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Economic Development And Transfrontier Shipments Of Waste In Poland – Spatio-Temporal Analysis

Abstract

The aim of the paper is to apply the spatio-temporal Environmental Kuznets Curve (SpEKC) to test the relationship between economic growth and the amount of collected mixed municipal waste. The analysis was conducted at the level of sixty-six Polish sub-regions. The study contained selected environmental indicators. The dependent variable - the amount of municipal waste generated in kilograms per capita characterized the state of the environment. The GDP per capita in constant prices (as an explanatory variable) presented the level of economic development of the sub-regions. In the empirical part of the research there were used spatial panel data models based on EKCs. It determined the levels of economic development, at which the amount of produced wastes has fallen or increased, depending on the wealth of the region. The application of different types of spatial weight matrices was an important element of this modelling. Data obtained the years 2005-2012. Models were estimated in the RCran package.

Keywords*: spatial panel data models, Environmental Kuznets Curve, sustainable development, waste management, spatial weight matrices*

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1. Introduction

At the time of global ecological threats more and more attention is paid to issues connected with sorting and recycling of waste. The theory of sustainable development assumes minimizing the impact of economic growth on the quantity of produced waste.[1] Economic globalization, enhancement of the material quality of life, increasing production of consumer goods and ever faster technological progress result in shorter and shorter “lives” of commonly used goods, hence contributing to the excessive production of waste (Holger 2010, pp. 501-511). Therefore, the implementation of the principles of sustainable development into local and global regional[2] policies has become not only a duty (arising from European and international laws)[3] but also a necessity. At present, along with the problem of global air degradation, the production and interregional shipments of waste have become a serious threat as well (EEA 2012, p.5). Unlike the protection of the atmosphere against pollution, progress in rationalizing waste management has been very slow.[4] There is still no effective mechanism created for the sorting, recycling and shipment of waste.[5] As a result, most of the waste ends up in landfills or is exported to countries technologically prepared to recycle it. In Poland, there is only one municipal waste incineration plant (Targówek-Warsaw) and six others are under construction[6], while there are as many as over 400 such facilities in Europe alone.[7] The transboundary shipment/movement of waste means its export, import, transit[8] and spatial interactions (autocorrelation) occurring in its volumes. In the case of the discussed phenomenon, spatial autocorrelation is a situation where the quantity

[1] Midterm aims of waste management till 2016th, see: Council of Ministers, *The National Environmental Policy for 2009-2012 and its 2016*, Warsaw 2008.

[2] In the paper the region means an administrative unit localised in the geographical area. Economic develomept means the quantitative and qualitative changes in the economy which drive to rise of GDP, standard of living and environmental sustaintibility.

[3] Council of European Union, *Review of the EU Sustainable Development Strategy (EU SDS) −Renewed Strategy*, Brussels 2006.

[4] Polish national Parliament, The Act of 13 September 1996 *on maintaining tidiness and order within communes*, Warsaw 1996.

[5] Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste, in Poland the a*ct of* 29 June 2007 on the *international shipments* of *waste.*

[6] http://budownictwo.wnp.pl/spalarnie-odpadow-co-zrobilismy-co-robimy-co-przed-nami, 220 908_1_0_0.html, date: 28.04.2014.

[7] http://spalarnie-odpadow.pl/spalarnie-w-polsce-i-na-swiecie/, date: 28.04.2014.

[8] Basel Convention from date: 22.03.1989., Polish status of ratification: 10.01.1992., Chief Inspector of Environmental Protection, Transgraniczne przemieszczanie odpadów - nadzór i kontrola Inspekcji Ochrony Środowiska, Aura 9/2012, pp. 19-22.

of waste collected in a region affects the level of that phenomenon in adjacent regions. The monitoring of the changing volume of generated waste dependent on a region's wealth is among the principles of sustainable development. On the other hand, the quantification and identification of economic, ecological and spatial relationships is possible through, among others, the use of appropriate measurement methods, e.g. spatial panel data models based on the Environmental Kuznets Curve (EKC). The aim of the paper is to verify the hypothesis of the Spatio-temporal Environmental Kuznets Curve (SpEKC), where the curve describes the relation between socio-economic growth and the quantity of collected municipal waste in kilograms per capita at the level of Poland's subregions. The empirical part uses spatial panel models based on EKC functions. That serves to determine economic development levels of specific units for which the quantity of waste decreased or increased depending on a subregion's development. An important element of models was the application of various types of spatial weights matrices. Data concerned the years 2005-2012. In order to meet the objective of the study, research questions that have been put forward concern: 1) the scale and algorithm of the impact of economic development on the quantity of collected waste; 2) the possibility to determine economic development levels of specific subregions for which the quantity of produced waste fell or rose depending on a subregion's wealth; and 3) the impact of different types of spatial weights matrices used on the values of received results.

2. Research methodology and characteristics of variables

The main assumption of the conducted analysis is to verify the relationship between the volume of municipal waste (reflecting the environmental pollution level) and the economic development of a subregion, taking into account interregional interactions. One of the methods of modelling economic and ecological relationships, considering the specificity of a region and spatial autocorrelation, are spatial panel data models based on the functions of the Environmental Kuznets Curve (EKC).[9] The EKC is a curve (its basic version is a second degree polynomial – the inverted "U" letter)[10] expressing a change in the volume of environmental pollution depending on an increase in economic development (1):

[9] More details of different EKCs, in: (Antczak, 2012, pp. 113-130).

[10] More about EKC assumptions in: (Stern, 2004, pp. 1419–1439).

$$lE_{it} = -\alpha_i + \alpha_1 lED_{it} - \alpha_2 (lED_{it})^2 + \mathbf{x}_{it}^T \boldsymbol{\beta} + u_{it} \qquad (1)$$

where: Eit-environmental degradation indicator, EDit- measurement of economic development, $\mathbf{x}_{it}^T$ - matrix/vector of explanatory variables,αi-fixed effects, uit–error term;

Theoretical premises of the curve support transforming variables into logarithms.[11] The idea of the classic EKC (formula 1) bases on seeking an inflection point or – for cubic functions – inflection points (extremum/a of a function). The inflection point of the basic EKC version is such a level of economic development past which a potential drop in environmental pollution begins.

In this analysis, the quantity of gathered moxed municipal waste was made dependent on the economic development level, population density, investments on waste management and number of emigrants. Table 1 contains values of characteristics and coefficients of correlation indicating the scale and direction of interactions among variables.

Table 1. Values of characteristics and correlation coefficients

	units	MU_{it}	lMU_{it}	average	min	max	CV in %
MU_{it}	kg/capita	1	-	162,5	55,5	360,4	31
lMU_{it}	-	-	1	5,1	4,0	5,9	6
GDP_{it}	PLN thousand/capita	0,59	-	30,4	14,6	124,8	46
$lGDP_{it}$	-	-	0,59	3,3	2,9	4,8	11
INV_{it}	PLN/capita	-0,64	-	21	0,1	273,9	151
$lINV_{it}$	-	-	-0,69	2,3	-3,3	5,6	55
PD_{it}	persons/square km	0,59	-	388	44	3318	192
lPD_{it}	-	-	0,62	5,1	3,8	8,1	22
PFE_{it}	%	-0,49		5,7	0,1	33,7	90
$lPFE_{it}$	-	-	-0,59	1,4	-3	3,5	63

MUit -amount of collected municipal waste during the year GDPit - gross domestic product in constant price, INVit - amount of expenditure on waste management, PDit - population density, PFEit - share of foreign emigration in the total number of emigrants; l -logarithm. Some of variables are characterised by asymmetry. However, it implies the heterogenity which in this case is a desirable property.
Tests results: Levin-Lin-Chu the presence of unit root for the panel indicated that all variables are stationary also with time trend, (the analysis was conducted in Stata 11).

Source: own elaboration.

[11] More in: (Antczak, 2012, pp. 65-66).

Data presented in Table 1 allow to observe the following relationship: the higher the economic development level and population density, the bigger the quantity of collected waste. The opposite situation occurs for variables concerning the value of outlays on waste management and the share of the number of emigrants going abroad in the total volume of emigration. Results of this part of analysis indicate that it is possible to use the presented quantitative methods (describing economic, social and ecological relationships). However, the cause and effect relationships among the described variables are also affected by other factors, not given in Table 1, e.g. spatial interactions. Thus, the next step in the study was to formally verify interregional relationships by using appropriately selected tools of exploratory spatial data analysis (compare: Table 2) and spatial econometrics (compare: Tables 3-4).

Table 2 presents results of the analysis which served to verify whether spatial autocorrelation occurred for the quantity of municipal waste in Poland.

Table 2. Values of global Moran's I statistics for dependent variable MUit

	Moran *I*	***p*-value**
	Variable: MU (*lMU*)	
2005	0,40	<0,01
	0,41	*<0,01*
2006	0,38	<0,01
	0,39	*<0,01*
2007	0,38	<0,01
	0,39	*<0,01*
2008	0,40	<0,01
	0,41	*<0,01*
2009	0,49	<0,01
	0,50	*<0,01*
2010	0,47	<0,01
	0,51	*<0,01*
2011	0,54	<0,01
	0,56	*<0,01*
2012	0,55	<0,01
	0,57	*<0,01*

Note: the accepted level of statistical significance: α = 0,05. Italic: variable transformed into the logarithms. The statistical significance verification is based on randomization tests, more e.g. in: (Suchecki, 2010, p. 120).

Source: own elaboration.

In all the years of the analysed period the quantity of waste collected in Poland's subregions was characterized by statistically significant positive spatial autocorrelation, which, in space, means the grouping together of subregions with similar quantities of municipal waste adjacent to one another (subregions producing large quantities of waste are adjacent to subregions with high values of that variable; similarly: units producing less waste are situated adjacent to regions with low levels of the phenomenon). Moreover, data contained in Table 2 indicate that the strength of statistically significant spatial relationships increased in the years 2005-2012 (an average rise of 38% in Moran's I statistic value in 2012 as compared to 2005). Thus, the production of waste in a subregion significantly affected the volume of that phenomenon in its adjacent subregions (according to the assumed spatial weights matrix).

In order to simultaneously take into account the above ecological and economic relationships (Table 1) and processes of the transboundary shipment of waste (Table 2), spatial panel data models with fixed effects based on the EKC function (FEM-EKC) and containing a spatially lagged dependent variable (SAR-FEM-EKC[12]) were used. Eventually, it appeared, however, that the most appropriate form of the EKC would be the inverted Kuznets cubic curve (2):

$$\begin{aligned} lMU_{it} &= \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 - \alpha_3 (lGDP)^3 - \alpha_4 lINV_{it} + \\ &+ \alpha_5 lPD_{it} - \alpha_6 lPFE_{it} + \rho l\mathbf{W}MU_{it} + u_{it} \end{aligned} \qquad (2)$$

The curve described by formula 2 expresses a relationship between an increase in economic development and the quantity of collected municipal waste per capita. Thus, there are three phases of the course of those phenomena over time (received signs of structural parameters at the lGDPit variable). Namely, in the first stage of modelling, a rise in GDP per capita results in a drop in the quantity of generated waste. In the second phase, past an inflection point, an increase in economic development leads to a rise in the volume of waste. In turn, in the third and last stage of the course of the phenomenon over time, the second inflection point appears (the second extremum of the function, a particular value of GDP per capita), past which a decrease in the quantity of municipal waste occurs. [13]

The use of a cross-sectional sample in the form of spatially located data requires taking into account spatial interactions. In SAR-FEM models, where spatial relationships concern the dependent variable (here: MUit), spatial autoregression occurs, i.e. the value of the dependent variable for other localities (areas, regions, geographical points) affect values of that variable in a given

[12] *Spatial AutoRegressive* panel data Models with *Fixed Effects based on EKC function.*

[13] Foreign literature: (Ichinose, et al., 2011).

i locality (WMUit). In spatial econometrics models, a difficult and important issue is to include spatial autocorrelation in the form of an appropriately chosen spatial weights matrix. The building and application of a particular type of the matrix should depend on the objective and assumptions of the conducted analysis, specificity of a phenomenon and used quantitative method. What is more, received research results may differ significantly depending on the assumed spatial weights matrix type as well. [14]

3. Spatial weights matrices - selection

The presence of statistically significant interregional relationships (concerning transboundary shipment of waste, compare: section 2 of the article) was a premise for considering an interaction element in econometric modelling. The applied FE panel models allow to estimate individual effects (specific to a region in this case). In turn, the selection of the SAR model assumes the introduction of a spatially lagged dependent variable (lWMUit) into the set of independent variables so that the variable retains the properties of a dependent variable. The spatial weights matrix should reflect the nature and specificity of interregional interactions (adjacency of a region affects the volume of produced waste in other units situated in that geographical space; compare: Table 1). In order to reflect the described spatial relationships, three spatial weights matrices were built: W1, W2, W3.

W1 – a matrix where values of weights were determined based on a spatial trend. The dependent variable in the estimated surface trend model was the quantity of municipal waste collected in subregions (MUit). The form of the model was described by formula (3):

$$MU_{it} = \beta_0 X_{coor}^{\beta_1} Y_{coor}^{\beta_2} e^{\varepsilon_{it}} \tag{3}$$

where: Xcoor, Ycoor-coordinates of centers of regions, ε_{it} -error term, β0, β1, β2-structural coefficients of the model;

Upon estimating parameter values, the model described by formula (3) took the form of (4):

[14] More about spatial weights matrixes in: (Suchecki, 2010).

$$\hat{MU}_{it} = 4{,}8 X_{coor}^{-1{,}4} Y_{coor}^{0{,}8} \qquad (4)$$

t (51,5) (-5,4) (0,9)
S(b_j) (0,1) (0,3) (0,9)

where: t-values of t-Student's statistics, S(bj)-average standard of coefficients errors;

Evaluations of the estimated parameters (β0, β1) of model (4) proved to be statistically significant at the assumed significance level of α=0,05 (for the critical value of t*=1,7).[15] That significance confirms the presence of a surface trend in Poland's subregions in respect of the quantity of collected municipal waste. What is more, the global spatial trend in the volume of the phenomenon was upward in the years 2005-2012 (β0=4,8). The sign of the parameter estimation at the X coordinate is negative (-1,4). That indicates a downward spatial trend from the West towards the East of Poland, i.e. Western subregions were characterized by a higher level of the analysed variable than Eastern subregions. The received model estimation results (4) revealed the absence of a statistically significant spatial trend in the quantity of collected municipal waste from the South towards the North. Based on information obtained about spatial trends in the average level of waste collected in Poland in the years 2005-2012, a spatial weights matrix was built. The matrix took into consideration the spatial trend through assigning higher weights to subregions in the West of Poland (reflecting the spatial trend) and lower – to subregions in the East.

W2 – a weights matrix built on the basis of the first order adjacency for the eight closest neighbours.[16] In some cases waste is shipped over a close distance (just across the boundary of a given subregion). Thus, the idea behind the weights matrix structure was to take the direct adjacency of a given area (subregion) into consideration.

W3 – a weights matrix built based on distances from the determined geographical centres of specific subregions. In the case of transboundary shipments of waste, waste is transported over short distances (below 50 km) but also over distances above a thousand kilometres. The largest recipients of municipal waste (suitable for recycling) include the Northern subregions of Poland, which further export the gathered waste to Scandinavian countries, and Western subregions, exporting the "raw material" further to Western Europe (to

[15] The chosen model was the exponential trend surface model because it was the most effective (test on normality of errors: Jarque-Bera=1,8 with p-value=0,4, diagnostics for heteroskedasticity: Breusch-Pagan=2,4 with p-value=0,3), lower Akaike and Schwarz info criterion than linear, models as a polynomial of the second and the third degree.

[16] The eight nearest neighbours because in Poland there is no region with more than eight adjoining regions. More about spatial weights matrices, see in: (Suchecki, 2010, pp. 28-33).

Germany or Switzerland). The main recipients of sorted municipal waste in Europe are: Switzerland, Germany, Austria, Portugal and Scandinavian countries. In those countries, highly developed state-of-the-art technologies intensify waste recycling processes (over 30% of locally generated waste is recycled)[17]. In the years 2005-2012 municipal waste was most commonly shipped within Poland to the following subregions: Włocławski, Grudziądzki, Wrocławski, Suwalski, Łomżyński and Ostrołęcko-Siedlecki.[18] Therefore, the constructed spatial weights matrix considered regions located at different geographical distances from one another. The lengths of the radii of circles (within which specific subregions, as potential recipients of waste, were located) were from 132 km to 648 km (the stretch of Poland). Weight values were assigned depending on geographical distances from the centre of a specific region.

The subsequent part of the article presents estimation results of spatial panel models based on the functions of the Environmental Kuznets Curve using the three different spatial weights matrices ($\mathbf{W_1}$, $\mathbf{W_2}$, $\mathbf{W_3}$).

4. Results

The aim of the performed econometric analysis was to verify the hypothesis of the spatiotemporal environmental Kuznets curve in respect of the volume of waste in Poland's subregions in the years 2005-2012, depending on the economic development level of selected regions. An important element of the analysis was the application of various types of spatial weights matrices. Results of the estimations of classic and spatial EKC models with spatial weights matrices W1, W2 and W3 are shown in Tables 3 and 4.

Table 3. Results of SAR-FEM-EKCs estimation, n=528

SAR1-FEM-EKC: $lMU_{it} = \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 + \alpha_3 (lGDP_{it})^3 - \alpha_4 lINV_{it} + \alpha_5 lPD_{it} - + \alpha_6 lPFE_{it} + \rho_1 l\mathbf{W_1} MU_{it} + u_{it}$

parameter	value	t-student	std.error	p-value
const	11,62	5,33	2,18	<0,01
α1	-7,97	-4,64	1,72	<0,01
α2	2,31	4,75	0,49	<0,01
α3	0,22	-4,91	0,05	<0,01
α4	-0,0004	-0,12	0,003	0,90
α5	0,24	2,74	0,14	0,01
α6	-0,02	2,75	0,005	0,01
ρ1	0,26	4,80	0,06	<0,01

[17] www.epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home, date: 20.04.2014.

[18] www.stat.gov.pl - Bank Danych Lokalnych, date: 28.04.2014.

pseudo R2=0,96; Chow's test on fixed effects significance F*(456, 65)=1,34, F=1,78, F>F*; normality of residuals: Shapiro-Wilk, W = 0,98, p-value = 0,14, stationary of residuals: Levin-Lin-Chu, without time trend H1 for -28,1 (0,000), with time trend H1 for -20,8 (0,000); t*=1,89, HQC=-2631				
Chow's test on spatial fixed effects: FSAR-FEM>F*; 3,92>2,94, SAR1-FEM–EKC better than FEM-EKC;				
SAR2-FEM-EKC $lMU_{it} = \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 + \alpha_3 (lGDP_{it})^3 - \alpha_4 lINV_{it} + \alpha_5 lPD_{it} - + \alpha_6 lPFE_{it} + \rho_2 l\mathbf{W}_2 MU_{it} + u_{it}$				
parameter	value	t-Student	std.error	p-value
const	10,3	4,75	2,17	<0,01
α1	-7,63	-4,46	1,71	<0,01
α2	2,21	4,56	0,49	<0,01
α3	-0,21	-4,71	0,05	<0,01
α4	-0,001	-0,31	0,004	0,75
α5	0,30	2,19	0,14	0,03
α6	-0,02	-2,43	0,01	0,02
ρ2	0,34	5,58	0,07	<0,01
pseudo R2=0,95; Chow's test on fixed effects significance F*(456, 65)=1,34, F=1,88, F>F*; normality of residuals: Shapiro-Wilk, W = 0,98, p-value = 0,11, stationary of residuals: Levin-Lin-Chu, without time trend H1 for -27,5 (0,000), with time trend H1 for -20,1 (0,000); t*=1,89, HQC=-2609				
Chow's test on spatial fixed effects: FSAR-FEM>F*; 4,44>2,94, SAR2-FEM–EKC better than FEM-EKC;				
SAR3-FEM-EKC $lMU_{it} = \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 + \alpha_3 (lGDP_{it})^3 - \alpha_4 lINV_{it} + \alpha_5 lPD_{it} - + \alpha_6 lPFE_{it} + \rho_3 l\mathbf{W}_3 MU_{it} + u_{it}$				
parametr	value	t-Student	stnd. error	p-value
const	9,87	7,85	1,26	0,000
α1	-8,43	-4,80	1,75	<0,01
α2	2,42	4,87	0,49	<0,01
α3	-0,23	-4,97	0,05	<0,01
α4	-0,001	-0,27	0,003	0,79
α5	0,32	2,24	0,14	0,03
α6	-0,02	-2,34	0,01	0,02
ρ3	0,43	3,23	0,13	0,001
pseudo R2=0,95; Chow's test on fixed effects significance F*(456, 65)=1,34, F=1,31, F<F*; normality of residuals: Shapiro-Wilk, W = 0,96, p-value = 0,09, stationary of residuals: Levin-Lin-Chu, without time trend H1 for -25,2 (0,000), with time trend H1 for -19,4 (0,000); t*=1,89, HQC=-2583				
Chow's test on spatial fixed effects: FSAR-FEM<F*; 1,20<2,94, SAR3-FEM–EKC not better than FEM-EKC;				

Spatial models are estimated by ML; characteristics of matrices see the 3rd part of the paper significance level: α=0,05, H1: Panels are stationary;

Source: own elaboration in RCran.

Evaluations of parameters at the spatially delayed variable in all the three models proved to be statistically significant, which means that a rise in the volume of generated waste was affected by the economic development and mutual adjacency of the regions. The strength of the impact depended on the type of the introduced spatial weights matrix (ρ1=0,26, ρ2=0,34, ρ3=0,43). Therefore, considering spatial interactions in the form of the W matrix proved to be justified. Furthermore, all the models confirmed the occurrence of two inflection points (GDP levels past which a rise and drop in the quantity of collected waste would respectively take place). However, not all the spatial models turned out to be qualitatively better than the zero and non-spatial models. Based on the values of Chow test statistics, a SAR3-FEM-EKC was rejected, for which the introduction of fixed and spatial effects appeared to be unjustified. In turn, as for the other two models: SAR1-FEM-EKC and SAR2-FEM-EKC, the model with weights matrix W1, built on the basis of the spatial trend in the quantity of municipal waste collected in subregions per year, was selected for the final analysis (among others: lower value of HQC, higher level of statistical significance of parameter evaluations, higher coefficient of determination). Then, the results were analysed in detail and compared with non-spatial modelling results (Table 4).

Table 4. Results of estimation of FEM-EKC and SAR1-FEM-EKC

FEM-EKC	$lMU_{it} = \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 + \alpha_3 (lGDP_{it})^3 - + \alpha_4 lINV_{it} + \alpha_5 lPD_{it} - \alpha_6 lPFE + u_{it}$			
parameter	value	t-student	std.error	p-value
const	13,02	5,39	2,42	<0,01
α1	-8,11	-4,26	1,90	<0,01
α2	2,33	4,31	0,54	<0,01
α3	-0,22	-4,41	0,05	<0,01
α4	-0,001	-0,21	0,003	0,83
α5	0,28	1,82	0,15	0,07
α6	-0,03	-3,19	0,01	0,02
αi	tr=13,29, sł=12,67, gd=13,15, el=13,13, ko=13,46, su=13,12, sa=13,38, eł=13,32, sz=13,55, ol=13,33, so=13,20, Szcz=12,98, gr=13,13, pi=13,33, ło=13,08, bt=13,17, bi=13,36, go=13,57, wł=13,07, po=13,22, ci=13,12, P=12,86, kń=13,20, W=13,05, wz=13,21, os=12,91, ww=12,97, sk=13,39, z=13,13, le=12,75, ba=12,97, ka=12,55, Ł=12,78, si=13,21, łó=13,02, ra=13,02, pi=12,66, pu=13,05, lu=13,15, wr=13,57, lg=12,79, Wr=13,44, je=12,80, ki=12,92, cz=12,63, op=13,28, sj=12,57, wa=13,38, ta=12,67, by=13,1, gl=13,00, ny=13,16, so=13,03, ka=12,81, kr=12,45, ry=12,86, ty=12,88, K=12,94, rz=12,55, ta=12,56, oś=12,46, be=12,73, pr=12,69, kś=12,84, no=12,87, no=12,6;			

pseudo R2=0,92; Chow's test on fixed effects significance F*(456, 65)=1,34, F=1,58, F>F*; normality of residuals: Shapiro-Wilk, W = 0,98, p-value = 0,09, stationary of residuals: Levin-Lin-Chu, without time trend H1 for -23,4 (0,000), with time trend H1 for -17,6 (0,000); t*=1,89, HQC=-837				
Turning points: 23,3 and 44,7 PLN per capita				
SAR1-FEM-EKC $lMU_{it} = \alpha_i - \alpha_1 lGDP_{it} + \alpha_2 (lGDP_{it})^2 + \alpha_3 (lGDP_{it})^3 - \alpha_4 lINV_{it} + \alpha_5 lPD_{it} - + \alpha_6 lPFE_{it} + \rho_1 l\mathbf{W_1} MU_{it} + u_{it}$				
parameter	value	t-student	std.error	p-value
const	11,62	5,33	2,2	<0,01
α1	-7,97	-4,64	1,72	<0,01
α2	2,31	4,75	0,49	<0,01
α3	0,22	-4,91	0,05	<0,01
α4	-0,0004	-0,12	0,003	0,90
α5	0,24	2,74	0,14	0,01
α6	-0,02	2,75	0,005	0,01
ρ1	0,26	4,80	0,06	<0,01
αi	tr=11,82, sł=11,34, gd=11,70, el=11,69, ko=11,97, su=11,67, sa=11,93, eł=11,90, sz=12,02 ol=11,92, so=11,69, Szcz=11,59, gr=11,68, pi=11,86, ło=11,67, bt=11,78, bi=11,99, go=12,09, wł=11,63, po=11,79, ci=11,68, P=11,53, kń=11,79, W=11,75, wz=11,83, os=11,50, ww=11,57, sk=11,56, z=11,91, le=11,65, ba=11,39, ka=11,55, Ł=11,28, si=11,33, łó=11,87, ra=11,63, pi=11,62, pu=11,32, lu=11,78, wr=11,66, lg=12,12, Wr=11,48, je=11,97, ki=11,45, cz=11,51, chz=11,27, op=11,85, sj=11,18, wa=11,93, ta=11,37, by=11,65, gl=11,57, ny=11,73, so=11,65, ka=11,42, kr=11,09, ry=11,47, ty=11,51, K=11,38, rz=11,22, ta=11,18, oś=11,35, be=11,28, pr=11,52, kś=11,54, no=11,29;			
pseudo R2=0,96; Chow's test on fixed effects significance F*(456, 65)=1,34, F=1,78, F>F*; normality of residuals: Shapiro-Wilk, W = 0,98, p-value = 0,14, stationary of residuals: Levin-Lin-Chu, without time trend H1 for -28,1 (0,000), with time trend H1 for -20,8 (0,000); t*=1,89, HQC=-2631				
Chow's test on spatial fixed effects: FSAR-FEM>F*; 3,92>2,94, SAR1-FEM–EKC better than FEM-EKC;				
turning points: 17,3 and63,4 PLN per capita				

tr-trójmiejski, sł-słupski, gd-gdański, el-elbląski, ko-koszaliński, su-suwalski, sa-stargardzki, eł-ełcki, sz-szczeciński, ol-olsztyński, so-starogardzki, Szcz- Szczecień, gr-gudziądzki, pi-pilski, ło-łomżyński, bt-bydgosko-toruński, bi-białostocki, go-gorzowski, wł-włocławski, po-poznański, ci-ciechanowski, P-Poznań, kń-koniński, W-Warszawa, wz-warszawski-zachodni, os-ostrołęcko-siedlecki, ww-warszawski-wschodni, sk-skierniewicki, z-zielonogórski, le-leszczyński, ba-bialski, ka-kaliski, Ł-Łódź, si-sieradzki, łó-łódzki, ra-radomski, pi-piotrkowski, pu-puławski, lu-lubelski, wr-wrocławski, lg-legnicko-głogowski, Wr-Wrocław, je-jeleniogórski, ki-kielecki, cz-częstochowski, chz-chełmsko-zamojski, op-opolski, sj-sandomiersko-jędrzejowski, wa-wałbrzyski, ta-tarnobrzeski, by-bytomski, gl-gliwicki, ny-nyski, so-sosnowiecki, ka-katowicki, kr-krakowski, ry-rybnicki, ty-tyski, K-Kraków, rz-rzeszowski, ta-tarnowski, oś-oświęcimski, be-bielski, pr-przemyski, kś-krośnieński, no-nowosądecki;

Spatial models were estimated by ML, non-spatial model by OLS; significance level: α=0,05.

Source: own elaboration in RCran.

Results contained in Table 4 reveal that both the non-spatial model (FEM-EKC) and the spatial model (SAR1-FEM-EKC) indicate that the third degree function (polynomial) was properly selected as the most appropriate form for the analysis of relationships between economic development and "production" of municipal waste in Poland (statistical significance of evaluations of estimated structural parameters at the GDPit variables). The first extremum of the model without interregional relationships (without the W matrix) indicated the economic development level (PLN 23,2 per capita), which was attained by 19 subregions before or in 2005 (which accounted for as few as 29% of the analysed units) and exceeded by as many as 92% of nuts3 in 2012. Hence, after a subregion achieved the GDP described by the first inflection point, the further process of GDP increase led to a rise in waste quantity. As for the models with spatial interactions, the first inflection point was at the level of PLN 17,3 per capita. Collected data suggest that before 2005 (or exactly at that point in time) as many as 50 subregions attained that development level, which accounted for 76% of all the analysed units. In 2012 all the subregions exceeded the first inflection point on the EKC curve, which clearly indicated the occurrence of the other inflection point in the course of the discussed economic and ecological relationship, which, in turn, is a property of inverted cubic EKC functions. According to the results of the non-spatial model estimations, the other inflection point was an unbelievably low level of economic development (PLN 44,7 per capita), past which further development generated the quantity of waste that did not pollute the environment. That would point to the effectiveness of actions carried out within the framework of waste management in Poland. Fourteen subregions attained such a GDP level (which accounted for 21% of all the units) in the years 2005-2012. Those were, among others, the city of Warsaw, Warszawski-Zachodni, Legnicko-Głogowski, Jeleniogórski, the city of Wrocław etc. On the other hand, results received in spatial modelling suggest an economic development level of PLN 63,4 per capita achievable by only four subregions in the analysed period: Warsaw, the city of Poznań, the city of Wrocław and the Legnicko-Głogowski subregion (where, despite the huge quantity of collected waste, its recycling reached 72%, with the national average at a little above 30%).[19] After exceeding that point, the above-mentioned subregions re-entered the path of sustainable development, regarding the natural environment as a luxury good (the effect of pro-ecological investments is the limiting and reduction of the annual quantity of collected waste).

The impact of the adjacency of regions on the quality of environment proved to be adverse (0.26·lW1MUit), which meant that a rise in the volume of

[19] SWD, Wojewódzki Plan Gospodarki Odpadami dla Województwa Dolnośląskiego 2012, Wrocław 2012.

waste in a subregion led to an average increase of 0,26% in the volume of that phenomenon in adjacent subregions (according to the assumed spatial weights matrix). [20] Moreover, interregional relationships caused the first inflection point to appear earlier than in the non-spatial model (PLN 17,3 per capita and PLN 23,3 per capita for the ordinary model respectively). That allows to infer that, at a lower level of economic development, every quantity of generated waste posed a threat to the environment. On the other hand, the other extremum of the function (past which a fall in the quantity of municipal waste occurred along with a rise in GDP per capita) "required" a higher level of subregions' development in spatial modelling than that indicated by the estimation results that did not take into account spatial relationships. That confirms the negative impact of adjacency on the level of the analysed phenomenon.

Estimation results of the spatial panel model with fixed effects revealed subregions which, to the largest and smallest extent, contributed to the total quantity of collected municipal waste (see Table 4), too. In the years 2005-2012 the smallest impact on environmental degradation by waste characterized the Krakowski and the biggest – the Legnicko-Głogowski subregions.

Other factors affecting the quantity of waste and considered in the study were population density, whose increase resulted in an average rise of 0,24% in the volume of collected waste, and the proportion of the number of emigrants going abroad in the total number of emigrants, whose rise caused the dependent variable to fall by an average of 0,02% (ceteris paribus). The value of outlays on waste management turned out not to exert a significant impact on the quantity of municipal waste collected over the year.

Eventually, the spatial model was of higher quality than the model without spatial interactions (higher values of statistics: R2 or the Chow test; lower values of the Hannan-Quinn Information Criterion).

5. Summary

Results of the conducted analysis indicate that there are relationships between the quantity of collected municipal waste and economic development of Poland's subregions - the third degree function of EKC (polynomial) was properly selected as the most appropriate form for the analysis of relationships between economic development and "production" of municipal waste in Poland (statistical significance of evaluations of estimated structural parameters at the

[20] Characteristics of weight matrices see part 3rd of the paper.

GDPit variables). Moreover, in most analysed Poland's subregions (94%), the processes of faster economic development threatened the quality of the environment, and thus the quality of life between years 2005-2012 (only 6% of the analysed regions exceeded the second inflection point past which the environment became a good worth investing in). As for the models with spatial interactions, the first inflection point was at the level of PLN 17,3 per capita. Collected data suggest that before 2005 (or exactly at that point in time) as many as 50 subregions attained that development level, which accounted for 76% of all the analysed units. The second turning point by the spatial modelling suggests the level of PLN 63,4 per capita of an economic development which was achievable only by four subregions in the analysed period: Warsaw, the city of Poznań, the city of Wrocław and the Legnicko-Głogowski subregion (where, despite the huge quantity of collected waste, its recycling reached 72%, with the national average at a little above 30%). After exceeding that point, the above-mentioned subregions re-entered the path of sustainable development, regarding the natural environment as a luxury good (the effect of pro-ecological investments is the limiting and reduction of the annual quantity of collected waste).

The results of the estimated EKC models confirmed that the level of the described phenomenon was also affected by interregional spatial interactions. The intensity and direction of transboundary shipments of waste were reflected by elements of the spatial weights matrix. The impact of the adjacency of regions on the quality of environment proved to be adverse (0.26·lW1MUit), which meant that a rise in the volume of waste in a subregion led to an average increase of 0,26% in the volume of that phenomenon in adjacent subregions. In turn, the occurring positive spatial autocorrelation resulted in an adverse impact of subregions' adjacency on the volume of waste. Furthermore, spatial panel models based on the Environmental Kuznets Curve reflected processes taking place on the specific planes of the analysed phenomenon more precisely than classic models.

The findigs are definitely relevant for policymaking. Since the results confirm that transboundary pollution associated with municipal waste is a major issue in Poland, one possible solution to reduce the amount of waste is to maximise recycling and re-use, to limit incineration to non-recyclable materials, to phase out landfilling to non-recyclable and non-recoverable waste, to ensure full implementation of the waste policy targets. However, the conducted study did not exhaust the issues raised in the article. They will be continued in further analyses aimed, among others, at the classification of subregions into groups (depending on the EKC function in a given region), replacement of the GDP variable with other variables and use of multi-equation spatial models. The analyses will still be focused on current issues such as: raising ecological awareness related to the rationalization of consumption and limiting of the quantity of generated pollution as well as the effective control of transboundary shipments of waste.

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Streszczenie

ROZWÓJ GOSPODARCZY A MIĘDZYREGIONALNE PRZEMIESZCZENIE ODPADÓW W POLSCE – ANALIZA PRZESTRZENNO-CZASOWA

Celem publikacji jest aplikacja przestrzenno-czasowej Środowiskowej Krzywej Kuznetsa (SpEKC, Spatiotemporal Environmental Kuznets Curve) do testowania zależności pomiędzy wzrostem gospodarczym a ilością zebranych zmieszanych odpadów komunalnych na poziomie podregionów Polski. Badanie przeprowadzono na podstawie wybranych wskaźników środowiskowych. Zmienna objaśniana, w postaci ilości zebranych odpadów komunalnych w kilogramach na mieszkańca, charakteryzowała stan środowiska naturalnego, a PKB na osobę w cenach stałych (jako zmienna objaśniająca) prezentowała poziom rozwoju gospodarczego poszczególnych podregionów Polski. W części empirycznej zastosowano przestrzenne modele panelowe oparte na funkcjach EKC. W ten sposób wyznaczono poziomy rozwoju gospodarczego poszczególnych jednostek, dla których ilość wytwarzanych odpadów spadała bądź wrastała w zależności od bogactwa podregionu. Ważnym elementem modeli była aplikacja różnych typów macierzy wag przestrzennych, które skonstruowano w oparciu o estymowane trendy przestrzenne dotyczące ilości produkowanych odpadów w Polsce oraz uwzględniając sąsiedztwo podregionów. Dane dotyczyły lat 2005–2012. Modele estymowano w pakiecie RCran.

Słowa klucze: *przestrzenne modele panelowe, Środowiskowa Krzywa Kuznetsa, zrównoważony rozwój, gospodarka odpadami, macierze wag przestrzennych*