Chapter 1

Interconnections Between Industrialization, Economic Growth, Environmental Degradation, Resource Depletion, and Energy Demand in CEE(S) Economies: Insights from Bootstrap Panel Causality Analysis

Maya Moalla[1]

Seyit Ali Miçooğulları[2]

Abstract

This paper investigates the causal relationships between energy demand (ED) and four macroeconomic variables which are: economic growth (EG), industrialization (IND), environmental degradation (ENV), and resource depletion (RD) in the economies of Central and Eastern European (CEE) countries, namely Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia during the period from 2004 to 2021. Three sub-variables were used for each macroeconomic variable to create a composite index. The causal associations between each macroeconomic variable and ED were investigated separately. Bootstrap Panel Granger causality method had been utilized. The results reveal cross-sectional dependence and country-specific heterogeneity within the CEE panel. The results demonstrated one-way causality from IND to ED in Estonia, Hungary, and Poland. In Slovakia, the causality test identifies a one-way causality from ED to IND. In Lithuania, ED is influenced by ENV in a one-way direction. In Poland, Slovakia, and Slovenia, there is a one-way causality relationship between ED and ENV. Except for the Czech Republic, all countries in the panel, demonstrate that EG drives ED. A two-way causality relationship between EG and ED is identified in Poland, Slovakia, and Slovenia, emphasizing the need for sustainable energy policies to balance energy use and environmental

1 Dr., mayamoalla@hotmail.com, ORCID: https://orcid.org/0000-0003-4076-2790.

2 Öğr. Gör. Dr, Kilis 7 Aralık Üniversitesi, SBMYO, Dış Ticaret Bölümü s.alimicoogullari@kilis.edu.tr, ORCID: 0000- 0001-9266-1559

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impacts. Furthermore, there is a one-way causality between RD and ED in Poland and a one-way causality from ED to RD in Slovakia. A two-way causality between RD and ED is observed in the Czech Republic, Hungary, Latvia, and Lithuania.

Introduction

Economic growth and industrialization are two fundamental factors that underpin the modern world. However, the increasing demands associated with these factors have led to environmental degradation and resource depletion problems, posing a long-term threat to a sustainable economy. As a result, macroeconomic variables such as economic growth (EG), industrialization (IND), environmental degradation (ENV), and resource depletion (RD) have been the subject of growing interest and research in recent years. These variables are closely interconnected with one another. In particular, energy demand (ED) plays a crucial role in the relationships among these variables. While an increase in ED is necessary to achieve IND and EG objectives in countries, it can also contribute to the rise of other macroeconomic variables such as ENV and RD. Consequently, understanding the relationships between ED and other macroeconomic variables is vital to attain sustainable development goals. Central and Eastern European (CEE) countries have undergone rapid economic transformation in recent years. These countries have focused on IND to increase their EG rates, but this has also led to an increase in ENV and (RD). Therefore, understanding the relationships between these variables is important for sustainable development. In this context, the purpose of this study is to examine the causal relationships of four macroeconomic variables - EG, IND, ENV, and RD - on ED in the economies of CEE countries, namely Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia. The selection of this group of countries is motivated by several important reasons such as their similar geographic, economic, and political structures, shared historical background, and their important role in the economic transformation process of Europe, as well as their membership in the European Union. Furthermore, studying the causal relationships among their levels of IN, EG, ENV, and RD not only provides insights specific to this group but also offers valuable lessons and examples for other countries facing similar challenges. This study provides several strengths. To our current awareness, it constitutes an inaugural investigation examining the causal relationships between EG, IND, ENV, RD, and ED using a Bootstrap Panel Granger causality method in the economies of CEE countries. Secondly, it takes into account the cross-sectional dependency and cross-country heterogeneity in the eight countries of CEE. This consideration acknowledges the potential differences and unique characteristics of each country within the region, providing a more comprehensive analysis. Thirdly, it utilizes the bootstrap causality approach developed by Kónya (2006), which enables the assessment of causality separately for each panel member. This approach enables a more detailed examination of the causal relationships within each country, providing valuable insights into the specific dynamics of ED and its drivers. Lastly, by mitigating the possible biases arising from small sample sizes using the bootstrap technique, the study's findings can be more reliable, enhancing the credibility of policy implications drawn from the research.

Review of Literature

This section reviews some studies investigating the nexus between energy consumption and four macroeconomic variables (IND, ENV, EG and RD). Mixed conclusions had been revealed in the literature due to variations in time periods, variables, samples, and methodologies employed in different studies. These variations can lead to differing findings and interpretations. It is important to consider these factors when evaluating the research and drawing conclusions. Table 1 summarizes some studies. Shahbaz et al. (2020) underscored the importance of prioritizing renewable energy investments as a means to foster economic development with minimal environmental impact. Chen et al. (2020) suggested that the nexus between renewable energy consumption and economic evolution varies depending on the extent of renewable energy utilization. Radmehr et al. (2021) demonstrated that policymakers can design comprehensive and effective environmental and energy policies that contribute to both economic development and sustainability while fulfilling the targets set by the European Union. Anser et al. (2021) suggested the need for comprehensive policy initiatives to address CO2 emissions and ENV in the South Asian region, focusing on clean energy policies as crucial strategies to improve environmental quality and achieve sustainable development goals. Sritrisniawati et al. (2022) asserted that the utilization of alternative energy sources in Indonesia is still notably low. Consequently, there is an urgent requirement for renewable energy innovations to facilitate the production of environmentally friendly energy within the country. Jamil (2022) suggests diversifying the energy mix and harnessing renewable sources to reduce their dependence on expensive energy options and create a more sustainable and cost-effective energy system. Hussain et al. (2020) revealed that in the BRI countries, a 1% increase in natural RD results in a 0.0286% increase in CO2 emissions and a 0.0117% increase in energy use. Kwakwa et al. (2020) emphasized the importance of enforcing regulations related to extractive activities and implementing trade policies that encourage environmentally friendly practices to create a safer and more sustainable environment. Zaman et al. (2017) emphasized the importance of recognizing and valuing Pakistan's natural resources and calls for the government and policy institutions to take responsibility for conserving and utilizing them wisely for the benefit of the nation's future. Khan et al. (2016) emphasized the critical nature of healthcare infrastructure, handling the irregularities of climate change, and protecting the foundation of energy resources, particularly when accounting for fiscal constraints. The research emphasizes the necessity of developing long-term policies in the region that prioritize healthcare, promote climate resilience, and foster sustainable energy management. By honing in on these fields, legislators can adeptly safeguard the welfare of the public, counteract the aftermaths of climate change, and secure a consistent and renewable energy source for future eras. Zandi and Haseeb (2019) underscore that elevating the use of renewable energy sources distinctly aids in lessening ENV. This conveys that turning to renewable energy sources can be instrumental in decreasing detrimental impacts on the environment. The panel causality study unveils a reciprocal association between carbon dioxide outputs and the deployment of renewable and non-renewable energy sources. Moreover, they underscore the significance of promoting the adoption of renewable energy and implementing sustainable EG strategies, while also considering the environmental consequences of trade practices. Abbas et al. (2020) proposed providing economic and financial support for clean technological innovations and green renewable energy sources to maximize the economic advantages of the BRI project (Belt and Road Initiative) while ensuring the preservation of the region's environmental conditions. By prioritizing sustainable energy solutions and incorporating environmentally friendly technologies, the project can achieve its economic goals while minimizing negative environmental impacts. Muhammad et al. (2021) argued that the proposed strategies should encompass not only mitigating ENV but also promoting the development and sustainable stewardship of fuel resources, minerals, metals and overall natural assets. It is important for policymakers in BRICS, developing, developed, and global countries to prioritize environmental protection while also considering the responsible utilization and development of natural resources for EG and societal well-being. Pan et al. (2019) emphasizes that IND affects energy intensity through both stimulating and inhibiting factors, primarily through technological innovation. However, the overall impact is positive, indicating that IND increases energy intensity. To address carbon emissions and improve energy efficiency in Bangladesh, policymakers should prioritize energy efficiency measures and implement suitable technologies. Industrial policies should be geared towards promoting technological innovations that reduce energy intensity. This can be facilitated through adequate funding for research and development in the industrial sectors and attracting foreign direct investments. Sadorsky, (2014) indicates that EG policies and IND can lead to increased energy consumption, mainly through the burning of fossil fuels. This poses a challenge to sustainable development goals, as reliance on fossil fuels is not environmentally sustainable. Therefore, there is a need to prioritize the transition to cleaner and more sustainable energy sources to align EG with sustainable development objectives. Li et al. (2020) proposed three implications, firstly, prioritizing new energy development in upper-middle-income regions to achieve EG and environmental sustainability, focusing on changing the energy consumption structure, increasing clean energy usage, and supporting new energy development through fiscal policies. Secondly, striving for harmonious industrial development and urbanization, given the nuances of upper-middle-income regions, like income differentials, population density, and IND measurements. Ultimately, boosting regional economic collaboration and governance by molding energy usage policies to fit local circumstances, streamlining energy distribution to achieve economic rewards and ecological balance, and synchronizing energy initiatives with wider regional plans for integrative progress. Mujtaba and Jena (2022) suggested that policymakers should focus on sustainable energy practices, diversify energy sources towards renewables, and utilize price mechanisms to encourage a shift away from nonrenewable energy, thereby reducing environmental impact and ensuring a more sustainable energy future. Further research is necessary to provide more definitive insights into the relationship between the variables and establish more consistent findings.

Table 1: Recapitulation of recent literature.

Author(s)	Period	Country(s)	Methodology	Result
The nexus between energy consumption and economic evolution				
Shahbaz et al., 2020	1990-2018	38 renewable-energy-consuming countries	The dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and heterogeneous non-causality approaches	Long-run nexus amidst energy consumption and economic evolution.
Chen et al., 2020	1995-2015	103-country sample	Threshold model	barely any effect observed in developed countries, while a clear and positive repercussion in OECD countries.
Radmehr et al., 2021	1995-2014	European Union (EU) countries	Panel spatial simultaneous equations models with a generalized spatial two-stage least squares (GS2SLS) method	Unidirectional nexus amidst economic evolution and renewable energy consumption.
Anser et al., 2021	1985-2019	Selected South Asian countries	Fully modified ordinary least square (FMOLS) method	Two-way causal nexus between economic progression and the usage of energy.
Sritrisniawati et al., 2022	1985-2020	Indonesia	VARX analysis	No significant impact on economic growth
Jamil, 2022	1971-2021	Different countries with different income levels	Causality tests and the ordinary least square model	One-way causal nexus between energy utilization and economic progression.
The nexus between resource depletion and energy demand				
Hussain et al., 2020	1990-2014	56 “Belt and Road Initiative” (BRI) countries	Augmented Mean Group (AMG) panel estimator, Common Correlated Effects Mean Group (CCEMG) estimator, and VECM Granger causality test	Feedback hypothetical interactions amid CO2 releases, energy consumption, economic growth, dwindling natural resources, urban expansion, and trade liberalization in the long run
Kwakwa et al., 2020	1971-2013	Ghana	Stochastic miens by Regression on Population, Affluence, and Technology Model	In Ghana, the aspects of income, urban expansion, and depletion of natural resources are linked to the escalating carbon emission and energy consumption woes.

Zaman et al., 2016	1975–2012	Pakistan	Bivariate cointegration and Granger causality technique	Reciprocal link between energy utilization and net loss of forests.
Khan et al., 2016	2000–2013	Austria, Czech Republic, Estonia, Germany, Ireland, Lithuania, Poland, Slovenia, and Slovak Republic	Panel Generalized Method of Moments (GMM)	Inverted U-shaped connection between the depletion of energy resources and GDP per capita.
The nexus between environmental degradation and energy demand				
Zandi and Haseeb, 2019	1990-2017	105 developed and developing countries	FMOLS and DOLS	There's a positive and pronounced nexus between energy utilization and environmental deterioration.
Abbas et al., 2020	1995-2014	Twenty-four emerging economies	Autoregressive distributed lags technique	Confirm the existence of EKC
Solarin and Al-Mulali, 2018	1982–2013	20 countries	Augmented mean group estimator supported by common correlated effect mean group estimator	GDP, energy utilization, and urbanization stand out as key culprits behind environmental deterioration.
Muhammad et al., 2021	1991-2018	BRICS, developing, developed, and global countries	Dynamic fixed effect model, GMM, and system GMM estimators	In BRICS, developing, developed, and worldwide nations, fuel stockpiles and harnessing renewable energy help curb environmental damage. However, tapping into ore and metal stocks obstruct environmental enhancement in more advanced nations.
Destek and Sinha, 2020	1980-2014	24 OECD countries	Second-generation panel data methods	Augmenting the intake of renewable energy curtails the ecological footprint, whereas escalating consumption of non-renewable sources compounds environmental degradation.

The nexus between industrialization and energy demand				
Pan et al., 2019	1986-2015	Bangladesh	Path model	Industrialization directly boosts energy intensity but indirectly contributes to its reduction.
Gungor and Simon, 2017	1970-2014	South Africa	Johansen co-integration test and vector error correction model with Granger causality test as estimation techniques	In the long-term, there's a bidirectional causality nexus between industrialization and energy utilization, as do FD and energy intake, and similarly between FD and the process of industrialization.
Sadorsky, 2014	1971–2008	18 emerging countries	Pooled mean group estimators	In the long run, industrialization rises energy consumption
Li et al., 2020	2000-2017	Upper-Middle-Income Regions of China	spatial autocorrelation test- ordinary panel data analysis-corresponding LM statistics	İndustrialization has a positive nexus with energy consumption
Mujtaba and Jena, 2022	1994–2018	Eight countries from the Asia-Pacific region	Panel ARDL model	Industrialization positively impacts energy demand

Data and Methodological Framework

This paper investigates the causal relationships between four macroeconomic variables (IND, EG, ENV, and RD) and another macroeconomic variable, (ED), in the CEE economies namely, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia. Yearly time series records spanning from 2004 to 2021 were harnessed to assemble a panel dataset.. The causal connections between each macroeconomic variable and ED were examined separately. Additionally, three sub-variables were used for each macroeconomic variable to create a composite index. Principal Component Analysis (PCA) method was employed in the construction of these indices. Table 2 provides information about the indices and the variables used in the indices.

Table 2: Variables description and data source

Variable	Explanation	Source
ED	Energy Demand Index	
	Fossil fuels (% equivalent primary energy)	Our World in Data
	Electricity generation (TWh)	Our World in Data
	Nuclear (% equivalent primary energy)	Our World in Data
IND	Industrialization Index	
	Food, beverages and tobacco (% of value added in manufacturing)	World Development Indicators
	Industry (including construction), value added (current US$)	World Development Indicators
ENV	Environmental Degradation Index	
	CO2 emissions (kt)	World Development Indicators
	Population density (people per sq. km of land area)	World Development Indicators
EG	Economic Growth Index	
	Agriculture, forestry, and fishing, value added (current US$)	World Development Indicators
	Services, value added (current US$)	World Development Indicators
	Manufacturing, value added (current US$)	World Development Indicators
RD	Resource Depletion Index	
	Energy depletion (current US$)	World Development Indicators
	Natural resources depletion (% of GNI)	World Development Indicators
	Net forest depletion (current US$)	World Development Indicators

In Figure 1, the causal connections between the ED index constructed using PCA and the indices of IND, EG, ENV, and RD are presented for the eight CEE countries. The Konya Causality Test approach was used to test the null hypothesis for four different models (provided in Figure 1).

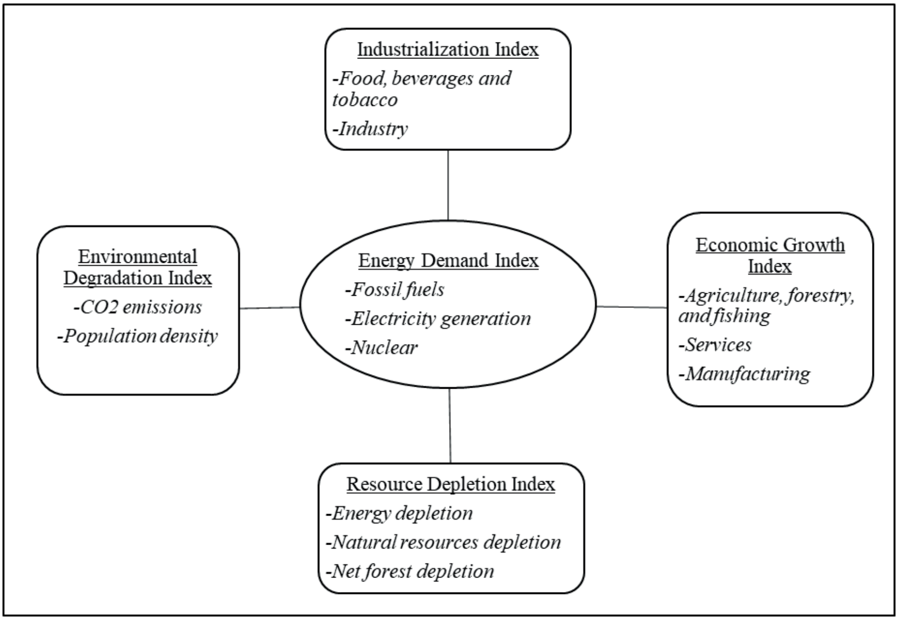

Figure 1: Framework of the study. Source: Authors' preparation.

Examining cross-sectional relationships among nations is crucial before performing causality examinations as broad globalization and strengthened economic and financial intertwining can create cross-sectional links in the worldwide economy, allowing disruptions in one nation to quickly spread to others (Nazlioglu et al. 2011; Destek and Aslan 2017). Hence, the initial phase involves assessing the cross-sectional interdependence among countries as a crucial component of our analysis. Cross-sectional dependency was examined using four different tests. The first one is the Lagrange Multiple (LM) test developed by Breusch and Pagan (1980) to examine cross-sectional dependency and is evaluated using the equation below.

$$y_{it} = a_i + \beta_i x_{it} + \varepsilon_{it} \text{ for } i = 1 \ldots, N \text{ and } t = 1 \ldots, T \quad (1)$$

Here i and t represent the cross-section dimension and time period, respectively. The null hypothesis H_0 is stated as Cov $(\varepsilon_{it}, \varepsilon_{jt}) = 0$, indicating no dependence between cross-sections, while the alternative hypothesis H_1 is stated as Cov $(\varepsilon_{it}, \varepsilon_{jt}) \neq 0$, indicating dependence between at least one pair of cross-sections. The calculation of the LM test is as follows

$$\mathbf{LM} = \mathbf{T}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2}\chi^{2}_{N(N-1)/2} \quad (2)$$

Here $\widehat{\rho}_{ij}$, represents the sample bidirectional correlation of the residuals from the ordinary least squares estimation for each cross-section in Equation 1. The LM test is suitable for panels that satisfy the condition of small N and sufficiently large T. However, for cases where T → ∞ and N → ∞, Pesaran (2004) developed the cross-sectional dependence Lagrange multiplier (CD_{LM}) test as follows:

$$CD_{LM} = \left(\frac{1}{N(N-1)}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \left(T\widehat{\rho}_{ij}^{2} - 1\right) N(0,1) \quad (3)$$

The CD_{LM}test may produce errors in cases of large N and small T, therefore Pesaran (2004) has developed a more understandable alternative test. The calculation of the new test for cross-sectional dependence (CD) is as follows:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \left(\widehat{\rho}_{ij} - 1\right) N(0,1) \quad (4)$$

On the other hand, the CD test may lack power in cases where the population average pairwise correlations are zero. Therefore, Pesaran and Yamagata (2008) propose a bias-adjusted test, which is a modified version of the LM test. The bias-adjusted LM test (LM_{adj}) is as follows:

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \widehat{\rho}_{ij} \frac{(T-k)\widehat{\rho}_{ij}^{2} - \mu_{Tij}}{\sqrt{v_{Tij}^{2}}} N(0,1) \quad (5)$$

Here, μ_{Tij} and v_{Tij}^{2} represent the number of regressors and the exact mean and variance of $(T-k)\widehat{\rho}_{ij}^{2}$ (Pesaran and Yamagata, 2008). Another important aspect to consider is the homogeneity of slopes, as homogeneity in the causal nexus amidst ED and macroeconomic variables among the countries in the sample can be deceptive. To address this issue, two different tests for homogeneity are used in this study. Pesaran and Yamagata (2008) developed a revised version of the Swamy test, called the $\widetilde{\Delta}$ test, to ascertain slope homogeneity in large panels. The revised version of the Swamy (1970) test is calculated as follows:

$$\tilde{S} = \sum_{i=1}^{N} \left(\widehat{\beta}_i - \widetilde{\beta}_{WFE}\right)' \frac{x_i' M_T x_i}{\widetilde{\sigma}_i^2} \left(\widehat{\beta}_i - \widetilde{\beta}_{WFE}\right) \quad (6)$$

Here, $\boldsymbol{\beta}_i$ and $\tilde{\boldsymbol{\beta}}_{\mathbf{WFE}}$, are the pooled OLS (ordinary least squares) and the weighted fixed effect pooled estimation of Equation (1) respectively. $\tilde{\boldsymbol{\sigma}}_{\mathbf{i}}^{\mathbf{2}}$ is the estimator of $\boldsymbol{\sigma}_{\mathbf{i}}^{\mathbf{2}}$ and $\mathbf{M_T}$ is an identity matrix of order T. The modified statistic is:

$$\tilde{\boldsymbol{\Delta}} = \sqrt{\mathbf{N}}\left(\frac{\mathbf{N^{-1}\tilde{S} - k}}{\sqrt{\mathbf{2k}}}\right) \quad \mathbf{(7)}$$

Here, k is the number of explanatory variables, under the null hypothesis and so long as $\sqrt{N}/T \to \infty$ with the condition $(N, T) \to \infty$. The small sample properties of the $\tilde{\boldsymbol{\Delta}}$ test can be improved under normally distributed errors by using the following bias adjusted version:

$$\tilde{\boldsymbol{\Delta}}_{\mathbf{adj}} = \sqrt{\mathbf{N}}\left(\frac{\mathbf{N^{-1}\tilde{S} - E(\tilde{z}_{it})}}{\sqrt{\mathbf{var\ (\tilde{z}_{it})}}}\right) \quad \mathbf{(8)}$$

Here the mean $\mathbf{E(\tilde{z}_{it})} = \boldsymbol{k}$ and the variance $\mathbf{var(\tilde{z}_{it})} = \mathbf{2}\boldsymbol{k}(\boldsymbol{T} - \boldsymbol{k} - \mathbf{1})/\boldsymbol{T} + \mathbf{1}$.

The panel bootstrap causality method devised by Kónya (2006) was used to determine the causal relationships in this study. Some reasons for choosing this method are as follows: 1- The panel bootstrap causality method is a commonly used approach for identifying causal relationships in economic data, particularly in macroeconomic issues such as ED and RD. 2- It is considered as the most suitable method in cases of both cross-sectional dependence and country-specific heterogeneity. 3- It allows for conducting individual causality tests for each country, helping to determine the causal relationships specific to each country.

This method relies on independent country-specific bootstrap critical values and seemingly uncorrelated regression (SUR) estimation of the equation set. It provides more accurate results by utilizing the critical values obtained through the bootstrap method. The bootstrap method involves resampling the data and performing calculations repeatedly using the resampled samples. The panel bootstrap causality method is robust to unit root and cointegration properties of variables, eliminating the need for pre-tests for panel unit root and cointegration. Based on the study by Kónya (2006), the model considers possible lags from 1 to 4 and estimates for each lag. The lag length that minimizes the Schwarz Bayesian Criterion is subsequently chosen as the optimal lag length. The system can be represented as follows:

$$ED_{1t} = a_{11} + \sum_{i=1}^{p_1} \beta_{11i} ED_{1t-i} + \sum_{i=1}^{p_1} \delta_{11i} INDXS_{1t-i} + \varepsilon_{11t}$$

$$ED_{Nt} = a_{1N} + \sum_{i=1}^{p_1} \beta_{1Ni} ED_{Nt-i} + \sum_{i=1}^{p_1} \delta_{1Ni} INDXS_{Nt-i} + \varepsilon_{1Nt} \quad (9)$$

$$INDXS_{1t} = a_{21} + \sum_{i=1}^{p_2} \beta_{21i} ED_{1t-i} + \sum_{i=1}^{p_2} \delta_{21i} INDXS_{1t-i} + \varepsilon_{21t}$$

$$INDXS_{Nt} = a_{2N} + \sum_{i=1}^{p_2} \beta_{2Ni} ED_{Nt-i} + \sum_{i=1}^{2} \delta_{2Ni} INDXS_{Nt-i} + \varepsilon_{2Nt} \quad (10)$$

Here, *ED* represents the energy demand index, and *INDXS* represents the index of other macroeconomic indicators (Industrialization Index, Environmental Degradation Index, Economic Growth Index and Resource Depletion Index). *N* denotes the count of nations, *t* represents time, and *i* represents the optimal lag length. In the Bootstrap Panel Causality test approach, different causal associations can be discerned. For example, if none of the δ_{1i} are zero but all of the δ_{2i} are zero, it can be said that there is one-way Granger causality from *INDXS* to ED. Similarly, if all δ_{1i} are zero but not all δ_{2i} are zero, then there is one-way Granger causality from ED to INDXS. If δ_{1i} and δ_{2i} are not zero then there is bi-directional Granger causality between ED and INDXS. If both δ_{1i} and δ_{2i} are zero, there is no causal relationship between ED and INDXS

Empirical Results

Prior to exploring the causal link between macroeconomic indicator indices (IND Index, ENV Index, EG Index, and RD Index) and (ED), it is necessary to examine cross-sectional dependence and slope homogeneity. The conclusions in Table 3 firmly refute the null hypothesis of absence of cross-sectional dependence among countries. This finding implies that a shock occurring in one developing country can spill over to other countries. Table 3 also indicates that the null hypothesis of slope homogeneity is rejected, confirming the presence of heterogeneity specific to the eight CEE countries.

Table 3: Cross-sectional dependence and homogeneity test.

	ED	IND	ENV	EG	RD
Cross-sectional dependence					
LM	50.510***	67.785***	55.857***	56.749***	45.545**
CD_{LM}	3.008***	5.317***	3.723**	3.842***	2.345**
CD	-1.594**	-1.556**	1.682**	-2.170**	-1.325**
LM_{adj}	1.056**	6.250***	2.022**	3.967***	5.377**
Homogeneity					
Δ	308.380***				
$\tilde{\Delta}_{adj}$	394.480***				

Note: *, **, *** indicate significance at 10, 5 and 1% level respectively in all tables.

Table 4 presents the conclusions of the Kónya (2006) causality test for IND and (ED). According to the results, causality from IND to ED is found in Estonia, Hungary, and Poland, while causality from ED to IND is found in Slovakia. In Estonia, Hungary, and Poland, the rapid increase in IND activities, development, and growth of the industrial sector can be said to lead to an increase in (ED). Therefore, IND can be seen as a factor that contributes to the increase in ED (Sadorsky 2014; Gungor and Simon 2017; Pan et al. 2019; Li et al. 2020). However, it has been concluded that the changes in ED did not affect IND in these three countries. This may be due to the fact that EG and the process of IND are not yet complete in these countries, and the increase in ED may be primarily driven by other sectors such as households and the commercial sector. Additionally, the increase in energy supply and diversification of energy sources in these countries can also influence the relationship between ED and IND. Due to these reasons, it has been determined that IND has a one-way effect on ED in these countries. As a result, the increase in industrial activities in these countries is anticipated to cause an upsurge in (ED), and this increase in ED can further drive the growth of the industrial sector. Advancing technology can also contribute to the industrial sector becoming more efficient, leading to a higher demand for energy (Sadorsky 2014; Gungor and Simon 2017; Pan et al., 2019; Li et al. 2020; Mujtaba and Jena 2022). On the other hand, in other countries (Czech Republic, Latvia, Lithuania, Slovakia, and Slovenia), no significant causal relationship between IND and ED has been found. These results indicate that there is no direct relationship between the increase in industrial activities and ED in these countries. Based on these findings, it can be inferred that the relationship between IND and ED may vary from country to country, and each country needs to formulate policies based on its own specific conditions. For example, countries like Poland, Estonia, and Hungary may need to implement energy conservation policies alongside industrial growth policies. On the other hand, in other countries, policies that regulate industrial activities to control the increase in ED may be more important.

Table 4: Model 1: Panel causality between Industrialization and energy demand

Countries	H0: IND does not cause ED				H0: ED does not cause IND			
	Statistic	Critical values			Statistic	Critical values		
		1%	5%	10%		1%	5%	10%
Czechia	1.443	16.868	10.040	7.009	8.953	67.413	35.616	30.470
Estonia	14.628***	11.105	5.463	3.701	2.239	47.680	23.689	13.746
Hungary	10.909**	13.471	7.628	5.486	2.797	36.057	15.053	9.161
Latvia	1.130	18.673	7.524	4.570	0.079	17.288	8.967	5.730
Lithuania	7.333	27.494	11.625	7.811	0.308	38.578	15.690	8.573
Poland	14.230**	17.512	8.306	5.459	2.027	33.271	13.646	9.994
Slovakia	1.591	16.404	8.268	5.465	17.477**	36.526	14.413	9.188
Slovenia	4.015	15.441	8.408	5.323	7.955	69.753	26.056	18.485

Critical values are based on 10000 bootstrap replications in all tables.

Table 5 showcases the conclusions of the Kónya (2006) causality test between Environmental Degradation ENV and (ED). According to the results, ED in Lithuania is unidirectionally affected by ENV, indicating that there is a statistically notable mien of ENV on ED in Lithuania at a significance level of 10%. However, this relationship is not evident in other countries. In Poland, Slovakia, and Slovenia, a unidirectional causality nexus between ED and ENV has been identified. These conclusions implies that energy consumption is a triggering factor for ENV in these countries. The findings align with the studies conducted by Solarin and Al-Mulali (2018), Zandi and Haseeb (2019), Abbas et al. (2020) and Destek and Sinha (2020). Countries in Central and Eastern Europe, such as Poland, Slovakia, and Slovenia, had high levels of ED and neglected environmental protection issues in the past due to their socialist economic systems. This situation might have led to an increase in ENV alongside the rise in energy consumption. Additionally, since most of these countries are in the process of IND, their energy demands are rapidly increasing. Proper management of industrial waste, implementation of environmental policies, and transitioning to renewable energy sources may still be underdeveloped in these countries, where IND is occurring intensively.

Table 5: Model 2: Panel causality between Environmental Degradation and Energy Demand

Countries	H0: ENV does not cause ED				H0: ED does not cause ENV			
	Statistic	Critical values			Statistic	Critical values		
		1%	5%	10%		1%	5%	10%
Czechia	0.302	112.577	75.412	59.146	21.605	97.452	62.062	47.832
Estonia	0.371	21.707	10.654	6.808	0.157	27.449	15.134	10.590
Hungary	0.067	15.981	10.639	8.186	0.001	48.76	28.618	20.464
Latvia	7.450	51.896	27.526	19.725	0.054	33.863	18.882	13.582
Lithuania	6.460*	13.286	8.544	5.462	0.177	27.36	10.398	6.886
Poland	0.001	60.112	30.897	22.592	55.508*	91.126	57.675	45.659
Slovakia	0.773	16.811	8.233	5.342	5.863*	23.871	9.71	4.470
Slovenia	1.223	22.509	10.5	6.857	12.655**	27.951	11.791	7.908

Table 6 presents the results of the Kónya (2006) causality test amidst EG and (ED). The results indicate that, except for the Czech Republic, ED drives EG in all the countries comprising the panel. This suggests that energy is a significant input for economic growth, and as the economy expands, ED increases. In the case of Poland, Slovakia, and Slovenia, a bidirectional causality is observed between EG and (ED). These findings align with previous studies conducted by Shahbaz et al. (2020), Chen et al. (2020), Radmehr et al. (2021), Anser et al. (2021), Sritrisniawati et al. (2022) and Jamil (2022). It implies that ED influences EG and, in turn, EG affects (ED). The reasons behind this relationship can be diverse. For instance, in these countries, EG may primarily occur in energy-intensive sectors, leading to increased (ED). Simultaneously, the rise in ED can facilitate the expansion of economic activities and, consequently, enhance economic growth.

Table 6: Model 3: Panel causality between EG and ED

Countries	H0: EG does not cause ED				H0: ED does not cause EG			
	Statistic	Critical values			Statistic	Critical values		
		1%	5%	10%		1%	5%	10%
Czechia	0.88	51.280	30.049	22.953	2.665	78.707	41.496	32.650
Estonia	1.735	29.238	14.148	10.281	22.521**	38.686	20.447	12.100
Hungary	0.662	5.273	2.534	1.852	13.815*	35.369	18.641	12.267
Latvia	0.073	36.811	15.775	10.863	10.706*	26.596	14.716	9.949
Lithuania	2.852	12.523	7.620	5.130	19.995**	21.683	19.120	9.176
Poland	14.101**	20.843	13.728	10.888	20.633*	41.644	23.930	18.294
Slovakia	6.902*	17.100	8.793	5.918	14.044**	22.111	11.878	7.800
Slovenia	12.905**	24.139	11.745	8.476	19.016**	33.302	17.195	11.836

Table 7 displays the conclusions of the causality tests conducted by Kónya (2006) examining the relationship between RD and ED. The results vary across countries. According to the findings, in Poland, a one-way causality from RD to ED is observed, indicating that RD influences ED, but ED does not affect RD (Hussain et al. 2020; Kwakwa et al. 2020). This result may be attributed to the specific factors related to Poland's economic structure and energy sector. In Slovakia, a one-way causality from ED to RD is detected. This implies that an increase in ED leads to RD, but RD does not affect ED. This result highlights that Slovakia's EG heavily relies on energy and that RD adversely affects economic growth. Moreover, the increase in ED can contribute to RD, emphasizing the need to consider this aspect in energy policies. The findings in Table 7 also demonstrate a two-way causality between RD and ED in the case of the Czech Republic, Hungary, Latvia, and Lithuania (Zaman et al. 2017; Khan et al. 2016). This suggests that EG in these countries increases (ED), and at the same time, the rising ED also contributes to (RD).

Table 7 Model 4: Panel causality between RD and ED

Countries	H0: RD does not cause ED				H0: ED does not cause RD			
	Statistic	Critical values			Statistic	Critical values		
		1%	5%	10%		1%	5%	10%
Czechia	7.948*	19.956	10.492	6.887	13.956*	35.079	17.683	12.176
Estonia	2.662	35.646	21.082	14.84	0.152	57.747	33.593	24.424
Hungary	12.514**	14.407	7.306	4.667	52.798***	31.089	19.469	14.410
Latvia	6.003*	30.912	11.733	5.893	6.875*	11.367	6.925	4.632
Lithuania	17.273***	16.560	9.383	6.831	13.991**	21.118	10.315	6.836
Poland	7.598**	9.703	5.795	3.707	2.370	24.869	12.995	8.001
Slovakia	0.800	16.524	9.061	5.512	12.807*	35.821	21.126	11.861
Slovenia	0.149	14.544	7.518	5.311	0.019	29.856	15.862	11.403

Conclusions and Remarks

The intent of this inquiry is to scrutinize the causal nexus between four macroeconomic variables (IND, EG, ENV, and RD) and ED in the economies of CEE countries, namely Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia, during the period from 2004 to 2021. To achieve this objective, the study employs the bootstrap panel Granger causality test, enabling consideration of cross-sectional dependence and country-specific heterogeneity among the mentioned countries. There are numerous studies in the literature that examine causal connections between different variables believed to be influential on (ED). However, there are two important issues to consider in econometric analysis: i. cross-country heteroskedasticity and ii. cross-sectional dependence. The results suggest that both cross-sectional dependence and country-specific heterogeneity are present in the panel of countries, indicating that a shock occurring in one CEE country can be transmitted to other CEE countries. According to the conclusions of the causality test between IND and (ED), one-way causality from IND to ED has been detected in Estonia, Hungary, and Poland. It can be said that factors such as the rapid increase in IND activities and the development and growth of the industrial sector contribute to an elevation in ED in these countries. However, it has been concluded that the changes in ED did not affect IND in these three countries. The possible reason for this is that EG and the process of IND may not be fully completed in these countries, and the increase in ED may predominantly come from other sectors such as households and the commercial sector. As a result, the findings indicate that industrial activities will result in a rise in ED in these countries, and as ED increases, it may further contribute to the growth of the industrial sector. In Slovakia, on the other hand, causality from ED to IND has been detected. The economic reasons behind the identification of causality from ED to IND in Slovakia can be explained as follows: i. The industrial sector in Slovakia is energy-intensive, and its expansion can contribute to a rise in energy consumption. ii. Slovakia has an economy that relies heavily on exports, and the industrial sector constitutes a significant part of its exports. The growth of the industry can result in increased exports, which, in turn, may lead to a higher ED necessary for economic growth. iii. The growth of the industry in Slovakia can also be associated with technological advancements. Developing technology can lead to increased efficiency in the industry, which in turn can result in higher (ED). Based on these findings, it can be inferred that the relationship between IND and ED may vary across countries, and each country needs to formulate policies based on its specific conditions. For example, countries like Poland, Estonia, and Hungary may need to implement energy conservation policies alongside industrial growth policies. On the other hand, in other countries, policies regulating industrial activities to control the increase in ED may be more crucial. According to the conclusions of the causality test between ENV and (ED), it has been found that in Lithuania, ED is influenced by ENV in a one-way direction. In other countries, this relationship is not significant. In Poland, Slovakia, and Slovenia, a one-way causality relationship between ED and ENV has been identified. These results indicate that energy consumption is a triggering factor for ENV in these countries. Therefore, various policies can be implemented in countries like Poland, Slovakia, and Slovenia to reduce the impact of ED on ENV. For example, increasing energy efficiency, transitioning to renewable energy sources, implementing stricter waste management measures, and effectively implementing environmental conservation policies can be important steps in these countries. According to the findings of the causality test between EG and (ED), except for the Czech Republic, all countries in the panel show that ED drives EG. This indicates that energy is an important input for EG, and as EG increases, ED also increases. In Poland, Slovakia, and Slovenia, a two-way causality relationship between EG and ED has been identified. These results are significant for energy policies. These countries should implement more sustainable energy policies to balance energy use and environmental impacts. For example, they can reduce ED by investing in renewable energy sources. Additionally, increasing energy efficiency and implementing energy-saving measures can also reduce ED and mitigate environmental impacts. The causality test results between RD and ED show that in Poland, there is a one-way causality between RD and ED. In Slovakia, there is a one-way causality from ED to RD. This suggests that an increase in ED leads to RD, but RD does not affect ED. This result indicates that Slovakia's EG relies heavily on energy and that RD has a negative impact on economic growth. Additionally, the increase in ED can lead to RD, ought to be factored in energy policies. The results in Table 7 also show a two-way causality between RD and ED in the Czech Republic, Hungary, Latvia, and Lithuania. This indicates that EG in these countries increases ED and, at the same time, increasing ED also leads to (RD). RD can result in environmental problems, increased pollution, and loss of biodiversity in these countries. Therefore, policies need to be developed to use resources more efficiently and increase the use of alternative energy sources. On the other hand, the increase in ED is closely related to EG and can accelerate RD due to the increased amount of energy used in production processes. Therefore, policies such as increasing energy efficiency, investing in renewable energy sources, and using production methods that have less impact on the environment can serve as solutions to the two-way causality issue between RD and (ED). In CEE countries, the connection between IND, EG, ENV, and RD in relation to ED can be examined more comprehensively through future studies utilizing time series analysis that incorporates sectors and energy sources.

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