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FOSTERING GREEN TRANSITION IN CENTRAL AND EASTERN EUROPE: CARBON DIOXIDE EMISSIONS, INDUSTRIALIZATION, FINANCIAL DEVELOPMENT, AND ELECTRICITY NEXUS

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Abstract. Climate change presents a substantial impediment for the global community and prompts policymakers worldwide to prioritize environmental goals when defining national development strategies. Prioritizing these goals is particularly challenging for governments of developing economies still relying on fossil fuels, foreign capital, and industry contribution to GDP. This study examines the relationships between carbon dioxide emissions, industry value added, financial development, and electricity generation in 15 Central and Eastern European countries from 1995 to 2021. To achieve this objective, we examined stationarity and cointegration and employed a vector error correction model to investigate causalities between the variables, along with a variance decomposition analysis. Our findings suggest that the short-run unidirectional causalities exist from industry value-added to carbon dioxide emissions and from carbon dioxide emissions to financial development and electricity generation. Long-term causality exists between carbon dioxide emissions and industry value added. The findings shed light on the challenges and opportunities these countries face in transitioning to climate neutrality and meeting the decarbonization targets. Within this context, the findings underscore the significance of crafting customized strategies for these economies to navigate the complex landscape of climate change while promoting sustainable industrial, electricity and financial sector development.

Keywords: CEE countries, CO_2 emission, industry, electricity generation, financial development.

JEL Classification: C33, O13, O14, Q43, Q50.

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1. Introduction

Climate change stands as one of the gravest challenges ever encountered by humanity (Wang et al., 2018a; Claudelin et al., 2020; Bouman et al., 2020). The amount of carbon dioxide (CO_2) in the atmosphere has increased due to human activity, and in 2021, emissions from all types of industrial processes and energy combustion reached 36.3 gigatons (International

Energy Agency [IEA], 2022). By the end of this century, global temperature is predicted to grow by 1.5 °C (or more), and the current amount of CO_2 will increase to 1.5 billion tons annually (Valone, 2021). The alarming evidence on the extent of pollution and climate change made policymakers concern and search for solutions to the growing environmental crisis. The exhaustion of resources and the proliferation of pollution have intensified, so current government policies must be reevaluated (Zeiger et al., 2019; Akhter et al., 2020). Environmental objectives, such as lowering greenhouse gas (GHG) emissions and boosting the share of renewable energy sources (RES), have become the priority in developing energy policies in the XXI century. In addition, the need to preserve energy independence has grown again in light of the Russia-Ukraine conflict and the COVID-19 pandemic (Jonek-Kowalska, 2022).

The environmental and energy challenges have grown to unprecedented levels, and disregarding them is no longer a viable choice. Since many developing economies still rely heavily on fossil fuels, particularly coal, these economies must prioritize phasing out coal use and increasing their RES investment to achieve net-zero global emissions by the middle of the XXI century. Achieving these objectives requires financial support for energy transition through reallocating economic welfare from developed to developing countries (Balsalobre-Lorente et al., 2023). Most academics concur that financial development is essential to technological development. Financial development can encourage investment with high returns, increase credit to individuals and businesses, and improve the distribution of resources (Khezri et al., 2021). Additionally, it stimulates companies and decision-makers to adopt technological advancements that can reduce GHG emissions and improve air quality (Jalil & Feridun, 2011; Tang & Tan, 2015; Lv & Li, 2021; Zhou & Huang, 2022).

Nevertheless, it remains to be seen how developing countries will strive without generating more CO_2 emissions because achieving this goal is exceedingly difficult, as they have to fight poverty and increase population welfare by improving national economic performance. Since these countries' primary and manufacturing sectors remain essential, a less stringent regulatory framework with higher emission limitations could determine their investment attractiveness (Santos & Forte, 2021; Cansino et al., 2021). Namely, environmental policies in developing countries are uneven, and globalization promotes the expansion of polluting-intensive sectors (Haseeb et al., 2018; Sabir & Gorus, 2019), reflecting the assumptions of the Pollution Haven Hypothesis (Mani & Wheeler, 1998). It is one of the theories explores the strategy of companies from developed countries seeking regions with lax environmental regulations to relocate their energy-intensive production facilities. This relocation in turn leads to environmental damage and pollution in the host countries. The disparities in environmental regulation between highly regulated developed countries and less regulated developing countries allow the latter to leverage this disparity as a competitive advantage in attracting investors operating in intense polluting industries.

Considering that a substantial reduction in emissions requires collective global action because the effects of climate change are borderless, the Paris Agreement was adopted in 2015 and signed by 195 nations (Pablo-Romero et al., 2021). Among these are Central and Eastern European (CEE) countries, characterized by a specific type of political economy named a Dependent Market Economy (DME) by Nölke and Vliegenhart (2009). The primary driving force behind the DMEs is foreign capital flow and the significant role of international companies, which relocate their manufacturing operations to CEE countries, attracted by the regions' low wages, reasonably proficient workforce, and favorable tax policies. Moreover, DMEs are characterized by significantly higher centralization of decision-making processes, lower levels of transparency, complex political party favoritism, and greater corruption levels than Western European countries. These factors decrease governing capabilities and hinder the deliberate efforts of countries to transform the domestic economy towards a green one (Innes, 2016). Besides that, these countries' governments are focused on ensuring energy security and affordable energy costs for both industrial and residential use regardless of the sources from which energy is generated. Several economic factors significantly shape government attitudes toward European Union (EU) energy and climate policies in market dynamics. These factors include the level of technological lock-in observed in energy sources derived from fossil fuels, the concentration of interests held by national energy companies, their economic and technological capabilities to capitalize on emerging energy and climate policies, and various other considerations. These factors have been identified as influential by Scheiring (2018).

So, a certain "delay" of CEE countries compared to the more advances Western European countries (Hatmanu & Cautisanu, 2023) regarding the conversion to a climate-neutral economy has roots in their former economic and political system which shaped their main characteristics:

1. There is an increasing perception of these countries being akin driven by commonalities in their political, economic frameworks, and energy landscapes (Ćetković & Buzogány, 2019).
2. The shared regional context provides an opportunity to explore the influence of region-specific issues that have not been adequately contemplated in the existing literature.
3. The geographical location of CEE countries means that GHG emissions in one country can depend on pollution generated by other countries within the region (Simionescu et al., 2022).
4. Despite efforts to shift their economies towards service sectors (Fedajev et al., 2019), these countries still rely heavily on energy-intensive manufacturing activities.
5. Due to their centrally planned past, these economies have energy mixes traditionally dominated by fossil fuels (Jonek-Kowalska, 2022).
6. CEE countries need assistance with low domestic investments and political will to finance the transition to a low-carbon economy, posing significant technological and economic difficulties in achieving energy transition.
7. CEE countries joined the EU relatively late or are still candidates for membership, putting pressure on their governments to meet targets set by EU regulations and strategies (Brodny & Tutak, 2021).

Therefore, considering their geopolitical location, the state and structure of their economies, their investment positions, and the need to align with EU decarbonization targets (Ćetković & Buzogány, 2019; Šikšnelytė-Butkienė et al., 2022), it is fully justified to research this particular group of countries.

The scientific motivation for investigating this subject arises from its relevance and the need to ensure effective governance in the post-pandemic era with uncertain global socio-political circumstances. Such analysis is crucial to support the development of green economies and Industry 4.0 in the CEE countries. In that context, this study explores connections between CO_2 emissions, industry value-added, financial development, and electricity generation, utilizing a panel dataset encompassing 15 CEE countries from 1995 to 2021. The selected CEE countries are Belarus, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, North Macedonia, Poland, Romania, Serbia, Slovakia, Slovenia, and Ukraine. By utilizing a methodological framework consisting of unit root tests, cointegration tests, vector error correction model (VECM), and variance decomposition, this research enriches the existing literature concerning the dynamics between energy, economics, and the environment, addressing the lack of consensus regarding these variables' nexus in CEE economies.

This study makes several significant contributions and introduces novelties in the context of investigating the nexus between CO_2 emissions, industry value-added, financial development, and electricity generation in CEE countries. Firstly, it addresses the relevance and imperative of effective governance in the post-pandemic era amid uncertain global socio-political circumstances, underscoring its timeliness and importance. Secondly, it actively supports the development of green economies in the CEE region by offering empirical insights into the relationships between CO_2 emissions, industry value-added, and electricity generation, thus facilitating informed policymaking for sustainability. Thirdly, the study uniquely integrates financial development as a pivotal variable, enhancing our comprehension of the intricate connections that link financial systems, industrial growth, and environmental impact. Fourthly, the study leverages a comprehensive panel dataset encompassing 15 diverse CEE countries over an extensive period, enabling nuanced insights into the region's varied dynamics. Lastly, it directly addresses the absence of a unanimous agreement in the existing literature regarding the nexus between energy, economics, and the environment in CEE economies, striving to provide clarity and evidence-based insights that inform both scholarly discourse and policymaking in the region.

The paper is organized in the following manner: Section 2 provides the theoretical background based on previous studies, Section 3 outlines the data and methodology employed, Section 4 presents the main findings and discusses the results, and finally, Section 5 concludes the paper.

2. Literature review

The majority of scholarly works in this domain focused on exploring the interplay between energy, economic growth, and environmental factors across various groups of countries (Khan et al., 2020; Vo et al., 2022a; Acuin et al., 2022; Mardani et al., 2019) and single countries (Duong & Tran, 2022; Adebayo et al., 2021; Raihan & Tuspekova, 2022a, 2022b). In these papers, most scholars have used CO_2 to evaluate environmental degradation, and they test the Environmental Kuznets Curve (EKC) for various countries. CO_2 emissions are used to denote environmental degradation in this study, since they are the predominant gas in GHG. In order to observe industrialization's specific impact on CO_2 emissions, this study replaces economic growth with industry value added. The first justification for this is the criticism leveled at the industrial sector's uncontrolled expansion. The second factor is the plethora of articles exploring the interconnection of economic growth and CO_2 emissions (Adom et al., 2012; Salahuddin et al., 2018; Raihan & Tuspekova, 2022a; Bako et al., 2022), although it is vital to pay attention to the causal links between carbon emissions and specific economic sectors, with the industry being one of the most significant (Gokmenoglu et al., 2015; Baležentis et al., 2023). Hence, industry value added is used in this study as a proxy of industrialization to emphasize the industry's specific role in CO_2 generation in CEE economies.

One of the studies using the industry value added is the analysis of Alam (2019), who applied the Johansen cointegration test and VECM to identify the relationship between CO_2 emissions, gross domestic product (GDP) per capita and industrial value-added in India. The paper's findings suggested a long-run relationship among CO_2 emissions, industrial value added, and GDP per capita. If GDP per capita remains constant, a rise in industry value-added results in CO_2 emissions increase. Otherwise, if industry value-added is fixed, the link amongst CO_2 emissions and GDP per capita takes a monotonous downward slope which is opposed to the inverted U-shaped curve that EKC suggests. In their extensive study, Jebli et al. (2020) analyzed the interplay between economic growth, the consumption of renewable energy, the added value of the industrial and service sectors and CO_2 emissions in four income categories across 102 countries from 1990 to 2015. Their findings, after utilizing the generalized method of moments (GMM) and Granger causality, indicated complex relationships, including positive links between industry value-added and economic growth with CO_2 emissions in low-income countries, while upper-middle-income countries displayed negative impacts of economic growth on CO_2 emissions.

Similarly, Lin and Li (2020) examined the effects of industrialization, electricity use, urbanization and population on carbon emissions using data from 114 countries between 2000 and 2014. They utilized the fixed effects panel model, and the results revealed that electricity use negatively influenced carbon emissions. In contrast, population, urbanization, and industrialization positively impacted carbon emissions. In a study, conducted by Mirza et al. (2022), the impact of structural and activity effects on CO_2 emissions in the EKC context for 30 developing countries from 1990 to 2016 were analyzed. The results showed that as developing countries undergo structural shifts towards more polluting sectors, CO_2 emissions tend to increase. In addition, the study found that the use of renewable energy was associated with a mitigating effect, while the process of industrialization had a beneficial impact on CO_2 emissions in developing countries. This research highlights the importance of sustainable energy sources in curbing environmental degradation and emphasizes the role of industrialization in the evolution of CO_2 emissions in developing countries.

In a recent empirical study by Wang et al. (2020), the researchers explored the repercussions of industrialization and urbanization on CO_2 emissions within the APEC countries. They employed a new panel estimation DSUR technique and analyzed data from 1990 to 2014. The study revealed that industrialization intensifies environmental deterioration by elevating CO_2 emission levels.

The previous literature suggests that numerous scholars have introduced financial development when analyzing the growth-energy-environment nexus (Pata, 2018; Abokyi et al., 2019; Akca, 2021; Okere et al., 2021). Their findings indicate that the financial sector plays a significant role in influencing environmental quality. Empirical research has explored the connection between finance, income, and the environment, explicitly identifying the main factors contributing to high CO_2 emissions. Most authors pointed out that financial development leads to CO_2 emissions reduction (Lv & Li, 2021; Khezri et al., 2021) through increased investments in research and development (R&D), technological advancements, and the implementation of environmentally friendly innovations by companies. Additionally, it improves economic activities that influence the environment, attracts foreign direct investment (FDI) as a means of technology transfer, and reduction of energy intensity. An alternative viewpoint argues that financial development contributes to higher CO_2 emissions due to lower borrowing costs and reduced liquidity pressures for listed firms, which encourage increased production, economic output, and electricity consumption, but also by attracting FDIs that bring energy-intensive and dirty technologies. Another standpoint is that CO_2 emissions impact financial development, confirmed in studies conducted by Kihombo et al. (2021) and Shoaib et al. (2020). These authors investigated the impact of higher pollution on financial development. They concluded a negative association because higher pollution determines higher costs for the population with restoring a good health condition and affects the status of the companies and thus deters further financial development.

Using the most suitable energy indicator remains a highly debated issue when analyzing the impact of economic growth on environmental degradation. The most commonly used indicators are energy use (Muhammad & Khan, 2019; Abbasi et al., 2021; Mesagan & Olunkwa, 2022; Wang et al., 2022; Phong et al., 2018; Kar, 2022; Raihan & Tuspekova, 2022a), energy demand (Shahzad et al., 2021; Can et al., 2021; Hussain & Zhou, 2022), electricity consumption (Shahbaz et al., 2014; Salahuddin et al., 2018; Chukwunonso Bosah et al., 2020), renewable energy (Charfeddine & Kahia, 2019; Radmehr et al., 2021; Vo et al., 2022b; Rahman & Alam; 2022), and electricity generation (Sharif Ali et al., 2020; Karmellos et al., 2021; Liu et al., 2022; Alajmi, 2022; Saqib et al., 2023). This research uses electricity generation to consider its impact on CO_2 emissions but also to incorporate the postulates of the DME system present in most of the analyzed countries, which prioritizes the provision of a sufficient electricity volume for the economy and the households, regardless of the sources from which it is produced.

Numerous studies have explored the relationship between electricity generation and CO_2 emissions, with the majority indicating that an increase in electricity generation leads to a corresponding rise in CO_2 emissions (Farhani & Shahbaz, 2014; Mohiuddin et al., 2016; Sharif Ali et al., 2020; Khan, 2021; Alajmi, 2022; Liu et al., 2022). However, Shreezal and Adhikari (2021) revealed a bidirectional causality between electricity generation and CO_2 emissions while analyzing Nepal from 1990 to 2018. Interestingly, these results align with the long-run coefficient of the $lnCO_2$ model, which demonstrated a negative relationship between CO_2 emissions and electricity generation. The authors attributed this outcome to the growth in electricity generation from renewable sources observed during the study period in Nepal.

Literature body covering similar topics in CEE countries is not as extensive as for other groups of countries and global studies, but some academics have explored the growth–energy–environment nexus (Jorgenson et al., 2014; Destek et al., 2016; Saud et al., 2019; Destek, 2020; Simionescu, 2021). Previous research suggests that finance and income have varied environmental effects. So, there is no consensus on this matter specifically for CEE countries. Saud et al. (2019) investigated the relationship between financial development, income level, and environmental quality in a panel of 18 CEE countries from 1980 to 2016 to address this gap. The findings confirmed feedback relationships between financial development and energy consumption and a negative relationship between the financial development index and environmental quality. Destek et al. (2016) examined the connection between CO_2 emissions, real GDP, energy consumption, urbanization, and trade openness in ten CEE countries from 1991 to 2011. Their findings indicated that energy consumption leads to an increase in CO_2 emissions. The Granger causality method revealed a bidirectional causal relationship between CO_2 emissions and real GDP, as well as between energy consumption and real GDP. Also, the results demonstrated bidirectional causal links between real GDP and CO_2 emissions, energy consumption and CO_2 emissions, and energy consumption and real GDP in the long run.

The literature review presented in this study revealed that none of the research conducted in the CEE region, as well as other developing countries, has comprehensively examined the relationship between CO_2 emissions, industrialization, electricity generation, and financial development while adequately accounting for the specific economic and political contexts of these developing countries.

3. Data and methodology

3.1. Data

This study's CO_2 emissions per capita data were sourced from the Global Carbon Atlas (Global Carbon Atlas, 2023; Friedlingstein et al., 2022; Andrew & Peters, 2022; Peters et al., 2011; United Nations [UN], 2019). The industry value-added data was obtained from The World Bank (The World Bank, 2023). DBnomics (2023) served as the data source for the financial development index values, while electricity generation data was acquired from Our World in Data (2023). A comprehensive overview of the variables and units employed in this scientific paper can be found in Table 1.

As previously briefly mentioned in the literature review, we employ CO_2 emissions as the primary proxy for evaluating environmental quality. Additionally, using IVA instead of GDP offers several advantages, enabling a more focused examination of the environmental impact of industrial activities within CEE countries. While GDP offers a comprehensive view, IVA narrows the focus to assess the value added by industries, which is valuable when addressing issues related to pollution, resource consumption, and sustainability within key (polluting) sectors of the CEE economies. In essence, IVA provides a tailored perspective for studying the environmental impact of industries in CEE countries, serving as a valuable tool for informed decision-making and sustainable development.

Table 1. Variable description (source: authors)

Variables	Abbreviation	Scale	Source
CO_2 emissions	CO_2	tons per capita	Global Carbon Atlas (2023)
Industry value-added	IVA	% of GDP	The World Bank (2023)
Financial Development Index	FDX	a score between 0 to 1	DBnomics (2023)
Electricity generation	ELE	TWh	Our World in Data (2023)

The FDX is a valuable variable due to its versatility in serving as a proxy for economic activity, evaluating access to green financing, gauging the effectiveness of environmental policies, and measuring resilience in the face of environmental challenges. It offers insights into the financial infrastructure and incentives for sustainable investments, rendering it a relevant indicator for understanding the connection between financial development and environmental sustainability.

Besides the aforementioned rationale for choosing electricity generation in the DME context, it also offers a direct measure of a country's environmental impact and its progress toward sustainable energy practices. Choosing electricity generation data over consumption data provides numerous advantages. It can serve as a quantifier of commitments to renewable energy, facilitating accurate assessments of efforts to reduce carbon emissions. Moreover, it highlights the reduction in dependence on nonrenewable energy sources, bearing economic and geopolitical implications. This approach enables effective evaluation of policies and investments, optimized resource allocation, and a comprehensive understanding of energy landscapes, encompassing both supply and demand dynamics. In the context of CEE countries, where energy profiles often feature a mix of conventional and renewable sources, analyzing electricity generation data becomes particularly relevant for environmental research. This approach allows researchers to pinpoint the environmental implications of this diverse energy portfolio, assess policy effectiveness in transitioning to cleaner sources, and monitor progress in reducing carbon emissions in a region where energy sustainability is of growing significance.

3.2. Methodology

The estimation procedure adopts a widely used approach in panel cointegration analysis, building upon the research conducted by Khan and Rana (2021), Kim (2019), Wang et al. (2018b), Destek et al. (2016), Al-mulali and Sab (2012), and Al-mulali (2011), amongst others. The procedure encompasses unit root testing, cointegration testing, and causality assessment.

Therefore, the methodology employed in this study is directed towards exploring long-term relationships between CO_2 emissions and specifically chosen model variables. The following functional form presents the model:

$$Y_{i,t} = +\beta' X_{i,t} + u_{i,t},\ t = 1,\ldots,T;\ i = 1,\ldots,N, \quad (1)$$

where $Y_{i,t}$ is a response variable, α is a scalar, β' is the m-dimensional vector of coefficients, $X_{i,t}$ is an m-dimensional vector of the predictor variables, $u_{i,t}$ is a random error, t denotes the period, and i is the cross-section unit denoting the country. Moreover, per Eq. (1), the response variable in the model is represented by CO_2 emissions, while the predictor variables encompass industry value-added (IVA), financial development index (FDX), and total electricity generation (ELE). Thus, the model is as follows:

$$CO_{2i,t} = \alpha + \beta_1 IVA_{i,t} + \beta_2 FDX_{i,t} + \beta_3 ELE_{i,t} + u_{i,t}. \quad (2)$$

Panel data analysis allows for individual heterogeneity control, provides more informative and varied data, and studies dynamic adjustments over time. Additionally, panel data models enable the identification of effects that may not be apparent in pure cross-sectional or time series data and allow for the construction and testing of more complex behavioral models (Baltagi, 2005; Klevmarken, 1989; Hsiao, 2003; Tang et al., 2012; Baltagi, 2007; Pradhan et al., 2014; Hsiao & Hsiao, 2006; Mitić et al., 2020).

3.2.1. Panel unit root testing

Stationarity is important in panel analysis to ensure reliable statistical inferences and model estimation. Non-stationary data can result in spurious regression outcomes and unreliable conclusions. By requiring stationarity, panel analysis ensures stable relationships over time, enabling accurate and meaningful data interpretation. Unit root tests for panel data serve as an extension of tests for individual time series, aiming to capture the characteristics of comparative data. It has been noted by Al-mulali (2011) that panel unit root tests possess greater statistical power compared to conventional unit root tests for individual time series. However, the selection of unit root tests is influenced by cross-sectional dependence, which tends to be prevalent in panel data (Mitić et al., 2023). Henningsen and Henningsen (2019) assert that this dependence is often attributed to the influence of undetected common factors that affect all units in varying ways. Mitić et al. (2023) further state that in scenarios where cross-sectional dependence is detected, the theoretical framework suggests utilizing second-generation panel unit root tests, such as CIPS (Pesaran, 2007) or PANIC (Bai & Ng, 2004).

Conversely, in situations where cross-sectional dependence is not observed, it is appropriate to consider first-generation panel unit root tests, including the IPS test (Im et al., 2003), LLC test (Levin et al., 2002), Breitung test (Breitung, 2001), Fisher-PP test (Choi, 2001), and\or Fisher-ADF test (Maddala & Wu, 1999). In all examinations, the null hypothesis posits that each individual process possesses a unit root, while the alternative hypothesis suggests that at least one of the processes lacks a unit root.

3.2.2. Panel cointegration tests

After the stationarity assumptions are satisfied, the estimation procedure advances to panel cointegration testing. In panel data context, cointegration analysis aims to investigate correlations between multiple variables across different countries. This analytical approach allows for assessing the long-term relationships among the examined variables.

This study will analyze the data using two commonly employed panel cointegration tests: the Johansen Fisher (Maddala & Wu, 1999) and the Pedroni panel cointegration test (Pedroni, 2004).

The foundation of the Johansen Fisher Panel Cointegration Test, as introduced by Johansen (1988), relies on the Vector Error Correction representation of the VAR(p) process:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{p=1}^{P-1} \Gamma_p \Delta Y_{t-p} + u_t, \tag{3}$$

where Y_t is a k-dimensional vector of potential cointegrating variables, Π and Γ_p are coefficients, and u_t is the error term.

To assess the existence of cointegration in non-stationary time series, two approaches are proposed: the likelihood ratio trace statistics and the maximum eigenvalue statistics. In the context of panel data, Maddala and Wu (1999) extend Johansen's (1988) univariate case by presenting a panel alternative.

"The Pedroni panel cointegration test utilizes different statistics to test the null hypothesis of no cointegration" (Petrović-Ranđelović et al., 2020, p. 429). Furthermore, according to Petrović-Ranđelović et al. (2020), Pedroni (2004) introduces two sets of panel cointegration test statistics to examine the presence of cointegration relationships. The first group comprises four statistics, assuming a common autoregressive (AR) process. The second group of statistics allows for variations in individual processes and consists of three measures.

As a result, Pedroni's panel cointegration test statistics provide researchers with a robust toolkit to investigate and assess cointegration across different panel structures and individual process variations. "Although the Pedroni test offers more test statistics, the Johansen-Fisher test has the advantage of indicating not only the presence of cointegration but also the number of cointegration vectors" (Petrović-Ranđelović et al., 2020, p. 430).

3.2.3. Panel causality tests

The presence of cointegration between variables indicates the existence of at least one causal link among them. The Granger causality test can be employed to determine the direction of causality within panel models, as it enables the identification of short-run causality by conducting a joint examination of the coefficients using F-statistics and χ^2 tests (Granger, 1988).

Moreover, examining long-run causal relationships can be done by analyzing the lagged error correction term within the VECM through t-tests. Including the error correction term in the VECM facilitates the assessment of the equilibrium adjustments between variables over time, providing insights into the long-term causality patterns. The VECM is an enhanced alternative to conventional error correction model (ECM) tests, as it incorporates error correction functions into the vector autoregressive model (VAR). Firstly, the VECM eliminates the need for pre-tests, simplifying the analytical process. Secondly, it allows for the inclusion of multiple cointegrating relationships, enabling a comprehensive analysis of the long-term dynamics. Additionally, all variables are treated as endogenous within the VECM framework, facilitating a comprehensive understanding of their interdependencies. Lastly, the VECM enables tests related to long-run parameters, further enhancing the depth of analysis (Hill et al., 2010).

The Granger causality test offers a comprehensive framework for investigating and determining the direction of causal relationships within panel models by employing both the short-run and long-run approaches (Granger, 1988). The subsequent equations depict the panel Granger causality:

$$\Delta CO_{2i,t} = \alpha^{a}_{i,t} + \sum_{i=1}^{l} \beta^{a}_{i,t} \Delta CO_{2i,t-1} + \sum_{i=1}^{l} \gamma^{a}_{i,t} \Delta IVA_{i,t-1} + \sum_{i=1}^{l} \varphi^{a}_{i,t} \Delta FDX_{i,t-1} + \sum_{i=1}^{l} \theta^{a}_{i,t} \Delta ELE_{i,t-1} + \tau^{a}_{i,t} ECT_{i,t-1} + u_{i,t}; \tag{4}$$

$$\Delta IVA_{i,t} = \alpha^{b}_{i,t} + \sum_{i=1}^{l} \beta^{b}_{i,t} \Delta IVA_{i,t-1} + \sum_{i=1}^{l} \gamma^{b}_{i,t} \Delta CO_{2i,t-1} + \sum_{i=1}^{l} \varphi^{b}_{i,t} \Delta FDX_{i,t-1} + \sum_{i=1}^{l} \theta^{b}_{i,t} \Delta ELE_{i,t-1} + \tau^{b}_{i,t} ECT_{i,t-1} + u_{i,t}; \tag{5}$$

$$\Delta FDX_{i,t} = \alpha^{c}_{i,t} + \sum_{i=1}^{l} \beta^{c}_{i,t} \Delta FDX_{i,t-1} + \sum_{i=1}^{l} \gamma^{c}_{i,t} \Delta CO_{2i,t-1} + \sum_{i=1}^{l} \varphi^{c}_{i,t} \Delta IVA_{i,t-1} + \sum_{i=1}^{l} \theta^{c}_{i,t} \Delta ELE_{i,t-1} + \tau^{c}_{i,t} ECT_{i,t-1} + u_{i,t}; \tag{6}$$

$$\Delta ELE_{i,t} = \alpha_{i,t}^{d} + \sum_{i=1}^{l} \beta_{i,t}^{d} \Delta ELE_{i,t-1} + \sum_{i=1}^{l} \gamma_{i,t}^{d} \Delta CO_{2i,t-1} + \sum_{i=1}^{l} \varphi_{i,t}^{d} \Delta IVA_{i,t-1} + \sum_{i=1}^{l} \theta_{i,t}^{d} \Delta FDX_{i,t-1} + \tau_{i,t}^{d} ECT_{i,t-1} + u_{i,t}, \tag{7}$$

where Δ is the first difference operator, $\alpha_{i,t}$ is a constant term, $\beta_{i,t}$, $\gamma_{i,t}$, $\varphi_{i,t}$, $\theta_{i,t}$, and $\tau_{i,t}$ are parameters, $ECT_{i,t-1}$ is the lagged error correction term, and $u_{i,t}$ is the white noise.

Granger causality tests provide insight into the direction of causal relationships between variables. To gain a more comprehensive understanding of the significance of one variable's causal influence on another and how each variable responds to changes in the others, a variance decomposition analysis is indispensable (Wang et al., 2018b). In essence, by decomposing forecast error variances for each variable and identifying the extent to which other variables explain the information within a particular variable, we can gauge the contribution of one variable toward the explanation of another. When a variable is predominantly explained by its own past values, it is considered mostly exogenous. Conversely, if other variables primarily account for the variation in a particular variable, it is deemed mostly endogenous.

Through this analysis, variables can be characterized as predominantly exogenous or predominantly endogenous, thereby shedding light on their individual contributions to explaining other variables. This analytical technique enhances our understanding of the intricate relationships among variables and provides a robust framework for examining their roles within the system under investigation.

4. Results and discussion

Countries in today's globalized world have become increasingly interdependent, particularly in regions where close geographic proximity and economic linkages facilitate cross-border spillovers. The transmission of shocks across borders, where changes in one country can impact other countries, is a clear example of this interconnectedness. It includes shifts in public policies, the adoption of new technology, investments in the environment, trade agreements, political changes, and conflicts, all of which have the potential to impact other countries. Consequently, it is crucial to recognize that all countries exhibit some degree of interdependence. Failure to account for cross-sectional dependence can lead to inefficient estimators and produce invalid or potentially misleading results. As a result, it is essential to consider the potential spillover effects of cross-sectional dependence when analyzing data in the context of interdependent countries.

Multiple tests are available to examine cross-sectional dependence in panel data. The LM test proposed by Breusch and Pagan (1979) is well-suited for panels with limited cross-sectional units. Conversely, the scaled LM test proposed by Pesaran (2004) is better suited for extensive panel datasets with numerous cross-sectional units and long time dimensions. In contrast, Pesaran's CD test is most appropriate when dealing with a limited number of cross-sectional units and shorter time spans. For panels comprising a substantial number of cross-sectional units and a constrained time dimension, the bias-corrected scaled LM test introduced by Baltagi et al. (2012) is the more fitting choice.

Considering the characteristics of our dataset, we utilized the Pesaran (2004) CD test, specifically chosen for its compatibility with datasets featuring a restricted number of cross-sectional units and a limited time dimension. This particular test, the Pesaran CD test, offers the capability to assess the presence of any cross-sectional dependence among the time series under examination. The outcomes of this assessment, as portrayed in Table 2, affirm the acceptance of the null hypothesis, signifying the absence of cross-sectional dependency or correlation within the analyzed time series in this study.

Table 2. Residual cross-section dependence test (source: authors' calculation)

Test	Statistics
Pesaran CD	–0.055312

Note: Asterisks indicate statistical significance: *** <0.001, ** 0.001 to 0.01, and * 0.01 to 0.05. The data exhibited non-zero cross-section means. To compute correlations, these cross-section means were removed.

Prior to delving into the examination of cointegration, it is imperative to establish the appropriate order of integration. To accomplish this, five different panel unit root tests were employed, each providing a unique perspective: Levin, Lin & Chu, Breitung, Im, Pesaran and Shin, ADF-Fisher, and PP-Fisher. The Levin, Lin & Chu and Breitung tests assume a common unit root process that extends across all cross-sections, whereas the remaining three tests assume an individual unit root process for each cross-sectional unit (Mitić et al., 2020). In all five tests, the null hypothesis assumes the presence of a unit root, while the alternative hypothesis suggests its absence.

The results of the unit root tests are summarized in Table 3. These findings are essential to determine the appropriate panel cointegration test to apply and establish the existence of long-term relationships between the variables. Moreover, identifying the integration order is fundamental for understanding the long-term relationship dynamics between the variables under study.

The tests show that variables are non-stationary at the level but become stationary after being differenced once. The null hypothesis of a unit root cannot be rejected at the 0.01 per cent significance level at level, but it can be rejected at the first difference. Thus, the variables are integrated of order 1 – $I(1)$. While only the Levin, Lin & Chu test at the level suggests stationarity for the financial development index, all four other tests indicate non-stationarity. Similarly, the ADF-Fisher and PP-Fisher tests for electricity generation suggest stationarity at the level, but the other three tests show non-stationarity. Given that the vast majority of tests, under all assumptions, show non-stationarity at the level and stationarity at the first difference, we proceed with testing for cointegration.

Table 4 presents the results of the Johansen Fisher Panel Cointegration test, indicating the existence of at least two cointegrated equations among the four variables, suggesting that they are cointegrated. The result indicates a panel long-run cointegration relationship, as Pao and Tsai (2011) suggested, which is a critical condition to eliminate the possibility of spuriously estimated relationships.

Table 3. Panel unit root test results (source: authors' calculation)

Variable	Levin, Lin & Chu t*	
	Level	1st diff
CO_2	–0.21455	–9.44875***
IVA	–0.73512	–12.7361***
FDX	–2.12695*	–14.3241***
ELE	–1.26115	–13.1915***
	Breitung t-stat	
	Level	1st diff
CO_2	1.01968	–7.27991***
IVA	–1.50736	–9.21917***
FDX	1.86402	–8.53915***
ELE	0.15993	–8.17947***
	Im, Pesaran and Shin W-stat	
	Level	1st diff
CO_2	–0.45861	–10.2366***
IVA	–0.81227	–11.9809***
FDX	–0.03547	–14.3695***
ELE	–1.15297	–13.9771***
	ADF - Fisher Chi-square	
	Level	1st diff
CO_2	33.6478	142.782***
IVA	36.9703	173.072***
FDX	33.0253	201.572***
ELE	46.2097*	197.446***
	PP - Fisher Chi-square	
	Level	1st diff
CO_2	26.9922	163.031***
IVA	25.4307	186.987***
FDX	27.1728	301.102***
ELE	47.8127*	799.233***

Note: Asterisks indicate statistical significance: *** <0.001, ** 0.001 to 0.01, and * 0.01 to 0.05. Schwarz automatic selection was used for lag length. An asymptotic Chi-square distribution for computing Fisher probabilities.

Moreover, our findings suggest that Granger causality exists in at least one direction. Confirming cointegration is required for drawing valid conclusions on Granger causality in panel data. Thus, cointegration among the variables supports the notion of a causal relationship between the variables.

Table 4. Johansen Fisher panel cointegration test results (source: authors' calculation)

H_0: Variables are not cointegrated		
Hypothesized No. of CE(s)	Trace	Maximum eigenvalue
r = 0	173.2***	125.7***
r ≤ 1	76.12***	56.25***
r ≤ 2	40.05	31.11
r ≤ 3	28.30	28.30

Note: Asterisks indicate statistical significance: *** <0.001, ** 0.001 to 0.01, and * 0.01 to 0.05. r is the number of cointegrating equations. Probabilities computed by asymptotic Chi-square distribution.

To further confirm the existence of cointegration, an additional test was conducted using the Pedroni residual cointegration test, assuming a deterministic intercept and trend (Table 5). The results of the test, including weighted statistics, have been reported. Six of the eleven statistics reject the null hypothesis of no cointegration, suggesting that all four variables are cointegrated. It proves that industry value-added, financial development index, and electricity generation have a long-run relationship with CO_2 emissions.

The utilization of the vector error correction approach allows for the estimation of cointegrating coefficients among the variables, as the results of both the Johansen Fisher and Pedroni cointegration tests indicate a long-term relationship among the series in our model.

The study identifies (Table 6) a short-run unidirectional panel causality from industry value-added to CO_2 emissions, which suggests that industrial activities significantly contribute to CO_2 emissions in the short run, consistent with existing literature (Lin & Li, 2020; Wang et al., 2020; Mirza et al., 2022). Manufacturing and production, which are energy-intensive processes, heavily rely on fossil fuels that release CO_2 emissions. For instance, coal-fired power plants, which are significant CO_2 emitters, predominate the electricity sector in many CEE countries. An increase in industrial activity can result in electricity consumption spikes, leading to a rise in CO_2 emissions from power plants. Also, the high-temperature procedures necessary to produce steel and cement demand significant energy and emit substantial amounts of CO_2. Therefore, an increase in industrial activities in the short run can lead to a rise in CO_2 emissions, making the short-run unidirectional panel causality from industry value-added to CO_2 emissions observed in the study plausible.

Furthermore, the study demonstrates a short-run unidirectional panel causality from CO_2 emissions to the financial development index, which coincides with the results of Kihombo et al. (2021) and Shoaib et al. (2020). CO_2 emissions have a variety of short-term effects on financial development. Creating harmful externalities that undermine a country's overall economic and social well-being is one of the most obvious ways CO_2 emissions can impact financial development. For instance, CO_2 emissions can result in pollution, which could harm the health of individuals, leading to increased healthcare costs and productivity losses. These negative externalities could weaken the overall economic performance of a country, diminishing the overall financial development in the short run. Additionally, countries that are significant emitters of CO_2 may face regulations that aim to reduce emissions and promote sustainability, leading to increased production costs and higher energy prices that ultimately impact the financial development of a country. Therefore, the short-run unidirectional panel causality from CO_2 emissions to the financial development index observed in the study implies that policymakers should consider the negative implications of CO_2 emissions on financial development when designing climate change policies in the CEE.

The study also identifies a short-run unidirectional panel causality from CO_2 emissions to electricity generation, as in Farhani and Shahbaz (2014), suggesting that an increase in CO_2 emissions may result in a rise in electricity generation in the short run. One of the most direct ways that CO_2 emissions can impact electricity generation is through the availability of energy sources. Some CEE countries still rely heavily on fossil fuels such as coal to generate electricity, and increased demand for electricity may lead to increased CO_2 emissions. As a result, an increase in CO_2 emissions may lead to a surge in electricity generation in the short run. Additionally, the cost of electricity generation may increase if there is increased use of fossil fuels, which are significant sources of CO_2 emissions, leading to higher energy prices. Therefore, policymakers should consider the need for effective energy policies to transition towards more sustainable and cleaner energy sources to mitigate the negative impacts of

Table 5. Pedroni residual panel cointegration test results (source: authors' calculation)

H_0: No cointegration		
Test	Deterministic intercept and trend	
H_a: common AR coefs. (within-dimension)		
	Statistics	Weighted Statistics
v-Stat	–1.165094	–0.988316
rho-Stat	1.097697	0.564987
PP-Stat	–2.037597*	–3.607325***
ADF-Stat	–3.081319***	–4.575570***
H_a: individual AR coefs. (between-dimension)		
	Statistics	Weighted Statistics
v-Stat	2.312583	–
rho-Stat	–1.683359*	–
PP-Stat	–2.098338*	–

Note: Asterisks indicate statistical significance: *** <0.001, ** 0.001 to 0.01, and * 0.01 to 0.05. Automatic lag length selection: SIC with a max lag of 4.

Table 6. Panel causality analysis results (source: authors' calculation)

Short-run Granger causality					Error correction	
	ΔCO_2	ΔIVA	ΔFDX	ΔELE	ECT (–1)	Coeff.
ΔCO_2	–	5.006549*	1.720779	2.871628	–2.666877***	–0.028040
ΔIVA	4.114465	–	0.568231	0.179244	–2.938419***	–0.012579
ΔFDX	7.667681**	0.402322	–	1.151527	–0.288259	–0.006318
ΔELE	5.111500*	0.020677	0.348441	–	1.117579	0.064132

Note: Asterisks indicate statistical significance: *** <0.01, ** 0.01 to 0.05, and * 0.05 to 0.1. Δ – first difference operator. ECT (–1) – error correction term lagged 1 year.

CO_2 emissions on the environment. Moreover, CO_2 emissions can indirectly affect electricity generation by promoting the adoption of cleaner and more sustainable energy sources. Countries may invest in renewable energy sources such as wind and solar power to reduce their dependence on fossil fuels and mitigate the negative impacts of CO_2 emissions on the environment. The shift towards cleaner energy sources could reduce CO_2 emissions and decrease electricity generation in the short run.

In the long run, our study investigated the speed of adjustment of variables towards their long-run equilibrium using the lagged error correction term (ECT (–1)) column and the estimated coefficient of the ECT. A statistically significant coefficient of ECT implies a long-run causal relationship between variables. The results indicate a significant long-run causal relationship between CO_2 emissions and industry value-added, as Alam (2019) suggested, but no long-run causal relationship between CO_2 emissions and financial development index or electricity generation.

These results suggest that policymakers in CEE countries should promote industrial and financial growth while mitigating economic activities' negative environmental impacts. It can be achieved by implementing policies that reduce carbon emissions and promote sustainable electricity generation. Our research outcomes offer a valuable resource for policymakers to craft effectual strategies fostering sustainable economic expansion while mitigating the unfavorable impacts of climate change.

The results also revealed that CEE countries should consider diversifying their energy mix and transitioning towards cleaner energy sources, such as renewables. It can help reduce their dependence on fossil fuels, lower their carbon emissions, and promote sustainable economic growth and industrial output in the long run. Furthermore, policies directed towards enhancing energy efficiency and curbing wasteful practices have the potential to alleviate the environmental footprint of economic endeavors, all the while fostering economic growth.

Overall, our findings highlight the need for policymakers to balance economic growth with environmental sustainability, particularly in the long run. Failure to do so could lead to adverse environmental impacts and undermine the long-term economic prospects of CEE countries.

Table 7 presents the variance decomposition results for the response variables: CO_2 emissions, industry value added, financial development index, and electricity generation over the 5 years. Considering the available years of observation, we selected a 5-year forecasting view. The values in each cell represent the percentage of variance in the response variable explained by the impulse variables (CO_2, IVA, FDX, and ELE) at each period.

Table 7. Variance decomposition results (source: authors' calculation)

Response variable	Period	Impulse variable			
		CO_2	IVA	FDX	ELE
CO_2	5	98.41289	1.310467	0.157640	0.119008
IVA	5	4.858737	94.81173	0.022670	0.306867
FDX	5	3.134281	4.099107	92.17683	0.589783
ELE	5	14.61875	0.102207	0.443197	84.83585

Upon analyzing the results of our study, it is evident that the response variables, including CO_2, IVA, FDX, and ELE, are primarily influenced by their own past values. It is evident from the high values of variance contribution from each response variable to itself. Specifically, CO_2's variance is predominantly explained by its own past values, demonstrated by the noteworthy percentage of 98.41% in the first column. The impulse variables IVA, FDX, and ELE have negligible effects on CO_2 variance. Similarly, IVA's variance is primarily explained by its own past values, with a high value of 94.81% in the second column. The other impulse variables, CO_2, FDX, and ELE, have little effect on IVA's variance.

Furthermore, FDX's variance is primarily driven by its past values, with 92.18% in the third column. The remaining impulse variables, CO_2, IVA, and ELE, have minimal influence on the variance of FDX. Finally, the variance of ELE is mainly explained by itself, with a value of 84.84% in the last column. The impulse variable CO_2 also contributes to the variance of ELE, although to a lesser extent (14.62%) than ELE itself.

These results can be valuable for policymakers in considered countries, particularly in mitigating the negative impacts of these response variables. Given that the response variables are primarily influenced by their past values, effective interventions must be primarily focused on individual variables. For example, in the case of CO_2 emissions, policymakers may consider implementing carbon pricing mechanisms, increasing renewable energy incentives, or improving energy efficiency standards to curb the undesirable impacts of CO_2 on the environment. In the case of IVA, policymakers could encourage sustainable business practices to reduce its negative environmental impacts. These policy implications can help reduce the negative impacts of these response variables and promote sustainable development.

Considering these countries still rely on FDI inflow, they should establish a selective approach to subsidies for foreign investors. They should approve more favorable subsidies for investors using environmentally friendly and energy-saving technologies. Also, they should consider using the exemption of reinvested profits from taxation to attract foreign investors for those companies that invest their retained profits in cleaner technologies.

Appendix contains a graphical representation of the variance decomposition that compares the relative contributions of the various variables to each other over five years. Specifically, the figure provides a year-to-year predicting horizons for all four variables. The representation allows for a visual assessment of the extent of each variable's contribution in relation to the others.

It is vital to highpoint that this study can serve as a foundational benchmark for other developing economies. The framework we recommend addresses several key issues that are common in developing countries. Consequently, this framework can be applied more broadly and benefit from its generalizability.

5. Conclusions

The paper investigates the relationship between CO_2 emissions, industry value-added, financial development index, and electricity generation in CEE countries. The region presents specific features in terms of electricity markets that are highly concentrated, with oligopolistic competition for producers, but also with delayed reforms in the electricity prices liberalization area and with subsidized prices for consumers (both household and non-household). Also, in terms of financial development, those countries display lower financial indices than Western European countries. So, we have checked the existence of cross-sectional dependence among this panel by applying the Pesaran CD test and found no cross-sectional dependence. Then we applied unit root tests and demonstrated that variables are integrated *I*(1). Johansen Fisher and Pedroni tests were used to check cointegration and demonstrated that variables are cointegrated in the long-run. We have used a VECM model to investigate causality between those variables and variance decomposition.

Our short-run results show a unidirectional causality from industry value-added to CO_2 emissions, from CO_2 emissions to electricity generation and financial development. In the long-run, the only causality was found between industry value-added and CO_2 emissions. Variance decomposition shows that the factor with the most substantial impact on pollution is industry value-added, followed by financial development, while electricity generation is the weakest. CO_2 emissions have the most substantial impact on industry value-added, followed by electricity generation and financial development. Factors impacting the financial development of CEE countries are in their impact descending order: industry value-added, CO_2 emissions, and electricity generation. Pollutant emissions display the most powerful impact on electricity generation, followed by financial development, and the last impacting factor is represented by industry value-added.

High levels of CO_2 pollution in some of the CEE investigated countries (such as Poland or even the Czech Republic) explain the still high dependence of those countries on fossil fuels and low shares of renewable energy sources for generating electricity for economic activities. It also explains the lower financial development level of the CEE region against Western European countries. The high dependence on industrial sectors, particularly manufacturing, which facilitates exports in the CEE region, is a significant factor contributing to elevated emission levels in this area. Delays faced by the reform in the energy sector in those countries and keeping the electricity prices at much lower levels compared to the EU average or some notable exemptions in the environmental regulations area contributed to high carbon emissions in this region.

The conclusions drawn from this study offer both theoretical and practical contributions that are highly relevant to the context of CEE countries.

There are several theoretical implications of this research. First, this study enriches the prevailing body of knowledge by providing a deeper understanding of the specific characteristics of the CEE countries, particularly in terms of their industrial development and CO_2 emissions, which are closely linked to the level and characteristics of financial sector development and electricity generation. There is little literature that examines the relationship amongst industrialization, pollution, and the development of the electricity and financial sectors in this region. By highlighting the role of the industrial sector in the high levels of emissions in the CEE region, this study also provides theoretical insights into the challenges of transitioning to cleaner energy sources in industrial-dependent economies. This is especially important for global efforts to reduce carbon emissions. Finally, the study of delayed energy sector reforms and environmental regulatory exemptions in the countries of CEE contributes to the theoretical deepening of understanding of the political obstacles to achieving environmental sustainability. It underscores the need for reforms aligned with global climate goals and the challenge of reconciling economic development and environmental protection.

The theoretical contribution of this study can also be evaluated from a methodological perspective. In particular, the application of advanced panel data analysis techniques such as the Pesaran CD test, unit root tests, Johansen Fisher and Pedroni tests represents a significant methodological enhancement to the current body of research. Researchers interested in similar regions or topics can draw on these techniques to conduct rigorous empirical analyzes in other contexts.

The study also offers valuable policy implications that are directly applicable to CEE countries. These implications recognize the need for comprehensive strategies that balance economic development and environmental sustainability. They underscore the urgent need for policymakers in CEE countries to address the interplay of industrial activities, CO_2 emissions, financial development, and electricity generation to achieve sustainable economic growth.

To mitigate the short-term impact of industrial activities on CO_2 emissions, policies should promote the adoption of cleaner technologies and energy efficiency measures in the manufacturing and production sectors. Considering this, CEE governments should offer substantial incentives and assistance to the industrial sector to diminish their carbon emissions, thereby alleviating the environmental consequences of industrial operations. This support should include enabling environmentally friendly industrial practices, promoting energy-efficient industries, raising awareness among manufacturers on how to deal with environmental issues, and promoting the implementation of eco-friendly technologies.

In addition, measures to reduce CO_2 emissions should be integrated into financial development strategies, taking into account the negative externalities of emissions on the overall economic well-being of a country. Policymakers should integrate objective environmental criteria into their financial policies and lending practices. Financial institutions should assess the environmental impact of the companies they support, thereby promoting sustainable investment and reducing the financial sector's exposure to carbon-intensive industries. In addition, governments in the CEE region should introduce a preferential lending framework. This strategy would ensure that the cost of financing green projects remains comparatively low, in contrast to the cost of polluting production projects. It is important to find an optimal balance between economic growth and CO_2 emission reduction. Countries with disproportionate emission rates should increase their commitment to energy conservation in order to strengthen the role of renewable energy in curbing CO_2 emissions.

Policymakers should prioritize the transition to cleaner energy sources to curb the short-term increase in electricity generation associated with rising CO_2 emissions. The timely implementation of reforms to promote competition, reduce oligopolistic tendencies, and encourage the integration of RES can accelerate the transition to cleaner and more sustainable electricity generation.

In the long run, a balanced approach is needed that promotes both industrial growth and environmental sustainability through policies that support sustainable economic activities and diversify the energy mix. In addition, selective incentives for foreign investors that embrace clean technologies can support both economic growth and environmental goals in these developing countries. Imposing environmental taxes is essential to alleviate the environmental consequences of industrialization and control its rate. The government should prioritize the adoption of cleaner and greener energy practices in industry by imposing environmental regulations on those companies that are less environmentally friendly. Conversely, regulators should provide financial incentives to industries that favor the use of clean and green technologies in their production processes. Overall, these policy recommendations can pave the way for a greener and more prosperous future for the CEE region.

Our research holds significance beyond influencing policy recommendations in the selected countries. It offers valuable insights that can aid policymakers and governments in other developing countries as they endeavor to implement substantial policy initiatives. Particularly, for the broader spectrum of developing regions, this policy framework can serve as a guide for the refinement and alignment of their existing policies. This approach enhances the potential for effective policy implementation across various contexts. Acknowledging the significance of this approach is vital, as policies necessitate tailored adjustments to suit the distinctive contextual conditions present in other developing nations. While reshaping these policies, this framework can be regarded as a central reference, underscoring the study's policy-level relevance in a wider context.

A central constraint of this study pertains to the limited availability of long-term annual data for the CEE countries included in our analysis. This data scarcity arises from the historical context wherein many CEE nations attained their independent statehood only during the final decade of the XX century. This temporal context diverges noticeably from Western European countries, which possess more extensive historical records. Nevertheless, this limitation underscores fertile ground for further scholarly exploration as we gain more annual data as time passes. One promising avenue for future research entails inclusion of additional explanatory variables. These variables may encompass but are not limited to trade, renewable energy, foreign direct investment, globalization, deforestation, monetary indicators, and urbanization. The incorporation of such variables aligns with the established empirical literature, thus augmenting the comprehensiveness and depth of subsequent investigations.

Moreover, it is imperative to acknowledge the substantial disparities in development levels among the CEE countries when discussing limitations. Recognizing these disparities is vital as they exert a profound influence on the intricate dynamics governing environmental, economic and energy trajectories within this region. Furthermore, upcoming research endeavors ought to focus on nuanced differentiation between the contributions of renewable and non-renewable energy sources within the energy landscape remains essential to furnish more precise insights into the environmental ramifications of energy choices.

To amplify the scholarly rigor, a country-specific examination and comparative evaluation are justified in the future. Such a methodological approach facilitates a granular exploration of each country's distinctive challenges and opportunities, thereby engendering the formulation of precise policy recommendations attuned to their specific contextual exigencies. Furthermore, a comparative analysis between the Western European countries and the CEE countries would also be thought-provoking.

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APPENDIX

Variance decomposition year-by-year results (source: authors' calculation)