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Pathway for Four Central and Eastern European Countries to Achieve Low Carbon Development Based on the STIRPAT Model

Shigang Yan[1], Zhaoke Zhang[1], Xingyun Yue[2] & Yi Liu[3]

[1] School of International Economics, China Foreign Affairs University, Beijing, China

[2] School of Management, Harbin Institute of Technology, Heilongjiang Province, China

[3] Hunan Provincial State Tax Bureau, Hunan Province, China

Correspondence: Shigang Yan, School of International Economics, China Foreign Affairs University, Beijing, China. E-mail: yanshigang@cfau.edu.cn

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Abstract

Poland, Hungary, the Czech Republic, Slovakia, as the Visegrad Group members in Central and Eastern Europe (CEE), play important roles in the green economy transition of Europe. The four CEE countries issued low carbon development strategies so as to realize climate change mitigation. However, the four countries faced various political and economic difficulties when transiting to a low carbon economy, including the energy consumption structure, the development of clean energy and the geopolitical conflict between Russia and Ukraine. The paper analyzed the factors influencing carbon emissions in the four CEE countries by using the STIRPAT model. Based on the empirical results, the paper put forward countermeasures and suggestions to promote low carbon development for the four CEE countries.

Keywords: low carbon development, central and eastern European, the Belt and Road

1. Introduction

In the 21st century, climate change has become a serious challenge faced by all the countries in the world. At the 2015 United Nations Climate Change Conference (COP 21), more than 190 participating countries signed the Paris Agreement on climate change mitigation, agreeing to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees (Acemoglu *et al*., 2016; Yu *et al*., 2021).To achieve such long-term climate goals, more than 130 countries and regions have proposed carbon neutrality targets in varying degrees by now. The European Commission (EU) aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and the European Climate Law. Poland, Hungary, the Czech Republic, Slovakia, as the Visegrad Group members in Central and Eastern Europe (CEE), play important roles in the green economy transition of Europe. In 2018 Czech Republic released the Climate Protection Policy, which specified the objectives in the field of climate protection up to 2030 with an outlook up to 2050 and represented a long-term strategy of a low-emission development. Energy Policy of Poland until 2040 (PEP2040) issued in 2021 sets the framework for the energy transition in Poland. The PEP2040 covered three main pillars, including just transition, zero-emission energy system and good air quality, so as to contribute to the implementation of the Paris Agreement and EU's climate and energy policy. In June 2020, Hungary passed a Climate Protection Act that required carbon-emissions reductions of at least 40 percent by 2030 compared with 1990 levels and becoming carbon neutral by 2050. Slovakia published the “Low–Carbon Development Strategy of the Slovak Republic until 2030 with a View to 2050” in 2020, which outlined options for a long-term strategic roadmap to achieve climate neutrality by 2050.

However, the four countries faced various challenges when transiting to a low carbon economy. Firstly, these four countries have a higher proportion of fossil energy in the energy consumption, which bring to more challenges in low carbon transformation. In 2022, the oil consumption of the four countries reached 55.4 million tons, accounting for 10.85 percent of total EU’s oil consumption. The natural gas consumption of the four countries reached 39.6 billion cubic meters, accounting for 11.53 percent of the EU’s natural gas consumption. The coal consumption of the four countries reached 2.56 EJ, accounting for 36.68 percent of the EU’s coal consumption. The renewable energy consumption of the four countries was 0.62 EJ, only accounting for 7.18 percent of the EU’s renewable energy consumption. Secondly, the carbon emissions of the four countries were 463.90Mt in 2022(Energy Institute, 2023). The share of the four countries carbon emissions in the EU was 15.0% in 2000, and increased to 17.02% in 2022. Especially the Czech Republic and Poland respectively remained the third and fourth largest GHG emitter per capita in the EU in 2021. Finally, the EU has already approved 13 rounds of sanctions against Russia since the outbreak of the Russia-Ukraine conflict in 2022, many of which intend to limit oil and gas importing from Russia. According to the EU's sanctions, the importing embargo on crude oil from Russia came into effect in December 2022, following by the importing embargo on refined petroleum products in February 2023. The EU discussed a proposal to ban the Russian LNG in May 2024.The four countries are dependent on Russian's oil and natural gas energy, the rising price of natural gas or supply interruption makes the energy transition policy hardly sustainable to reduce the carbon emission by coal-to-gas transformation resulting from the Russia-Ukraine conflict.

China-CEE cooperation mechanism, officially launched in April 2012, is an important bridge to integrate the Belt and Road Initiative (BRI) into the European economic circle. The green BRI has been promised by China's President in 2017 and established to promote new BRI investment projects emphasizing environmental friendliness, including utilization of green financial instruments (Nedopil, 2021). Since then, China has kept improving its green policies and promoting green investment to support the sustainable development of BRI region (Coenen *et al*., 2023). In terms of ecological and environmental cooperation, China proposed the "China-CEE Cooperation Year of Green Development and Environmental Protection in 2021" as an opportunity to focus on green development and motivate clean energy cooperation. Under this background, the paper explores the main factors influencing carbon emissions in the four CEE countries by using the STIRPAT model. Based on the study's results, the paper would draw up specific carbon reduction pathways so as to promote the low carbon development for these four countries under the Belt and Road. The results of the study will provide theoretical and practical references for the four countries to realize low-carbon development.

2. Literature Review

An economy's natural resource endowments are thought to be major factors affecting the carbon emission levels (Ulucak and Ozcan, 2020). For example, the large-scale infrastructure construction brought about by industrialization and urbanization and subsequent operation consume large amounts of cement, steel and fossil energy, and bring to high carbon emissions (Chin *et al*., 2022; Fan et al., 2022). In addition, since natural resources are considered to be the primary energy input for electricity generation, the utilization of these natural resources is expected to emit carbon into the atmosphere. Financial development is also thought to be linked to carbon emission levels (Chen *et a*l., 2024). The development of the financial sector in an economy ensures access to credit for private investment, which in turn can promote rapid industrialization and urbanization and lead to higher carbon emissions. On the other hand, financial development can also attract inflows of green foreign direct investment (FDI), which in turn can lower carbon emissions. Thus, financial development can also enhance green investment, which can collectively account for lower carbon emissions (Li *et al*., 2021).

The STIRPAT model is a time series analysis tool widely used in energy, environment and other fields, which can reveal the impact of population, economy, technology and other factors on carbon emissions (Huang et al., 2021). The model could predict the trend of future environmental changes and help formulate long-term strategies, analyze the influence of different factors and provide targeted policy recommendations. As STIRPAT framework explains different aspects that might be contributing to environmental degradation, number of studies have employed the STIRPAT model to empirically examine the main factors affecting the carbon emissions (Abdallh and Abugamos, 2017; Nosheen *et al*., 2020; Sun *et al*., 2022; Wu *et al*.,2021; Zhou *et al*., 2023). Abdallh and Abugamos (2017) investigated the relationship between urbanization and CO_2 for twenty Middle East and North Africa (MENA) countries during 1980-2014 by using STIRPAT model. The results revealed that the energy use and per capita GDP resulted in the increase of CO_2, while there was little support of the significant relationship between urbanization and CO_2.Nasrollahi *et al*. (2020) employed STIRPAT model to examine the relationships among population, industrialization, affluence, technology, and sustainability for MENA countries and OECD countries during 1975–2015. The results indicated industrialization and population deteriorated the environment whereas technology and environment agreements helped to improve the environment. Wu *et a*l. (2021) selected a peak-decline panel of 18 OCED countries and used the extended STIRPAT model to disaggregate CO_2 emissions for six contributing factors. The results showed that the CO_2 and the six determinants maintained a cointegration relationship. Zhou *et al*. (2023) examined the direct and hysteresis effects of carbon-related news attention and contents on carbon emissions and carbon transfer from the global perspective by using the extended STIRPAT model.

The rapid economic development and urbanization of the BRICS countries has increased pressure on their reducing carbon emissions and environment issues. Bhat (2018) studied the relationship between economic growth and CO_2

for the five BRICS countries for the period of 1992–2016 by using STIRPAT model, and found that population, GDP per capita and nonrenewable energy consumption contributing to pollution in the given countries. Wang and Zhao (2015) adopted STIRPAT model to identify carbon emission factors in different regions of China, and found that EI was the leading factor of carbon emission in more developed regions of China. Liu and Xiao (2018) set different development scenarios to predict carbon emission peaking of China by using extended STIRPAT model. The scenario analysis showed that there was a 2% reduction in carbon emissions growth compared to the baseline scenario to achieve a carbon peak in 2030. Xu *et al*. (2021) analyzed the impact of Chinese urbanization on pollutant discharge by constructing STIRPAT model. The empirical study confirmed the inverted U-shaped relationship between the urbanization and industrial pollutants during 2003-2015. Nosheen *et al*. (2020) examined the positive impact of energy use and urbanization on carbon emissions for India, China, and other Asia countries over the period of 1995-2018 by using the extended STIRPAT model. Manocha (2023) introduced the STIRPAT model to empirically examine the positive impact of population, income per capita, FDI and trade openness on India's carbon emissions by using data from 1971 to 2020. Somoye *et al*. (2023) checked the effect of urbanization, GDP, and EI on CO_2 in Brazil by adopting the STIRPAT model. The finding showed that the urbanization had a negative impact on the CO_2, while the growth of GDP and EI led to the increase of CO_2.

As for the four CEE countries' low carbon development, Diana *et a*l. (2002) integrated the assumptions, methods, and final results of different countries such as Poland and Hungary into a framework, which makes policy makers and project designers to compare these assumptions, methods, and final results across geographical and technological boundaries. The results stated to mitigate greenhouse gases through technological improvements in the CEE region. Józef *et al*. (2020) introduced the development status of Poland Renewable Energy Policy (RES) based on EU energy policy obligations, described the current situation and prospects of the use of renewable energy in Poland and the European Union, and analyzed the relationship between the reference price of specialized RES auction and the Levelized Cost of Energy (LCOE) in Poland. Horváthová *et al*. (2021) focused on the energy policy formulation of four CEE countries, including the Czech Republic, Hungary, Poland and Slovakia, discussed the extent to which these energy interest intermediary systems tend to be more corporatism based decision-making paradigm. In summary, researchers have made an empirical study of carbon emission reduction path using STIRPAT model. They put forward suggestions from the aspects of policy, renewable energy, and urbanization, etc., which laid a solid foundation for this paper.

3. Model Establishment

Based on the previous studies, this paper expands the components of the STIRPAT model to explore the low-carbon development path according to the current situation of the four CEE countries. The paper selects carbon dioxide emissions as the indicator of environmental pressure, and selects seven driving factors—population, urbanization level, GDP per capita, energy intensity, clean energy, industry structure, and trade level—to expand the STIRPAT model:

$$lnC= \alpha+\beta_1 lnP+\beta_2 lnU+\beta_3 lnPGDP++\beta_4 lnCE+\beta_5 lnEI+\beta_6 lnIV+\beta_7 lnTR$$

Whereas, C refers the carbon emissions, which is the total amount of CO_2 emitted from consumption of oil, gas and coal for combustion related activities; P refers the total population of the four CEE countries, and U refers the level of urbanization. PGDP refers the GDP per capita of the four CEE countries; CE refers the proportion of clean energy, which can reflect the direction of energy policies, the degree of optimization of energy consumption structure, and the friendliness of the ecological environment. EI refers the intensity of energy consumption and reflects the optimization of industrial structure and the improvement of energy efficiency. IV refers the proportion of industrial added value, reflecting the importance of large industrial enterprises in the economy. TR refers the proportion of trade, an indicator used to measure economic openness.

This paper selects four countries, including Poland, Hungary, Czech Republic, and Slovakia, with a time span of 2000-2022. All the information on the total population, urbanization level, GDP per capita, and the proportion of industrial added value of the four CEE countries are sourced from the World Development Indicators (WDI) Database of the World Bank. Energy consumption is based on the Eurostat (https://ec.europa.eu/eurostat/). The carbon dioxide emissions and the proportion of clean energy are sourced from or compiled from the 72nd edition Statistical Review of World Energy (Energy Institute,2023), The description of variables is shown in Table 1.

Table 1. The description of variables

Types	Variables	Abbrev	Unit	Variable description
Explained variable	Carbon dioxide emission	C	Million tons	The total amount of carbon dioxide emitted by all types of energy consumption
Explanatory variables	Total population	P	Ten thousand	Total population of the four CEE countries
	level of urbanization	U	%	Proportion of urban population
	Per capita of Gross domestic product	PGDP	10,000 USD	GDP/ population (2015 prices)
	Clean energy	CE	%	Proportion of clean energy
	Energy intensity	EI	Kilograms	Oil equivalent consumption per thousand euro
Control variables	Proportion of industrial added value	IV	%	The ratio of industrial-added value to GDP
	Proportion of trade	TR	%	The ratio of trade to GDP

4. Empirical Results and Discussions

4.1 Descriptive Analysis

In this paper, STATA is used to conduct descriptive statistical analysis of the relevant variables of the four CEE countries included in the model, and the descriptive statistics of relevant variables are shown in Table 2.

Table 2. Descriptive statistics of relevant variables

Variable	Sample size	Mean value	Median	Standard deviation	Minimum value
lnC	92	4.509	0.848	3.379	5.807
lnP	92	7.097	0.715	6.286	8.250
lnU	92	4.160	0.117	3.984	4.309
lnPGDP	92	9.490	0.256	8.902	9.915
CE	92	0.064	0.082	0.000	0.386
lnEI	92	5.577	0.204	5.222	6.055
lnIV	92	3.379	0.098	3.185	3.536
lnTR	92	4.848	0.301	4.063	5.319

4.2 Pre-Estimation Tests

In order to ensure the validity of the model fitting results, it is necessary to perform unit root tests and cointegration tests to avoid pseudo regression results. The data is processed with first-order difference, and IPS, ADF-Fisher and HT tests are used to determine whether the sequence is stationary. As shown in Table 3, the test results indicate that there are no unit roots; the sequences of each variable are stationary.

Table 3. Results of unit root tests

Variables	IPS	ADF-Fisher	HT
ln*C*	-1.359*	6.224	0.722
D.ln*C*	-4.631***	41.096***	0.042***
ln*P*	-0.341	6.256	0.372***
D.ln*P*	-4.541***	5.520	-0.089***
ln*U*	2.497	45.468***	1.043
D.ln*U*	-2.647***	1.802	0.974
ln*PGDP*	1.613	5.132	0.928
D.ln*PGDP*	-3.616***	29.197***	0.449***
CE	1.035	0.578	0.772
D.*CE*	-3.851***	19.033**	0.497**
ln*EI*	-0.288	2.362	0.788
D.ln*EI*	-4.873***	49.623***	0.064***
ln*IV*	-1.458*	7.523	0.566*
D.ln*IV*	-5.618***	48.941***	-0.248***
ln*TR*	-1.933**	3.822	0.606
D.ln*TR*	-4.089***	51.069***	0.189***

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The research applies the Kao and Pedroni method to test for the cointegration of panel data (as shown in Table 4. According to the cointegration test results, the significance of Kao and Pedroni method indicate a long-term equilibrium relationship between variables.

Table 4 Results of cointegration test

Test method	T Value	P Value
Kao	-2.338	0.0097
Pedroni	3.186	0.0007

4.3 Empirical Results

In this section, F test and Hausman test are first used to determine whether there are individual effects and random effects in panel data. The median value of F test is 35.05, and the p value is 0.0000. As shown in table 5, the result indicates that the null hypothesis is rejected, so there is no mixed effect in this model. In Hausman test, the Chi-square test value is 47.45 and the p value is 0.0000, which also means that the null hypothesis is rejected for the existence of random effects. Therefore, the fixed effects model will be used in this section for regression analysis.

Table 5. Panel data regression model test

Test method	Test value		Results
F test	F median value	35.05	Rejected
	P value	0.000	
Hausman test	Chi-square value	47.45	Rejected
	P value	0.000	

The fixed-effect model is used to regress the core variables, such as total population, and urbanization level, GDP per capita, clean energy share, energy intensity, industrial value added share, and the control variables for the four CEE countries to obtain the quantitative relationships among these indicators. Table 6 shows the regression results. Thus the regression equation of this paper is obtained in the following form:

$$lnC=-4.876+0.136lnP-1.563lnU+0.995lnPGDP-0.212lnCE$$
$$+1.168lnEI+0.442lnIV-0.120lnTR$$

From the regression results of the four CEE countries in the table, the goodness of fit R-squared is 0.943, the explanatory power of each explanatory variable to the dependent variable reaches 94.3%, which indicates that the STIRPAT model is reasonable in its setting and valid to some extent. Meanwhile, the p-values of core variables and control variables, including U, PGDP, CE, EI, IV and TR, pass the significance test with a significance level of 1%. However, the total population (lnP) in the fixed effects has low significance in the regression and fails the test, which indicates that this variable does not drive total carbon emissions significantly in the fixed-effect model.

Table 6. The regression results of the four countries

Variables	ln*C*	ln*C*	ln*C*
	(1)	(2)	(3)
ln*P*	-0.550	-0.352	-0.136
	(0.362)	(0.327)	(0.319)
ln*U*	-2.028***	-1.707***	-1.563***
	(0.189)	(0.183)	(0.180)
ln*PGDP*	0.998***	0.943***	0.995***
	(0.081)	(0.073)	(0.072)
CE	-0.252***	-0.264***	-0.212***
	(0.081)	(0.073)	(0.071)
ln*EI*	1.281***	1.199***	1.168***
	(0.073)	(0.068)	(0.066)
ln*IV*		0.361***	0.442***
		(0.078)	(0.079)
ln*TR*			-0.120***
			(0.039)
cons	0.255	-2.735	-4.876
	(3.828)	(3.489)	(3.392)
Observations	92	92	92
R-squared	0.919	0.936	0.943

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.4 Discussions of Empirical Results

According to the empirical results, energy intensity has a deeper impact on carbon emissions in the four CEE countries as the most dominant positive driver with fitted coefficients of 1.168. It shows that energy is an essential part of human production and economic life. With the growth of PGDP and the expansion of economic scale in the four CEE countries, the total amount of energy consumption will also rise, resulting in the further increase of carbon emissions. As EI rises, the energy consumed per unit of GDP increases, and the energy intensity of the four CEE countries generally shows a decreasing trend from 2000 to 2022, which indicates the improvement of energy utilization and the innovation of emission reduction and energy saving technologies in the four CEE countries.

Secondly the PGDP of four CEE countries is also a positive driver of carbon emissions with a fitted coefficient of

0.995, which indicates that as the affluence of CEE economy increases, their carbon emissions will further increase. The four CEE countries are the more rapidly developing economic regions in the EU, which have a greater demand for energy. At the same time, the rise of PGDP will also boost consumption upgrading. Although all four CEE countries are high-income countries, their economies still have some room for improvement compared with other countries in the EU, so the PGDP of the four CEE countries has a positive driving effect on the carbon emissions. There is a great challenge for the four CEE countries to achieve carbon peaking. Meanwhile, the fitted coefficient of industrial added share is positive, which indicates that the variable has a positive driving effect on carbon emissions. It is consistent with the actual data of four CEE countries. The industrial added share in the four countries decreased from 2000 to 2022, and their industrial structure gradually shifted to service industry. Compared with the service industry, industry consumed more energy and emitted more carbon, thus the fitted coefficient of industrial added share is positive.

Thirdly, the fitted coefficient of U is -1.563, which shows a negative driving effect on carbon emissions. With the increase of urbanization level, various factors of production are gathered to improve the utilization efficiency. Carbon emissions generated in the construction of public facilities and housing are offset by the efficiency improvement. Although people's lifestyles and consumption levels also change in the city, the total amount of carbon emissions remains in a declining trend.

Fourthly, the fitted coefficient of four CEE countries is -0.212 in terms of the CE, which has a significant negative driving effect on carbon emissions. The share indirectly reflects the energy consumption structure and the level of optimization. The higher the value, the greater the share of solar, wind and nuclear energy, and the lower the consumption of traditional fossil energy sources such as coal, oil and natural gas. From 2000 to 2022, the proportion of CE in the four CEE countries continued to rise, indicating the continuous optimization of energy consumption in the four CEE countries. Finally, the fitting coefficient of the TR is -0.120, which has a negative driving effect on carbon emissions. The negative effect indicated that the foreign trade of the four countries helps to reduce their carbon emissions. In the future, the four countries could adjust the trade structure in order to achieve low carbon development.

5. Conclusions and Suggestions

Poland, Hungary, the Czech Republic, Slovakia, as the Visegrad Group members in Central and Eastern Europe (CEE), undertake severe pressure of economic development and carbon emission reduction to achieve low carbon development. Based on the data of the four CEE countries with the time span of 2000-2022, the paper expands the components of the STIRPAT model to explore the low-carbon development path. According to the regression results, factors that significantly affect the carbon emissions of the four countries include urbanization level, GDP per capita, clean energy, energy intensity, industrial added share and trade. It is noteworthy that energy intensity, GDP per capita and industrial added share have significant positive driving effects on carbon emissions, while the proportion of clean energy, urbanization level and trade play negative driving roles. Based on the above results, the following policy implications of the current study are as follows.

Firstly, it is necessary to optimize the industrial layout, promote the further upgrading of traditional industries, and make the industry move forward to the goal of low-carbon. The four CEE countries need to improve R&D investment and the development of high-tech industries and service sector, so as to promote the economic transformation to low energy consumption and low carbon emission. At the same time, promoting the development of service sector can also promote the green circular economy.

Secondly, the four CEE countries should focus research and development funds on improving energy efficiency and efficient use of clean energy in order to further reduce energy intensity and increase the proportion of clean energy. To improve clean energy technology, the four CEE countries could adopt advanced green technologies from other EU countries to realize technological upgrading and improving environmental protection standards. Moreover, China's installed capacity of solar photovoltaic and wind power ranks first in the world, and has formed an integrated industrial chain advantage in solar photovoltaic and wind power. The four CEE countries could strengthen the international cooperation, absorb technological achievements from China, and implement green production capacity cooperation under the BRI.

Finally, the four countries can promote regional coordinated development and implement coordinated emission reduction. As for the four CEE countries have different industrial structures and different carbon emissions, they could further develop in a coordinated manner and complement each other in technology advantages to enhance the positive driving effect of carbon reduction. Moreover, cities in the four countries have different industrial structures and different carbon emissions, policymakers of the four CEE countries could advocate the concept of low-carbon life, encourage green consumption and green travel to further reduce urban carbon emission levels.

The research has some limitations and needs to be improved further. It is necessary to strengthen the verification of data quality and reliability, and expand the consideration of influencing factors and nonlinear relations to improve the accuracy and reliability of the model in the future research. Moreover, the four CEE countries are selected to analyze the pathway to achieve low carbon development in this paper, which can not fully reflect the overall situation of CEE. It is necessary to consider more CEE countries and carry out heterogeneity analysis regarding the low-carbon pathways to make the research more practical and robust.

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Authors contributions

The main Author Prof. Shigang Yan drafted the manuscript and was responsible for whole study design and revising. Zhaoke Zhang and Xingyun Yue were responsible for data analysis. Yi Liu provided some secondary materials about the China-CEE cooperation mechanism. All authors have thoroughly read and given their approval for the final manuscript to be published.

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Obtained.

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Data sharing statement

No additional data are available.