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SPATIAL AUTOREGRESSIVE PANEL DATA MODELS APPLIED TO EVALUATE THE LEVELS OF SUSTAINABLE DEVELOPMENT IN EUROPEAN COUNTRIES[1]

Abstract. The aim of this paper is the presentation of a spatial panel models application to analyzing the level of sustainable development realization in 32. European Countries. This type of spatial models has not been used in Poland in this field of research. Models construction was based on Environmental Kuznets Curve hypothesis. It assumes the existence of a relationship between various indicators of environmental degradation and income per capita. In the early stages of economic growth pollution increases. However, above a certain level of high income per capita high-income levels economic growth leads to environmental improvement. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita. Selected statistics tools to present the phenomena were also used The data include the years from 1990 to 2006. According to the existence of spatial autocorrelation and results obtained from both parts of the research, assessment and comparison analysis of sustainable development level in Europe were conducted.

1. INTRODUCTION

The consumption-based model as pursued by the developed countries and demographic explosion are phenomena leading to environmental crisis. At the same time, they discourage alternative thinking about the future and make governments take not only local, but also global actions on behalf of the environment. Irrational management brings about ecological disasters, considerably impairs human health and makes the rate of economic development vary between the countries. Environmental degradation has been recognized as an important economic and social problem since mid-20th c. Earlier on, people tended to ignore the fact that intensively exploited natural environment produces nega-

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[1] This paper is based on the results of the analysis discussed in the doctoral thesis of Elżbieta Antczak written under the supervision of Prof. Jadwiga Suchecka (*Zrównoważony rozwój Polski i Europy*, *modele i analizy przestrzenno–czasowe*, Biblioteka Uniwersytetu Łódzkiego, Łódź 2010).

tive economic, social and ecological changes. With the environmental crisis reaching a global scale, the need for gradual mitigation of global risks and reducing environmental pressures were recognised. This awareness triggered research into the path of socio-economic development that would be friendly to the use and protection of the environment. As a result, the concept of sustainable development (SD) was formulated.

This article discusses the results of spatial panel data models used for evaluating the achievement of sustainable development objectives in 32 European countries. It presents the estimates provided by the spatial panel data models based on the environmental Kuznets curve (EKC) that have not been used in this field of science in Poland yet. According to the EKC, economic growth degrades the environment along a curve shaped like an inverted U shape. The point where *per capita* income exceeds a set level stands for is turning point, behind which environmental degradation decreases in spite of continued economic growth. The data used in the investigation spanned the years 1990 - 2006.

2. SUSTAINABLE DEVELOPMENT IN EUROPE

Assuming that ecology, sustainable and permanent development can be used interchangeably, their definition dates back to the late 18th c. At the turn of the 1960s the interest in the consequences of irrationally managed environmental resources increased. The discussions and actions gave rise to a broad range of environmental reports, documents and conferences.

The definition of sustainable development (otherwise eco-development) was formulated and published in 1975. However, words and statements conveying its sense had circulated even before that year. Sustainable development was then understood as: „[…] the type of an inevitable and desired path of economic development that does not substantially and irreversibly affect the environment where people live, does not degrade the biosphere and reconciles the laws of nature, economy and culture"[2]. A commonly quoted definition of sustainable development was provided in the Brundtland Report [1987], where eco-development is described as: „ social and economic advance to assure human beings a healthy and productive life, but one that did not compromise the ability of future generations to meet their own needs"[3]. „The Earth Charter" of 1992

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[2] Kozłowski S., [1996], *Czy transformacja polskiej gospodarki zmierza w kierunku rozwoju zrównoważonego?*, [in:] *Mechanizmy i uwarunkowania ekorozwoju,* vol. 1, Wyd. KEiZOŚ Politechniki Białostockiej, Białystok, p.34.

[3] Waortman D., [2002], *Von der Vision zur Strategie: Grundelmente und Entwicklungsmuster einer Politik der Nachhalichkeit*, [in:] Selbaldt M., *Sustainable development – Utopie oder realistiche Vision?*, Verlag Kovac, Hamburg, p.95.

formulated the basic principles of sustainable development with respect to climate changes and clean energy, sustainable consumption and production, conservation and management of natural resources, protection of health, social justice, migration, demography and fight against global poverty, etc.[4]

It was also stressed that the major principles of eco-development should be implemented along the four lines: environmental, socio-demographic, economic and spatial. Poor countries concentrate on the economic and social dimension of eco-development, as meeting the basic needs of their populations is crucial to them. Because developed countries are at a higher level of environmental awareness, they enact laws protecting the environment. Given that the environment and particularly its protection and degradation naturally step outside the administrative borders, the principles of eco-development should be implemented under transborder cooperation.

The EU's economic policy is based on rules that aim to protect the environment. The first pro-environmental scheme was conceived and carried out in the European Economic Community between 1973 and 1975. The European environmental-protection programmes evolved since then and their scopes were being extended to include new tasks.

The principle of sustainable development was officially approved as a systemic principle underpinning all economic activity in the Community in 1992, with the signing of the European Treaty in Maastricht. It was decided then that particularly decisions with respect to transport, agriculture, and international have to be made taking account of their environmental impacts[5]. The Single European Act (art. 100a, items 3 and 4) and the EU Treaty (art. 2) underline that the European Community will follow the line of eco-development. Entering into the European Union in 2004, Poland explicitly assumed the obligation to accept unconditionally the provisions contained in the European Treaties and the EU Constitution. This practically means that the country made a pledge to pursue sustainable development and embark on joint programmes designed to protect the natural environment in Europe[6].

A very important aspect of the struggle against environmental degradation is ecological awareness and education that teaches people and raises them to respect natural resources. Any person undertaking any economic activity should do that bearing in mind the well-being and the quality of life of the future gen-

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[4] European Commission, [2007], *A sustainable future in our hands*, A guide to the EU's sustainable development strategy, Belgium, p.8.

[5] Website: www.jjszkolenia.pl, J&J Szkolenia, Grupa Szkoleniowo-Doradcza, [2009], article: *Fundusze Europejskie a kwestie ochrony środowiska*, last access: 13 Feb. 2009.

[6] In Poland, the country's Constitution of 1997 also provides for sustainable development; its article 5 states that the Republic of Poland protects the environment and follows the principle of sustainable development;

erations, and should feel responsible for all environmental damage that may ensue. Environmentally-aware people treat the environment as a luxury good that deserves investment.

The monitoring of how successfully various levels of administration accomplish objectives of sustainable development is important for assessing whether the territorial units develop as planned.[7] The creation and implementation of measures relevant to sustainable development (indicators, models, etc.) predetermines effective implementation of the concept at each level of governance. Besides, the evaluation of policy impacts is equivalent to learning about the country's progress in the field of eco-development.

3. DESCRIPTION OF THE DATABASE AND SD MEASUREMENT METHODS

Within the system composed of people and environment there is a whole range of complex relationships that a non-sustainable process of socio-economic development may transform and disturb. Therefore, to ensure rational and environmental-friendly development as well as a safe use of the natural resources, the relationships occurring inside the people- economy-environment system must be identified and known. These multi-directional relationships keep changing as a result of passing time and spatial interactions. One way of capturing the nature of the relationships and demonstrating the environment's production capacity, and testing it for quality, is to apply selected quantitative methods that encompass indicators, measures, models, analyses, as well as mathematical, statistical or econometric tools.

This article uses selected some indicators and constructed measures to find out how effectively the sustainable development objectives are met in 32 European countries (table 1, AT - Austria, BE - Belgium, BG – Bulgaria, CH – Switzerland, CZ – the Czech Republic, CY – Cyprus, DE – Germany, DK – Denmark, EE – Estonia, ES – Spain, FI – Finland, FR – France, GR – Greece, HR – Croatia, HU – Hungary, IE – Ireland, IT – Italy, LI – Lichtenstein, LT – Latvia, LV – Lithuania, LU – Luxemburg, MT – Malta, NL – the Netherlands, NO – Norway, PL – Poland, PT – Portugal, RO – Romania, SE – Sweden, SI – Slovenia, SK – Slovakia, TU – Turkey, UK – United Kingdom). The investigation covered the years 1990-2006.

[7] Ministry of the Environment, [1999], *Strategia Zrównoważonego Rozwoju Polski do 2025 roku*, Warsaw, chapter 5.10.

Tab. 1. Characteristics of the variables,
number of observations in the panel: $n = 544$, $i = 32$, $t = 17$

NAME AND DEFINITION OF VARIABLE	AVERAGE	σ	MIN	MAX	V
***PKB* (*GDP*)** gross domestic product *per capita* in PPS	18687	10331	2500	69246	0,55
SO_2 total yearly emission sulphur dioxide in tones *per capita*	0,035	0,035	0,001	0,232	0,99
NO_X total yearly emission nitro oxides in tones *per capita*	0,028	0,011	0,002	0,072	0,74
CO total yearly emission carbon monooxide in tones *per capita*	0,097	0,051	0,032	0,555	0,52
CO_2 total yearly emission carbon dioxide in tones *per capita*	8,73	4,2	0,84	31,79	0,48
GHG total yearly emission green house gases in tones *per capita*	2,070	1,008	0,097	6,807	0,49
EN energy intensity of the economy - gross inland consumption of energy divided by GDP at constant prices, 1995=100 - kgoe (kilogram of oil equivalent) per 1000 euro	20506	29480	335	141500	1,44
AGS adjusted genuine savings *per capita* as % of national income	87,5	502,4	0,2	6256,5	5,74
GZ density in number of people on 1 km^2	153	206	13	1282	1,34
BIZ foreign direct invest as % GDP	4,26	7,80	0	53,37	1,83
IM value of foods and services import in mln PPS	82645	125131	872	919116	1,55
DZ life expectancy at birth in years	76	3	66	82	0,76
SK gross enrollment ratio (secondary school) in %	98,6	12,1	48,0	131,0	0,67
EX value of foods and services export in mln PPS	82867	134198	461	1131360	1,66
TEL number of telephone lines and mobile cellular subscribers per 1000 inhabitants	78	44	9	212	1,78
NET internet users per 1000 inhabitants	29	21	3	86	1,87
HDIM modified human development index	0,87	0,06	0,71	0,97	0,64
HDI human development index	0,38	0,03	0,18	0,80	0,64
ARCO measurement of technological progress	0,87	0,06	0,71	0,97	0,84
AIR aggregate indicator of air quality	0,058	0,024	0,0067	0,189	0,59

Source: developed by the authors using the STATA 11 software.

The structure of the measure AIR is discussed in the next part of this article. Note: n –number of cross-sectional-time observations, i – number of objects, t – number of periods, V – coefficient of variability, σ – standard deviation[8].

[8] For the construction of the measures ARCO, HDIM and AGS see the doctoral dissertation by Antczak E., [2010], pp. 56-57.

All indicators in table 1 have appropriately high values of the variability coefficients.

The econometric models whose estimates are presented in the fifth section of the article use the synthetic measure AIR as an explained variable, while *PKB*, *EX*, *IM*, *GZ*, *HDIM*, *ARCO*, *NET*, *EN*, *AGS* and *CZAS* were selected to form a set of exogenous variables showing the impacts of human activity. For factual and technical reasons, all variables were transformed into logarithms and then used in the econometric analysis. Because of their quantitative character, the indicators show progress in meeting the objectives of sustainable development. The above choice of explanatory variables for the set was supported by both theoretical and technical reasons (e.g. the Pearson's linear correlation coefficients). The values and impacts (correlation) of the variables determine the degree of air pollution in Europe. It is generally known that computations of correlation coefficients disregard the cross-sectional-time character of the data. The interdependence ratios were calculated for the total sample (n = 544). It was decided that the coefficients of correlation should be computed for the selected variables but for a specific object (a country), allowing for the analysed years (a times series of 17 years, t = 17). Table 2 presents the Pearson's linear correlation coefficients for the set of Polish variables.

Tab. 2. Matrix of correlation coefficients between particular variables in a time series, n = 1, t = 17, Poland

	SO_2	NO_x	CO	CO_2	GHG	PKB	HDIM	ARCO	HDI	AGS	DEN	IM	EX	EN	NET	AIR
SO_2	1															
NO_x	0,35	1														
CO	0,41	0,33	1													
CO_2	0,46	0,42	0,69	1												
GHG	0,40	0,42	0,49	0,08	1											
PKB	-0,95	0,87	-0,85	0,83	-0,20	1										
HDIM	-0,99	-0,93	-0,91	-0,84	-0,36	0,76	1									
ARCO	-0,51	-0,50	-0,44	-0,20	-0,73	0,35	0,49	1								
HDI	-0,16	-0,13	-0,13	-0,40	0,61	0,37	0,19	-0,72	1							
AGS	0,46	0,45	0,39	0,15	0,72	-0,31	-0,43	0,00	0,74	1						
DEN	0,17	0,26	0,05	0,40	-0,37	-0,37	-0,19	0,28	-0,68	-0,28	1					
IM	-0,87	-0,75	-0,77	-0,71	-0,12	0,77	0,59	0,36	0,37	-0,32	-0,40	1				
EX	-0,80	-0,69	-0,70	-0,69	0,00	0,74	0,53	0,25	0,47	-0,21	-0,52	0,39	1			
EN	0,58	0,63	0,48	0,65	-0,02	-0,69	-0,61	-0,10	-0,49	0,07	0,75	-0,66	-0,72	1		
NET	-0,95	-0,85	-0,93	-0,74	-0,41	0,89	0,75	0,44	0,14	-0,39	0,01	0,81	0,73	-0,42	1	
AIR	0,96	0,99	0,88	0,92	0,43	-0,88	-0,94	-0,45	-0,17	0,40	0,21	-0,75	-0,69	0,59	-0,55	1

Source: developed by the authors using the STATA 11 software.
The critical value (for a two-sided 5% critical area) is 0.0841, for n = 544.

According to table 2, *PKB*, *HDIM*, *ARCO*, *AGS*, *IM*, *EX*, *EN* and *NET* unquestionably contribute to considerable pollution of the air. Interestingly, the directions of the relationships occurring between the variables are determined by the socio-economic situation in the country. For instance, the major drivers of carbon dioxide emissions in Poland are GDP and the volume of energy produced (consumed) in the economy. On the other hand, factors comprising the *HDMI* indicator, the volume of import and less significantly the expansion of the Internet network, decrease pollutant emissions the most.

Tab. 3. Results of test for unit roots in panel data

Test	Hypothesis	Variable	Values of stats.		*p- value*	Results
Levin-Lin-Chu	H_0:panels contain unit roots H_1: panels are stationary	IPKB	bez trendu	-4,26	<0,0001	H_1
			z trendem	-1,6	0,045	
		ISO_2	bez trendu	-9,36	<0,0001	H_1
			z trendem	-7,99	<0,0001	
		INO_x	bez trendu	-7,87	<0,0001	H_1
			z trendem	-8,68	<0,0001	H_1
		ICO	bez trendu	-3,9	<0,0001	H_1
			z trendem	-3,12	0,0009	H_1
		ICO_2	bez trendu	-4,26	<0,0001	H_1
			z trendem	-5,51	<0,0001	H_1
		IGHG	bez trendu	-7,27	<0,0001	H_1
			z trendem	-5,35	<0,0001	H_1
		IAIR	bez trendu	-8,87	<0,0001	H_1
			z trendem	-9,35	<0,0001	H_1
		IEN	bez trendu	-0,77	0,22	H_0
			z trendem	-5,7	<0,0001	H_1
		IAGS	bez trendu	38,6	1	H_0
			z trendem	397	1	H_0
		IGZ	bez trendu	3,32	0,99	H_1
			z trendem	-2,75	0,003	H_1
		IIM	bez trendu	-9,4	<0,0001	H_1
			z trendem	-10,02	<0,0001	H_1
		IEX	bez trendu	-10,5	<0,0001	H_1
			z trendem	-11,83	<0,0001	H_1
		INET	bez trendu	-9,58	<0,0001	H_1
			z trendem	-8,89	<0,0001	H_1
		IHDIM	bez trendu	0,8	0,79	H_0
			z trendem	4,44	1	H_0
		IARCO	bez trendu	227	1	H_0
			z trendem	336	1	H_0
Hadri LM	H_0: panels are stationary H_1: some panels contain unit roots	IPKB	bez trendu	0,97	0,09	H_1
			z trendem	-0,67		
		ISO_2	bez trendu	-2,48	0,99	H_0
			z trendem	-1,13	0,87	
		INO_x	bez trendu	-0,99	0,84	H_0
			z trendem	-2,15	0,98	
		ICO	bez trendu	0,44	0,33	H_0
			z trendem	0,23	0,41	
		ICO_2	bez trendu	2,35	0,09	H_1
			z trendem	-0,29	0,62	H_0
		IAIR	bez trendu	-0,45	0,67	H_0
			z trendem	-1,01	0,84	
			z trendem	26,6	<0,0001	
		IEN	bez trendu	41,3	<0,0001	H_1
			z trendem	20,3	<0,0001	
		IAGS	bez trendu	6,4	<0,0001	H_1
			z trendem	3,4	0,0004	
		IGZ	bez trendu	52,7	<0,0001	H_1
			z trendem	25,9	<0,0001	
		IIM	bez trendu	-2,23	0,99	H_0
			z trendem	-0,53	0,7	
		IEX	bez trendu	-2,67	0,99	H_0
			z trendem	-1,49	0,93	
		INET	bez trendu	1,5	0,07	H_0
			z trendem	0,62	0,27	
		IHDIM	bez trendu	45,6	<0,0001	H_1
			z trendem	19,9	<0,0001	
		IARCO	bez trendu	6,14	<0,0001	H_1
			z trendem	6,42	<0,0001	

Source: developed by the authors using the STATA 11 software.
Explanations: "bez trendu" : without trend, "z trendem": with trend.

Among the frequently formulated assumptions about the desired properties of a time series, stationarity is given an important place. Stationarity can be understood as the non-existence of trend, the absence of regular change in the variance and the non-existence of periodic fluctuations. Accordingly, the variables were tested for unit roots by means of two different procedures using the panel data sample (the Levin-Lin-Chu and Hadri's LM tests)[9], tab. 3.

The null hypothesis of the Levin-Lin-Chu test assumes that a unit root does exist. On the other hand, the zero hypothesis of the Hadri LM test states that a panel is stationary. The values of the statistics presented in table 3 show that the only variables positively tested for a the unit are *AGS*, *HDIM*, *ARCO*, while variables *EN* and *GZ* (the Levin-Lin-Chu test) and *ARCO* in the Hadri LM test are stationary around the trend.

Sustainable development takes place in both time and space. Furthermore, as countries and regions are not islands in space, they are vulnerable to the influences of other units. According to Tobler's first law „Everything is related to everything else, but near things are more related than distant things"[10]. As a result, similar values of variables may either cluster (positive auto-correlation) or disperse (negative autocorrelation) in space. While time-series show one-way relationships, spatial data usually display multi-directional relationships. Therefore, in addition to the set of indicators that are necessary for measuring and evaluating progress in implementing the principles of eco-development, modern spatial quantitative methods operated by econometricians and statisticians were also applied, for instance Moran's I statistics and spatial panel data models based on the environmental Kuznets curve.

The above tools were applied to:

1) measure the quality and condition of the environment and evaluate progress in eco-development,
2) identify relationships occurring within the triangle humans-environment-economy,
3) account for the strong spatial relationships taking place between countries;
4) make international comparisons of countries' achievements and failures as far as the meeting of eco-development objectives is concerned,
5) find countries running the highest risk of excessive environmental degradation,

[9] A detailed discussion of the tests' properties can be found, for instance, in Levin A., Lin C., Chu C.J., [2002], *Unit Root Tests in Panel data: Asymptotic and Finite-Sample Properties*, Journal of Economics, 108, pp.1-24, and Kluth K., [2007], *Konwergencja gospodarcza w zakresie kryteriów Traktatu z Maastricht – analiza ekonometryczna*, [in:] *Dynamiczne Modele Ekonometryczne,* X Ogólnopolskie Seminarium Naukowe, 4–6 September 2007 in Toruń, Department of Econometrics and Statistics, Nicolaus Copernicus University in Toruń, pp.307-314.

[10] Tobler W.R., [1970], *A computer movie simulating urban growth in the Detroit region*, Economic Geography 46, USA, pp.234–240.

6) promote and support pro-environmental activities (development of science and technology, international co-operation),
7) obtain information on the rational management of natural resources, the possibilities of adjusting the structure of consumption and production, and on the effect of environmental quality on the level of well-being.

Spatial weight matrices are classical elements of spatial analyses. They measure and capture relationships, spatial structures, the strength of the interactions taking place between objects and the closeness of observation[11]. Autocorrelation was investigated based on the spatial weight matrix using Moran's *I* statistics[12].

In this paper, spatial panel data models were used for modelling sustainable development processes between 1990 and 2006 in the selected European countries.

Classical panel data models allow analysing the cross-sectional-time data. Quite recently, foreign researchers started to use spatial panel data models that account for spatial interactions taking place between the investigated objects (spatial autocorrelation) and for the objects' spatial heterogeneity (spatial structure). The spatial panel data models represent a rather large group[13], but this paper will use different variants of the Spatial Autoregressive Fixed Effect Model (SAR-FEM) – formula (1):

$$\mathbf{y}_{it} = \alpha_i + \mathbf{X}'_{it}\boldsymbol{\beta} + \rho\mathbf{W}\mathbf{y}_{it} + \mathbf{u}_{it} \qquad (1)$$

where:
ρ – spatial lag parameter, $\mathbf{W}$ – row-standardised spatial weight matrix,
α_i – individual effect constant in time and different for various units,
$\mathbf{y}_{it}$ – vector of endogenous variables,
$\mathbf{X}'_{it}$ – explanatory variable matrix for unit *i* in period *t,*
$\mathbf{u}_{it}$– vector of error terms,
$\boldsymbol{\beta}$ – vector of the explanatory variables' parameters;
$t = 1, \dots, T$ number of periods, $i = 1, \dots, N$ number of units.

Anselin [1988] proposed that the spatial panel data models be estimated with the Maximum Likelihood Method. An alternative approach is the method of

[11] More in Kopczewska K., [2006], *Ekonometria i statystyka przestrzenna z wykorzystaniem programu R CRAN*, CeDeWu.PL. Warsaw, p.56.

[12] For the full discussion of Moran's *I* statistics see, for instance, Antczak E., Lewandowska-Gwarda K., [2009], *Zastosowanie metod eksploracyjnej analizy danych przestrzennych w badaniu poziomu umieralności w Polsce*, Taksonomia 16, Klasyfikacja i analiza danych – teoria i zastosowania, Uniwersytet Ekonomiczny, Wrocław, pp. 324-333.

[13] Elhorst J.P., [2003], *Specification and Estimation of Spatial Panel Data Models*, International Regional Science Review 26 (3), pp. 244-268.

moments by Conley [1999][14] and Kelejian and Prucha [1999][15]. Baltagi and Li [2002][16] estimated spatial data panels using the Generalised Least Square Method. Estimator compatibility and effectiveness can also be ensured by estimating models using the instrumental variable methods: two-stage and three-stage least squares methods.

To model sustainable development and find linkages between economic development and environmental quality ,the EKC spatial panel data models of the FEM-SAR type were applied. These analyses have not been performed in Poland so far.

The EKC captures the relationship between GDP *per capita* and "demand" for clean environment. The EKC hypothesis indicates that environmental degradation deepens until a set moment. Once the extreme point is attained, the degradation comes to a halt. Investments appear that improve the quality of the environment. The first to verify the EKC hypothesis were Grossman and Krueger [1990][17]. They proved empirically that economic growth degrades the environment following a curve shaped as an inverted U. The point where the *per capita* incomes cross a set level (their double or even triple growth is mentioned) marks a turning point from which environmental degradation start to recede notwithstanding continued economic growth. The measures of environmental quality as used in the EKC-based investigation consisted of the volumes of major air pollutants per capita. According to empirical research, the largest amounts of pollutants originate in the poor and developing countries and not in developed ones. However, this is not always the case. The EKC hypothesis has not been verified for Polish economy so far.

Building an EKC-based econometric model, a researcher has to take certain assumptions about its form and the methods to be used for parameter estimation. In the first place, it is a second-order polynomial function. The country's economic development degrades the environment until a set point in time,. After the turning point is reached, growing GDP *per capita* improves the quality of the

[14] Conley T.G., [1999], *GMM estimation with cross sectional dependence*, Journal of Econometrics 92, pp.1-45.

[15] Kelejian H.H., Prucha I., [1999], *A generalized moments estimator for the autoregressive parameter in a spatial model*, International Economic Review 40, pp.509-533.

[16] Baltagi H.H., Li Q., [2002], *On instrument al variable estimation of semiparametric dynamic panel data models*, Economics Letters, 76, pp.1-9.

[17] The curve was conceptualized by Simon Kuznets in 1955. He proved that economic growth initially makes income inequalities grow and then decrease. He illustrated this phenomenon using a curve shaped like an inverted U, which was afterwards called the Kuznets curve, see Kuznets S., [1955], *Economic growth and income inequality*, American Economic Review 45(1), pp.1-28; Grossman, G., Krueger A., [1995], *Economic growth and the environment*, Quarterly Journal of Economics 110(2), UK, pp.353-377.

environment[18]. The EKC hypothesis underling the importance of the relationships between the economic growth of an area and the growth's impact on environmental quality is confirmed by the negative signs of the constant term and the parameter for the squared explanatory variable.

Empirical research demonstrates that the fit between the model and the real-life data can be improved by finding the variables' logarithms. Besides, the variables 'GDP *per capita*' and 'environmental pollution' invariably take values greater than zero[19].

There are economic reasons and empirically proven theses in support of the transformation of the EKC function into a square form. The criterion for choosing a square function is confirmed based on two assumptions: the environment is recognized as a luxury good and the degree of country's economic development is accepted as being „ conducive to" environmental degradation. Higher population's incomes (the doubling of their level) make income elasticity of the demand for clean environment (treated as a luxury good) exceed 1. With growing incomes, the better-off societies are willing to pay more to be able to live in a clean and unpolluted environment. Local authorities, entrepreneurs or organizations also take action. Companies install state-of-the-art technologies designed to reduce the amounts of discharged pollutants. Regional development strategies provide for the introduction of pertinent laws and economic instruments to save the environment. Researchers have formulated a thesis that the degree of environmental pollution in developed economies falls considerably or at least remains unchanged. In a developing country, economic development initially inflicts substantial damage on the natural environment. Over time, its economy transforms from agricultural to heavily industrialized. Later on, it leaves industry behind to emphasise services. This is the time when modern technical solutions are implemented, environmental investments appear, subsidies enabling the purchase of green technologies are made available, etc. Of course, research needs to take account of the special character of the analyzed region to a possible degree. To this end, some modifications were introduced to the basic EKC shape.

In the literature, more rarely in practice (even more so in the literature and practice in Poland), various types of the EKC curve can be found. This paper employs spatial modifications of the following types of curves:

1) ***a basic Kuznets curve*** – i.e. one showing that economic development initially leads to excessive exploitation of natural resources and environmental

[18] More in Wiszniewska (Antczak) E., [2009], *Weryfikacja hipotezy Środowiskowej Krzywej Kuznetsa na przykładzie Polski. Analiza ekonometryczna*, [in:] Pociecha J. (ed.), *Współczesne problemy modelowania i prognozowania zjawisk społeczno gospodarczych*, Studia i Prace Uniwersytetu Ekonomicznego w Krakowie, Kraków, pp.375-387.

[19] Stern D., [2004], *The Rise and Fall of the Environmental Kuznets Curve*, World Development Vol. 32, No. 8, pp.1419–1439.

degradation, but once a set level of GDP is attained the quality of the natural environment stops deteriorating,

2) ***an inverted curve*** – this graph illustrates a reverse situation to that described above; the first stage of economic development does not produce general negative effects for the environment, however it starts doing so when a turning point corresponding to a set level of GDP *per capita* is attained (consumption is excessive, environmental investments are not made, society lacks pro-environmental awareness).
3) ***a cubic curve*** – this curve occurs when two turning points are present; the graph represents a combination of the basic curve and the inverted curve in the indicated order.
4) ***a cubic inverted curve*** – combines a reverse curve and a basic curve in the indicated order.

Only few investigations into the EKC have been conducted in Poland so far[20]. Contemporary research on the EKC (at the beginning of the 21st c.) and generally on sustainable development adds space to time to allow for the fact that sustainable development and other economic, demographic or ecological phenomena have both temporal and spatial dimension. When spatial interactions occur, classical quantitative methods fall short of their purpose. In this situation, spatial statistics tools and spatial econometric models are used to address and measure the so-called spatial autocorrelation processes (spatial dependencies). Researchers investigating sustainable development and generally ecological scientists reached for the EKC-based spatial econometric models only after 2003 (Rupasingha [2003][21], Mizobuchi [2007][22], Wiszniewska (Antczak) [2008][23]). In addition to spatial models taking account of spatial interactions, tools accounting for an extended time factor are designed more and more often within their framework. To this end, the spatial panel data models are constructed (Baltagi

[20] For Polish publications discussing the EKC see, for instance, Antczak E., [2010], *Degradacja powietrza a rozwój gospodarczy w Europie. Modele panelowe z efektami przestrzennymi,* [in:] *Modelowanie i prognozowanie zjawisk społeczno – gospodarczych,* Materiały IV Konferencji Naukowej im. prof. Aleksandra Zeliasia:, publication under review, Zakopane; Antczak E., [2009], *Sustainable development of Poland and Europe – spatiotemporal analysis and spatial EKC models,* [in:] *Mikro- i makroekonomiczne aspekty integracji europejskiej – ocean efektywności funkcjonowania UE*, VIII Międzynarodowa Konferencja, Łódź, Folia Oeconomica UŁ, in print.

[21] Rupasingha A., Goetz S., Debertin D., Pagoulatos A., [2004], *The environmental Kuznets curve for US counties: A spatial econometric analysis with extensions*, Regional Science 83, USA, pp.407-424.

[22] Mizobuchi K., [2007], *Simulation Studies on the CO2 Emission Reduction Efficiency in Spatial Econometrics: A Case of Japan*, *Economics Bulletin,* Vol. 18, No. 4, Japan, pp. 1-9.

[23] Wiszniewska (Antczak) E., [2008], *Spatiotemporal Analysis of Sustainable Development in Poland and in Other European Union Countries. Economic Growth & Air Quality*, European Summer School on Space in Unified Models of Economy and Ecology, Italy. The electronic version of the publication is under review: www.feem-web.it/ess/files/wiszniewska.pdf.

2008).[24] This paper presents the applications of different variants of the EKC-based models dealing with spatiotemporal interactions occurring between the selected European countries.

The SAR-FEM panel data model investigates the significance of a spatially-lagged explained variable. For the EKC, the spatial lag model takes the form (2):

$$\ln AIR_{it} = \rho \mathbf{W} \ln AIR_{it} + \alpha_{it} + \beta_1 \ln PKB_{it} + \beta_2 \ln(PKB)^2_{it} + \sum_{i=1}^{k} \boldsymbol{\beta}_i \mathbf{X}_{it} + \mathbf{u}_{it} \quad (2)$$

where: ρ – spatial lag parameter,
$\rho \mathbf{W} \ln AIR_{it}$ – spatially-lagged explained variable in the region i and time t,
$\ln AIR_{it}$ – explained variable (i.e. indicating environmental degradation),
$\ln PKB_{it}$ – GDP *per capita* in constant prices,
$\ln(PKB)^2_{it}$ – the square of GDP *per capita*,
$\mathbf{W}$ – row-standardized spatial weight matrix.

If a lag is significant, then the variable's value (environmental degradation) in the region can be explained through the average level of this phenomenon in the neighbouring regions.

In addition to some basic technical assumptions on the quality and choice of the model variables and appropriate research tools, the cross-sectional-time-space econometric analysis needed other research assumptions too. They assumptions enabled a more precise diagnosis of the eco-development processes in Europe between 1990 and 2006 thus helping create a more adequate picture of the actual situation.

4. RESEARCH ASSUMPTIONS

Variables *PKB*, SO_2, NO_x, *CO*, CO_2, *GHG* and *AIR* were tested for autocorrelation using tests based on Moran's *I* statistics. The variables are subjectively considered to be crucial to identifying the possible existence and strength of relationships between human activity and environmental quality (i.e. air). Table 4 presents values of Moran's *I* statistics by variable in the years 1990-2006.

For each of the analyzed measures a distinct positive spatial autocorrelation was found. In other words, the European countries form clusters characterized by similar levels of pollution and economic development. As shown by table 4, for *PKB*, *NO*, CO_2, *GHG* and *AIR* the values of Moran's *I* statistics decline in time. This should not be mistaken for the erosion of the spatial relationships; a more probable interpretation is that the analyzed phenomena diverge. As far as pollutant emissions are concerned, the reason may be cooperation and activities undertaken in support of eco-development. There are countries, however, where

[24] Baltagi H. B., [2008], *Econometric Analysis of Panel Data, John Wiley & Sons*, Ltd., 4th Edition.

production and economic activity excessively exploit natural resources. Spatial autocorrelation is stronger in the case of sulphur dioxide and carbon dioxide. This means that not only do gas emissions increase in the country where originate, but they also flow outside its borders (table 4).

One of the assumptions made within the spatial statistical and econometric analysis involved an appropriate selection of the order of neighbourhood for the spatial weight matrix. Based on the values of Moran's *I* statistics for particular years and environmental indicators (tab. 4) it is possible to conclude that the strength of spatial relationships declines with extending distance. Correspondingly, a spatial weight matrix of first order neighbourhood was accepted in this article to investigate eco-development processes in Europe.

Moreover, it follows from the investigation into the strength of spatial autocorrelation in the case of particular indicators of environmental pollution (table 4) that the volumes of each pollutant discharge (as well as the aggregate indicator *AIR*) strongly contribute to the pollutant's amounts in the neighbouring countries.

Tab. 4. Spatial autocorrelation of variables in the selected European countries based on Moran's *I* statistics in the years 1990-2006, number of observations *n*=544

Rok	SO2		NO		CO		CO2		GHG		AIR
Moran *I*	**W1**	**W2**	**W1**	**W2**	**W1**	**W2**	**W1**	**W2**	**W1**	**W 2**	**W1**
1990	-0,01	-0,01	0,11	0,07	0,11	0,01	0,06	-0,01	-0,03	-0,08	0,10
p-value	0,38	0,34	0,14	0,12	0,07*	0,23	0,17	0,29	0,5	0,38	0,15
1991	-0,01	-0,001	0,21	0,21	0,11	0,01	0,1	0,06	0,17	0,13	0,12
p-value	0,37	0,33	0,06*	0,02***	0,03**	0,18	0,13	0,11	0,05**	0,07*	0,05**
1992	0,04	-0,02	0,07	0,16	0,37	0,3	0,14	0,03	0,22	0,16	0,17
p-value	0,28	0,42	0,06*	0,01***	0,005***	0,002***	0,06*	0,15	0,02**	0,04**	0,02**
1993	0,02	-0,01	0,27	0,23	0,02	-0,002	0,14	-0,001	0,25	0,19	0,16
p-value	0,3	0,4	0,02**	0,004***	0,2	0,21	0,04**	0,27	0,02**	0,03**	0,02**
1994	0,02	0,01	0,33	0,28	0,03	-0,03	0,14	0,03	0,27	0,19	0,21
p-value	0,3	0,3	0,004***	0,004***	0,18	0,43	0,06*	0,16	0,02**	0,02**	0,01***
1995	0,07	0,04	0,3	0,25	0,06	-0,03	0,18	0,034	0,27	0,2	0,21
p-value	0,18	0,18	0,02**	0,01***	0,14	0,5	0,07*	0,17	0,01***	0,01***	0,01***
1996	0,08	0,05	0,23	0,23	0,07	0,01	0,19	0,05	0,26	0,18	0,17
p-value	0,15	0,17	0,04**	0,01***	0,17	0,25	0,07*	0,14	0,02**	0,02**	0,03**
1997	0,09	0,07	0,3	0,3	0,13	0,07	0,15	0,02	0,24	0,2	0,21
p-value	0,13	0,12	0,01***	0,01***	0,08*	0,12	0,09*	0,3	0,03**	0,02**	0,01***
1998	0,15	0,12	0,33	0,29	0,09	0,03	0,22	0,07	0,2	0,15	0,19
p-value	0,07*	0,05**	0,01***	0,004***	0,10	0,14	0,04**	0,13	0,04**	0,04	0,02**
1999	0,27	0,22	0,38	0,34	0,15	0,14	0,22	0,09	0,09	0,06	0,17
p-value	0,02**	0,02***	0,002***	0,03**	0,07*	0,02***	0,03**	0,10	0,16	0,20	0,02**
2000	0,16	0,12	0,36	0,31	0,18	0,13	0,2	0,07	0,06	0,02	0,15
p-value	0,06*	0,06*	0,05**	0,002***	0,04**	0,04**	0,04**	0,1	0,22	0,31	0,03**
2001	0,19	0,13	0,28	0,23	0,19	0,15	0,18	0,05	0,03	-0,01	0,12
p-value	0,04**	0,05**	0,02**	0,01***	0,03**	0,03**	0,05**	0,12	0,32	0,42	0,03**
2002	0,21	0,14	0,21	0,17	0,23	0,18	0,15	0,04	-0,01	-0,04	0,11
p-value	0,02**	0,02**	0,02**	0,02**	0,04**	0,02**	0,05**	0,14	0,44	0,44	0,05**
2003	0,19	0,14	0,17	0,16	0,27	0,18	0,11	0,01	-0,04	-0,08	0,10
p-value	0,05**	0,06*	0,07*	0,04**	0,01***	0,02**	0,15	0,28	0,42	0,27	0,09*
2004	0,23	0,16	0,16	0,15	0,22	0,21	0,11	0,01	-0,08	-0,12	0,07
p-value	0,03**	0,04**	0,07*	0,04**	0,03**	0,02**	0,10	0,31	0,41	0,21	0,11
2005	0,31	0,21	0,12	0,11	0,21	0,21	0,08	0,01	-0,07	-0,12	0,06
p-value	0,01***	0,02**	0,12	0,11	0,04**	0,01***	0,14	0,23	0,31	0,21	0,12
2006	0,31	0,21	0,11	0,11	0,23	0,21	0,09	0,02	-0,13	-0,14	0,04
p-value	0,01***	0,01***	0,18	0,11	0,02**	0,02**	0,11	0,17	0,21	0,11	0,15

Source: developed by the authors based on EUROSTAT data using the STIS software.
*Note: significance level p-value ≤ 0,01***; for p-value ≤ 0,05**, p-value≤0,1*; Moran's I statistic values were calculated using spatial neighbourhood weighting matrices of 1st (W1) and 2nd order (W2).*

Accordingly, the panel data models with a spatially lagged endogenous variable (SAR-FEM-EKC) were selected to make econometric analyses of how effectively the selected European countries implemented sustainable development. This approach allowed identifying the influence of spatial autocorrelation on the scale of environmental degradation in Europe in particular years, as well as obtaining information on the change trends and the interregional interactions' contribution to air pollution in the adjacent countries.

It must be re-emphasised that the sets of global, national, local and aggregate indicators continue to be the main tool with which the attainment of sustainable development is measured and evaluated. In addition to the generally available measures of eco-development, aggregate indicators (herein called total indicators) are also constructed. These are combinations of individual indicators' weights. The main reason for constructing them is that they enable a collective (total) evaluation of the dynamics of concurrent changes in many eco-development variables, while performing the same functions as the individual indicators do. Therefore, they are used to find out how effectively the eco-development objectives are accomplished, make regional and international comparisons of the implementation of sustainable development principles, or prepare forecasts and quantitative economic, social and ecological analyses.

One of the goals the presented investigation assumed to attain was to test the hypothesis about spatial relationships influencing European countries' effectiveness and progress in attaining the objectives of eco-development. Accordingly, it became necessary to build an indicator capable of identifying eco-development levels (the condition of the environment) in particular countries. The synthetic measure *AIR* showing the quality of the key component of the natural environment (air) was built using the calculated values of Moran's *I* statistics (tab.4). The indicator consists of the weighted volumes of particular pollutants (SO_2, NO_x, CO, CO_2, GHG). The weights were assigned based on the average values and the number of statistically significant values of the statistics for particular air degradation indicators, see formula 3:

$$AIR = 0,2 \cdot SO_2 + 0,4 \cdot NO_x + 0,3 \cdot CO + 0,05 \cdot CO_2 + 0,05 \cdot GHG \quad . \qquad (3)$$

Therefore:

0.2 – nine significant Moran's *I* statistics for SO_2 (0.22 on average),
0.4 – fourteen significant Moran's *I* statistics for NO_x (0.26 on average),
0.3 – twelve significant Moran's *I* statistics for CO (0.21 on average),
0.05 – ten significant Moran's *I* statistics for CO_2 (0.18 on average),
0.05 – eight significant Moran's *I* statistics for GHG (0.19 on average);

Table 4 shows that NO_x emissions contribute the most strongly to its volumes emitted in the neighbouring countries. Therefore, *AIR* was constructed bearing in mind that the spatial impacts of NO_x emissions on the neighbouring countries are the strongest (weight 0.4, average value of Moran's *I* statistics = 0.26), while those exerted by carbon dioxide and other greenhouse gases are the weakest (e.g. a weight of 0.05 for *GHG*, average value of Moran's *I* statistics = 0.19).

AIR values presented in table 5 show that the emissions of air pollutants were decreasing in Europe between 1990 and 2006.

In the years 1990-2006, the volume of air pollutants decreased by 15% on average. Throughout the period in question, Luxembourg produced the largest amounts of pollutants, even though their emissions diminished by 20%. Therefore, the state poses a threat to clean air in the adjacent countries. Poland noted a 17% decline in the same period.

Tab. 5. *AIR* values in European countries in the selected years

kraj	1990	1997	2006	Zmiana 2006/1990
AT	0,000573	0,000563898	0,000586	2,40%
BE	0,000786	0,000757509	0,000685	-12,75%
BG	0,000765	0,000565497	0,000529	-30,80%
CH	0,000426	0,000383446	0,000372	-12,58%
CY	0,000564	0,000623376	0,000686	21,67%
CZ	0,001043	0,000793904	0,000751	-28,01%
DE	0,000839	0,000688575	0,00063	-24,90%
DK	0,000737	0,000810946	0,000691	-6,30%
EE	0,001439	0,000826975	0,000751	-47,83%
ES	0,000422	0,000465107	0,00053	25,72%
FI	0,000775	0,00078703	0,000806	3,99%
FR	0,000549	0,000521234	0,000461	-16,08%
GB	0,000743	0,000650219	0,000563	-24,18%
GR	0,000569	0,000608604	0,000643	13,01%
HR	0,000382	0,000305248	0,000374	-2,29%
HU	0,000531	0,000427482	0,000415	-21,76%
IE	0,000844	0,000908276	0,000854	1,21%
IT	0,000508	0,000511244	0,000508	-0,12%
LV	0,000553	0,000288227	0,000297	-46,27%
LI	0,000426	0,000422149	0,000406	-4,68%
LT	0,00073	0,00035313	0,000366	-49,85%
LU	0,001826	0,001243574	0,001452	-20,47%
MT	0,000358	0,000425714	0,000428	19,54%
NL	0,00074	0,000747481	0,000652	-11,96%
NO	0,000658	0,000660984	0,000617	-6,29%
PL	0,000677	0,000628915	0,00056	-17,20%
PT	0,000337	0,000391806	0,000423	25,66%
RO	0,000585	0,00040895	0,000393	-32,83%
SE	0,000465	0,000448084	0,000388	-16,63%
SI	0,000512	0,000535835	0,000542	5,88%
SK	0,000759	0,000502259	0,000477	-37,11%
TU	0,000175	0,000228062	0,000252	43,76%
średnia	0,000666	0,000577617	0,000565	-15%

Source: developed by the authors.

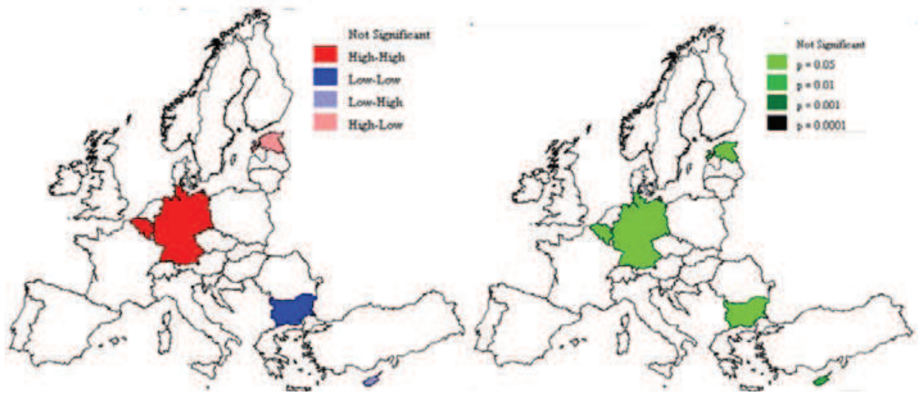
Although Turkey generated the smallest amounts of air pollutants, the country should not be viewed as a model for eco-development, as its *AIR* values increased between 1990 and 2006 by as much as 44%. There was no other country in Europe where the emissions of air pollutants to that degree.

The most favourable situation was found in Latvia, where pollutant emissions dropped by as much as 50% (tab. 5).

The values of the total and local autocorrelation show the strength and type of spatial relationships, thus producing more complete descriptions of the spatial structures and relationships between the examined objects than the traditional measures do. Moreover, the results of the spatial econometric analysis presented in the next section of the article indicate that spatial relationships significantly delay the time when particular countries attain the *point of ecological and economic equilibrium*, i.e. the line behind which environmental degradation starts decelerating. The same mechanism extends the distance between countries at a high level of *eco-development*_and those that are still unable to cope with the adverse impacts of economic activity on the quality of particular components of the natural environment.

The values of Moran's *I* statistics for the variable *AIR* were analyzed in detail. It was found that during the seventeen analysed years the amounts of emitted pollutants were clearly and positively autocorrelated in spatial terms. This means that objects with similar levels of air pollution caused by gases tend to cluster. In the years 1991-2003, the values of the total Moran's *I* statistics for the *AIR* index were statistically significant, and this fact is additionally confirmed by the picture created based on the LISA statistics in the illustrative year 1997 (graph 1).

Graph 1. Types of spatial relationships and significance levels according to LISA values in the illustrative year 1997, *AIR*



Source: developed by the authors based on table 4 data, graphics made with the Geoda 095i package.

In 1997, spatial clusters of units having similar values of the variable are noticeable. South Europe has a homogenous area where the values are low, while Central and Western Europe has several clusters characterized by high *AIR* values. Poland did not significantly contribute to *AIR* changes in the neighbouring countries (Moran's *I* statistics is statistically insignificant). As special country in the analysed years was Estonia. Her *AIR* level was relatively high compared with the adjacent countries.

The findings provided by the spatial statistical analysis show that at the turn of the analysed years spatial relationships were losing their strength, which promised well. The situation obviously followed from much lower emissions of particular pollutants in the selected countries and the countries' slow but determined pursuit of eco-development. However, the above analysis of the measures characterising the environmental dimension of sustainable development also proves that the countries diverge rather than converge.

Information on the countries where broadly understood human activity pollutes the air with particular substances and on the levels of economic activity that arrest environmental degradation was obtained at the next stages of the detailed analysis, during which panel data models were estimated for groups of countries. The main reasons for putting the countries into groups were the following: (1) for each pollutant and for each country there exist specific levels of economic development where degradation either comes to a halt or continues; (2) this approach allows accounting for the special characteristics of particular countries. By grouping the countries, group-specific effects could be captured.

A detailed comparative analysis could be made, where the specific effects where addressed and particular regions were treated as separate units in space. The results of model estimation with groups of countries and with all countries for the same dependent variable provided different results, thus justifying the decomposition of the countries.

Moreover, the statistics verifying whether it was correct to introduce dummy effects, for instance into the endogenous variable $lAIR_{it}$, turned out to be statistically insignificant. In contrast, in the models where the countries were appropriately separated the group effects were significant. This gave the economic-environmental-sectoral-cross-sectional character to the analysis, which was confirmed by the econometric analysis.

5. RESULTS AND CONCLUSIONS FROM THE ANALYSIS

The analysis provided many pieces of valuable information on how particular countries manage to accomplish their objectives of sustainable development. Its results allowed identifying the levels of economic development that either support or obstruct this process in particular countries. Besides, countries where the socio-economic principles of sustainable development were fully implemented or progressing and regions where economic activity still degraded the natural environment in Europe could also be identified. Additionally, the research results allowed verifying whether the novel statistical and econometric tools used in the analyses met their purpose. Table 6 presents the findings of the investigation into the influence of particular „constituents" of economic and social activity on environmental quality that took account of the special character of the neighbouring regions and their impacts.

Analyses omitting groups only provides a general picture of a problem. Moreover, apart from the occurring aspects of eco-development, i.e. space, time and cross-section, they disregard the structure and special character of particular economies. Unlike the above, the conducted analyses of particular sets of countries offered valuable conclusions on how effective particular European countries were in accomplishing the objectives of sustainable development, as well as demonstrating the pertinence of the research instruments applied[25].

Table 6 presents estimates obtained for the spatial autoregressive panel data models allowing for the special characteristics of particular economies. The countries where economic growth polluted the air with gaseous emissions constituted a larger group. With country-specific effects and inter-country spatial interactions added to the model good quality models were produced[26] and the results seemed to be empirically correct. Therefore, the proximity between countries was found to have an adverse effect on environmental quality ($0.36 \cdot lWAIR_{it}$). Moreover, the clustering of the objects emitting similar volumes of pollutants delayed the time when certain countries could attain the turning point (17154 PPS *per capita* and 11449 PPS *per capita* for the regular model). Model estimates calculated omitting the spatial arrangement of the dependent variable pointed out that between 1990 and 2006 the group with ten countries effectively pursued the objectives of sustainable development.

The results of spatial modelling show, however, that the UK, Greece and Ireland failed to follow the path of sustainable development throughout the investigated period. It turned once more that spatial interactions delay the time when the socio-economic and demographic development of the country can be recognised as balanced. Between 1990 and 2006, Switzerland contributed to the degradation of air quality the least (α_2 = - 51.1), while Denmark represented the greatest hazard to it (α_3 = -1.7).

[25] The reasons for grouping countries and time-series models' estimates are discussed more in detail in doctoral dissertation: Antczak E., [2010], *Zrównoważony rozwój Polski*..., pp.132-134, tables 4.6-4.8.

[26] For detailed estimates of the non-spatial econometric models see Antczak E., [2010], *Zrównoważony rozwój Polski*..., p.138, table 4.10.

Tab. 6. The EKC-based spatial panel data models for *AIR*

1) $lAIR_{it} = \alpha_i const + \beta_1 lPKB_{it} + \beta_2 (lPKB_{it})^2 + \beta_k X_{kit} + \rho(lWAIR_{it}) + \mu_{it}$ 2) $lAIR_{it} = \alpha_i const + \beta_1 lPKB_{it} + \beta_2 (lPKB_{it})^2 + \beta_3 (lPKB_{it})^3 + \beta_k X_{kit} + \rho(lWAIR_{it}) + \mu_{it}$		
	1) i=10	**2) i=22**
Countries in the group	BE, CH, DK, FR, GR, IE, NL, NO, SE, GB	AT, BG, CY, CZ, DE, EE, ES, FI, HR, HU, IT, LI LT, LU, LV, MT, PL, PT, RO, SI, SK, TU
Variables	**Values of coefficients (t – Student's statistic)**	
const	-52,45 (-5,64)***	113,45 (4,14)***
Individual effects α_i	α_1BE=-18,1, **α_2CH=-51,1, α_3DK=-1,7**, α_4FR=-46,3, α_5GR=-4,3, α_6IE=-19,6, α_7NL=-21,8, α_8NO=-3,8, α_9SE=-15,6, α_{10}GB=-22,6	α_1AT=61, α_2BG=34,7, α_3CY=33,1, α_4CZ=19,6, α_5DE=120,1, α_6EE=131,8, α_7ES=22,9, α_8FI=195, α_9HR=24,5, **α_{10}HU=68**, α_{11}IT=126,8, α_{12}LI=13,9, α_{13}LT=108,7, α_{14}LU=17, α_{15}LV=102,8, **α_{16}MT=236,2**, α_{17}PL=77,8, α_{18}PT=9,8, α_{19}RO=19,4, α_{20}SI=84,8, α_{21}SK=23,6, α_{20}TU=44,5,
$lPKB_{it}$	9,72 (5,15)***	-36,04 (-4,13)***
$(lPKB_{it})^2$	-0,48 (-5,17)***	3,99 (4,32)***
$(lPKBit)^3$	-	-0,15 (-4,49)***
$lWAIR_{it}$	0,56 (1,99)**	0,66 (3,37)***
$lARCO_{it}$	0,07 (0,11)	-0,23 (-1,82)**
$lHDIM_{it}$	2,97 (0,38)	-0,05 (-0,06)
lEX_{it}	-0,53 (-0,44)	0,32 (-2,03)**
lIM_{it}	0,11 (0,11)	-0,05 (-0,28)
lGZ_{it}	-5,94 (-0,43)	-1,28 (-3,48)***
lEN_{it}	-0,22 (-0,64)	0,03 (1,39)
$lCZAS_{it}$	-0,05 (-0,34)	-0,06 (-0,54)
$lAGS_{it}$	-0,006 (-0,21)	-0,01 (-1,21)
R^2	0,64	0,85
$\bar{R}^2$ for spatial model	0,63	0,84
R^2 for Basic model	0,48	0,41
F^{Ch}_{obl}/F_k^{Ch}	4,09/1,94 ($F^{Ch}_{obl} > F_k^{Ch}$)	51,24/1,91 ($F^{Ch}_{obl} > F_k^{Ch}$)
F^{W}_{obl}/F_k^{W}	8,5/2,27 ($F^{W}_{obl} > F_k^{W}$)	240,9/1,71 ($F^{W}_{obl} > F_k^{W}$)
TP of spatial model	17154	4915 & 24343
Countries on ZR track	GR: from 2000, IE: from 1995, GB: from 1991	AT: od 1997r., ES: od 2003r., FI, IT, DE: od 1999r., LI: do 1994r., LU: 1990 – 2006, LV, RO, TU: do 1993r., SI: od 2006r.;
Notes	Rest countries crossed TP from 1990	**Countries out of ZR track (after TP):** AT: do 1996 r., BG, MT, PL, SK, PT, CY, CZ, EE, HR, HU, LT : 1990 – 2006, ES: do 2002r., FI, IT, DE: do 1998r., LI: od 1995r., LV, RO: od 1994r., SI: do 2005r.,TU: od 1994r,
TP of basic model	11449	7331 & 12708
Countries on ZR track	All countries crossed TP	**PL: do 1995r. i od 2004r.**, BG: do 2003r., DE: od 2005r., EE: do 1997r. i od 2003r., HR: do 1996r. i od 2005r., LI: do 2000r i 2006r., LT: do 1993r. i od 2004r., LV: do 2000r. i od 2005r., AT, DE, ES, FI, IT, LU: 1990 -2006, RO: do 2003r., SI :od 1996r., SK: od 2002r., TU: do 2004r., PT: od 1992r., MT: od 1995r., HU: od 2000r., CZ: od 1995r., CY: od 1991r.,
Notes	-	**Countries out ZR track (between TPs):** BG: od 2004r., Cz: do 1994r., CY: 1990r., EE: 1998-2002, HR: 1997-2004, LI: 2001-2005r., LT: 1994-2003, LV: 2001-2004., **PL: 1996-2003r.,** HU: do 1999r.,RO: od 2004r., SI: do 1996r., SK: do 2001r.,TU: od 2005r., PT: do 1991r., MT: do 1994r.,

Source: developed by the authors using the STATA 11 software.

*Note: ZR – sustainable development, "od" means "from", "do" means "to", "i" means "and", "r" means "year", EKC models verifying the EKC hypothesis, F_k^{Ch}- critical values of **F** statistics (Chow), F_k^{W} – critical values of **F** statistics (α=0,05) comparing the ordinary model with the spatial model;* p-value<0.1; ** p-value<0,05; *** p-value<0.01; TP - turning point(s); estimation method: instrumental variables, 2SLS.*

As a developing country, Poland belongs to the group of states where economic growth affects air quality. The inverted cubic Kuznets curve was assumed to characterise Poland and the other countries in that group (positive parameter values for the variables *const* and $(lPKB_{it})^2$). This means that economic and social activity in those countries does not hurt the environment before they achieve the first turning point (4915 PPS *per capita*), but then air degradation processes start building up. As soon as the second turning point is attained (substantial GDP – 24343 PPS *per capita*), the countries re-enter the path of sustainable development. However, as shown by the results obtained for this group of countries, only the wealthiest of them treat the natural environment as a luxury good. This means that environmental projects help improve air quality.

The spatial interactions observed turned to be very important for eco-development processes in particular European countries. Firstly, the influence of the variables on the volumes of emitted pollutants diminished (in the spatial model and the regular model).

Secondly, spatial relationships cause that the developing countries (i.e. those growing richer) start deteriorating environmental quality sooner and faster (4915 PPS *per capita* for the spatial model and 7331 PPS *per capita* for the regular one). The values of the second turning points (12708 PPS *per capita* for the regular model and 24343 PPS *per capita* for the spatial model) also show that spatial interactions have an unfavourable effect on countries' effectiveness in achieving eco-development. In other words, countries have to become rich enough for their socio-economic wealth to allow them to invest in the clean environment. For instance, Austria implemented eco-development objectives from 1997 according to the spatial model, however the regular model shows that it was even before 1990. Denmark followed the path of sustainable development from 1999, but when the spatial interactions are deducted the process starts in 1991. The spatial model indicates that Poland's economy did not follow the lines of eco-development throughout the analysed period, but the regular model points to eco-development being implemented in the country before 1995 and then from 2004. Malta's contribution to the level of emissions of gaseous pollutants was the largest (α_{16}=236.2), while Luxemburg's the smallest (α_{14}=17).

6. CONCLUSION

The results provided by both statistical analysis and econometric modelling made it possible to evaluate and compare the levels of eco-development across Europe, while taking into consideration the effects of spatial interactions. The choice and application of tools such as the measures of the quality of the environment and life, aggregate indicators, Moran's I statistics and EKC-based spatial panel data models to modelling the sustainable development processes in 32 European countries between 1990 and 2006 turned out to be right and pertinent. The F-test values and the determination coefficients (table 6) show that the spatial models are not only superior to the regular ones, but also provide information on the negative effects of the spatial inter-country relationships on environmental quality in the neighbouring countries, thus offering a more accurate picture of the investigated dimension of reality.

The results of the analysis show that while economic growth initially decreases the quality of the country's environment, it helps improve it once the turning point is attained. The basic Kuznets hypothesis was confirmed for ten countries (Belgium, Switzerland, Denmark, France, Greece, Ireland, Netherlands, Norway, Sweden and the UK). In those countries, the turning point from which socio-economic development does not contribute to excessive exploitation and degradation of the environment any longer is GDP *per capita* of 17154 PPS. For the other group of 22 countries the inverted cubic EKC was found to be more appropriate (tab. 6). This means that broadly understood economic development did not seriously damage their environments until the first turning point (4915 PPS *per capita*) was reached, but then air quality deteriorated. However, reaching the second turning point (GDP of 24343 PPS per capita), the countries re-enter the path of sustainable development. This is the case of the wealthiest countries (as for Poland, the country did not manage to attain a level of economic development suggesting that the country followed a path of eco-development throughout the period in question, i.e.1990-2006).

The above proves that walking on the path of sustainable development, while paying attention to spatial interactions, may help improve environmental quality and thus raise the quality of life. In the period 1990-2006, the group of countries that were worth following consisted of Belgium, Switzerland, Denmark, Netherlands, France, Norway, Sweden and Luxemburg.

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Celem niniejszego artykułu jest zaprezentowanie zastosowania modeli panelowych z efektami przestrzennymi do oceny poziomu realizacji założeń zrównoważonego rozwoju w 32. krajach Europy. Pokazane i dyskutowane są wyniki estymacji przestrzennych modeli panelowych dla weryfikacji hipotezy Środowiskowej Krzywej Kuznetsa, która zakłada, iż wzrost gospodarczy wpływa na poziom degradacji środowiska przybierając kształt odwróconej litery U. Punkt przekroczenia pewnego poziomu dochodów na osobę w danej gospodarce będzie punktem zwrotnym, od którego, pomimo dalszego rozwoju gospodarczego, nastąpi spadek degradacji środowiska. W części statystycznej zastosowano metody porządkowania linowego (taksonomiczne wzorce rozwojowe). Zakres danych obejmował lata 1990 - 2006. Uzyskane wyniki pozwoliły na dokonanie oceny i porównania poziomu ekorozwoju w Europie, z uwzględnieniem wpływu zachodzących interakcji przestrzennych.