The analysis of the relationship between CO2 emissions and economic growth using the Environmental Kuznets Curve

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Abstract

In the literature the relations between environmental pollution and economic growth are usually tested within the so-called Environmental Kuznets Curve (EKC). The aim of this study is to confirm the existence of the relationship (U-shaped or N-shaped) between environmental degradation and economic development in the European Union countries. The analyses conducted so far have taken into account the volume of CO2 emissions related to production in a given country, but have not taken into account a certain part of CO2 emissions related to trade. In order to fill this gap, our study of the relationship between CO2 emissions and economic growth will include both production-based accounting (PBA) and consumption-based accounting (CBA).

The results of previous studies lead to ambiguous conclusions. Some studies concerning the selected EU countries confirm the Environmental Kuznets Curve, while others do not. The selection of countries for the panel analysis can partially explain this discrepancy and constitutes a basic objection to these studies. That is why in our study the analyses are country-specific, and, additionally, include variables influencing CO2 emissions, such as energy efficiency and renewable energy sources.

Keywords: Environmental Kuznets Curve, production-based CO2 emissions, consumption-based CO2 emissions

JEL Classification: C2, Q4

1. Introduction

Climate change, including global warming, is one of the most pressing problems the world faces today. Global warming is mainly caused by greenhouse gas (GHG) emissions, among which CO2 emissions constitute its largest share. In order to be effective, policies aimed at reducing CO2 emissions need to take into consideration the determinants of what has the greatest impact on these emissions. Reducing CO2 emissions is an objective of many international agreements, as only coordinated action in this area can bring the desired results.

CO2 emissions are closely linked to the economic activities of countries, especially in the area of their production. The energy, industrial, and transport sectors account for the largest share of total CO2 emissions. The conflict between the need to reduce emissions and to maintain economic activity seems unavoidable. However, the question arises whether economic

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growth that does not result in excessive CO2 emissions – and thus is more environmentally-friendly – is possible.

The relationship between income inequality and economic development suggested by (Kuznets, 1955) was adopted by (Grossman and Krueger, 1995) to study the environmental impact of economic development. The Environmental Kuznets Curve (EKC) has been used in a number of studies whose results suggest that, in the early stages of a country's economic growth, pollution tends to increase rapidly because the priority is given to production and minor attention is devoted to negative spillovers of growth on the environment. However, in the next phases of growth, as national income continues to rise and more advanced technological solutions appear, governments, individuals, and businesses are willing to invest in improving the environmental quality. That is why initially the studies assumed that this curve has the form of the inverted-U. However, subsequent researchers (including e.g. Millimet *et al.*, 2003; Dogan and Seker, 2016) propose to extend the traditional inverted-U EKC, on the basis of the observation that the relationship between pollution and economic development may be more complex, and the pattern may actually be N-shaped (or even invertedly N-shaped). The N-shape assumes that when the level of economic development continues to increase (after reaching the inverted-U shape), the pollution trend may reverse and start to increase again. This may be due to the fact that, at some point, the economic activity is so intense that its negative impact on the environment cannot be compensated for by structural or technological factors.

Despite extensive literature on environmental Kuznets hypothesis, there is no clear answer as to whether or not the EKC exists and, if so, what its shape is.

The empirical literature on the EKC reports mixed results, and an exhaustive review of this literature can be found in the paper (Shahbaz and Sihna, 2019). Different results seem to be obtained mainly due to the availability of data, depending on whether time series, cross-sectional data or panel data are adopted in a particular study. Many studies confirm the existence of the country-specific traditional (inverted-U) EKC based on time series [i.e. in Croatia (Ahmad *et al.*, 2017); in the UK (Sephton and Mann, 2016); in Romania (Shahbaz *et al.*, 2013)]. The results of panel data are often ambiguous. Differences may be due to e.g.: the time frame adopted(i.e. 1830-2003 in Sephton and Mann, 2016), the selection of objects chosen for the analysis [25 African countries (Zoundi, 2017); 28 OECD countries (Álvarez-Herránz *et al.*, 2016); 189 countries (Dong *et al.*, 2016)], or the estimation method employed (OLS Sephton and Mann, 2016; ARDL bounds Ahmad *et al.*, 2017; Panel Regression Álvarez-Herránz *et al.*, 2016). Moreover, various control variables are often used [concerning trade openness (Ozturk and Acaravci, 2013; Dogan and Seker, 2016); related to fossil fuel energy consumption

(Álvarez-Herránz *et al.*, 2016; Zoundi, 2017) or renewable energy consumption (Zoundi, 2017)]. It should also be noted that the studies in this area assume different types of pollution as an explanatory variable and sometimes even use different methods of measuring CO2 emissions.

The aim of this study is to analyse the relationship between CO2 emissions and economic growth in the EU countries using the Environmental Kuznets Curve. The paper contributes to the existing literature in two main aspects.

Firstly, the study is based on two types of CO2 measurements. Most other studies take into consideration only production-based CO2 emissions, while ours refers also to consumption-based CO2 emissions, which are caused by goods and services at the level of their consumption, i.e. they are assigned to the final consumer. Given that the EU is a significant importer, the method of measuring CO2 emissions can influence the assessment of the relationship between GDP and CO2 emissions, including the shape of the EKC.

Secondly, as a result of the analysis, the EU countries are grouped according to the shape of their EKC. In papers comparing groups of countries most often the results for individual units are given on the basis of panel data. Such averaging may be misleading due to heterogeneity of countries belonging to the EU. The country-specific analysis conducted in our study, which concerns the same time frame, is based on homogeneous data concerning both CO2 and GDP emissions, in which the same estimation methods are used to compare the results. Importantly, it offers the possibility to explain the reasons for the differences obtained. Additional variables, such as energy efficiency and renewable energy sources, are added to the characteristics of the groups identified on the basis of the shape of their EKC.

2. Data and methodology

The analysis covers the period 1995-2016 and takes into account 28 European Union countries.

Gross domestic product in current prices (PPP US dollars) obtained from IMFs World Economic Outlook (WEO) database is used as a measure of the economic output. GDP per capita is measured in purchasing power parities to eliminate the effect of currency fluctuations. The log of GDP per capita is based on purchasing power parity in constant.

Two kinds of measurement of CO2 emissions are used. Both sets of data – those related to production-based CO2 emissions and those related to consumption-based CO2 emissions that include the net emissions embodied in international trade – are taken into account in the assessment of CO2 emissions. The data are obtained from the Eora multi-region input-output (MRIO) database[2].

Generally, we can specify the following model to estimate the EKC at the country-specific level:

$$CO2 = \alpha + \beta_1 GDP + \beta_2 (GDP)^2 + \beta_3 (GDP)^3 + e \tag{1}$$

where: CO2 denotes carbon emissions per capita; GDP refers to per capita GDP; α, β and ϕ are unknown parameters; and e denotes the error.

The model is based on the logarithmic processing of variables because the natural logarithm transformation of data can avoid violent fluctuation caused by the change of data; this form not only smoothens out the outliers in the data sets but also directly gives elasticity through its coefficients.

Depending on the values of the estimated coefficients, the EKC curve may have a different shape, which is presented in Table 1.

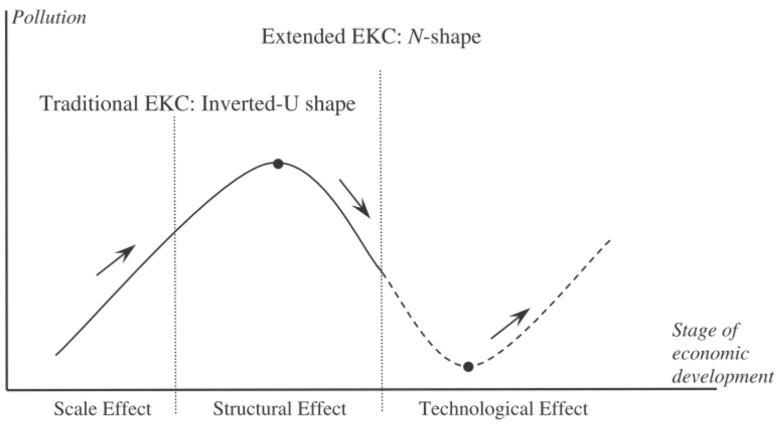

Figure 1. Traditional EKC (Inverted-U shape) and Extended EKC (N-shape)

Table 1. The shape of the EKC depending on the values of the coefficients

$\beta_1 = 0; \beta_2 = 0;\ \beta_3 = 0$	no relationship
$\beta_1 > 0; \beta_2 = 0;\ \beta_3 = 0$	monotonically increasing linear relationship
$\beta_1 < 0; \beta_2 = 0;\ \beta_3 = 0$	monotonically decreasing linear relationship
$\beta_1 > 0; \beta_2 < 0;\ \beta_3 = 0$	traditional EKC (inverted-U)
$\beta_1 < 0; \beta_2 > 0;\ \beta_3 = 0$	inverted EKC (U-shaped)
$\beta_1 > 0; \beta_2 < 0;\ \beta_3 > 0$	extended EKC (N-shaped)
$\beta_1 < 0; \beta_2 > 0;\ \beta_3 < 0$	inverted extended EKC (\/\)

[2] The Eora global supply chain database consists of a multi-region input-output table (MRIO) model that provides a time series of high-resolution IO tables with matching environmental and social satellite accounts for 190 countries, https://worldmrio.com/footprints/carbon.

It is possible to determine the turning point for the traditional (inverted-U) or inverted (U-shaped) EKC, which is equal to: $GDP^* = \frac{-\beta_1}{2\beta_2}$. In case of the extended (N-shaped) or inverted extended (\/\) EKC, the turning points are equal to[3]: $GDP^* = \frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3}$.

The EU's environmental directives place emphasis on three elements. In addition to reducing CO2 emissions, they advocate increasing energy efficiency and the share of renewable energy sources in final energy consumption. Energy efficiency is understood as the introduction of savings in energy consumption. Therefore, the aim is to reduce final energy consumption. The data on final energy consumption and the share of energy obtained from renewable sources are taken from the European Commission webpage[4].

3. Analyses and results

Depending on the chosen method of measuring CO2 emissions, the estimated regression models take the form of (2) for production-based CO2 emissions and (3) for consumption-based CO2 emissions in each country:

$$\ln(PBApc) = \beta_0 + \beta_1 \ln(GDPpc) + \beta_2\,[\ln(GDPpc)]^2 + \beta_3\,[\ln(GDPpc)]^3 \tag{2}$$

$$\ln(CBApc) = \beta_0 + \beta_1 \ln(GDPpc) + \beta_2\,[\ln(GDPpc)]^2 + \beta_3\,[\ln(GDPpc)]^3 \tag{3}$$

Table 2. The shape of the extended EKC depending on the values of the coefficients for production-based CO2 and GDPpc level (international dollars) for the turning points

	β_1	β_2	β_3	GDP*	
Extended EKC (N shaped)					
Greece	245.130**	-79.008**	8.466**	19146	26292
Ireland	45.808**	-12.497**	1.120**	26515	63916
Inverted extended EKC (\/\)					
Austria	-94.161**	27.775**	-2.723**	24948	35986
Bulgaria	-15.516**	6.439**	-0.877**	8563	15561
Finland	-187.673**	56.913**	-5.740**	23286	31886
Lithuania	-8.986**	3.402**	-0.417**	9555	24139
Luxemburg	-565.7663***	134.567***	-10.649***	56265	80993
Latvia	-7.881***	2.964***	-0.358***	9320	26748
Malta	-11.088***	37.548***	-4.001***	19225	27094
Poland	-12.032***	4.319***	-0.514***	13332	20366
Slovenia	-45.848*	15.701*	-1.785*	15403	22893

[3] Provided that there is a value under the square root is non-negative.
[4] Energy datasheets: EU-28 countries (https://ec.europa.eu/energy/en/data-analysis/country) accessed on 04.02.2020.

Table 3. The shape of the Inverted extended EKC (\/\) depending on the values of the coefficients for consumption-based CO2 and GDP* level (international dollars) for the turning points

	β_1	β_2	β_3	GDP*	
Austria	-143.779***	41.189***	-3.924***	28063	38956
Bulgaria	-16.386**	7.554**	-1.125**	6331	13878
Czechia	-33.343**	11.468**	-1.309**	15227	22612
Denmark	-1002.34*	279.49*	-25.94*	31475	41885
Estonia	-15.35**	5.67**	-0.68**	10449	24691
Finland	-120.90*	36.57*	-3.68**	23445	32193
France	-165.11*	49.43*	-4.93*	26704	29883
Croatia	-57.04**	22.33***	-2.88***	9904	17885
Lithuania	-7.41**	3.00**	-0.38**	7370	25769
Luxemburg	-360.60***	85.91***	-6.81***	54358	83176
Latvia	-6.59**	2.66**	-0.33**	7219	27714
Malta	-94.25*	30.08*	-3.19**	19680	27222
Netherlands	-124.48**	35.08**	-3.29**	29644	41376
Poland	-10.670***	3.98***	-0.49***	10782	22031
Slovenia	-74.419**	25.130**	-2.812**	15626	24764
Slovakia	-14.025**	5.242**	-0.642**	10609	21861

The recently postulated extended EKC (N-shaped) is confirmed in two countries (Table 2) and only when their production-based CO2 emissions are taken into account. This suggests that further economic development in Greece and Ireland may be linked to an increase in CO2 emissions. However, in many countries the inverted extended EKC (\/\) (Table 2, 3) are confirmed, which indicate possible further economic growth with lower CO2 emissions.

The traditional form of the EKC (inverted-U) is confirmed in most EU countries (Table 4), which means that their further economic growth will be accompanied by a decrease in CO2 emissions. In two countries – Germany and Estonia – the inverted (U-shaped) EKC are observed when production-based CO2 emissions are analysed.

Table 4. The shape of the EKC depending on the values of the coefficients and GDP* level (international dollars) for the turning point

	PBA			CBA		
	β_1	β_2	GDP*	β_1	β_2	GDP*
Traditional EKC (inverted-U)						
Belgium	9.032***	-1.380**	26409	5.139*	-0.800*	25275
Czechia	2.479**	-0.439**	16803			
Denmark	10.477**	-1.587**	27118			
Spain	16.271**	-2.523***	25136	17.947***	-2.750***	26143
France	8.991***	-1.388***	25501			
Croatia	5.753***	-1.022***	16687			
Hungary	2.800**	-0.530**	14012	4.628***	-0.818***	16928

	PBA			CBA		
	β_1	β_2	**GDP***	β_1	β_2	**GDP***
Ireland				4.036***	-0.581***	32219
Italy	28.246***	-4.214***	28542	28.505**	-4.227**	29124
Portugal	15.783***	-2.602***	20763	15.723***	-2.588***	20868
Romania	1.613*	-0.353*	9790	2.643***	-0.506**	13610
Slovakia	1.686***	-0.281***	11801			
Sweden	5.723***	-0.884***	25491	2.656*	-0.395*	28900
United Kingdom	9.617***	-1.509***	24220	9.180***	-1.384***	27544
Inverted EKC (U shaped)						
Germany	-2.395**	0.294**	59046			
Estonia	-1.522**	0.296**	13099			

When the analysis is based on production-based CO2 emissions, Netherlands reveals a monotonically decreasing linear relationship (β_1 =-0.423***). When the analysis is based on consumption-based CO2 emissions, Germany reveals a monotonically decreasing linear relationship (β_1 =-0.371***), and no correlation is found in Greece, which is also true in Cyprus, regardless of the method used to measure CO2.

The analysis demonstrates that if consumption-based CO2 emissions are taken into account, further economic development in all EU countries will be accompanied by the reduction of CO2 emissions. Interestingly, in countries where the traditional EKC (inverted-U) is confirmed, the inflection point determined on the basis of consumption-based CO2 is higher than the one determined on the basis of production-based CO2. This may mean that a higher level of income is necessary for environment protection (i.e. the reduction of CO2 emissions) not only in the production of goods and services but also in relation to their consumption. In countries where the inverted extended EKC (\/\) is found, such dependence can be seen too. Only in Bulgaria, the GDP value at which CO2 emissions begin to decrease is lower in case of consumption-based CO2 emissions than in case of production-based CO2 emissions.

The analysis of the groups of countries determined on the basis of the shape of their EKC resulting from consumption-based CO2 emissions reveals that the countries characterised by the traditional EKC (inverted-U) are those in which final energy consumption is at a much higher level (see Fig. 2a), although this is basically connected with their size. If per capita final energy consumption is considered, there are no differences between the analysed groups of countries (Fig. 2b).

a) final energy consumption b) per capita final energy consumption

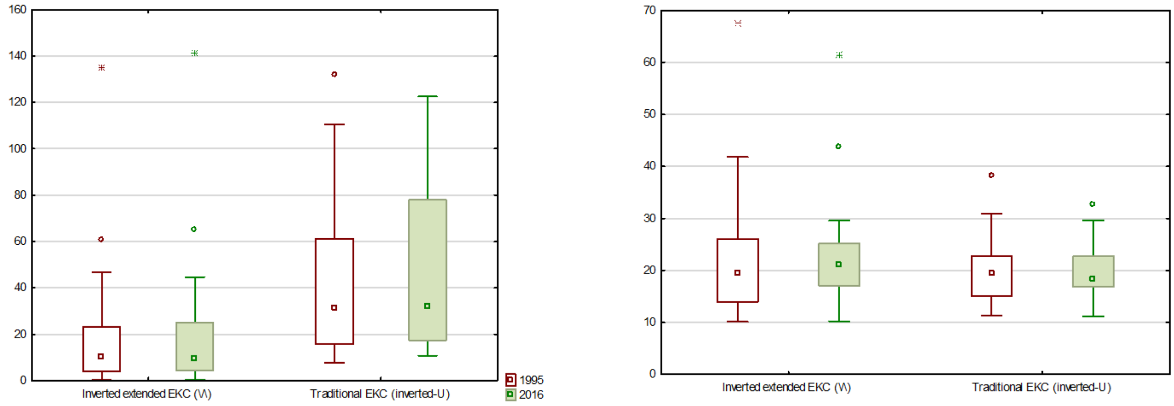

Figure 2. Boxplot demonstrating final energy consumption in the groups of countries determined on the basis of the shape of the EKC (for consumption-based CO2) in 1995 and 2016

Fig. 3 demonstrates a significant difference in the share of renewable energy sources in final energy consumption of the selected groups of countries. The countries characterized by the inverted extended EKC (V\) are those in which this share is higher and has a growing trend over the entire analysed period. The countries in the second group have a lower share of RES on average and a significant increase in this share is observed only since 2004.

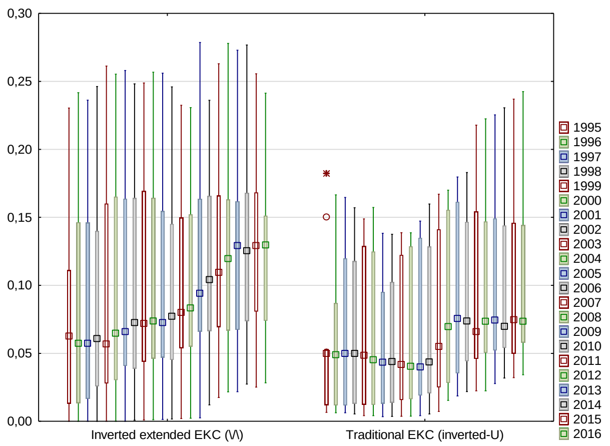

Figure 3. Boxplot demonstrating the share of renewable energy sources in final energy consumption in the groups of countries determined on the basis of the shape of the EKC (for consumption-based CO2) in 1995-2016

4. Conclusions

The aim of this study is to assess the relationship between CO2 emissions and economic growth using the Environmental Kuznets Curve. The analysis covers the individual EU countries over the period 1995-2016. The study takes into account both production-based and consumption-based CO2 emissions and its findings can be summarized in three main points.

First of all, the results of the analyses based on different methods of measuring CO2 emissions are different. In case of production-based CO2 emissions, the EKC of all possible shapes presented in the literature is observed. The results are more homogeneous when consumption-based CO2 emissions are taken into account. In this case, the EU countries are divided into two groups. One of them is characterized by the traditional EKC (inverted-U), while the other by the inverted extended EKC (\/\). It can be expected that in both groups further economic growth will be accompanied by reduced CO2 emissions.

Secondly, in most cases, the level of GDP at which the trend in CO2 emissions changes is higher for consumption-based CO2 emissions than for production-based CO2 emissions. This may result from the fact that economic growth is the most decisive factor contributing to investing in greener production methods. Moreover, a higher level of wealth is necessary in order to consciously manage consumption, which also leads to decreasing pollution.

Thirdly, the attempt to indicate the characteristics of individual groups of countries determined on the basis of the shape of the EKC does not yield clear results. It seems that the observed shape of the EKC is not influenced by energy efficiency. However, the groups of the EU countries analysed in the study differ in terms of their share of renewable energy sources.

Further research in this area should focus on finding determinants which influence the shape of the EKC. It is also advisable to extend the analysis both in terms of the time frame and the number of objects.

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References

Ahmad, N., Du, L., Lu, J., Wang, J., Li, H.Z., Hashmi, M.Z. (2017). Modelling the CO2 emissions and economic growth in Croatia: is there any environmental Kuznets curve? *Energy*, *123*, 164-172.

Álvarez-Herránz, A., Balsalobre, D., Cantos, J.M., Shahbaz, M. (2017). Energy innovations-GHG emissions nexus: fresh empirical evidence from OECD countries. *Energy Policy*, *101*, 90-100.

Dogan, E., Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Renewable Energy*, *94*, 429-439.

Dong, B., Wang, F., Guo, Y. (2016). The global EKCs. *International Review of Economics & Finance*, *43*, 210-221.

Grossman, G.M., Krueger, A.B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353-377.

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review*, *45*(1), 1-28.

Millimet, D.L., List, J.A., Stengos, T. (2003). The environmental Kuznets curve: Real progress or misspecified models? *Review of Economics and Statistics*, *85*(4), 1038-1047.

Ozturk, I., Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Economics*, *36*, 262-267.

Sephton, P., Mann, J. (2016). Compelling evidence of an environmental Kuznets curve in the United Kingdom. *Environmental and Resource Economics*, *64*(2), 301-315.

Shahbaz, M., Sinha, A. (2019). Environmental Kuznets curve for CO2 emissions: a literature survey. *Journal of Economic Studies*, *46*, 106–68.

Shahbaz, M., Mutascu, M., Azim, P. (2013). Environmental Kuznets curve in Romania and the role of energy consumption. *Renewable and Sustainable Energy Reviews*, *18*, 165-173.

Zoundi, Z. (2017). CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*, 1067-1075.