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Multi-criteria Evaluation of the Eco-innovation Level in the European Union Countries

Wielokryterialna ocena poziomu ekoinnowacji w krajach Unii Europejskiej

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Abstract
The purpose of this paper is to analyze and evaluate the level of eco-innovations in the European Union countries. For this purpose, a new method of multi-criteria analysis were used, i.e. PROTERRA method, which was developed by the authors of this article. Analysis concerns a data from the year 2015. There have been determined aggregate ratings, which characterized the eco-innovation level of particular European Union countries. Four classes of innovation level were defined: eco-innovation leaders, good eco-innovators, week eco-innovators and eco-innovation outsiders. Then, based on the calculated global ratings, European Union countries were assigned to the appropriate classes.

Key words: eco-innovation level; evaluation, multi-criteria analysis

Streszczenie
Celem niniejszego artykułu jest analiza i ocena poziomu ekoinnowacji w krajach Unii Europejskiej. W tym celu została użyta nowa metoda analizy wielokryterialnej, tzn. metoda PROTERRA, która została opracowana przez autorów tego artykułu. Analiza obejmuje dane z roku 2015. Zostały wyznaczone oceny zagregowane, które charakteryzują poziom ekoinnowacji w poszczególnych krajach Unii Europejskiej. Zostały zdefiniowane cztery klasy ekoinnowacji: liderzy ekoinnowacji, dobrzy ekoinnowatorzy, słabi ekoinnowatorzy oraz outsiderzy ekoinnowacji. W rezultacie, na podstawie obliczonych ocen globalnych, kraje Unii Europejskiej zostały przyporządkowane do odpowiednich klas.

Słowa kluczowe: poziom ekoinnowacji, ocena, analiza wielokryterialna

1. Introduction

The essence of eco-innovation refers to the development of products and processes that contribute to sustainable development, applying the commercial application of knowledge to elicit direct or indirect ecological social improvements. The term eco-innovation takes into account three kinds of changes towards sustainable development: technological, social and institutional innovation (Rennings, 2000). In the book (Bossink, 2013) author notes that sustainability is a phenomenon that must be pursued in a complex system of interrelated elements of business, society, and ecology. This book presents an approach, according to which sustainable innovation as the systematic coherence of drivers of eco-innovation and sustainability has to be envisioned, conceptualized, realized, and improved.

Innovations, and especially eco-innovations, and sustainable development are of fundamental importance for the economic growth. Sustainable development has been one of European priorities for a long time. At present it has acquired a new significance in the light of the crisis connected with climate changes and the financial crisis. It is a great challenge for EU countries. Eco-innovations may relate to environmental changes in technology, organizational structure and management: establishment, business or economy of the country.

Eco-innovation can be included in the products or services, production processes, management and organization. Eco-innovation in the products or services help to reduce or eliminate environment pollution. Currently, it is known that it is easier and cheaper to use new technologies, than to look for ways to reduce the pollution caused by the use of outdated technologies (Janasz and Kozioł, 2007). Relationships between the eco-innovation and the sustainable development were the subject of discussion in many works. This is illustrated by the paper (Sarkar, 2013) that includes a holistic and strategic literature review on how the eco-innovations and their eco-specific promotional and developmental efforts to stimulate the sustainable development.

There are different definitions of eco-innovation and related definitions such as environmental innovation. Past studies of eco-innovation have focused on environmentally motivated innovation, overlooking the environmental gains from *normal* innovations. Kemp and Pearson (2008) define eco-innovation as *the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*. In the Eco-Innovation Observatory (www.eco-innovation.eu), the aspect of resource use is made the central element of eco-innovation, i.e. *Eco-innovation is innovation that reduces the use of natural resources and decreases the release of harmful substances across the whole life-cycle.*

The concept of eco-innovation is quite young. One of the first appearances of the concept of eco-innovation in the literature is in the book (Fussler and James, 1996). Eco-innovation as area of research is of increasing concern for policy makers, academics and practitioners. The article (Díaz-García et al., 2015) includes an overview of the existing body of literature on eco-innovations, and identification of the most relevant publications in the field and the topics of interest. This review of literature includes 384 articles and shows that there is a clear increase in the relevance of this issue within academia and several thematic trends arise in eco-innovation research, with drivers of eco-innovation being the most popular.

An important role in the development of eco-innovation play an appropriate regulatory frameworks and policy instruments. There is much interest in the role of environmental policy in encouraging environmental innovation, and also some empirical evidence for the importance of policy actions (i.e. Ashford et al, 1985; Jaffe et al., 2002; Kemp and Pontoglio, 2008; Wijen et al., 2012). Most developed countries have innovation policies for green innovation. These issues are analyzed e.g. in the articles (Leitner et al., 2010; Kemp, 2013). The first article shows how regulation drives innovation and how various diffusion pathways can be used by external stakeholders to direct and promote innovation. The second article proposes a framework for eco-innovation policy-making and policy evaluation, which should be based on the ten principles of eco-innovation defined by the author.

In shaping the right eco-innovation policy are helpful information about the degree of achievement of the objectives of eco-innovation policy. It is important to explore and identify relevant indicators for environmental innovation that could be used to develop innovation policy for all economic sectors, as well as for the field of environmental technologies (Arundel et al., 2006). For example (Kanerva et al., 2009), based on literature and data analysis, were chosen key indicators include five fields (environmental regulations and venture capital for the eco-industry; environmental publications, patents and business R&D; eco-industry exports and FDI; sales from environmentally beneficial innovation across sectors; and environmental impacts related to energy intensity and resource productivity of economies). It was found there that finding key eco-innovation indicators related to such factors is important for policy makers, as environmental innovation policy is required to counter the two market failures associated with environmental pollution and the innovation and diffusion of new technologies. Other works, which raised issues of building the system of eco-innovation indicators, are for example (Fukasaku, 2005; Legler et al., 2003; Oltra et.al., 2007; van der Voet et al., 2005).

A useful tool for national governments may be the European Innovation Scoreboard, which includes eco-innovation indicators developed by the Eco-Innovation Observatory (www.eco-innovation.eu). The Eco-Innovation Scoreboard illustrates eco-innovation performance across the European Union member states. Based on these eco-innovation indicators, later in this article was assessed level of eco-innovation in each European Union country using one of the methods of multi-criteria analysis, which is the PROTERRA method developed by the authors of this article. Then, on this basis, were made adequate rankings of EU countries, as well as those countries were assigned to the appropriate class in terms of eco-innovation level (eco-innovation leaders, good eco-innovators, week eco-innovators and eco-innovation outsiders)

2. Characteristics of the analyzed data

As mentioned in section 1, the Eco-Innovation Scoreboard illustrates eco-innovation performance across the EU member states. The scoreboard aims at capturing the different aspects of eco-innovation by applying 16 indicators grouped into five thematic areas: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes (Table 1). It thereby shows how well individual member states perform in different dimensions of eco-innovation compared to the EU average and presents their strengths and weaknesses. The Eco-Innovation Scoreboard complements other measurement approaches of innovativeness of European Union countries and aims to promote a holistic view on economic, environmental and social performance. The Eco-Innovation Scoreboard shows how well individual member states perform in different dimensions of eco-innovation compared to the EU average.

Currently, the Eco-Innovation Scoreboard covers a time series from 2010 to 2015. Recent data on the achievements of the EU countries in the field of eco-innovation apply to the year 2015. As the previous versions, the 2015 scoreboard is based on 16 indicators in 5 thematic areas:

- Eco-innovation inputs
  Eco-innovation inputs contain investments (financial resources, human resources, technical resources) that ensure an initiative for eco-innovation activities at companies, research organisations, and other institutions. Therefore, eco-innovation investments are an important determinant of eco-innovation performance at the level of companies, sectors and countries.
- Eco-innovation activities
  Eco-innovation activities are defined as the eco-innovation efforts regarding to developing new or improved products and services, changing business models, and introducing eco-management in companies or organisations. The scoreboard aggregates company level data to present the country level of performance.
- Eco-innovation outputs
  Eco-innovation outputs are the instant results of eco-innovation activities. Indicators in this ingredient are used to verify the extent to which knowledge outputs generated by businesses and researchers are related to eco-innovative capacity.
- Resource efficiency outcomes
  Resource efficiency outcomes of eco-innovation include indicators, which can reinforce the realization of a low-carbon, resource efficient economy through increasing the resource efficiency performance of sectors and countries. Eco-innovation can have a double positive impact on resource efficiency. It can lead to increase of the generated economic value, while at the same time to decrease pressures on the natural environment.
- Socio-economic outcomes
  Socio-economic outcomes of eco-innovation include both the benefits and disadvantages of eco-innovation activities. Their scope includes jobs created or eliminated, changes in competitiveness, as well as turnover, revenues, profits and expenses of companies.

A detailed analysis of the scoreboard and its components will be provided in the upcoming Eco-Innovation Observatory Annual Report 2016.

The authors of this article have proposed a different approach to the assessment of the eco-innovation level in each EU country. For processing the initial data in the form of a set of values of eco-innovation indicators they used a multi-criteria analysis tools. Concretely, it is a new method of multi-criteria analysis, which was developed by the authors of this article. The analysis covered the latest sets of initial data, included recently in the Eco-Innovation Scoreboard (ec.europa.eu/environment/ecoap/scoreboard _en), which cover the different above-mentioned aspects of eco-innovation. The analyzed values of individual indicators are presented in Table 2.

3. Proposed method of multi-criteria evaluation

Much attention has been paid in the past years to multi-criteria evaluation approaches (MCE) for solving of various decision problems. Multi-criteria evaluation represents many techniques useful for improving the transparency, control and analytic rigour of these decisions (Dunning et al., 2007). The MCE allows the processing of ratings of alternative decision options in the light of multiple criteria which are typically measured in different units. Today MCE is an established methodology (Figueira et al. 2005; Tzeng and Huang, 2011, Zopounidis and Pardalos, 2010) which has numerous applications in various fields (Doumpos and Grigoroudis, 2013; Mateo, 2012).

MCE can be defined as a decision model which includes a set of decision options which need to be ranked or scored by the decision maker, a set of criteria, typically measured in different units and a set of performance measures, which are the raw scores for each decision option against each criterion. In this sense, the MCE is identical to methods which are known as multi-criteria analysis (MCA) or multi-criteria decision analysis (MCDA). A minimum requirement for the MCE model is at least two criteria and two decision options ($m \geq 2$ and $n \geq 2$). The importance of each criterion is usually given in a one dimensional weights vector $\mathbf{w}$ containing n we-

Table 1. The eco-innovation indicators according to Eco-Innovation Scoreboard 2015, source: http://www.eco-innovation.eu

Type of indicators	Eco-innovation dimension	Indicator number	Indicator	Short description
INPUTS	Eco-innovation inputs	1.1	Governments environmental and energy R&D appropriations and outlays (% of GDP)	The relative priority given by governments to investing in research and development in the areas of energy, including renewables, and environment
		1.2	Total R&D personnel and researchers (% of total employment)	Indicator of the knowledge and research capabilities of a country. Since the data for R&D personnel involved in eco-innovation or environmental or cleantech research is not available, the generic indicator in used
		1.3	Total value of green early stage investments (USD/capita)	The value of early stage investments in cleantech industries
	Eco-innovation activities	2.1	Firms having implemented innovation activities aiming at a reduction of material input per unit output (% of total firms)	Indicator of material efficiency oriented eco-innovation in companies
		2.2	Firms having implemented innovation activities aiming at a reduction of energy input per unit output (% of total firms)	Indicator of energy efficiency oriented eco-innovation in companies
		2.3	ISO 14001 registered organisations (per mln population)	The importance of observing environmental management requirements for business. Can be seen as a proxy indicator for the level of environmental awareness and management capability of business.
OUTPUTS	Eco-innovation outputs	3.1	Eco-innovation related patents (per mln population)	According to OECD's scoping of patents in environmentally-related technologies: Energy generation from renewable and non-fossil sources PLUS Combustion technologies with mitigation potential PLUS Emissions abatement and fuel efficiency in transportation PLUS Energy efficiency in buildings and lighting PLUS Complementary Patstat queries conducted by EIO team
		3.2	Eco-innovation related academic publications (per mln population)	Institutions being involved in publications with the following list of English key-words in title and/or abstract: eco-innovation, energy efficient/efficiency, material efficient/efficiency, resource efficient/efficiency, energy productivity, material productivity, resource productivity
		3.3	Eco-innovation related media coverage (per numbers of electronic media)	Number of hits in all electronic media covered by *Meltwater News* with key-word *Eco-innovation* (translated in all EU-27 languages)
	Resource efficiency outcomes	4.1	Material productivity (GDP/Domestic Material Consumption)	Illustrates the GDP generated by material consumption of a country
		4.2	Water productivity (GDP/Water Footprint)	Illustrates the GDP generated by domestic water consumption
		4.3	Energy productivity (GDP/gross inland energy consumption)	Illustrates the GDP generated by domestic energy use
		4.4	GHG emissions intensity (CO2e/GDP)	Illustrates the amounts of GHG emissions generated per unit of GDP
	Socio-economic outcomes	5.1	Exports of products from eco-industries (% of total exports)	Based on selected list of trade codes referring to *environmental goods and services*
		5.2	Employment in eco-industries and circular economy (% of total employment across all companies)	Indicates the share of employment in eco-industry and circular economy in total employment. Total employment is an aggregate employment in all companies across sectors in a specific country. Data have been sourced from the Orbis database.

				Eco-industry company population was selected based on NAICS codes for eco-industries, including waste treatment, water sector, environmental technologies, recycling, reuse and recovery. The selection excludes companies engaged in energy generation and storage. The scope has been defined specifically for the EcoIS. Annex I provides the full list of NAICS codes selected for data extraction. Annex II provides additional information on how this indicator was calculated.
		5.3	Revenue in eco-industries and circular economy (% of total revenue across all companies)	Indicates the share of revenue from eco-industry in total revenue across sectors in a specific country. Total revenue is aggregate revenue in all companies across sectors in a specific country. Data have been sourced from the Orbis database. Eco-industry company population was selected based on NAICS codes for eco-industries, including waste treatment, water sector, environmental technologies, recycling, reuse and recovery. The selection excludes companies engaged in energy generation and storage. The scope has been defined specifically for the EcoIS. Annex I provides the full list of NAICS codes selected for data extraction. Annex II provides additional information on how this indicator was calculated.

ights, where w_j denotes the weight assigned to the j th criterion. The MCE model is represented by an evaluation matrix **D** of m decision alternatives and n criteria:

$$\mathbf{D} = \begin{bmatrix} D_{1,1} & D_{1,2} & \dots & D_{1,n} \\ D_{2,1} & D_{2,2} & \dots & D_{2,n} \\ \dots & \dots & \dots & \dots \\ D_{m,1} & D_{m,2} & \dots & D_{m,n} \end{bmatrix} \quad (1)$$

The individual values $D_{i,j}$ are ratings of the analyzed alternatives A_i (i = 1,2,...,m) in the light of the assumed criteria C_j (j = 1,2…,n).

Later in the article, a new technique (which is the original authors proposal) will be used in the evaluation of eco-innovation level in the EU member states. The proposed method were named as PROcessing TEchnique of Ratings for Ranking of Alternatives (PROTERRA). The starting point of the analysis is evaluation matrix **D** given by Eq. (1). The consecutive steps of the process include appropriate processing of the ratings for each pair of the alternatives. The normalization of the initial matrix **D** is the first step in the analysis, so that all criteria are reduced to benefits. This can be done using the following formulas:

- for benefits criteria:

$$d_{i,j} = \frac{D_{i,j}}{D_{\max}} \quad (2)$$

- for cost criteria:

$$d_{i,j} = \frac{D_{\min}}{D_{i,j}} \quad (3)$$

In the above equations, values $D_{\min}$ and $D_{\max}$ denote, adequately, the lowest and highest ratings of the elements considering criterion C_j (j = 1,2,…,n).

After the normalization of the decision matrix **D**, can be derived the normalized matrix **d**:

$$\mathbf{d} = \begin{bmatrix} d_{1,1} & d_{1,2} & \dots & d_{1,n} \\ d_{2,1} & d_{2,2} & \dots & d_{2,n} \\ \dots & \dots & \dots & \dots \\ d_{m,1} & d_{m,2} & \dots & d_{m,n} \end{bmatrix} \quad (4)$$

Next, for each pair of the alternatives A_i and A_k (i = 1,2,…m and k = 1,2,…m, $\forall i \neq k$) it is necessary to calculate the ratio of normalized ratings $d_{i,j}$ and $d_{k,j}$:

$$q_{i,k}^{(j)} = d_{i,j} / d_{k,j} \quad (5)$$

Using the value $d_{i,k}^{(j)}$, we can create matrix $\mathbf{q}^{(j)}$:

$$\mathbf{q}^{(j)} = \begin{bmatrix} q_{1,1}^{(j)} & q_{1,2}^{(j)} & \dots & q_{1,m}^{(j)} \\ q_{2,1}^{(j)} & q_{122}^{(j)} & \dots & q_{2,m}^{(j)} \\ \dots & \dots & \dots & \dots \\ q_{m,1}^{(j)} & q_{m,2}^{(j)} & \dots & q_{m,m}^{(j)} \end{bmatrix} \quad (6)$$

In this manner, a appropriate component matrix $\mathbf{q}^{(j)}$ is created for each of the assumed criteria (j = 1,2,…,n).

If $q_{i,k}^{(j)} > 1$, then the individual elements of $q_{i,k}^{(j)}$ located in the i th row of matrix $\mathbf{q}^{(j)}$ determine whether and to what any alternative A_i is better than alternative A_k. If $q_{i,k}^{(j)} = 1$, then both alternatives are equivalent. Otherwise (if $q_{i,k}^{(j)} < 1$) alternative A_i is worse than alternative A_k. In view of (5), the elements of matrix $\mathbf{q}^{(j)}$ located symmetrically with respect to the main diagonal for any $i \neq k$ pair are:

Table 2. The values of eco-innovation indicators according to Eco-Innovation Scoreboard 2015, source http://www.eco-innovation.eu

Country	INPUTS						OUTPUTS									
	Eco-innovation inputs			Eco-innovation activities			Eco-innovation outputs			Resource efficiency outcomes				Socio-economic outcomes		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	4.4	5.1	5.2	5.3
	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	benefits criterion	costs criterion	benefits criterion	benefits criterion	benefits criterion
(AT) Austria	89,49	129,60	73,82	156,31	160,68	61,68	160,61	150,99	94,92	79,85	119,82	105,61	121,90	117,55	68,34	33,27
(BE) Belgium	74,50	120,05	73,79	136,94	163,75	48,59	42,71	108,03	181,21	115,81	95,96	83,68	98,08	55,42	71,32	85,03
(BG) Bulgaria	5,44	50,88	0,00	50,53	53,58	108,82	16,06	26,38	39,99	35,24	28,53	63,98	55,07	23,46	100,44	119,48
(CY) Cyprus	6,71	36,41	2,24	62,11	70,94	29,71	8,56	237,52	150,13	75,30	48,72	104,62	79,62	17,41	14,56	17,80
(CZ) Czech Republic	82,89	103,36	170,30	165,32	172,32	205,78	45,15	78,13	18,86	72,29	67,44	65,43	57,67	99,21	183,40	159,36
(DE) Germany	172,06	120,05	801,34	223,24	220,81	42,73	230,37	88,08	101,40	105,07	123,10	103,90	95,31	147,47	50,14	64,27
(DK) Denmark	135,73	167,40	16,19	-	-	71,21	195,60	227,17	49,68	80,19	116,58	120,78	113,11	141,95	54,64	61,69
(EE) Estonia	145,25	73,94	100,55	159,48	61,53	167,41	16,23	122,02	19,91	33,96	41,90	59,30	55,07	49,63	131,52	120,03
(ES) Spain	90,76	91,43	207,83	-	-	133,51	45,65	101,44	160,00	148,98	59,40	117,99	120,63	53,10	136,79	126,36
(FI) Finland	172,06	167,40	66,63	172,81	159,93	124,19	230,37	284,32	56,14	43,22	119,20	59,30	85,56	100,84	143,00	116,78
(FR) France	137,29	130,39	0,00	143,26	131,63	56,44	164,80	66,54	92,90	121,61	96,72	89,43	126,22	101,72	181,80	129,97
(GR) Greece	58,66	97,00	15,83	-	-	37,25	38,24	141,86	123,54	81,38	53,52	107,99	69,83	34,02	74,47	74,15
(HR) Croatia	5,07	50,88	8,48	-	-	100,26	18,87	85,79	162,44	81,40	45,33	99,65	93,74	48,76	-	-
(HU) Hungary	139,84	72,35	3,80	95,13	97,75	101,13	8,56	54,39	18,86	87,57	35,84	98,03	102,26	112,83	162,89	102,07
(IE) Ireland	25,32	104,15	801,34	164,98	176,41	64,75	25,66	146,16	22,12	64,30	140,41	125,45	87,75	41,05	94,35	53,35
(IT) Italy	91,75	88,25	43,80	71,53	82,02	200,20	53,54	107,80	189,23	147,28	73,33	120,65	121,74	105,80	101,45	96,36
(LT) Lithuania	44,00	68,38	16,28	91,77	82,67	107,54	17,01	69,23	89,58	63,18	42,68	118,81	97,79	52,06	110,98	97,53
(LU) Luxembourg	77,78	163,78	76,86	139,23	148,86	57,02	141,87	284,32	189,23	170,47	137,28	103,29	114,80	147,47	14,56	17,80
(LV) Latvia	59,07	51,68	18,47	50,53	53,58	74,72	64,53	120,33	99,58	43,06	32,59	94,95	109,14	50,54	125,03	151,22
(MT) Malta	5,07	69,17	0,00	88,82	94,12	31,58	12,88	26,38	124,72	116,77	55,24	125,45	118,96	17,41	-	74,42
(NL) Netherlands	64,86	118,46	14,92	79,09	88,07	64,14	65,33	144,21	108,65	170,47	131,92	98,92	96,45	70,97	93,94	159,36
(PL) Poland	63,70	52,47	2,80	67,71	65,91	29,71	71,07	32,65	71,60	53,14	50,76	86,84	58,90	84,65	33,67	111,37
(PT) Portugal	149,06	83,48	4,54	223,24	220,81	56,72	15,98	182,41	50,54	71,74	47,01	116,16	107,58	60,70	118,31	116,64
(RO) Romania	79,18	36,41	0,00	107,73	101,75	205,78	34,26	56,04	70,13	33,96	28,53	107,64	86,64	54,56	168,65	136,40
(SE) Sweden	137,21	139,14	86,45	133,08	142,81	185,22	170,23	269,56	39,43	74,74	128,72	79,85	126,22	88,53	93,43	97,20
(SI) Slovenia	93,12	128,80	0,00	-	-	92,32	55,47	182,77	55,49	90,67	60,35	77,22	83,25	87,28	183,40	155,87
(SK) Slovakia	53,86	58,83	0,00	75,23	79,50	149,30	14,10	93,50	46,92	89,46	59,49	80,08	83,96	50,15	105,95	106,00
(UK) United Kingdom	78,67	100,97	198,56	-	-	116,09	56,93	113,72	50,23	152,62	140,41	107,09	105,19	104,51	72,24	84,92

If $q_{i,k}^{(j)} > 1$, then the individual elements of $q_{i,k}^{(j)}$ located in the i th row of matrix $\mathbf{q}^{(j)}$ determine whether and to what any alternative A_i is better than alternative A_k. If $q_{i,k}^{(j)} = 1$, then both alternatives are equivalent. Otherwise (if $q_{i,k}^{(j)} < 1$) alternative A_i is worse than alternative A_k. In view of (5), the elements of matrix $\mathbf{q}^{(j)}$ located symmetrically with respect to the main diagonal for any i $\neq$ k pair are:

$$q_{k,i}^{(j)} = 1 / q_{i,k}^{(j)} \quad (7)$$

Further procedure is similar to one which is used in the PROMETHEE method, which is a very popular method of multi-criteria decision analysis (Brans et al., 1984; Brans and Mareschal, 2005). Nevertheless, the proposed approach does not specify a preference function. Values of appropriate outranking indices, which determine the strengths and weaknesses of each alternative, are calculated on the basis of ratios described by (5). They will be named as global superiority index and global inferiority index. In turn, the global superiority index indicates the degree to which alternative A_i dominates other alternatives. The global inferiority index indicates the degree to which A_i is dominated by the alternatives. These indices are calculated as follows:

- global superiority index

$$E_i^{+} = \frac{1}{m-1} \sum_{j=1}^{n} \sum_{\substack{k=1 \\ k \neq i}}^{m} w_j q_{i,k}^{(j)} \quad (8)$$

- global inferiority index

$$E_i^{-} = \frac{1}{m-1} \sum_{j=1}^{n} \sum_{\substack{k=1 \\ k \neq i}}^{m} w_j q_{k,i}^{(j)} \quad (9)$$

whereby the criteria weights w_j (j = 1,2,…,n) satisfy the condition

$$\sum_{j=1}^{n} w_j = 1 \quad (10)$$

The weighting of the criteria can be performed by applying any of the commonly used methods.
Basing on the indices described by Eqs. (8) and (9), a global ranking index can be calculated:

$$E_i = E_i^{+} - E_i^{-} \quad (11)$$

It is the balance among the global superiority and global inferiority indexes. The higher the global ranking index, the better is the alternative, so that:

$$\begin{cases} A_i \succ A_k & if \quad E_i > E_k \\ A_i \sim A_k & if \quad E_i = E_k \end{cases} \quad (12)$$

4. Evaluation of the eco-innovation level in European Union countries

Evaluation of the eco-innovation level in the European Union member states focuses on the latest data, which includes a Table 2. The indicators in the groups Eco-innovation inputs and Eco-innovation activities were considered jointly as INPUTS. Whereas, indicators belonging to groups Eco-innovation outputs, Resource efficiency outcomes and Socio-economic outcomes were considered jointly as OUTPUTS. All indicators (as evaluation criteria) were treated as equally important and have received equal weight values. The analysis was performed in three variants: separately for INPUTS (Enablers and Firm activities), OUTPUTS, and also generally, taking into account all eco-innovation indicators. The calculations results are presented in Tables 3 and 4 (Table 3 shows the aggregated ratings separately for INPUTS and OUTPUTS, Table 4 shows the aggregated ratings, which result of all indicators analyzed jointly). At the bottom of these tables are also given statistical measures, which were used in subsequent analyzes. Namely, on the basis of the ratings shown in Tables 3 and 4 all European Union countries were classified into four groups: eco-innovation leaders, good eco-innovators, week eco-innovators and eco-innovation outsiders. It was used at the following criteria:

- eco-innovation leaders, when
  $$E_i \geq \overline{E} + s_{\overline{E}} \quad (13)$$
- good eco-innovators, when
  $$\overline{E} + s_{\overline{E}} > E_i \geq \overline{E} \quad (14)$$
- weak eco-innovators, when
  $$\overline{E} > E_i \geq \overline{E} - s_{\overline{E}} \quad (15)$$
- eco-innovation outsiders, when
  $$\overline{E} - s_{\overline{E}} > E_i \quad (16)$$

where:
E_i - the aggregated rating of i th alternative (country)
$\overline{E}$ - an average value of all aggregated ratings,
$s_{\overline{E}}$ - standard deviation.

Assignment of the particular countries to the above classes is illustrated by table 5. The results shown in Table 5 allow to conclude that:

1. The individual EU countries are characterized by wide differences in the values of global ranking indexes, as illustrated by Figures 1, 2 and 3.
2. A large group of EU countries shows such a level of eco-innovation, which allows to include them to the same class both in terms of INPUTS, OUTPUTS, as well as GENERALLY. This applies to Austria, Belgium, Cyprus, Germany, Spain, Greece, Italy, Lithuania, Luxembourg, Portugal, Slovenia, Slovakia and United Kingdom.

Table 3. Aggregated ratings in the field of INPUTS (Eco-innovation inputs, Eco-innovation-activities) and OUTPUTS (Eco-innovation outputs, Resource efficiency outcomes, Socio-economic outcomes)

EU member country	Aggregated ratings for INPUTS			Aggregated ratings for OUTPUTS		
	Global superiority index (E^+)	Global inferiority index (E^-)	Global ranking index (E)	Global superiority index (E^+)	Global inferiority index (E^-)	Global ranking index (E)
(AT) Austria	2,2386	0,9648	1,2738	1,8180	1,1030	0,7150
(BE) Belgium	2,0668	1,0938	0,9730	1,4700	1,0894	0,3806
(BG) Bulgaria	0,5282	3,7314	-3,2032	0,8199	2,4570	-1,6371
(CY) Cyprus	0,3665	11,3434	-10,9769	1,0530	3,1485	-2,0956
(CZ) Czech Republic	3,6161	0,6737	2,9424	1,3920	1,4578	-0,0658
(DE) Germany	11,0901	0,7465	10,3436	2,1238	1,0118	1,1120
(DK) Denmark	1,5682	1,4860	0,0822	2,0199	1,0478	0,9721
(EE) Estonia	2,9072	0,9250	1,9823	1,0247	2,0135	-0,9888
(ES) Spain	3,4350	0,5242	2,9107	1,5720	1,0321	0,5399
(FI) Finland	2,9448	0,7372	2,2076	2,3263	0,9575	1,3687
(FR) France	1,6475	0,7366	0,9108	2,0201	0,8895	1,1306
(GR) Greece	0,8335	1,9364	-1,1030	1,2120	1,3054	-0,0934
(HR) Croatia	0,4642	5,3583	-4,8941	0,9510	1,2463	-0,2953
(HU) Hungary	1,5731	5,3595	-3,7863	1,0977	2,3415	-1,2439
(IE) Ireland	10,0319	1,1644	8,8675	1,1253	1,6671	-0,5417
(IT) Italy	1,9453	1,2139	0,7314	1,6926	0,9434	0,7492
(LT) Lithuania	1,0835	2,1277	-1,0442	1,0626	1,5955	-0,5329
(LU) Luxembourg	2,2215	0,9964	1,2252	2,2070	1,7319	0,4751
(LV) Latvia	0,9903	2,3170	-1,3267	1,3588	1,2593	0,0995
(MT) Malta	0,4812	3,9464	-3,4652	0,9039	2,1587	-1,2548
(NL) Netherlands	1,1928	2,1395	-0,9467	1,7679	0,8628	0,9050
(PL) Poland	0,7728	7,7512	-6,9784	1,1430	1,6305	-0,4875
(PT) Portugal	1,8976	4,5117	-2,6141	1,1969	1,5037	-0,3068
(RO) Romania	1,3536	0,9985	0,3552	1,1474	1,5976	-0,4502
(SE) Sweden	2,9586	0,7149	2,2437	1,9752	0,9897	0,9855
(SI) Slovenia	1,0876	0,4468	0,6408	1,6029	0,9981	0,6048
(SK) Slovakia	1,0252	1,0527	-0,0276	1,0661	1,6320	-0,5658
(UK) United Kingdom	3,2304	0,5544	2,6761	1,5447	1,0231	0,5216
		$\overline{E}$	0,0000		$\overline{E}$	0,0000
		$s_{\overline{E}}$	4,1779		$s_{\overline{E}}$	0,9070
		$\overline{E}+s_{\overline{E}}$	4,1779		$\overline{E}+s_{\overline{E}}$	0,9070
		$\overline{E}-s_{\overline{E}}$	-4,1779		$\overline{E}-s_{\overline{E}}$	-0,9070

Figure 1. Values of the global ranking indexes in the case of INPUTS

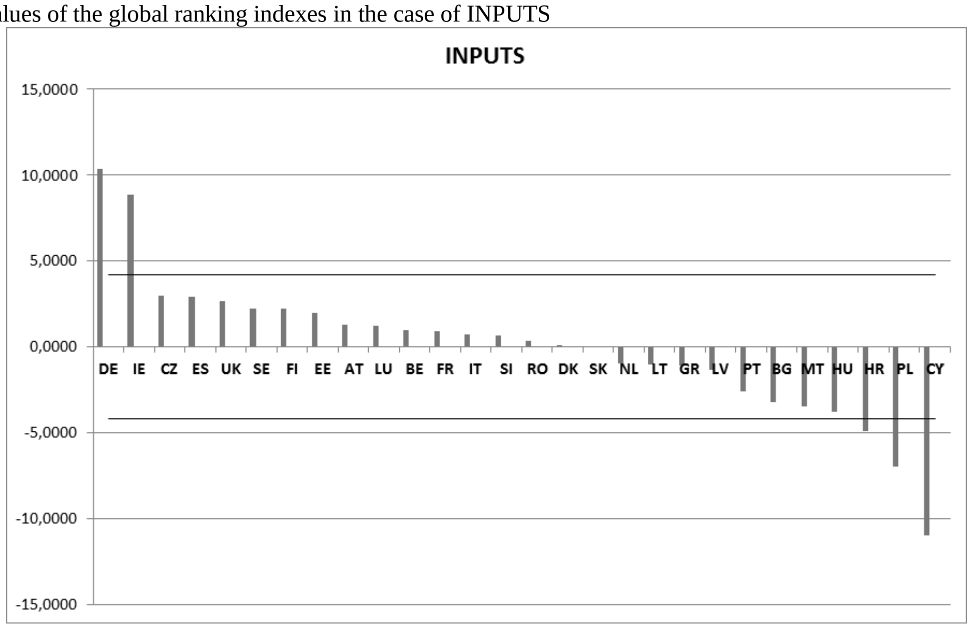


Table 4. Aggregated ratings of the eco-innovation level in European Union countries (GENERALLY)

Country	Global superiority index (E^+)	Global inferiority index (E^-)	Global ranking index (E)
(AT) Austria	1,9757	1,0511	0,9246
(BE) Belgium	1,6938	1,0911	0,6027
(BG) Bulgaria	0,7105	2,9349	-2,2244
(CY) Cyprus	0,7956	6,2216	-5,4261
(CZ) Czech Republic	2,2261	1,1637	1,0623
(DE) Germany	5,4862	0,9123	4,5739
(DK) Denmark	1,8505	1,2121	0,6384
(EE) Estonia	1,7306	1,6053	0,1253
(ES) Spain	2,2706	0,8416	1,4290
(FI) Finland	2,5582	0,8749	1,6833
(FR) France	1,8804	0,8322	1,0482
(GR) Greece	1,0700	1,5420	-0,4720
(HR) Croatia	0,7684	2,7883	-2,0199
(HU) Hungary	1,2760	3,4732	-2,1973
(IE) Ireland	4,4653	1,4786	2,9867
(IT) Italy	1,7874	1,0449	0,7425
(LT) Lithuania	1,0705	1,7951	-0,7246
(LU) Luxembourg	2,2125	1,4561	0,7564
(LV) Latvia	1,2206	1,6560	-0,4353
(MT) Malta	0,7454	2,8291	-2,0837
(NL) Netherlands	1,5522	1,3416	0,2106
(PL) Poland	1,0042	3,9257	-2,9216
(PT) Portugal	1,4596	2,6317	-1,1721
(RO) Romania	1,2247	1,3729	-0,1482
(SE) Sweden	2,3439	0,8866	1,4573
(SI) Slovenia	1,4096	0,7914	0,6183
(SK) Slovakia	1,0508	1,4147	-0,3640
(UK) United Kingdom	2,1769	0,8474	1,3295
		$\overline{E}$	0,0000
		$s_{\overline{E}}$	1,9500
		$\overline{E} + s_{\overline{E}}$	1,9500
		$\overline{E} - s_{\overline{E}}$	-1,9500

Figure 2. Values of the global ranking indexes in the case of OUTPUTS

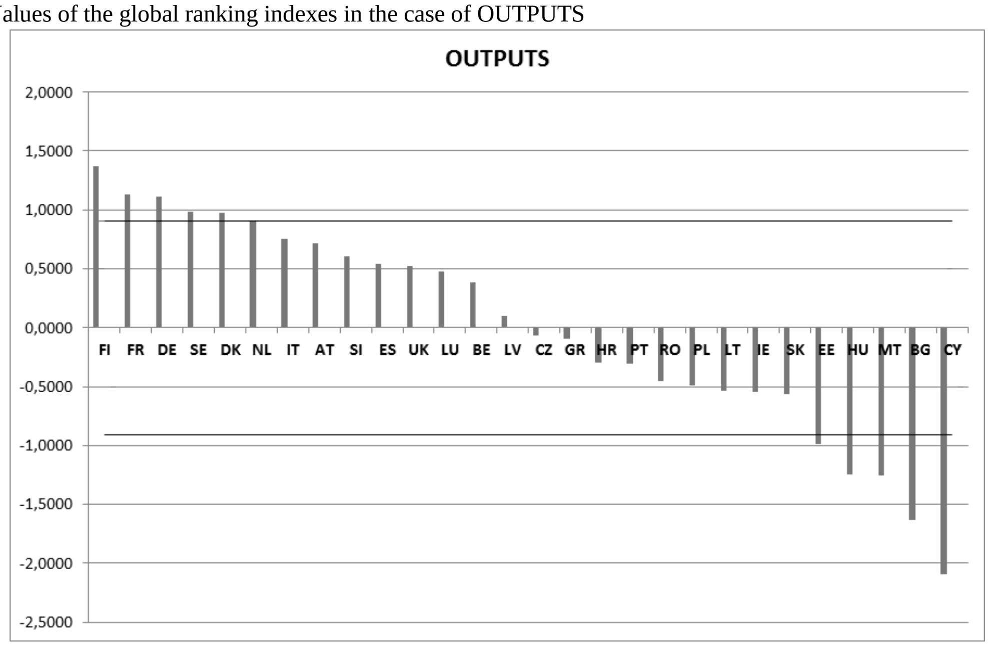
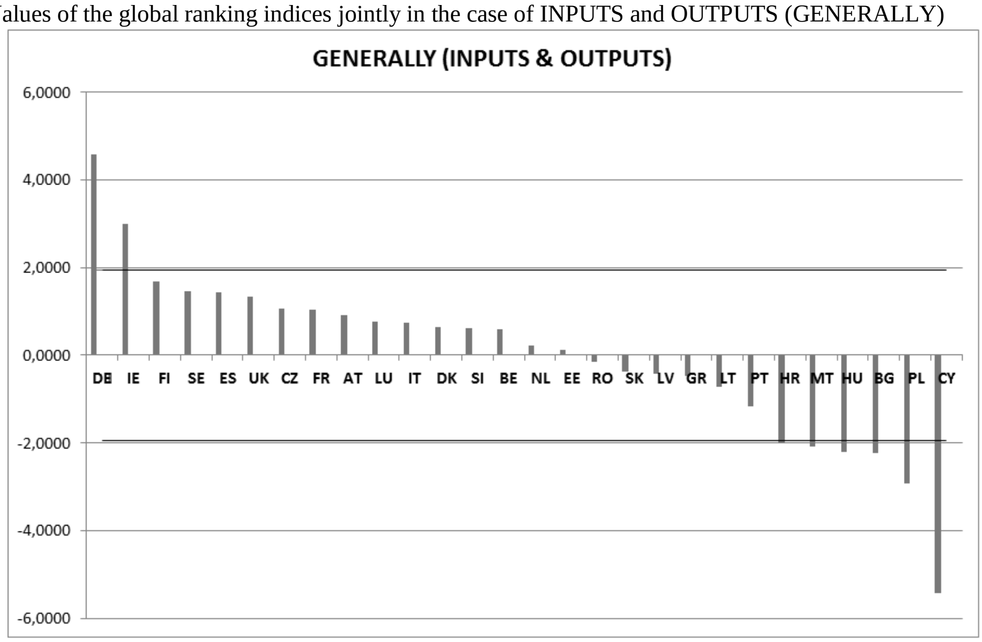


Table 5. Assignment of the European Union countries to defined eco-innovation classes

	INPUTS				OUTPUTS				GENERALLY			
	Eco-innovation leaders	Good eco-innovators	Weak eco-innovators	Eco-innovation out-siders	Eco-innovation leaders	Good eco-innovators	Weak eco-innovators	Eco-innovation out-siders	Eco-innovation leaders	Good eco-innovators	Weak eco-innovators	Eco-innovation out-siders
(AT) Austria		X				X				X		
(BE) Belgium		X				X				X		
(BG) Bulgaria			x					x				x
(CY) Cyprus				X				X				X
(CZ) Czech Republic		x					x			x		
(DE) Germany	X				X				X			
(DK) Denmark		x			x					x		
(EE) Estonia		x						x		x		
(ES) Spain		X				X				X		
(FI) Finland		x			x					x		
(FR) France		x			x					x		
(GR) Greece			X				X				X	
(HR) Croatia				x			x					x
(HU) Hungary			x					x				x
(IE) Ireland	x						x		x			
(IT) Italy		X				X				X		
(LT) Lithuania			X				X				X	
(LU) Luxembourg		X				X				X		
(LV) Latvia			x			x					x	
(MT) Malta			x					x				x
(NL) Netherlands			x			x				x		
(PL) Poland				x			x					x
(PT) Portugal			X				X				X	
(RO) Romania		x					x				x	
(SE) Sweden		x			x					x		
(SI) Slovenia		X				X				X		
(SK) Slovakia			X				X				X	
(UK) United Kingdom		X				X				X		

Attention:
X – the same assignment to a specific class in terms of Inputs, Outputs and Generally
x – assignment to a specific class in terms of Inputs, Outputs or Generally

Figure 3. Values of the global ranking indices jointly in the case of INPUTS and OUTPUTS (GENERALLY)



3. A leader of eco-innovation is Germany, and to a slightly lesser extent, Denmark, Finland, France, Ireland and Sweden.
4. A group of good eco-innovators includes Austria, Belgium, Spain, Italy, Luxembourg, Slovenia and United Kingdom, and to a slightly lesser extent, Czech Republic, Netherlands and Estonia.
5. A group of weak eco-innovators includes Greece, Lithuania, Latvia, Portugal, Romania and Slovakia.
6. An outsider of eco-innovation is Cyprus, and to a slightly lesser extent, Bulgaria, Croatia, Hungary, Malta and Poland.
7. For the 15 countries (Austria, Belgium, Cyprus, Germany, Spain,. Finland, France, Greece, Italy, Lithuania, Luxembourg, Portugal, Slovenia, Slovakia and United Kingdom), it can be stated that they have a consistent assignment to a specific class of eco-innovation level both in terms of INPUTS and OUTPUTS. This shows that the indicators system of The Eco-Innovation Observatory is well designed and through OUTPUTS appropriately reflects the effects of eco-innovation policy, which is characterized by the INPUTS.

5. Conclusions

The Eco-Innovation Scoreboard can be important for each country to monitor their own eco-innovation level, as well as to compare this state with the achievements of other countries. In this paper there were analyzed values of the eco-innovation indicators, which are recently published by the Eco-Innovation Observatory as Eco-Innovation Scoreboard 2015. The evaluation of the eco-innovation level was carried out using a new multi-criteria analysis method (PROTERRA), that is a new method developed by the authors of this article.

Based on the analysis of the calculation results, the group of the eco-innovation leaders includes Germany, Denmark, Finland, France, Ireland and Sweden. Whereas, to the outsiders of eco-innovation may be qualified Cyprus, Bulgaria, Croatia, Hungary, Malta and Poland.

In the opinion of authors of this article, the results of analysis of the eco-innovation level broken down into INPUTS, OUTPUTS and GENERALLY (which base on indicators of The Eco-Innovation Scoreboard) show the strength and / or weakness of the European Union countries in this regard. As a result, they can be a valuable material that can help shape an appropriate eco-innovation policy by the governments of these countries.

References

1. ARUNDEL A., KEMP R., PARTO S., 2006, Indicators for environmental innovation: What and how to measure, in: *The international handbook on environmental technology management*, ed. Marinova D., Annandale D. and Phillimore J., Edward Elgar, Cheltenham.
2. ASHFORD N.A., AYERS C., STONE, R.F., 1985, Using regulation to change the market for innovation, in: *Harvard Environmental Law Review*, vol. 9, p. 419-466.
3. BEHZADIAN M., KAZEMZADEH R.B., ALBADVI A., AGHDASI, M., 2010, PROMETHEE: A comprehensive literature review on methodologies and applications, in: *European Journal of Operational Research*, vol. 200, p. 198-215.
4. BOSSINK B., 2013, *Eco-Innovation and Sustainability Management*. Routledge – Taylor & Francis Group, New York.
5. BRANS J.P., MARESCHAL B., VINCKE PH., 1984, PROMETHEE: A new family of outranking methods in multicriteria analysis, in: *Operational Research'84*, North-Holland, Amsterdam.
6. BRANS J.P., MARESCHAL B., 2005, PROMETHEE methods, in: *Multiple Criteria Decision Analysis: State of the Art Surveys*, ed. Figueira J., Greco S., Ehrgott M., Springer, New York.
7. DÍAZ-GARCÍA C., GONZÁLEZ-MORENO Á., SÁEZ-MARTÍNEZ F.J., 2015, Eco-innovation: insights from a literature review, *Innovation: Management, Policy & Practice*, vol.17, p. 6-23.
8. DIME.EU, http://www.dime-eu.org/files/active/0/Foxon_Speirs_Pearson_final.pdf, (09.12.2016).
9. DOUMPOS M., GRIGOROUDIS E. (eds.), 2013, *Multicriteria decision aid and artificial intelligence. Links, theory and applications*,. John Wiley & Sons, Ltd., Chichester.
10. FIGUEIRA J., SALVATORE G., EHRGOTT M. (eds.), 2005, *Multiple criteria decision analysis: state of the art surveys*. Springer, Berlin-Heidelberg-New York.
11. FUKASAKU Y., 2005, The need for environmental innovation indicators and data from a policy perspective, in: *Towards environmental innovation systems*, ed. Weber M. and Hemmelskamp J., Springer, Berlin.
12. FUSSLER C., JAMES P., 1996, *Driving eco-innovation: A breakthrough discipline for innovation and sustainability*. Pitman Publishing, London.

13. JAFFE A.B., NEWELL R.G., STAVINS R.N., 2002, Environmental policy and technological change, in: *Environmental and Resource Economics*, vol. 22, p. 41-69.
14. JANASZ W., KOZIOŁ K., 2007, *Determinanty działalności innowacyjnej przedsiębiorstw*. PWE, Warszawa.
15. KANERVA M., ARUNDEL A., KEMP R., 2009, *Environmental innovation: Using qualitative models to identify indicators for policy*. United Nations University – MERIT, Maastricht.
16. KEMP R., PEARSON P., 2008, *Measuring eco-innovation (Final Report MEI project*), UNU-MERIT, Maastricht.
17. KEMP R., PONTOGLIO S., 2008, The innovation effects of environmental policy instruments – A typical case of the blind men and the elephant. *Paper for DIME WP 2.5 Workshop on Empirical Analyses of Environmental Innovations*, Fraunhofer Institute for Systems and Innovation Research (ISI), 17-18 January, Karlsruhe.
18. KEMP R., 2011, Ten themes for eco-innovation policies in Europe. *S.A.P.I.E.N.S.*, vol. 4, p. 1-20.
19. LEGLER H., SCHMOCH U., GEHRKE B., KRAWCZYK O., 2003, Innovationsindikatoren zur Umweltwirtschaft, *Studien zum deutschen Innovationssytem, Nr.* 2., NIW and Karlsruhe: Fraunhofer Institut, Hannover.
20. LEITNER A., WEHRMEYER W., FRANCE CH., 2010, The impact of regulation and policy on radical eco-innovation: The need for a new understanding, in: *Management Research Review*, vol. 33, p. 1022-1041.
21. MATEO J.R., 2012, *Multi-criteria analysis in the renewable energy industry*. Springer-Verlag, London.
22. OLTRA V., KEMP R., DE VRIES F., 2007, *Patents as a measure for eco-innovation. Report for the MEI project*. University of Bordeaux, UNU-MERIT and University of Stirling, Bordeaux.
23. RENNINGS K., 2000, Redefining innovation – eco-innovation research and the contribution from ecological economics, in: *Ecological Economics*, vol. 32, p. 319-332.
24. SARKAR A.N., 2013, Promoting eco-innovations to leverage sustainable development of eco-industry and green growth, in: *European Journal of Sustainable Development*, vol. 2, p. 171-224.
25. SPEIRS J., PEARSON P., FOXON T., 2008, Adapting Innovation Systems Indicators to assess Eco-Innovation, in: *DIME working paper*, Brussels.
26. TZENG G.H., HUANG J.J., 2011, *Multiple attribute decision making. Methods and applications*. CRC Press, Taylor&Francis Group, Boca Raton.
27. VAN DER VOET E., VAN OERS L., MOLL S., SCHUTZ H., BRINGEZU S., DE BRUYN S., SEVENSTER M., WARRINGA G., 2005, *Policy review on decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries*. Report commissioned by the European Commission, Leiden.
28. WIJEN F., ZOETEMAN K., PIETERS J., VAN SETERS P. (eds.), 2012, *A Handbook of globalisation and environmental policy*, Second edition. National government interventions in a global arena. Edward Elgar Publishing, Northampton.
29. ZOPOUNIDIS C., PARDALOS P.M. (eds.), 2010, *Handbook of multicriteria analysis*. Springer Verlag, Berlin-Heidelberg.