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THE ROLE OF ENVIRONMENTAL EFFICIENCY IN INTEGRATED MANAGEMENT – EXAMPLE OF ELECTRICITY PRODUCTION SECTOR IN POLAND

Abstract: The paper presents the role of environmental efficiency in integrated management. Author also proposes to use as a tool to measure it. As an example Polish energy producers: power and CHP plants are used. Author uses the regionally aggregated data on their employment, installed capacity, energy production, coal consumption and pollution emissions to develop model to evaluate their environmental efficiency. Efficiency scores are obtained by the decomposition of environmental efficiency from overall efficiency. Author uses the efficiency scores to evaluate Polish electricity porduction sector.

Keywords: environmental efficiency, Data Envelopment Analysis, electricity production sector

Introduction

Integrated management involves all the aspects of company's functioning. In the context of implementing sustainability as a priority for company development, environmental efficiency plays one of the most important roles in it.

Environmental efficiency, together with technological, economic and social efficiency[1] is considered as a part of overall efficiency of a company. Environmental efficiency is defined as the efficiency of resources use, generation of wastes and pollution in the production process and in general impact on the environment. Environmental eficiency is very often called eco-efficiency and has recently become one of the dircetions of gaining competitive advantages. Eco-efficiency[2] points out one important aspect: limiting the resource use and environmental impact should also lead to the increase of added value of products and services.

Environmental efficiency is one of the most important characteristics of electricity production sector nowadays. The meaning of environmental efficiency is even more significant in coal-based production facilities, which is the case in Poland. Author proposes to use Data Envelopment Analysis (DEA) models as a tool for efficiency evaluation[3]. But the traditional DEA models consider only regular inputs and outputs, while for environmental evaluation another category is needed. These are undesirable outputs, represented by all kinds of air pollution emissions. Therefore, in the evaluation of environmental efficiency Fare et al.[4] approach is used, based on decomposing overall productive efficiency into several components.

Decomposition of environmental efficiency

Denote inputs by $x \in R_{+}^{N}$, desirable outputs by $y \in R_{+}^{M}$, undesirable outputs by $w \in R_{+}^{J}$. No *a priori* statement is required as to the units of measurement, however, it is important to notice that we will deal with input-use efficiency, not purely technical efficiency (because some variables will be measured in monetary units), nor allocative efficiency (most of the variables will be measured in

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[1] Pfohl, H., Zarządzanie logistyką. Funkcje i instrumenty. Zastosowanie koncepcji logistyki w przedsiębiorstwie i w stosunkach między przedsiębiorstwami. Biblioteka Logistyka, Instytut Logistyki i Magazynowania, Poznań, 1998, p. 32.

[2] Eco-efficiency. Creating more value with less impact. WBCSD, 2000, http://www.wbcsd.org/, p. 5.

[3] for the explanation of DEA methodology see Cooper, W. W., L. M. Seiford, K. Tone, Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Kluwer Dordrecht, 2001.

[4] Fare, R., S. Grosskopf, D. Tyteca, An activity analysis model of the environmental performance of firms – application to fossil-fuel-fired electric utilities. [in] Ecological Economics, Nr 18, 1996, pp.161-175.

physical units). The notion of input-use efficiency should be more similar to the technical efficiency, but for the moment it is not the point of this paper to make such a distinction. Nevertheless, it would be quite interesting to place input-use efficiency on the proper position between the mentioned two. The technology set S consists of feasible quadruples:

$$S = \{(x, z, y, w): x \text{ can produce } y \text{ and } w\} \tag{1}$$

General assumptions for disposability are the following:

- inputs are strongly disposable (the same level of outputs can be produced with higher quantities of inputs),
- desirable outputs are strongly disposable (lower quantities of outputs can be produced at no cost using the same inputs),
- undesirable outputs are weakly disposable (leveling off the undesirable outputs requires either increased quantities of inputs or decreased output production),

The key tool used in Fare et al.[1] to formulate the indicator is the input distance function $D_i(y, w, x)$, which is inverse to the traditional efficiency measures[2]. In this case some more distance functions will be derived, always basing on existing methodology. To start we present most basic distance function that could be defined on S as:

$$D_{iE}(x+z, y, w) = \max\{\gamma:((x) / \gamma, y, w) \in S\} \tag{2}$$

where the index 'i' stands for inputs, and index 'E' stands for environmental factors. The value taken by γ gives an indication of the extent to which the inputs can be decreased, based on observations in the data set. That is, if γ cannot take values larger than 1, no reduction in inputs is possible (and therefore $D_{iE} = 1$), while the opposite would mean that a given production unit is not efficient in terms of its use of inputs (i.e. $D_{iE} > 1$). It should be noted that the same factor γ is applied to all inputs, and therefore that only equiproportional reductions are considered. It follows that:

$$(x, z, y, w) \in S \Leftrightarrow D_{iE}(x, y, w) \geq 1 \tag{3}$$

and that the input distance function is homogeneous of degree 1 in inputs[3].

Following Fare et al.[4], we assume that the distance function is separable in a sense of:

$$D_{iE}(x, y, w) = W(w)\ \hat{D}_i\ (y, x) \tag{4}$$

where

$$\hat{D}_i(y, x) = \max\{\mu:((x)/\mu, y) \in \hat{S}\} \tag{5}$$

$$\hat{S} = \{(x, y): x \text{ can produce } y\} \tag{6}$$

and where the set $\hat{S}$ is the technology set restricted to (x, y) without undesirable outputs being considered. Without getting into details on the separability assumption imposed[5] [3], we can define environmental performance indicator:

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[1] Fare, R., S. Grosskopf, D. Tyteca, An activity analysis model of the environmental performance of firms – application to fossil-fuel-fired electric utilities. [in] Ecological Economics, Nr 18, 1996, pp.161-175.

[2] Charnes, A., W. W. Cooper, A. Y. Lewin, L. M. Seiford, Data Envelopment Analysis: Theory, Methodology and Application. Kluwer Academic Publishers, Massachusetts, 1994, p. 257.

[3] Fare, R., Fundamentals of production theory: Lecture notes in Economics and Mathematical Systems. Vol. 311, Springer, Berlin, 1988.

[4] Fare, R., S. Grosskopf, D. Tyteca, An activity analysis model of the environmental performance of firms – application to fossil-fuel-fired electric utilities. [in] Ecological Economics, Nr 18, 1996, pp.161-175.

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$$W(w) = D_{iE}(x, y, w) / \hat{D}_i(y, x) \tag{7}$$

This indicator will take values less than or equal to 1, corresponding to environmental inefficiency or efficiency, respectively. Of course it should be noted that these notions are relative to observed data.

To present the computation procedure of (7), suppose that we have $k = 1,\dots,K$ observations on inputs x^k, desirable outputs y^k and undesirable outputs w^k. From these we can construct the best practice reference technologies:

$$\begin{aligned}
&S = \{(x, y, w): \\
&\sum_{k=1}^{K} \lambda^k x z^k_{n\alpha} \le x_n, n = 1,\dots,N \\
&\sum_{k=1}^{K} \lambda^k y^k_m \ge y_m, m = 1,\dots,M \\
&\sum_{k=1}^{K} \lambda^k w^k_j = w_j, j = 1,\dots,J \\
&\lambda^k \ge 0, k = 1,\dots,K\}
\end{aligned} \tag{8}$$

and

$$\begin{aligned}
&\hat{s} = \{(x, y): \\
&\sum_{k=1}^{K} \lambda^k x^k_n \le x_n, n = 1,\dots,N \\
&\sum_{k=1}^{K} \lambda^k y^k_m \ge y_m, m = 1,\dots,M \\
&\lambda^k \ge 0, k = 1,\dots,K\}
\end{aligned} \tag{9}$$

The inequality and equality signs correspond to strong disposability and weak disposability, respectively. The intensity variables λ^k serve to construct convex combinations of the observed inputs and outputs, forming a best practice frontier.

Now for each observation k' we can compute two distance functions in (7) as:

$$D_{iE}(x^{k'}, y^{k'}, w^{k'}) = \max\{\gamma : (\gamma^{-1}(x^{k'}), y^{k'}, w^{k'}) \in S\} \tag{10}$$

and

$$\hat{D}_i(y^{k'}, x^{k'}) = \max\{\mu : (\mu^{-1}(x^{k'}), y^{k'}) \in \hat{S}\} \tag{11}$$

These can be stated more explicitly as:

$$\begin{aligned}
&(D_{iE}(x^{k'}, y^{k'}, w^{k'}))^{-1} \\
&\quad = \min_{(\rho,\lambda)} \rho \\
&\quad s.t. \ \sum_{k=1}^{K} \lambda^k x^k_n \le \rho x^{k'}_n, n = 1,\dots,N \\
&\quad \sum_{k=1}^{K} \lambda^k y^k_m \ge y^{k'}_m, m = 1,\dots,M \\
&\quad \sum_{k=1}^{K} \lambda^k w^k_j = w^{k'}_j, j = 1,\dots,J \\
&\quad \lambda^k \ge 0, k = 1,\dots,K\}
\end{aligned} \tag{12}$$

and

$$\begin{aligned}
&(\hat{D}_i(y^{k'}, x^{k'}))^{-1} \\
&= \min_{(\sigma,\lambda)} \sigma \\
&s.t.\ \sum_{k=1}^{K} \lambda^k x_n^k \le \sigma x_n^{k'}, n = 1,\ldots,N \\
&\sum_{k=1}^{K} \lambda^k y_m^k \ge y_m^{k'}, m = 1,\ldots,M \\
&\lambda^k \ge 0, k = 1,\ldots,K\}
\end{aligned} \tag{13}$$

Note that the choice variables include (ρ,λ) in (12) and (σ,λ) in (13). Therefore, for each observation $k' = 1,\ldots,K$ the solution value ρ^* or σ^* will be the proportional scaling of all inputs required to project the observed point onto best practice frontier. The projected point will be determined as a weighted average (convex combination) of the 'closest' best practice frontier points, where the 'weights' will be solution values of the λ^k's. These are determined separately for each observation. And finally the ratio of the distance function values obtained after solving these linear programs yields the indicator value of environmental performance as proposed in (7).

Environmental efficiency evaluation in electricity production sector in Poland

The evaluation of environmental efficiency of Polish electricity production sector was made in regional scale. The basic administrative division unit in Poland is voivodship. Whole country is divided into 16 voivodship. The division was determined by historical, geographical, social and economic factors. The number of units is quite small as for DEA models use, and therefore number of variables used in models is limited. The following information on the functioning of electricity production sector was used as variables:

as inputs:

- employment (number of employees),
- installed capacity (MW),
- coal use to produce electricity (tons),

as outputs:

- electricity production (GWh);

as undesirable outputs:

- emission of carbon dioxide (tons of CO_2),
- emission of carbon oxide (tons of CO),
- emission of sulphur dioxide (tons of SO_2),
- emission of nitrogen dioxide (tons of NO_2),
- emission of ashes (tons).

All the variables for every voivodship are presented in the Table 1 and were used to construct DEA models that are decomposing environmental factors.

There are several variables that stand for environmentally undesirable variables and therefore number of environmental models was created. Models decomposing environmental efficiency were created according to the methodology presented above. As the undesirable variables the date on specific emissions were used. Environmental efficiency scores were obtained by dividing distance function $(D_{iEx})^{-1}$ by the basic distance function $(\hat{D}_i)^{-1}$. $(D_{iEx})^{-1}$ uses information on employment, coal use and installed capacity as inputs, electricity production as outputs and different kind of air emissions as undesirable outputs. Basic distance function $(\hat{D}_i)^{-1}$ omits the undesirable outputs variables. Decomposed environmental efficiency scores are presented in Table 2) for models using as

Table 1. Basic information on functioning of polish electricity production sector in voivodships in 2004 - variables for DEA models

	Electricity related emissions					Coal use	Installed capacity	Electricity production	Employment
	Ashes	SO_2	NO_2	CO_2	CO				
			tons				MW	GWh	No. of empl.
Voivodship	(1)	(2)	(3)	(4)	(5)	(6)	(10)	(11)	(12)
Dolnośląskie	2860,0	44092,0	18207,8	13893589	1042,9	11594190	2437,8	12971,9	2697
Kujawsko-pomorskie	2099,0	16724,0	5732,0	3126922	1340,0	1540053	315,3	1105,8	639
Lubelskie	277,0	896,0	722,0	860944	223,0	66636	237,0	1680,8	407*
Lubuskie	439,5	2217,0	1276,0	1039588	121,4	206442	349,5	1437,7	722*
Łódzkie	4298,0	154093,0	46253,0	34242553	15214,0	36470124	4976,8	30478,1	7007
Małopolskie	5268,0	37328,0	12942,0	7543431	1307,0	3953002	1054,7	4369,5	2035
Mazowieckie	7401,0	105316,0	34661,0	17931549	3161,0	8545897	4439,0	17311,6	4284
Opolskie	1422,0	6848,0	12817,0	8018300	975,0	3630773	1492,0	8562,3	1486*
Podkarpackie	982,0	10477,0	3307,0	2329898	426,0	794987	587,2	2644,0	1204
Podlaskie	626,0	2512,0	1504,0	923115	61,0	352000	203,5	590,0	352*
Pomorskie	533,0	11444,0	4047,0	2284064	291,0	1016187	364,1	1770,8	1217
Śląskie	10809,0	126825,0	55347,0	30284076	9037,0	15082614	7544,0	33656,7	8299
Świętokrzyskie	1614,0	24384,0	11266,0	5678282	343,0	2866424	1600,0	6316,9	446*
Warmińsko-mazurskie	210,0	773,0	489,0	313703	55,0	146835	49,0	144,1	366*
Wielkopolskie	5315,0	129517,0	24177,0	15369120	1273,0	15804963	3025,7	13773,6	2583
Zachodniopomorskie	399,0	11358,0	9823,0	5079023	520,0	2343735	1808,0	5337,3	2653

Source: author's elaboration based on data from Energy Market Agency SA and directly from electricity production companies (marked with undesirable output the following emissions: ashes (model W_{E1}), sulphur dioxide (W_{E2}), nitrogen dioxide (W_{E3}), carbon dioxide (W_{E4}) and carbon oxide (W_{E5}). In every case the undesirable output is treated accordingly to the weak disposability assumption. All the component distance functions are input-oriented and assume variable return-to-scale.

Table 2. Environmental efficiency scores for decomposing models

	W_{E1}	W_{E2}	W_{E3}	W_{E4}	W_{E5}
Voivodship:	(1)	(2)	(3)	(4)	(5)
Dolnośląskie	0,9632	0,9966	0,9325	0,9570	0,9325
Kujawsko-pomorskie	0,6034	0,6034	0,6034	0,6034	0,6034
Lubelskie	1,0000	1,0000	1,0000	1,0000	1,0000
Lubuskie	0,6337	0,7299	0,5970	0,7774	0,5930
Łódzkie	1,0000	1,0000	1,0000	1,0000	1,0000
Małopolskie	0,6633	0,6782	0,6633	0,6633	0,9693
Mazowieckie	0,8942	0,8942	0,8942	0,8942	0,8942
Opolskie	1,0000	1,0000	1,0000	1,0000	1,0000
Podkarpackie	0,7395	0,7076	0,7790	0,7076	0,9609
Podlaskie	1,0000	1,0000	1,0000	1,0000	1,0000
Pomorskie	0,9252	0,6916	0,6916	0,7147	0,9328
Śląskie	1,0000	1,0000	1,0000	1,0000	1,0000
Świętokrzyskie	1,0000	1,0000	1,0000	1,0000	1,0000
Warmińsko-mazurskie	1,0000	1,0000	1,0000	1,0000	1,0000
Wielkopolskie	0,9566	0,9566	0,9566	0,9566	0,9566
Zachodniopomorskie	0,7611	0,9664	0,7621	0,8254	0,8633

Source: author's elaboration

The structure of environmental efficiency scores obtained from decomposing models is quite flat. In every model there is the same number of full efficiency scores (7) and the average score is similar (52,9 % - 60,3 %). It is worth to notice that voivodship obtaining full efficiency score in one model obtains it also in all the other models. And reversely all the inefficient voivodships obtains inefficiency scores in every model. This is due to the small number of the units involved in the evaluated group. Another factor that resulted in flattening the structure of efficiency scores is the diversification of the evaluated units. There are voivodships where there are numerous power and CHP plants, like śląskie or łódzkie voivodships, or ones with just one or two plants, like warmińsko-mazurskie or lubelskie. In such case linear programming procedure does not have enough peer points to evaluate properly all the units, especially those with extreme characteristics. In every such case, when given voivodship has some unique, more often maximal or minimal, level of given variable, it achieves full efficiency scores. There are 7 voivodships that achieved full environmental efficiency in every model. One of them, namely śląskie voivodship, is the biggest electricity producer and has the biggest number of power and CHP plants. On the other hand two others, warmińsko-mazurskie and lubelskie voivodships, are the smallest producers. This kind of determinants makes full environmental efficiency of other units, like opolskie, podlaskie or świętokrzyskie, even more appreciable.

Conclusions

Big number of environmentally inefficient voivodships shows that Polish electricity production sector is still lagging behind the worlds leaders. One of the major reasons for that is the coal orientated technology used to produce electricity, which is connected to the huge environmental impact. Secondly, lack of capital to modernize and renew the capacity installed causes also poor environmental efficiency. But overall, decomposing models proofed to be important tool to evaluate environmental performance of power and CHP plants.

Bearing in mind that environmental efficiency constitutes important part of overall efficiency of electricity production sector DEA could be considered as an important tool for supporting decision-making process in integrated management. Moreover, DEA as well as decomposing models, could be easily adjusted to the evaluation of all kind partial efficiencies and even overall efficiency too. And since integrated management needs really complex information support DEA and its decomposing models could be used as one of the tools in this field.

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СТОИМОСТНАЯ ОЦЕНКА В УПРАВЛЕНИИ РЕКРЕАЦИОННО-ТУРИСТИЧЕСКИМИ РЕСУРСАМИ ОХРАНЯЕМЫХ ЭКОСИСТЕМ

Abstract: The paper presents primary results of the case study aiming to optimise key decisions concerning the Bieraście lakes group being a part of International Biosphere Reserve "Prybuskaje Paleśsie" on the basis of valuation of its recreation and tourist ecosystem services.

Keywords: protected areas, valuation, ecosystem services, travel cost method

Введение

Помимо прочих благ, экосистемы, функционирующие в режиме близком к естественному, являются источником комплекса полезных свойств, содействующих восстановлению психофизических кондиций человека, аттрактивных с точки зрения рекреации и туризма и представляющих собой особый вид экосистемных услуг. Способность охраняемых экосистем к их устойчивому предоставлению является рекреационно-туристическим ресурсом экосистем, составляющей интегрального природного ресурса особо охраняемой природной территории. На практике рекреационно-туристическое использование охраняемых экосистем входит в определённое противоречие с интересами консервации, трудноразрешимое в отсутствие научно-обоснованного плана их охраны и использования. Оптимизация режима управления охраняемыми экосистемами возможна лишь при условии приведения его разнообразных экологических и экономических аспектов к единому измерителю. Таким измерителем может выступать стоимостная оценка. Теоретической базой стоимостной оценки природных благ является неоклассическая концепция экономики благосостояния, согласно которой стоимость благ формируется не в процессе производства, а при их потреблении. В настоящее время в