesaran et al., 2008):

$$\text{L}= T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2}, \quad \sim X^2 N(N-1)/2 \qquad (1)$$

Under the null hypothesis, the LM test demonstrates an asymptotic chi-square distribution with degrees of freedom equal to $N(N-1)/2$, where N represents the number of cross-sectional units. The LM test is considered valid when N is small and the time dimension (T) is sufficiently large. The test statistic introduced by Pesaran (2004) is articulated as follows:

$$\text{CD}= \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \qquad (2)$$

Under the null hypothesis, the standardized CD function converges to a standard normal distribution with N approaching infinity as T becomes sufficiently large. Moreover, in contrast to the LM test, the standardized CD function maintains a mean of zero for any fixed values of T and N.

Pesaran (2004) establishes the capability of the CD test to identify heterogeneous dynamic models that encompass multiple breakpoints in slope coefficients and/or error variances, provided that the unconditional means of both dependent and independent variables remain constant over time and the innovations follow symmetric distributions. Nevertheless, the CD test may exhibit reduced sensitivity in situations where the population average of cross-sectional correlations is zero despite the existence of non-zero pair-wise correlations among individual units within the population. Moreover, the CD test may show diminished effectiveness in specific scenarios where the average cross-pair correlations in the population are zero while the individual population pair-wise correlations underneath remain non-zero.

For large panels, when $T \to \infty$ and then $N \to \infty$, Pesaran et al. (2008) introduce a modified variant of the LM test that incorporates the complete mean and variance of the LM statistic, referred to as the bias-corrected LM test:

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\tilde{\rho}^2{}_{ij}-\mu_{Tij}}{\sqrt{v^2{}_{Tij}}} \sim N(0,1) \qquad (3)$$

In the above context, k represents the number of regressors, μ_{Tij} and $\text{v}^2{}_{Tij}$ are the mean and variance, respectively, of $(T-k)\,\tilde{\rho}^2{}_{ij}$ provided by Pesaran et al. (2008). Another preliminary test that must be carried out involves examining whether the slope coefficients exhibit homogeneity or heterogeneity. Knowledge about the homogeneity or heterogeneity of the slope coefficients will guide the subsequent cointegration test. If the test results indicate that the slope coefficients are heterogeneous, cointegration analyses considering heterogeneity will be necessary.

The homogeneity of slope coefficients in the cointegration equation is determined via the Slope Homogeneity Test proposed by Pesaran and Yamagata (2008). Swamy's (1970) S test, ΔSHT, and ΔASHT tests are employed to examine slope homogeneity. The following equations represent the tests for slope homogeneity:

$$\hat{\text{S}} = \sum_{i=1}^{N}\left(\hat{\beta}_i-\hat{\beta}_{WFE}\right)'\frac{x'_i M_\tau x_i}{\sim\sigma_i{}^2}\left(\hat{\beta}_i-\hat{\beta}_{WFE}\right) \qquad (4)$$

where $\hat{\beta}_i$ is the weighted fixed effect estimate of the aggregated OLS and $\hat{\beta}_{WFE}$ equation (1), M_τ is an identity matrix of the order T, and $\sim\sigma_i{}^2$ is the estimator of $\sigma_i{}^2$. The definition of the test statistic is as follows:

$$\tilde{\Delta}= \sqrt{N}\left(\frac{N^{-1}\hat{S}-k}{\sqrt{2k(T-k-1)/T+1}}\right) \sim N(0,1) \tag{5}$$

$$\tilde{\Delta}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \tag{6}$$

As (N, T)→∞, the error term shows normal distribution under the null hypothesis. The delta test adheres to an asymptotic normal distribution.

The calculation of the delta test statistic is as follows:

$$\tilde{\Delta}_{adj}= \sqrt{N}\left(\frac{N^{-1}\tilde{S}-E(\tilde{Z}_{iT})}{\sqrt{Var(\tilde{Z}_{iT})}}\right) \tag{7}$$

Average in the above equation $E(\tilde{Z}_{iT}) = k$ and $Var(\tilde{Z}_{iT}) = \left(\frac{2k(T-k-1)}{T+1}\right)$ equals variance.

In this study, we used the second-generation test (CIPS analysis). The following is the CIPS test equation (3).

$$\Delta I_{it} = a_i + b_i I_{i,t-1} c_i I_{t-1} + \sum_{l=0}^{p} d_{il}\Delta I_{t-1} + \sum_{l=0}^{p} e_{il}\Delta I_{t-1} + e_{it} \tag{8}$$

In the equation above, CS means of lagged levels and first differences are presented by I_{t-1} and ΔI_{t-1}, respectively. The CADF statistics can be computed utilizing Equation (4), whereas the CIPS test statistic can be obtained through the following equation:

$$\widehat{CIPS} = \frac{1}{N}\sum_{i=0}^{n} CADF_i \tag{9}$$

The study investigated the long-term relationship between the variables with the D-H panel cointegration. We chose this test because of the presence of CSD within the model. The D-H test is a method developed by Westerlund (2008), and it evaluates the cointegration relationship by separating factors based on residuals in scenarios involving CSD. Furthermore, this test enables the investigation of cointegration relationships in cases where the dependent variable is first-order integrated (I(1)), and the explanatory variables are not required to demonstrate a high level of cointegration. The following general equation formulates the D-H cointegration test:

$$y_{it} = \beta_i x_{it} + \alpha_i'\delta_t + u_{it}, \quad x_{it} = \gamma_i x_{it-1} + \varepsilon_{it} \tag{10}$$

The symbol δ_t in the equation represents the deterministic terms. When $\delta_t = (1)$, the model assumes a constant term, whereas if $\delta_t = (1, \mathrm{t})$, it includes both a constant and a trend term. The Dickey-Fuller (DF) function for the explanatory variable does not require $\gamma_i = 1x_{it} \sim I(1)$. The fundamental hypothesis for the D-H cointegration test is "No Cointegration Relationship." Test statistics developed by Choi (1994) are employed to test these hypotheses. The D-H test statistic is calculated in the following manner:

$$DHg = \sum_{i=1}^{N} \hat{S}_i(\hat{\rho}_{i,OLS} - \hat{\rho}_{i,IV})^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{11}$$

$$DHp = \hat{S}_N(\hat{\rho}_{OLS} - \hat{\rho}_{iV})^2 \sum_{i=1}^{N}\sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{12}$$

DHp computes the panel statistic assuming homogeneous slope parameters in the model, whereas *DHg* calculates the group statistic assuming heterogeneous slope parameters. The symbol $\hat{\rho}_{OLS,}$ represents OLS estimate of ρ, while $\hat{\rho}_{iV}$ represents the estimate of ρ_i obtained using instrumental variables .

The CCEMG is used as a cointegration estimator in this study. This estimator can be used in the presence of CSD and heterogeneity. Pesaran obtained the CCEMG by extending the following general panel equation and performing N-group regressions:

Following the cointegration test, the estimation process will utilize the CCEMG estimator developed by Pesaran (2006). This estimator takes into consideration the heterogeneity and CSD in the slope parameters. Pesaran derived the CCEMG by extending the general panel equation below and conducting N-group regressions:

$$y_{it} = a_i d_t + \beta_{ki} x_{kit} + u_{it} \quad , \quad u_{it} = \gamma_{im} H_{tm} + \varepsilon_{it} \tag{13}$$

The following model is estimated for each cross-section:

$$y_{it} = a_i d_t + \beta_{ki} x_{kit} + \theta_{1i} \bar{y}_t + \theta_{2i} \bar{x}_{kt} + u_{it} \quad (14)$$

In this equation, Pesaran makes the assumption that rather than unobserved factors (H_t) causing the relationship between errors, CSD, and explanatory variables to exhibit heterogeneity. Under this assumption, a random process is assumed for each slope parameter.

$$\beta_i = \beta + v_i \quad (15)$$

The calculation of the average effect involves dividing these coefficients by N, essentially taking their arithmetic mean, as illustrated below.

$$\hat{\beta}_{CCEMG} = N^{-1} \sum_i^N \hat{\beta}_i \quad (16)$$

Empirical Results

In this section, the findings of the empirical analysis are presented. Firstly, the descriptive statistics of the variables (Table 3) and the correlation matrix (Table 4) are provided. Then, VIF results are given (Table 5), and CSD results (Table 6) are presented. CSD analysis results play an important role in determining the tests that will be used later. CSD is of fundamental importance in the context of evaluating panel data. When CSD is ignored, the findings are inconsistent (Yang et al., 2022). Following the CSD results, the unit root process was investigated with CIPS (Table 7). The results of the homogeneity test are presented in Table 8. The existence of a long-term relationship was revealed by the D-H cointegration test (Table 9), and the CCEMG coefficient estimator (Table 10) was used.

The descriptive statistics for the variables are outlined in Table 3. The table shows that energy efficiency and fossil fuel use variables occupy an important place in the sample on average. However, it is seen that the highest volatility is in the energy prices variable. This is due to the high energy price increases in the economies of the countries included in the analysis. This volatility may cause negative expectations in terms of sustainable macroeconomic balance.

Table 3: Descriptive Statistics of Variables

Var.	*Mean*	*Median*	*Maximum*	*Minimum*	*Std. Dev.*	*Observations*
CO_2	0.291	0.263	0.860	-0.287	0.259	320
PRC	2.795	2.448	6.034	-2.932	1.529	320
EE	8.206	8.203	8.861	7.524	0.389	320
FOS	3.929	3.900	4.487	3.342	0.262	320
MHEXP	1.433	1.431	1.708	1.083	0.134	320

The correlation matrix results are presented in Table 4. The table indicates low correlations among the independent variables. The presence of low correlation values indicates that the variables show a suitable alignment with the model. Moreover, these low correlation values effectively alleviate concerns about multicollinearity. As a result, the results of the model are strengthened and have increased reliability thanks to these decreased correlation values.

Table 4: Results of the Correlation

Correlation^{prob} (t-Statistic)	***PRC***	***EE***	***FOS***	***MHEXP***
PRC	1			
EE	0.320^{***} (6.021)	1		
FOS	-0.337^{***} (-6.378)	-0.333^{***} (-6.296)	1	
MHEXP	-0.057 (-1.010)	0.407^{***} (7.944)	0.408^{***} (7.957)	1

Note: Expression *** indicates significance at the 1% level.

Table 5 shows the VIF values. If the variance amplification factors (VIF) are above 10, the problem of multicollinearity may exist (Iddrisu and Alagidede 2020: 7; Abbas, 2020: 8). According to the table, VIF values were obtained as low.

Table 5: Results of VIF

Variable	VIF	1/VIF
MHEXP	2.00	0.500338
EE	1.97	0.508718
FOS	1.92	0.522064
PRC	1.20	0.833815
MEAN VIF	1.77	0.591234

The test results regarding the cross-section dependency are shown in Table 6. Cross-section dependency tests reveal whether a macroeconomic shock in a country analyzed can also affect other countries. According to the table, it shows the existence of cross-section dependence. This result indicates that the CSD of the cointegration test and cointegration estimator to be used should be taken into account.

Table 6: Results of CSD Tests

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
CO_2	713.370^{***} (0.000)	70.370^{***} (0.000)	70.291^{***} (0.000)	13.293^{***} (0.000)
PRC	1121.585^{***} (0.000)	113.482^{***} (0.000)	113.321^{***} (0.000)	33.295^{***} (0.000)
EE	801.081^{***} (0.000)	79.698^{***} (0.000)	79.537^{***} (0.000)	15.099^{***} (0.000)
FOS	831.390^{***} (0.000)	82.893^{***} (0.000)	82.732^{***} (0.000)	16.327^{***} (0.000)
MHEXP	274.117^{***} (0.000)	24.151^{***} (0.000)	23.990^{***} (0.000)	0.128 (0.899)

Note: Expression *** indicates significance at the 1% level.

Drawing on the results presented in Table 6, identifying cross-section dependence led to the requirement for employing new-generation unit root tests that address CSD. Table 7 contains the results of the CIPS unit root test.

Table 7: Results of CIPS Unit Root Test

Variables	Level		Δ	
	C	C+T	C	C+T
CO_2	-1.844	-2.437	-3.745^{***}	-4.565^{***}
PRC	-2.504^{**}	-3.347^{***}	-3.736^{***}	-2.997^{**}
EE	-2.066	-2.177	-3.796^{***}	-3.469^{***}
FOS	-1.320	-1.810	-3.919^{***}	-3.933^{***}
MHEXP	-2.492^{**}	-3.214^{***}	-3.012^{***}	-3.167^{***}

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

When the results of Table 7 are examined, it is seen that the energy prices (PRC) and medium-high technology exports (MHEXHP) variables for the level values of the variables are stationary for both fixed and fixed-trend models. Other variables were found to have unit roots. On the contrary, the first difference is applied to all variables, leading to the determination that all variables display stationarity in both constant and constant-trend models. Therefore, the integrated degree of the variables was obtained as mixed as I(0) and I(1).

The heterogeneity of the slope coefficient in the model was tested, and the test results are given in Table 8.

Table 8: Results of Slope Heterogeneity Test

Statistics	Test value	p-value
Delta tilde	8.245^{***}	0.000
Delta tilde adjusted	8.976^{***}	0.000

Note: Expression *** indicates significance at the 1% level.

In Table 8, H0 proposing the homogeneity of the model in the delta tests was dismissed at the 1% significance level. This result showed that the cointegration coefficients of the model established in the economies of 10 countries included in the analysis are heterogeneous. This result showed that the change in 10 country groups affected other countries at different levels. D-H panel cointegration test findings are shown in Table 9.

Table 9: Results of D-H Panel Cointegration Test

Tests	C		C+T	
	Test statistic	p-value	Test statistic	p-value
Durbin-H panel statistics	-1.437^{*}	0.075	-1.420^{*}	0.078
Durbin-H group statistics	-1.425^{*}	0.077	0.878	0.810

Note: Expression * indicates significance at the 10% level.

When Table 9 is examined, there are two test results, namely Durbin-H panel statistics and Durbin-H group statistics. When the model slope coefficient is obtained homogeneously, the results of the Durbin-H panel statistics will be interpreted. However, if the slope coefficient is heterogeneous, Durbin-H group statistics results will be preferred for interpretation. Therefore, according to the results of Table 7, Durbin-H group statistics were used for interpretation, and the presence of a 10% cointegration relationship was obtained for the fixed model.

The findings for the long-term coefficients are presented in Table 10 below.

Table 10: Results of CCEMG

	Coefficients	*Std. err.*	*p-values*
PRC	*0.203******	*0.006*	*0.000*
EE	*-0.350******	*0.122*	*0.004*
FOS	*1.081******	*0.045*	*0.000*
MHEXP	*-0.038**	*0.020*	*0.053*
C	*0.721*	*2.280*	*0.752*

Note: *** and * show significance at the 1% and 10% levels, respectively

The results in Table 10 indicate that PRC, EE, and FOS were statistically significant at the 1% significance level. The variable MHEXP achieved statistical significance at the 10% significance level. According to the findings from the CCEMG, a 1% increase in PRC leads to a 0.20% rise in CO_2 emissions; a 1% increase in EE results in a 0.35% reduction in CO_2 emissions; a 1% increase in FOS leads to a 1.09% increase in CO_2 emissions and a 1% increase in MHEXP results in a 0.04% reduction in CO_2 emissions.

Conclusion and Recommendations

Driven by a rising global aspiration for wealth and economic development, heightened utilization of natural resources across various industries has increased emissions of pollutants, notably CO_2. This article investigates the dependence between energy prices, energy efficiency, fossil fuel use, medium-high technology exports and CO_2 emissions for the economies of 10 countries. The aforementioned research is important in terms of raising awareness on how these countries can achieve sustainable development in the new millennium, where they are faced with the economic, political, and social crises that arise from time to time. These countries also have special features that make them more interesting from a research point of view. The fact that the countries included in the analysis experienced the highest energy price increase on average in the 1990-2021 period makes the energy price-environment relationship important in these countries. Empirical findings obtained in the study showed that increases in energy prices and fossil fuel use increase CO_2 emissions. It has been revealed that energy efficiency and medium-high technology export increases reduce CO_2 emissions. The anticipated outcome aligns with expectations that medium and high technology exports have a positive effect in reducing environmental pollution. This observation can be clarified by the reality that technological progress frequently gives rise to the creation of production processes and products that are both environmentally friendly and more efficient. In addition, with the presence of environmentally friendly technologies, the mechanism for exporting green products and services to other countries comes into play. This development can help increase the export of environmentally friendly technologies and products and contribute to economic growth by increasing the demand for these products. Considering the countries included in the analysis, it can be said that most of them (Brazil, Türkiye, Romania, Argentina, Peru, Indonesia, Pakistan, and Colombia) are developing countries that are high energy importers. In addition, considering that the relevant countries are emerging market economies, energy consumption is considered to be important for sustainable development. The predominant use of fossil fuels in realizing these targets leads to increased environmental problems. With the beginning of the use of oil in the world economy, gasoline has become a basic material and natural gas has been included in the energy equation for many countries. These three hydrocarbon products have played crucial roles in benefiting humanity, but they have also caused harm to ecosystems, affecting all living species on Earth, including humans. In 2020, the onset of the COVID-19 pandemic served as a wake-up call for numerous countries, necessitating a carbon-neutral solution to the energy equation. Hydrogen comes to the fore for the realization of this situation. To solve these problems, it is often recommended that renewable energy consumption be encouraged and increased. At the same time, a policy approach that covers all sectors and provides flexibility to CO_2 reduction at the lowest cost (for example, an emissions trading system) to address energy prices will prevent emissions leakage and achieve long-term reductions in targeted CO_2 emissions. It is thought that taking these measures will reduce the demand for fossil fuels and increase environmental quality by reducing environmental degradation. However, the relevant countries must increase their high-technology exports and energy efficiency besides these measures. On the other hand, hydrogen, which has been frequently emphasized recently, has been a historical turning point, and while closing the carbon age, it basically started the hydrogen age. Numerous developed countries have commenced the announcement of their strategic plans and roadmaps. It is being evaluated that countries becoming carbon neutral and increasing green hydrogen agreements will improve environmental quality. It is recommended that the developing countries analyzed in this study take steps to support the Hydrogen 1.0 era.

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