QUANTITATIVE METHODS IN ECONOMICS
Vol. XV, No. 2, 2014, pp. 296 – 306

CONSTRUCTION OF THE ENVIRONMENTAL PERFORMANCE INDEX USING DEA

Ewa Chodakowska
Faculty of Management
Bialystok University of Technology
e-mail: e.chodakowska@pb.edu.pl

Abstract: There is wide range of environmental performance indicators. The more sophisticated they are, the more arbitrary viewpoint they take. The EPI weights are established based on experts' judgments form Yale University and Columbia University team. In the article was analysed the changes in the EPI when the weights had been replaced with the weights determined by Data Envelopment Analysis. DEA determines weights that maximize the performance of each unit with some assumptions. Not for every European country this approach turned out to be the better option.

Keywords: EPI (environmental performance index), DEA (data envelopment analysis)

INTRODUCTION

Environmental Performance Index

The sustainable development and environmental performance are the subjects of unwavering popularity. The popularity has given rise to a considerable wealth of research in this area. Increasing consciousness about environmental problems was the origin of introduction of measurements like the Environmental Performance Index (EPI). "The Environmental Performance Index (EPI) ranks how well countries perform on high-priority environmental issues in two broad policy areas: protection of human health from environmental harm and protection of ecosystems" [Hsu at al. 2014]. The EPI can be used by environmental advocates, business leaders, politicians to improve management decisions and enable more sustainable choice. Although, it is used more often only as a public relations and marketing tool.

The EPI indicators are constructed in several steps in detail described on its project website: http://epi.yale.edu/. Generally speaking, first, the raw data values are transformed by dividing by population, GDP or some other denominator in order to make the data comparable across countries. Second, a logarithmic transformation is performed on most of the variables. Third, the transformed and logged data are converted into indicators using a proximity-to-target methodology. The proximity-to-target methodology measures each country's performance on any given indicator based on its position within a range established by the lowest performing country (equivalent to 0 on a 0-100 scale) and the target (equivalent to 100). Then explicit weights are assigned to the indicators, policy categories, and objectives in order to create the aggregate EPI score [Emerson at al. 2012; Hsu at al. 2014]. The weights and indicators are presented in Table 1.

Table 1. Statistical Weightings Used for the 2014 Environmental Performance Index (EPI)

EPI	Objective	Issue Category	Indicator
Environmental Performance Index (EPI)	Environmental Health (40%)	Health Impacts (33%)	Child Mortality (100%)
		Air Quality (33%)	Household Air Quality (33%)
			Air Pollution - Average Exposure to PM2.5 (33%)
			Air Pollution - PM2.5 Exceedance (33%)
		Water and Sanitation (33%)	Access to Drinking Water (50%)
			Access to Sanitation (50%)
	Ecosystem Vitality (60%)	Water Resources (25%)	Wastewater Treatment (100%)
		Agriculture (5%)	Agricultural Subsidies (50%)
			Pesticide Regulation (50%)
		Forests (10%)	Change in Forest Cover (100%)
		Fisheries (10%)	Coastal Shelf Fishing Pressure (50%)
			Fish Stocks (50%)
		Biodiversity and Habitat (25%)	Terrestrial Protected Areas (National Biome Weights) (25%)
			Terrestrial Protected Areas (Global Biome Weights) (25%)
			Marine Protected Areas (25%)
			Critical Habitat Protection (25%)
		Climate and Energy (25%)	Trend in Carbon Intensity (weighting varies according to GDP)
			Change of Trend in Carbon Intensity (weighting varies according to GDP)
			Trend in CO2 Emissions per KWH (33%)
			Access to Electricity (N/A)

Source: based on [Hsu at al. 2013]

The weights are determined based on expert judgments on the suitability of the data or the quality of the underlying data through an iterative process. The

EPI developers are aware that “the selection of weights is not a completely objective process and that disagreements are inevitable based on political preferences and even the performance of individual countries on different facets of environmental performance” [Hsu at al. 2014]. And there may be legitimate differences of opinion regarding the relative importance of selected indicators [Emerson at al. 2012].

Data Envelopment Analysis

Data Envelopment Analysis (DEA), developed by [Charnes at al. 1978], is a well-established method for evaluating the relative efficiency of a set of comparable entities — decision making units (DMUs). Due to the fact that the method allows to evaluate systems with multiple inputs and outputs, DEA has been widely investigated and applied in various areas. Since DEA does not necessarily require the use of financial data and can take into account uncontrolled inputs (such as environmental circumstances) is well suited especially for the evaluation non-profit organizations [Chodakowska at al. 2010; Nazarko 2010]. DEA has also gain the popularity in environmental performance measurements [Callens at al. 1999; Meng at al. 2013; Zhou at al. 2008; Zhou at al. 2007]

To measure the EPI by DEA often are used the concept of environmental DEA technology described inter alia in [Meng at al. 2013]. In the technology all outputs are classified into desirable (e.g. GDP) and undesirable outputs (e.g. CO_2). It is assumed that outputs are weakly disposable which implies that the proportional reduction in desirable and undesirable outputs is possible, whereas it may not be feasible to reduce undesirable outputs solely. Desirable and undesirable outputs are null-joint. In other words, the assumptions mean that undesirable outputs must be produced in order to produce desirable outputs and the only way to remove all the undesirable outputs is to cease the production process [Meng at al. 2013]. The DEA Radial Environmental Index models for measuring the environmental performance of (DMU*o*) can be written as [Meng at al. 2013]:

$$REI = \left(X_o, Y_o, Q_o\right) = \min \theta \quad (1)$$

$$\sum_{i=1}^{I} \lambda_i x_{im} \le x_{om}, \quad m = 1, \ldots, M$$

$$\sum_{i=1}^{I} \lambda_i y_{in} \ge y_{on}, \quad n = 1, \ldots, N$$

$$\lambda_i \ge 0, \quad i = 1, \ldots, I$$

where:

$X_i = (x_{i1}, x_{i2}, x_{i3}, \ldots, x_{iM})$ – input vector,

$Y_i = (y_{i1}, y_{i2}, y_{i3}, \ldots, y_{iN})$ – desirable output vector,

$Q_i = (q_{i1}, q_{i2}, q_{i3}, \ldots, q_{iJ})$ – undesirable output vector,

λ_i – intensity levels at which the production activities are conducted by the DMUs,

I – number of DMUs.

If specific DMU has a larger REI, it has better environmental performance [Zhou at al. 2008].

The EPI created by researchers from Yale University and Columbia University contains only desirable outputs. Despite the sometimes confusing names such as child mortality, higher index value indicates a better situation in the country in terms of the environment. Undesirable outputs are included indirectly in some indices. It means that to apply environmental DEA technology it is necessary to use raw data. Taking into account the proximity-to-target methodology used for the construction of these indicators it would be difficult to compare the results of DEA and the EPI, because in fact they would use different data.

In the article DEA was applied to choose the weights of the indicators used in the construction of the EPI so as to maximize the position of each country in the ranking of environmental performance. By confronting purely mathematical approach with substantive approach involving experts the sensitivity of the EPI to the assumptions was tested.

For this purpose the following primal mulitplier CCR DEA model was used [Ramanathan 2003]:

$$\max \sum_{n=1}^{N} \upsilon_{no} y_{no} \tag{2}$$

$$\sum_{n=1}^{N} u_{mo} y_{mo} = 1$$

$$\sum_{n=1}^{N} \upsilon_{ni} y_{ni} - \sum_{n=1}^{N} u_{mi} x_{mi} \le 0, \qquad i = 1, \ldots, I$$

$$u_{mi}, \upsilon_{ni} > 0, \quad n = 1, \ldots, N, \quad m = 1, \ldots, M$$

In this linear programming problem the weights (u_{mi}, υ_{ni}) are chosen to maximize the weighted sum of outputs to the condition that the sum of the weighted inputs is equal to 1, and that the efficiencies of other DMUs (calculated using the same set of weights) is restricted to values between 0 and 1.

EPI FOR EUROPEAN COUNTRIES — A CASE STUDY

Units, Variables and Weights

The EPI in 2014 was calculated for 178 countries, 42 of them are located in Europe. Assuming a constant, identical level of inputs for each European country, weights for outputs were adjusted to maximize the assessment of environmental performance. Selected weights for other DMUs – European countries – (calculated using the same set of weights) do not exceed the range 0 and 1.

Without going into the construction of aggregated indicators, at the beginning weights were chosen for two variables: Environmental Health (EH) and Ecosystem Vitality (EV). In the 2014 EPI they have fixed weights: 40% and 60%. Weights for 42 European countries adjusted using DEA methodology have 2 patterns. European countries and theirs weights are presented in Table 2.

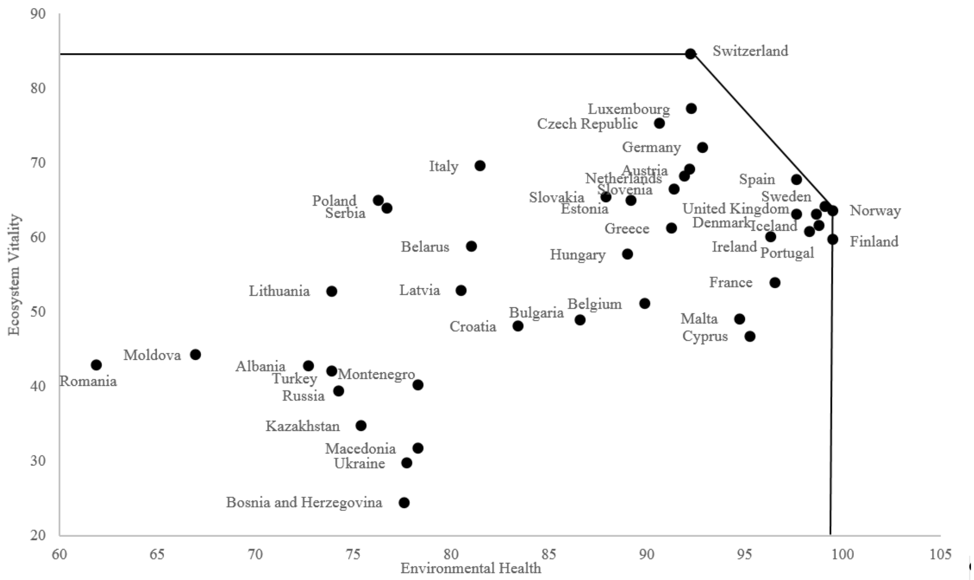
Table 2. Weights Calculated Using DEA Methodology

Country	Environmental Health (EH)	Ecosystem Vitality (EV)
Albania Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Finland, France, Iceland, Ireland, Kazakhstan, Macedonia, Malta, Montenegro, Norway, Portugal, Russia, Turkey, Ukraine, United Kingdom	0,0100563	0,0000001
Austria, Belarus, Czech Republic, Denmark, Estonia, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Moldova, Netherlands, Poland, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland	0,0082263	0,0028536

Source: own calculations

The EPI for the first group of states should base only on the variable EH, while for the second group of states should take into account 0,008 EH and 0,003 EV. This is due to the fact that the aggregated EH indices are higher for all countries. It is worth noting that the weights determined by DEA method does not add up to 1 and are chosen to maximize the weighted sum of outputs to the condition the efficiencies of other DMUs calculated using the same set of weights is between 0 and 1. In Figure 1 is shown the EH and EV with the frontier imposed by the best DMUs.

Figure 1. Environmental Health and Ecosystem Vitality



Source: 2014 Environmental Performance Index (2014 EPI)

Weights for variables exploited in prior level of aggregation of the EPI were also determined. Due to the lack of data there were used eight out of nine variables that make up the index EH and EV with the following weights: Health Impacts (HI) – 33%, Air Quality (AQ) – 33%, Water and Sanitation (W&S) – 33%, and Water Resources (WR) – 25%, Agriculture (A) – 5%, Forests (F) – 10% , Biodiversity and Habitat (B&H) – 25%, Climate and Energy (C&E) – 25%. In this case, each country received its own unique set of weights highlighting its strengths. The only exceptions are Greece and Italy (Table 3).

Table 3. Weights Calculated Using DEA Methodology

Unit name	EH - HI	EH - AQ	EH - W&S	EV - WR	EV - A	EV - F	EV- B&H	EV - C&E
Albania	0,00001	0,00001	0,00001	0,00001	0,00001	0,00001	0,00001	0,01162
Austria	0,00001	0,00001	0,00976	0,00001	0,00028	0,00001	0,00001	0,00003
Belarus	0,00001	0,00001	0,00001	0,00355	0,00943	0,00060	0,00001	0,00001
Belgium	0,00001	0,00001	0,00978	0,00001	0,00024	0,00001	0,00001	0,00003
Bosnia and Herz.	0,00021	0,00001	0,00001	0,00001	0,00001	0,00974	0,00005	0,00001
Bulgaria	0,00001	0,00001	0,00645	0,00001	0,00001	0,00293	0,00201	0,00001
Croatia	0,00933	0,00001	0,00001	0,00001	0,00017	0,00046	0,00032	0,00001
Cyprus	0,00993	0,00001	0,00002	0,00001	0,00002	0,00001	0,00001	0,00001
Czech Republic	0,00315	0,00001	0,00001	0,00001	0,00161	0,00001	0,00472	0,00167
Denmark	0,00128	0,00001	0,00001	0,00270	0,00839	0,00001	0,00001	0,00094
Estonia	0,00001	0,00005	0,00001	0,00001	0,00001	0,00001	0,00992	0,00001
Finland	0,00001	0,00001	0,00740	0,00013	0,00334	0,00001	0,00001	0,00037
France	0,00001	0,00001	0,00994	0,00001	0,00002	0,00001	0,00001	0,00001
Germany	0,00001	0,00001	0,00001	0,00583	0,00066	0,00001	0,00398	0,00001
Greece	0,00994	0,00001	0,00001	0,00001	0,00002	0,00001	0,00001	0,00001
Hungary	0,00001	0,00001	0,00005	0,00001	0,00001	0,00991	0,00002	0,00001
Iceland	0,00001	0,00383	0,00001	0,00001	0,00001	0,00035	0,00230	0,00584
Ireland	0,00001	0,00001	0,00001	0,00001	0,00001	0,00995	0,00001	0,00001
Italy	0,00994	0,00001	0,00001	0,00001	0,00002	0,00001	0,00001	0,00001
Kazakhstan	0,00001	0,01012	0,00001	0,00001	0,00001	0,00001	0,00001	0,00001
Latvia	0,00001	0,00935	0,00001	0,00001	0,00065	0,00001	0,00053	0,00001
Lithuania	0,00534	0,00167	0,00001	0,00001	0,00329	0,00001	0,00117	0,00001
Luxembourg	0,00001	0,00032	0,00001	0,00580	0,00062	0,00001	0,00379	0,00001
Macedonia	0,00335	0,00001	0,00001	0,00001	0,00429	0,00001	0,00001	0,00479
Malta	0,00001	0,00238	0,00706	0,00001	0,00001	0,00124	0,00001	0,00001
Moldova	0,00001	0,00001	0,00001	0,00001	0,00002	0,00994	0,00001	0,00001
Montenegro	0,00011	0,00001	0,00001	0,00001	0,00007	0,00981	0,00001	0,00001
Netherlands	0,00001	0,00001	0,00001	0,01007	0,00001	0,00001	0,00001	0,00001
Norway	0,00001	0,00003	0,00992	0,00001	0,00001	0,00001	0,00001	0,00002
Poland	0,00697	0,00001	0,00001	0,00003	0,00063	0,00159	0,00187	0,00001
Portugal	0,00001	0,00131	0,00016	0,00001	0,00001	0,00001	0,00143	0,00944
Romania	0,00586	0,00001	0,00001	0,00001	0,00269	0,00034	0,00051	0,00251
Russia	0,00001	0,01011	0,00001	0,00001	0,00001	0,00001	0,00002	0,00001
Serbia	0,00001	0,00001	0,00001	0,00001	0,00001	0,00995	0,00001	0,00001

Unit name	EH - HI	EH - AQ	EH - W&S	EV - WR	EV - A	EV - F	EV- B&H	EV - C&E
Slovakia	0,00001	0,00001	0,00417	0,00001	0,00315	0,00001	0,00140	0,00364
Slovenia	0,00013	0,00001	0,00001	0,00001	0,00006	0,00005	0,00978	0,00001
Spain	0,00001	0,00001	0,00001	0,00804	0,00170	0,00001	0,00001	0,00170
Sweden	0,00001	0,00001	0,00679	0,00001	0,00374	0,00001	0,00001	0,00094
Switzerland	0,00001	0,00001	0,00001	0,00968	0,00001	0,00001	0,00001	0,00073
Turkey	0,00001	0,01010	0,00001	0,00001	0,00003	0,00001	0,00002	0,00001
Ukraine	0,00001	0,00589	0,00001	0,00001	0,00621	0,00005	0,00001	0,00001
United Kingdom	0,00001	0,00001	0,00001	0,00975	0,00001	0,00094	0,00001	0,00001

Source: own calculations

Due to the design of the EPI with multiple weighted indexes, DEA for choosing the weights can be used at any stage. There are plenty of combinations of weights obtained by solving the linear program tasks and weights determined by experts. Moreover, DEA can be used to raw, untransformed data. It is worth mentioning that DEA models can also take into account additional constraints and experts' knowledge of weight.

Rankings of Environmental Performance

The rankings of countries according to the experts' EPI and the one obtained using DEA were compared. Countries' environmental performance indices and rankings are presented in Table 4.

Table 4. EPI and DEA results

Unit name	EPI Score	EPI Rank	EPI Europe Rank	DEA 1 Efficiency	DEA 1 Rank	DEA2 Efficiency	DEA 2 Rank
Albania	54,73	67	35	73,04%	40	100,00%	1
Austria	78,32	8	6	95,53%	16	99,96%	24
Belarus	67,69	32	25	83,42%	28	99,20%	34
Belgium	66,61	36	27	90,33%	23	99,91%	28
Bosnia and Herz.	45,79	107	42	78,01%	35	99,85%	30
Bulgaria	64,01	41	30	87,06%	25	100,00%	1
Croatia	62,23	45	31	83,86%	27	95,84%	38
Cyprus	66,23	38	28	95,77%	15	99,90%	29
Czech Republic	81,47	5	3	96,06%	14	100,00%	1
Denmark	76,92	13	11	98,31%	9	100,00%	1
Estonia	74,66	20	17	91,87%	21	100,00%	1
Finland	75,72	18	15	100,00%	1	100,00%	1
France	71,05	27	21	97,02%	11	100,00%	1
Germany	80,47	6	4	96,98%	12	100,00%	1
Greece	73,28	23	20	92,53%	20	99,93%	26
Hungary	70,28	28	22	89,69%	24	100,00%	1
Iceland	76,5	14	12	99,33%	6	100,00%	1

Unit name	EPI Score	EPI Rank	EPI Europe Rank	DEA 1 Efficiency	DEA 1 Rank	DEA2 Efficiency	DEA 2 Rank
Ireland	74,67	19	16	96,81%	13	100,00%	1
Italy	74,36	22	19	86,88%	26	99,95%	25
Kazakhstan	51,07	84	38	75,82%	37	97,35%	36
Latvia	64,05	40	29	81,38%	30	99,59%	33
Lithuania	61,26	49	32	75,85%	36	96,55%	37
Luxembourg	83,29	2	2	97,96%	10	100,00%	1
Macedonia	50,41	89	40	78,70%	33	100,00%	1
Malta	67,42	34	26	95,23%	17	99,92%	27
Moldova	53,36	74	37	67,67%	41	99,85%	30
Montenegro	55,52	62	33	78,75%	32	100,00%	1
Netherlands	77,75	11	9	95,07%	18	100,00%	1
Norway	78,04	10	8	100,00%	1	100,00%	1
Poland	69,53	30	23	81,29%	31	99,85%	30
Portugal	75,8	17	14	98,79%	8	100,00%	1
Romania	50,52	86	39	63,14%	42	90,12%	40
Russia	53,45	73	36	74,64%	38	95,78%	39
Serbia	69,13	31	24	81,39%	29	100,00%	1
Slovakia	74,45	21	18	90,99%	22	99,19%	35
Slovenia	76,43	15	13	94,13%	19	100,00%	1
Spain	79,79	7	5	99,69%	5	100,00%	1
Sweden	78,09	9	7	99,77%	4	100,00%	1
Switzerland	87,67	1	1	100,00%	1	100,00%	1
Turkey	54,91	66	34	74,27%	39	85,43%	42
Ukraine	49,01	95	41	78,15%	34	88,85%	41
United Kingdom	77,35	12	10	99,17%	7	100,00%	1

Source: 2014 Environmental Performance Index and own calculations

In Table 4 are shown the EPI values (EPI scores) and places in a ranking based on the EPI of all 178 classified countries (EPI Rank) and of 42 European countries (EPI Europe Rank). There are also presented the indicators calculated using DEA for determining the weights to the variables of the last phase of the EPI procedure (DEA 1) and for the weights to the indicators of the previous step (DEA 2).

The inclusion of DEA in the final stage of the EPI to determine the weights of EH and EV slightly changed the countries' positions. The three countries occupy the first place: Finland, Switzerland and Norway. Switzerland is classified in the first place regardless the way of choosing the weights. Norway to the first position among European countries moved from 8th place, Finland from the 15th. General, use of DEA turned out to be a favourable alternative to 21 countries. In particular, for countries with large, more than 30, discrepancy between the values of EH and EV.

However, the use of the linear programming model (2) for 8 variables forming EH and EV radically changed the countries' ranking. As could be expected, DEA taking into account the strengths of each country, is able to find for each at least one distinguishing element. And in this way 31 of 42 countries received 100% environmental performance score and occupy the 1st place.

Unfortunately Poland does not belong to this group. In the case of Poland, experts' recommendations for weights are optimal. The weights for Poland, chosen so as to maximize its index under assumption that other countries' efficiencies do not exceed 1 at Polish set of weights, do not improve Poland position in the rankings.

The results of the compatibility between rankings based on the Pearson and Spearman correlation coefficient is given in Table 5.

Table 5. Correlation Coefficient

	EPI Score	EPI Rank	EPI Europe Rank	DEA 1 Effic.	DEA 1 Rank	DEA2 Effic.	DEA 2 Rank	
EPI Score		-0,986	-0,972	0,883	-0,866	0,520	-0,587	Pearson
EPI Rank	-1,000		0,944	-0,863	0,834	-0,525	0,565	
EPI Europe Rank	-1,000	1,000		-0,865	0,868	-0,472	0,621	
DEA 1 Efficiency	0,871	-0,871	-0,871		-0,964	0,541	-0,621	
DEA 1 Rank	-0,870	0,870	0,870	-1,000		-0,490	0,643	
DEA2 Efficiency	0,593	-0,593	-0,593	0,606	-0,606		-0,593	
DEA 2 Rank	-0,642	0,642	0,642	-0,664	0,664	-0,988		
	Spearman							

Source: own calculations

Strong relationship was noted between the results of DEA 1 (efficiency and rank) and the ranking of the EPI (score, rank). Other correlations, although statistically significant with $p < 0,05$, are weak.

SUMMARY

There is wide range of environmental performance indicators, from simple indexes to more sophisticated ones, in which there is a possibility to take arbitrary viewpoints [Tyteca 1996]. The aggregated measurements of environmental performance, which is often in the form of an environmental performance index, can provide condensed information for analysts and decision makers dealing with energy and environmental related issues [Zhou at al. 2007]. Whatever weightings and aggregation methodologies are eventually chosen, there will always be individuals who disagree with the final decision [Hsu at al. 2013]. DEA has gained great popularity because it provides synthetic indicator that take into account the strengths of each analysed entity and do not require the specification of any a priori weight on the variables.

In this article DEA was used to adjust weights for variables that construct the 2014 EPI created by scientists of the Yale University and Columbia University. Depending on which steps of constructing the EPI DEA was incorporated, weights estimating via solving linear programing tasks provide better assessments in case of 21 or 31 countries. Other countries should rather rely on the experts' recommendation.

The article can be regarded as part in the discussion about the choice of weights to achieve a predefined order of a ranking. DEA applied to two variables and 42 objects improves assessments for 50% of the units. If more variables are considered, the easier is to find the strengths of a larger number of units.

It is worth noting that there are also the possibility of including the DEA method for choosing the weights at other stages of the EPI. In particular, it may be interesting to implement DEA to the raw data or at least not converted into indicators using a proximity-to-target methodology.

REFERENCES

Callens I., Tyteca D. (1999) Towards indicators of sustainable development for firms. A productive efficiency perspective, Ecological Economics, vol. 28, issue 1, pp. 41–53.

Charnes A., Cooper W.W., Rhodes E. (1978) Measuring the Efficiency of Decision Making Units, European Journal of Operational Research, vol. 2, issue 6, pp. 429–444.

Chodakowska E., Komuda M. (2010) Zgodność rankingów jednostek sektora edukacji uzyskanych za pomocą metody obwiedni danych, Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, Taksonomia 107, pp. 492–500.

Emerson J.W., Hsu A., Levy M.A., Sherbinin de A., Mara V., Esty D.C., Jaiteh M. (2012) Environmental Performance Index and Pilot Trend Environmental Performance Index. New Haven: Yale Center for Environmental Law and Policy. Available: http://www.epi.yale.edu/.

Hsu A., Emerson J., Levy M., Sherbinin de A., Johnson L., Malik O., Schwartz J., Jaiteh M. (2014) The 2014 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. Available: www.epi.yale.edu.

Hsu A., Johnson L.A., Lloyd A. (2013) Measuring Progress: A Practical Guide From the Developers of the Environmental Performance Index (EPI). New Haven:Yale Center for Environmental Law & Policy.

Meng F.Y., Fan L.W., Zhou P., Zhou D.Q. (2013) Measuring environmental performance in China's industrial sectors with non-radial DEA, Mathematical and Computer Modelling, vol. 58, issue 5-6, pp 1047–1056.

Nazarko J. (2010) DEA method in efficiency assessment of public higher education institutions, Performance Management and Measurement with Data Envelopment Analysis, American University of Beirut, Lebanon, pp. 177–182.

Ramanathan R. (2003) An introduction to Data Envelopment Analysis: a tool for performance measurement, Sage Publications, New Delhi.

Tyteca D. (1996) On the Measurement of the Environmental Performance of Firms — A Literature Review and a Productive Efficiency Perspective, Journal of Environmental Management, vol. 46, issue 3, pp. 281–308.

Zhou P., Ang B.W., Poh K.L. (2008) Measuring environmental performance under different environmental DEA technologies, Energy Economics, vol. 30, issue 1, pp. 1–14.

Zhou P., Poh K.L., Ang B. W. (2007) A non-radial DEA approach to measuring environmental performance, European Journal of Operational Research, vol. 178, issue 1, pp. 1–9.