CO 2 emissions, energy consumption and economic growth in the Visegrad Group countries: a panel data analysis

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Abstract. This paper examines causal relationships between carbon dioxide emissions, energy consumption and economic growth using panel vector error correction modelling techniques based on the panel data for the Visegrad Group countries over the period 1992–2010. Panel cointegration tests show the existence of long-run relationships among carbon dioxide emissions, energy consumption and economic growth. The long-run equilibrium indicates that energy consumption has a positive and statistically significant impact on emissions. However, the results obtained cannot confirm the Environmental Kuznets Curve (EKC) hypothesis for the Visegrad Group countries. The results of panel short-run Granger causality tests reveal the existence of bidirectional causality between CO2 emissions and economic growth. Also, the short-run dynamics suggests unidirectional causality from energy consumption to carbon dioxide emissions and from energy consumption to economic growth in the Visegrad Group countries. The findings indicate that there is no causality running from carbon dioxide emissions to energy consumption and from economic growth to energy consumption.

Keywords: Carbon dioxide emissions, energy consumption, economic growth, panel cointegration.

JEL Classification: C33, Q43, Q50, Q56
AMS Classification: 91B76, 62M10

1 Introduction

The Visegrad Group originated in 1991 after the dissolution of the Communist Bloc and consisted of the Czech Republic, Slovakia (after the dissolution of Czechoslovakia in1992), Hungary and Poland. Up till 1990 the economy of these countries was centrally planned, and in 1992 they had low gross domestic product per capita. Poland was the country with the lowest GDP per capita (2936 in constant 2000 US$) and the Czech Republic was the country with the highest GDP per capita (4756 in constant 2000 US$). For comparison, GDP per capita in the European Union countries was 14660 in constant 2000 US$. These countries also exhibited a very high energy intensity of the economic activity in 1992. Energy consumption in relation to GDP in Slovakia equalled to 337 (kg of oil equivalent per $1,000 GDP in constant 2005 PPP), in Poland 331, in the Czech Republic 292, and in Hungary 215. In the European Union countries energy consumption in relation to GDP equalled to 162 (kg of oil equivalent per $1,000 GDP in constant 2005 PPP). Numerous reforms introduced in the period 1992 - 2010 resulted in rapid economic growth and reductions in the energy intensity of the economy. Currently the most important areas of the Visegrad Group activity embrace culture, environmental protection, infrastructure, transportation, tourism, and energy.

The dynamic changes which took place in the Central European countries pose a question whether and to what extent economic growth influenced the environment. One of the methods of measuring the impact of economic development on the environment is the Environmental Kuznets Curve (EKC). It indicates the relationship between GDP per capita and the 'demand' for clean environment. Additional variables taken into consideration in this relationship can include other factors indicating environmental degradation. The Environmental Kuznets Curve (EKC) hypothesis states that the level of environmental degradation will rise to a certain point and then will drop (it can be presented by a curve shaped as an inverted U).

The aim of the paper is to verify the Environmental Kuznets Curve (EKC) hypothesis for the Visegrad Group countries based on the panel data over the period 1992 – 2010. Additionally, causal relationships between carbon dioxide emissions, energy consumption and economic growth will be examined using panel vector error correction modelling techniques. The paper is structured in the following way: Section 2 presents brief literature review, Section 3 presents methodology, data, the discussion of the methods and results are given in Section 4, while Section 5 contains the main conclusions.

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2 Brief literature review

The relations between economic growth and environmental pollution have been intensely analysed empirically over the past two decades. These analyses can be divided according to causal relations examined in them. Most of them focus on the analysis of short-term causal relations and long-term relations between energy consumption, economic growth and CO2 emission. The analyses have been conducted for single countries (e.g. France (Ang [2]), the United States (Soytas et al. [22]), China (Wang et al. [23]), and Turkey (Halicioglu [6], Ozturk and Acaravci [12]) as well as for groups of countries (e.g. BRIC (Pao and Tsai [18]), Central America (Apergis and Payne [3]), ASEAN (Lean and Smyth [9])) with the use of panel data sets Numerous analyses of relations between environmental pollution, energy sources prices and economic growth included additional factors (for example, foreign direct investment proposed by Pao and Tsai [19] or the financial development suggested by Sadorsky [20], Śmiech and Papież [21], Al-mulali and Che Sab [1], Papież and Śmiech [13], [14]).

3 Methodology

The first step in the estimation of dynamic panels is to test whether the variables contain unit roots. For this study three panel unit root tests were chosen, namely Levin–Lin–Chu (LLC) test (Levin et al. [8]), Im, Pesaran and Shin (IPS) test (Im et al. [7]), and Fisher-type tests using Augmented Dickey–Fuller (Fisher-ADF) (Maddala and Wu [11]; Choi [5]). The null hypothesis of those three panel unit root tests states that the panel series has a unit root (nonstationary).

If the variables contain a unit root, the second step is to test whether there exists any long-run equilibrium relationship between the variables using the Pedroni panel cointegration test (Pedroni [15], [17]). To test for the null hypothesis of no-cointegration against the cointegration in the panel, Pedroni [15] developed seven cointegration statistics. Four of them are based on pooling the residuals of the regression along the within-dimension (panel test) of the panel. The other three are based on pooling the residuals of the regression along the between-dimension (group test) of the panel. The equation for Pedroni cointegration tests can be formulated as follows:

$$\ln CO2_{it} = \beta_{0i} + \beta_{1i} \ln EC_{it} + \beta_{2i} \ln GDP_{it} + \beta_{3i} \ln^2 GDP_{it} + u_{it}\,, \tag{1}$$

where $i = 1,\dots,4$ denotes the country and $t = 1,\dots,T$ denotes the time period. Equation (1) describes the Environmental Kuznets Curve (EKC). The variables in equation (1) denote respectively: carbon dioxide emissions per capita (CO2), energy consumption per capita (EC), and GDP per capita (GDP).

If a long-run relationship between the variables is found, the third step is to estimate the equation of long-run relationship. To obtain the long-run estimates for the cointegrating relationship, the panel fully modified ordinary least squares (FMOLS) is used, the method developed by Pedroni [16], [17]. The FMOLS procedure accommodates the heterogeneity that is typically present, both in the transitional serial correlation dynamics, and in the long-run cointegrating relationships.

If a long-run relationship between the variables is found, the final step is to estimate a panel vector error correction model in order to determine Granger causal relations between the variables. The Granger causality test is based on the model with a dynamic error correction term. The panel VECM can be written as follows (Apergis and Payne [3], [4]):

$$\begin{aligned}\Delta \ln CO2_{it} = {} & \alpha_{1i} + \sum_{j=1}^{p} \beta_{11ij} \Delta \ln CO2_{it-j} + \sum_{j=1}^{p} \beta_{12ij} \Delta \ln EC_{it-j} + \sum_{j=1}^{p} \beta_{13ij} \Delta \ln GDP_{it-j} \\ & + \sum_{j=1}^{p} \beta_{14ij} \Delta \ln GDP2_{it-j} + \theta_{1i} ECT_{it-1} + \varepsilon_{1it}\,,\end{aligned} \tag{2a}$$

$$\begin{aligned}\Delta \ln EC_{it} = {} & \alpha_{2i} + \sum_{j=1}^{p} \beta_{21ij} \Delta \ln CO2_{it-j} + \sum_{j=1}^{p} \beta_{22ij} \Delta \ln EC_{it-j} + \sum_{j=1}^{p} \beta_{23ij} \Delta \ln GDP_{it-j} \\ & + \sum_{j=1}^{p} \beta_{24ij} \Delta \ln GDP2_{it-j} + \theta_{2i} ECT_{it-1} + \varepsilon_{2it}\,,\end{aligned} \tag{2b}$$

$$\Delta \ln GDP_{it} = \alpha_{3i} + \sum_{j=1}^{p} \beta_{31ij} \Delta \ln CO2_{it-j} + \sum_{j=1}^{p} \beta_{32ij} \Delta \ln EC_{it-j} + \sum_{j=1}^{p} \beta_{33ij} \Delta \ln GDP_{it-j} + \sum_{j=1}^{p} \beta_{34ij} \Delta \ln GDP2_{it-j} + \theta_{3i} ECT_{it-1} + \varepsilon_{3it}, \tag{2c}$$

$$\Delta \ln GDP2_{it} = \alpha_{4i} + \sum_{j=1}^{p} \beta_{41ij} \Delta \ln CO2_{it-j} + \sum_{j=1}^{p} \beta_{42ij} \Delta \ln EC_{it-j} + \sum_{j=1}^{p} \beta_{43ij} \Delta \ln GDP_{it-j} + \sum_{j=1}^{p} \beta_{44ij} \Delta \ln GDP2_{it-j} + \theta_{4i} ECT_{it-1} + \varepsilon_{4it}, \tag{2d}$$

where $i = 1, \ldots, N$ denotes the country, $t = 1, \ldots, T$ denotes the time period, p is the optimal lag length(s) determined by the SBC, ECT term is the residuals from the panel FMOLS estimation of the Eq. (1), and the error term ε_{it} is assumed to be i.i.d with a zero mean and constant variance.

4 Data and empirical results

The analysis of causal relationships between carbon dioxide emissions, energy consumption and economic growth was based on the annual panel data for the Visegrad Group countries (the Czech Republic, Hungary, Poland, and Slovakia) over the period 1992 – 2010. The following variables were chosen: carbon dioxide emissions in metric tons per capita (CO2), energy consumption in kg of oil equivalent per capita (EC) (data taken form the International Energy Agency), and GDP per capita in constant 2000 US$ (GDP) (data taken from the World Bank Development Indicators). The summary statistics are presented in Table 1.

Variable		Czech Republic	Hungary	Poland	Slovakia
CO2	Min	10.50	4.86	7.31	6.12
	Mean	11.68	5.64	8.08	7.22
	Max	12.73	6.08	9.06	8.55
EC	Min	3756.3	2209.6	2317.5	2959.4
	Mean	4098.9	2346.8	2496.1	3272.6
	Max	4488.1	2544.8	2679.0	3482.0
GDP	Min	4754.4	3707.1	2936.2	4059.4
	Mean	6198.7	4785.0	4612.7	5991.2
	Max	8042.0	5947.2	6574.3	8545.6

Table 1 Summary statistics, 1992-2010

In the panel data analysis, the panel unit root test must be taken into consideration first in order to identify the stationary properties of the relevant variables. Thus, Table 2 presents the results of the panel unit root tests (Levin–Lin–Chu (LLC), Im, Pesaran and Shin (IPS) test, and Fisher-type tests using Augmented Dickey–Fuller (Fisher-ADF) for each variable. It can be seen from Table 2 that each variable is integrated of order one, i.e. I(1), which meets the requirements of the cointegration test.

Variable	LLC	IPS	Fisher- ADF
lnCO2	-1.13628	-0.09570	8.07581
lnEC	-1.26301	-1.19207	11.4000
lnGDP	-1.25857	1.38311	5.32871
lnGDP2	-0.96798	1.55955	5.29957
Δ lnCO2	-6.60337 ***	-6.08031 ***	45.0505 ***
Δ lnEC	-5.41123 ***	-6.11110 ***	45.0172 ***
Δ lnGDP	-2.80443***	-2.37235 ***	21.8439 ***
Δ lnGDP2	-2.77632***	-2.37467 ***	21.6868 ***

Note: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively

Table 2 Results for panel unit root tests

Given that each of the variables contains a panel unit root, the existence of a long-run relationship between the variables is examined using the Pedroni panel cointegration test (Pedroni [15]). Pedroni's testing approach requires the estimation of the Eq. (1) for each cross-sectional unit. The results for the panel cointegration tests are presented in Table 3. The results allow us to reject the null hypothesis of no cointegration for the tests at 5% or higher significance level apart from the panel and group rho-Statistic and panel v-Statistic. On the other hand, three Pedroni test statistics which do not allow us to reject the null hypothesis are negligible for short periods (Pedroni, [17]). That is why it can be assumed that the variables in Eq. (1) are panel cointegrated.

Test Statistics	Statistics	Weighted Statistics
Panel v-Statistic	0.888622	0.426102
Panel rho-Statistic	0.017867	-0.362482
Panel PP-Statistic	-1.728883 **	-2.731571 ***
Panel ADF-Statistic	-3.170544 ***	-3.486382 ***
Group rho-Statistic	0.447631	
Group PP-Statistic	-2.680004 ***	
Group ADF-Statistic	-3.832084 ***	

Notes: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.

Table 3 Pedroni results for panel cointegration tests

Once the cointegration relationship is established, the next step is to estimate the long-run parameters of the model (1) by using the FMOLS technique. The FMOLS corrects the standard OLS for bias induced by the endogeneity and serial correlation of the regressors (Lee [10]). The results from the panel FMOLS estimations are illustrated in Table 4. For each country, all the coefficients are significant at the 5% level or higher. The results for individual countries indicate that for all countries an increase in energy consumption per capita affects the increase in carbon dioxide emissions per capita. The results show that a 1% increase in energy consumption per capita increases CO2 emissions per capita by 0.52% in Slovakia, by 0.87% in the Czech Republic, by 1.10% in Poland and by 1.67% in Hungary.

The results of the analysis of the relationship between GDP and CO2 emissions, however, are not conclusive. It is worth noting that only for Poland and Hungary the coefficients have the expected sign, that is are the same as the EKC hypothesis suggests: $\beta_2 > 0$ and $\beta_3 < 0$. In case of the Czech Republic and Slovakia the coefficients have the reverse signs for variables lnGDP and lnGDP2. The results, different from those given in Ang [2], Apergis and Payne [3], [4] and Lean and Smyth [9], are contrary to the EKC hypothesis. However, similar results (the reverse coefficient) were obtained by Wang et al. [23], who used panel cointegration techniques based on the panel data for 28 provinces in China over the period 1995–2007. Thus, it is advisable to conduct a detailed analysis of a reverse impact of GDP on CO2 emissions in those countries.

	Czech Republic	Hungary	Poland	Slovakia	PANEL
lnEC	0.87 (6.96) ***	1.67 (8.74) ***	1.10 (17.15) ***	0.52 (2.09) *	1.04 (17.46) ***
lnGDP	-8.09 (-2.34) **	17.54 (3.93) ***	2.05 (2.46) **	-8.28 (-2.38) **	0.80 (0.84)
lnGDP2	0.44 (2.25) **	-1.07 (-4.03) ***	-0.13 (-2.64) **	0.46 (2.29) **	-0.07 (-1.07)
Intercept	32.00 (2.16) **	-83.29(-4.32)***	-14.48(-3.78)***	34.94 (2.47) **	-7.71 (-1.73) *
Adjusted R-squared	0.794	0.735	0.965	0.826	

Notes: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.

Table 4 The panel cointegration coefficients

The long-run panel cointegration equation (1) can be written as:

$$\ln CO2 = \underset{(-1.73)}{-7.71} + \underset{(17.46)}{1.04}\ln EC + \underset{(0.84)}{0.80}\ln GDP - \underset{(-1.07)}{0.07}\ln^2 GDP\,, \tag{3}$$

where the numbers in parentheses denote the values of t-statistics.

For the panel of countries as a whole, all the coefficients have the expected sign, but only the coefficient of lnEC is significant at the 1% level. So, the results for the panel indicate that a 1% increase in energy consumption per capita is associated with an increase in carbon dioxide emissions per capita of 1.04%. On the other hand, CO2 emission is positively related to GDP and negatively related to GDP2, although the coefficients of lnGDP and lnGDP2 seem not to be significantly different from zero. Most probably, the lack of significance of the coefficients of lnGDP and lnGDP2 results from two different forms of Eq. 3 (one for Poland and Hungary and one for the Czech Republic and Slovakia). The results obtained indicate the need to extend the analysis to the remaining post socialist countries.

The existence of panel long-run cointegration relationship between CO2 emissions, energy consumption and economic growth allowed us to estimate a panel vector error correction model using Eq. (2a-2d). The estimated panel-based VECM allows us to investigate both short-run and long-run Granger causality. Table 5 presents the results of the panel short-run and long-run Granger causality analysis.

Dependent variable	Source of causation (independent variables)			
	Short run			Long run
	Δ lnCO2 F-statistics	Δ lnEC	Δ lnGDP& Δ lnGDP2	ECT t-statistics
Δ lnCO2		5.393 **	15.803 ***	-8.693 ***
Δ lnEC	0.013		1.169	2.419 **
Δ lnGDP	5.511 **	5.858 **		-7.774 ***
Δ lnGDP2	5.628 **	6.239 **		- 8.043 ***

Notes: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.

Table 5 Panel Granger causality results.

The results of panel short-run Granger causality tests show the existence of bidirectional causality between CO2 emissions and economic growth in the Visegrad Group countries at 5% significance level. Also, the short-run dynamics suggests unidirectional causality from energy consumption to carbon dioxide emissions and from energy consumption to economic growth. It indicates that an increase in energy consumption will lead to an increase in CO 2 and an increase in energy consumption will lead to a decrease in economic growth. The results indicating a reverse relation between energy consumption and economics growth can be explained by a decrease in energy intensity of the economy. The results presented in Table 5 indicate that there is no causality running from carbon dioxide emissions to energy consumption and from economic growth to energy consumption. The estimated coefficients of ECT are statistically significant at least the 5% level in each equation. Apart from the equation for energy consumption, the coefficients of the ECT are negative, which implies that all three variables dynamically interact to restore long-run equilibrium whenever there is a deviation from the cointegrating relationship.

5 Conclusions

The results of the analysis of four Visegrad Group countries indicate that it is not possible to conclusively verify the Environmental Kuznets Curve (EKC) hypothesis based on the panel data over the period 1992–2010. The long-run panel cointegration equation reveals statistical significance only between carbon dioxide emissions and energy consumption. Unfortunately, the analysis did not allow us to identify the impact of economic growth on carbon dioxide emissions. The results of the panel data analysis may result from a different character of the countries taken into consideration. A detailed analysis of the relations in particular countries revealed that the Environmental Kuznets Curve (EKC) hypothesis can be confirmed for Poland and Hungary. However, in case of the Czech Republic and Slovakia the results obtained are contrary to the Environmental Kuznets Curve (EKC) hypothesis. Thus, it can be concluded that it is justified to conduct further detailed analyses of the impact of GDP on CO2 emissions in the four countries in question as well as other post socialist countries.

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