AN FFICIENCY EVALUATION OF EMISSION ALLOWANCES FOR EU COUNTRIES WITH THE USE OF THE ZERO SUM GAME DATA ENVELOPMENT ANALYSIS

CHYTILOVÁ Lucie[1], ZAPLETAL František[1]

[1]*VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU*

Abstract

Nowadays one of the most important global issues in the heavy industry and specially in metallurgical sector is the allocation of carbon dioxide emission allowances. The equity in allocation of emission allowances is discussed offend with this problematic. In the metallurgical sector the unfair allocation may cost problem of development of some metallurgical sectors or countries. Therefore, the proper emission trading system must be used and all countries have to accept and implement the system properly. This paper is based on the model by Gomes and Lins (2008) and uses the zero sum game data envelopment analysis (ZSG-DEA). The emission allowance is input variable and energy consumption, spending and gross domestic product are output variables. The paper explore and evaluate the allocation of emission allowances in European Union countries. The empirical results show that allocation of emission allowances is inefficient as in paper by Chiu et al. (2015).

Keywords: CO_2 emission allowances, data envelopment analysis, zero sum gains, EU ETS, EUA.

1. INTRODUCTION

The global climatic changes caused by people and an impact of human existence are seen all over the world. The changes of the environment are receiving much more attention nowadays. Especially, a carbon dioxide (CO_2) emission is defined as very problematic and makes up the largest proportion of greenhouse gas (GHG) emission. This emission has been already regulated by the mechanisms of Emission Trading in the Kyoto Protocol, Clean Development Mechanism or Joint Implementation.

For the European countries the European Union Emission Trading Scheme (EU ETS) has been established by Directive 2003/87/EC for GHG emission allowance trading. This first phase runs from 1st January 2005 to 31st December 2007. Since that time the CO_2 emission regulation has been set up for 25 member countries of the EU. The idea of the scheme is: If a specific industry in country (energy-incentive industries or industries with thermal capacity over 20 MW) wants to legally emit GHG then there must be a GHG emission permit for this industry. Each member state's National Allocation Plan draws up an emission amount of GHG and submits the draft for approval to the European Commission.

The EU ETS allowance may use three types of regulations. First, all member states obtain an emission allowance based on a post emission record, this is called a grandfathering principle of regulation. Then there is regulation called a benchmarking principle. It means that the EU ETS allocation rules consider the member states' production technology and specific production inputs and outputs. The third principle of regulation is an auctioning principle. The auctioning principle is form member states to bid on the CO_2 emission allowance. The auctioning principle was identified as the best by Sijm et al [10]. According to their work, this principle fit the economic efficiency.

First, this paper uses two basic DEA models to measure the efficiency of the CO_2 emission allowance allocation for a metallurgy industry. Then the paper proposes the alternative CO_2 emission allowance allocation model to reallocate the CO_2 emission allowance in the metallurgy industry. The alternative model is the Zero Sum Gains Data Envelopment Analysis (ZSG-DEA). This model should be more fair and reasonable for the allocation of emissions in the metallurgy industry for all EU countries.

In literature, there exist more alternative models for allocation of the O_2 emission allowance. Chang [7] in his work introduces ZSG-DEA based on input-oriented CCR model and the Cooperation and Alliance model. He applies these models into the EU countries and suggests that both models give better and fairer results than it is offered by the EU ETS. Also Chiu et al [8] uses the ZSG-DEA SBM model to measure the efficiency of the EU's allocation of O_2 emission allowances with the same results. For whole world is the model ZSG-DEA used as well. In work by Gomes and Lins [6] are mentioning more types of ZSG-DEA models – CCR, BCC etc; and some shortcuts for the use of them for the reallocation of O_2 emission allowance.

The remainder of the paper is structures as followed. Next section discusses the review of the methodology of DEA models. Section 3 introduces the used data in this paper and the empirical results are there presented. Last section provides some final considerations and conclusions.

2. DEA MODELS

Data envelopment analysis (DEA) is non-parametric linear programming based technique for measuring the relative efficiency of a set of similar decision making units (DMUs). Since the work of Charnes et al [3], DEA has demonstrated an effective technique for measuring the relative efficiency of set homogenous DMUs. In application, DMUs may include banks, hospitals, schools, different types of industries and other. Each DMU allocates its resources into a number of inputs to produce various outputs. The relative technical efficiency of the unit is define as the ratio of its total weighted output to its total weighted input or vice versa. DEA allows each production unit to choose its own weights of inputs and outputs in order to maximize its efficiency score. A technically efficient production unit is able to find such weights that it lies on the production frontier. The production frontier represents the maximum amounts of output that can be produced by given amounts of input in the output maximization model or, alternatively, the minimum amounts of inputs required to produce the given amount of output in the input minimization model. DEA calculates the efficiency score for each production unit and identifies peers for each production unit that is not technically efficient.

2.1 CLASIC DEA MODELS

The first two known DEA models are called CCR and BCC. The CCR model is formulates for the assumption of constant return to scale (CRS). The origin model was extended by Banker et al [1] for the assumption of variable return to scale (VRS). There are also other types of models – additive, super efficiency, two stage DEA or ZSG-DEA models. All of them are looking for an efficiency frontier that envelops data. DEA models are able to classify DMUs as efficient and inefficient.

The mathematical formulation of the origin DEA model was done by Charmes at al [3]. Suppose that there are T DMUs (DMU$_k$ for $k = 1, ..., T$), let input and output data for be $\boldsymbol{X} = \{ x_{ik}, i = 1, ...R; k = 1, ...T\}$ and $\boldsymbol{Y} = \{y_{jk}, , j = 1, ...S; k = 1, ...T\}$, u_i, for $i = 1, ...R$ and v_j, for $j = 1, ..., S$ be the weights of i-th input and j-th output, respectively. The mathematical model to measure the efficiency score of the under evaluation unit, DMU$_Q$ where $Q \in \{1, ..., T\}$ is flowed:

$$\begin{aligned} \max e_Q &= \sum_{j=1}^{S} v_j y_{jQ} \\ s.t. \quad & \sum_{i=1}^{R} u_i x_{iQ} = 1 \end{aligned} \qquad (1)$$

$$\sum_{j=1}^{S} v_j y_{jk} \le \sum_{i=1}^{R} u_i x_{ik} \qquad k = 1,\dots,T,$$
$$u_i \ge 0, v_j \ge 0 \qquad i = 1,\dots,R,\ j = 1,\dots S.$$

This model must be solved for each DMU. Notice that DMU_Q is CCR-efficient if and only if $e^* = 1$ and there exists at least one optimal solution (u_i^*, v_j^*) with $u_i^*>0$ and $v_j^*>0$. Inefficient units have a degree of relative efficiency less than one. The model (1) is called a multiplier input-oriented model.

However, for computing and data interpretation is preferable to work with a model that is dual associated to model (1). The model is referred as envelopment input oriented model is following:

$$\begin{aligned} &\min \theta_Q \\ &s.t. \quad \sum_{k=1}^{T} \lambda_k x_{ik} \le \theta_Q x_{iQ} \qquad i = 1,\dots,R, \\ &\qquad \sum_{k=1}^{T} \lambda_k y_{jk} \ge y_{jQ} \qquad j = 1,\dots,S, \\ &\qquad \lambda_k \ge 0 \qquad \forall k, \\ &\qquad \theta_Q \in (-\infty, \infty), \end{aligned} \tag{2}$$

where λ_k is the weight for DMU_k *for* $k = 1, \dots, T$. It is dual-variable unit. The θ_Q represents the efficiency score of DMU_Q. It can also be interpreted as a reduction rate of inputs to reach the efficient frontier. There also exist the multiplier output-oriented model, but this model is not in this used paper and presented.

BCC model by Banker et al [1] has convex envelope of data and generally more units are efficient. The results of input-oriented and output-oriented models are same. Because the dual models are more useful, just the dual model is presented. The mathematical model of dual BCC model is following:

$$\begin{aligned} &\min \theta_Q \\ &s.t. \quad \sum_{k=1}^{T} \lambda_k x_{ik} \le \theta_Q x_{iQ} \qquad i = 1,\dots,R, \\ &\qquad \sum_{k=1}^{T} \lambda_k y_{jk} \ge y_{jQ} \qquad j = 1,\dots,S, \\ &\qquad \lambda_k \ge 0 \qquad \forall k, \\ &\qquad \sum_{\kappa} \lambda_\kappa = 1, \end{aligned} \tag{3}$$

λ_k is the vector of the dual variables units. DMU_Q is BCC-efficient the radial variable θ_Q is equal to one, ie. the optimal value of the objective function of the model (6) $e^*= 1$, otherwise it is BCC-inefficient. Units that are not effective have a value of $e^*< 1$.

2.2 ZSG-DEA MODELS

Original DEA models assume complete input (output) independence that is the input (output) of any given DMU does not affect the input (output) of the others. However, this independence does not always exist, for example: in competition or if there exist constant demand after production. In these cases ZSG-DEA models may be used.

The DMU reaches the target in the efficient frontier implies changing the frontier. Lins et al [9] proposed strategies in DEA targets searching, with emphasis on the proportional reduction strategy. In this case the inefficient DMU searches to be efficient and it must lose some amount of input (or receive some quantity of output). In order to keep the total sum constant, the other DMUs must receive that amount of input (lose that quantity of output) proportionally to their original values of that input (output).

In work of Gomes et al [4, 6] is presented the ZSG-DEA CCR input-oriented model for the case that one DMU searches for the efficient frontier and assumption that the sum of input is constant. The model is used in this paper and the mathematical model is following:

$$\begin{aligned} & \min h_{Ro} \\ s.t. \quad & h_{Ro} x_o \geq \sum_k \lambda_k x_k \left[1 + \frac{x_o (1 - h_{Ro})}{\sum_{k \neq o} x_k} \right] \\ & \sum_k \lambda_k y_k \geq y_o \\ & \lambda_k \geq 0 \qquad \forall k, \end{aligned} \tag{4}$$

h_{Ro} is the DMU o efficiency under the restriction that the input sum must be constant. x_j and y_j are the inputs and outputs original values, respectively. y_o and x_o are the outputs and inputs for the DMU$_o$. *j* are DMU contributions to the efficient projection. Note, ZSGD EA BCC is analogous, including the convexity restriction $\sum_j \lambda_j = 1$ and can be found in Lins et al [9].

Gomes and Lins [6] presents this model (4) as a case where a single DMU aims at the efficient frontier. They do not look at the case if more than one DMU will search for the maximizing the efficiency at same time. And also this may be done in cooperation or competition of DMUs. However, later same authors [4] presented same model with more knowledge about the cooperative case. They present that according to the ZSG-DEA paradigm, the cooperation strategy implies that the DMUs belonging to the 'cooperation group' do try to take input amounts out only from the DMUs that are not in this group.

Based on their previous work [4, 5] and work by Lins et al [9] they also introduced in their paper [6] the final equation (5) that must be solved when modelling ZSG-DEA CCR and BBC models with input orientation. The equation is as followed:

$$h_{R\iota} = h_i \left(1 + \frac{\sum_{k \in W} \left[y_k \left(1 - q_{ik} h_{Ri} \right) \right]}{\sum_{k \notin W} y_k} \right) \tag{5}$$

where *W* is the cooperative DMUs set, $q_{ik} = h_i/h_k$ is the proportionality factor that comes from the proportional strategy and h_i, h_k are the classical DEA efficiencies. They also defined equation for output-oriented models. Note, that the equation (5) represents the way how to define the frontier of ZSG-DEA model in a direct way, with all inefficient DMUs taking part in the cooperative group *W*.

The result of the ZSG-DEA model is called uniform DEA frontier or the maximum efficiency DEA frontier. All inefficient DMUs from the original DEA frontier after the total reallocation of the input (output) with assumption of constant sum will be on this uniform DEA frontier ans will be efficient. The uniform DEA frontier is located at a lower level according to the original frontier. It is the result of gains and losses of inputs (outputs) by the DMU and the assumption about constant sum. The strategy of the uniform DEA frontier can be appropriate when a regulatory agent can induce the DMUs behaviour aiming at resources (or production) allocation where all DMUs would be efficient.

3. EFFICIENCY EVALUATION OF CO_2 EMISSON ALLOWANCES

3.1 DATA DESCRIPTION

The aim of the paper is the fair allocation of the CO_2 emission in metallurgical industry for countries in the European Union. By metallurgical industry, we mean the CO_2 emission from the following activities: all metal ore roasting or sintering, all production of pig iron or steel, production or processing of ferrous metals, production of primary aluminium, production of secondary aluminium, production or processing of non-ferrous metals.

We consider that the maximum emission concentration is the sum of CO_2 emissions from 2012 (most recent data available). The fair allocation means that it is the allocation which all countries become DEA efficient and lie on the uniform DEA frontier.

The variables used for this paper are CO_2 emission allowance (tonne of CO2 equ.) as input, gross domestic product – GDP (US $) as output, energy consumption (1 000 tonnes of oil equivalent) as output, government spending (percentage of gross domestic product, recalculated) as output. These all data were gathered for 23 EU countries from CITL, Eurostat or the Data World Bank. All data, except GDP were focused just on the metallurgical industry. This cost some problems. Some countries were excluded because data were missing. For the same reason the year 2012 was chosen. There were no available some data for recent years.

3.2. CO2 EMISSION ALLOWANCE MODELS

From Table 1 it is seen that results for the CCR DEA model were not really good. Two DMUs were efficient in the CCR DEA model: Bulgaria and Denmark. These efficient units contribute just 0.004% to the total CO_2 emissions. The average efficiency is 11.1%. This is low efficiency and we can almost speak about not inefficiency for the allocation of CO_2 emission allowances. This low efficiency can be cost mainly by the variable – government spending. There are many countries where government is not spending anything at metallurgical sector. However, in case of efficient DMUs this variable is also different. Analysing the two efficient countries, we see that Bulgaria has really low emissions (2^{nd} lowest) and the government is actually spending in the sector 1% of GDP, which is helpful for the sector. Denmark has the lowest emissions and actually government is not spending anything. On the other hand the GDP of Denmark is six times higher then in Bulgaria. So it is seen that all combination of outputs are important. In both cases where input is low, also the outputs are lower – energy consumption of both countries is among the lowest and GDP is as well.

The BCC DEA model gave better results. There have been seven DMUs identified as efficient: Bulgaria, Germany, Denmark, France, United Kingdom, Italy and Norway. These efficient units contribute 57.3% to the total CO_2 emissions. The average efficiency is 50.3%. This gives much better results. This is due to the assumption of variable return to scale. Analysing the efficient DMUs, it is seen that generally efficient are those DMUs with higher emissions but also with more then average GDP. The energy consumption does not show much influence. The government spending is in three cases and may be said that helps in cases where emissions are high.

Based on results, we decided to make better allocation for the CCR DEA model. ZSG-DEA CCR model made reallocation of the CO_2 emissions allowances that the generally we can say that this reallocation is fair for all the countries. From this model, it can be seen that countries as Austria, Belgium, Germany, Finland, United Kingdom, Greece and other must decrease its emissions. They should search for partners, as Bulgaria, Czech Republic and so on, that want or can reduce their emissions, in order to keep the global emission unchanged. The result show similar trends as in work by Chnag [7] and Chiu [8]. Both these works were made just for European countries, but the first paper just little bit different outputs and the second one used ZSG-DEA SBM model. This and also different time line may cost these differences. The average efficiency of the model is 99.9% and we can conclude that the allocation of CO_2 emission allowances is efficient.

Table 1 DEA CCR efficiency, BCC efficiency and reallocation promoted by ZSG-DEA CCR model for 2012

country	country code	CO2 emission allowance	CCR efficiency	BCC efficiency	optimal reallocation	ZSG-DEA efficiency	difference
Austria	AT	6,912,795	0.004	0.524	7,109,063	0.997	196,268
Belgium	BE	12,721,814	0.002	0.202	12,804,371	0.997	82,557
Bulgaria	BG	4,044	1.000	1.000	1,396	1.000	-2,648
Czech Republic	CZ	3,382,060	0.005	0.206	3,347,161	0.998	-34,899
Germany	DE	59,449,590	0.009	1.000	59,568,978	0.997	119,388
Denmark	DK	3,809	1.000	1.000	221,901	1.000	218,092
Spain	ES	12,319,512	0.004	0.802	12,333,390	1.000	13,878
Finland	FI	6,808,997	0.003	0.031	6,817,682	0.997	8,685
France	FR	14,675,752	0.004	1.000	14,855,065	1.000	179,313
United Kingdom	GB	7,328,680	0.006	1.000	7,332,022	1.000	3,342
Greece	GR	1,357,999	0.014	0.149	1,034,101	0.999	-323,898
Hungary	HU	1,397,482	0.004	0.010	1,261,689	0.997	-135,793
Italy	IT	19,316,462	0.033	1.000	19,330,616	1.000	14,154
Luxembourg	LU	299,811	0.007	0.013	301,172	0.998	1,361
Latvia	LV	399,236	0.004	0.010	407,827	0.998	8,591
Netherlands	NL	11,724,487	0.005	0.216	11,216,987	1.000	-507,500
Norway	NO	73,118	0.228	1.000	251,550	1.000	178,432
Poland	PL	7,027,134	0.005	0.777	6,952,565	1.000	-74,569
Portugal	PT	335,436	0.100	1.000	336,079	1.000	643
Romania	RO	1,495,918	0.009	0.044	1,480,578	0.999	-15,340
Sweden	SE	8,762,656	0.005	0.137	8,819,874	1.000	57,218
Slovenia	SL	174,921	0.015	0.022	175,314	0.998	393
Slovakia	SK	171,420	0.087	0.415	183,752	1.000	12,332
total		176,143,133	0.111	0.573	176,143,133	0.999	0

CONCLUSION

The allocations of CO_2 emission allowances by original DEA models were not efficient. The level of average efficiencies for CCR model was almost 0% and for the BCC model over 50%. So it is seen that the situation is not really fair for the EU countries. ZSG-DEA model for CCR model brought reallocation of CO_2 emission allowances. After the reallocation the model obtained average efficiency equal to 99.9%. It is seen that ZSG-DEA useful even for this type of case – measurements of CO_2 emission allowances for metallurgy industry. By analysing the result we assume that most important for the reallocation is actually GDP, on the other hand this was not the case for all countries. Overall, we can suggest some future improvements for this research. The first one is to consider some other type of outputs. The output government spending for metallurgy industry is problematic and should be replaced with something more relevant. In some researches the number of population is used, but for just one part of industry does not seem to be relevant. The second improvement may be to create weights restrictions for each output to actually be more fair in the reallocation for this specific sector. The last improvement would be to try different models of ZSG-DEA to see how the assumption of variable scale is important.

ACKNOWLEDGEMENTS

This paper was created under SGS project (SP2015/117) of Faculty of Economics, VŠB-Technical University of Ostrava, Operational Programme Education for Competitiveness – Project CZ.1.07/2.3.00/20.0296 and also the grant no. 14-31593S of the Czech Science Foundation. The support is greatly acknowledged.

REFERENCES

[1] BANKER R.D., CHARNES A., COOPER W.W. Some models for estimating technical and scale inefficiency in data envelopment analysis. Management Science, Vol. 30, No.9, 1984, pp. 1078–1092.

[2] DLOUHÝ M. Efficiency and resource allocation within a hierarchical organization. IN MME 2012: 30th International Conference Mathematical Methods in Economics. Karviná: Slezská univerzita, 2010, pp. 112-116.

[3] CHARMES A., COOPER W. W., RHODES E. Measuring the inefficiency of decision making units. European Journal of Operational Research, Vol. 2, 1978, pp. 429–444.

[4] GOMES E.G., LINS M.P.E. Modelling undesirable outputs with zero sum gains data envelopment analysis models. Journal of the Operational Research Society, Vol. 59, 2008, pp. 616-623.

[5] GOMES E.G., SOARES DE MELLO J.C.C.B., LINS M.P.E. Busca sequencial de alvos intermediarios em modelos DEA com soma de outputs constante (Step by step target search in Zero Sum Gains DEA models). Investigacao Operacional, Vol. 23, pp. 1–16.

[6] GOMES E.G., SOARES DE MELLO J.C.C.B., LINS M.P.E. Uniformizac ao da fronteira eficiente em modelos de Anaalise de Envoltoria de Dados com Ganhos de Soma Zero e Retornos Constantes de Escala (Uniform efficient frontier in Zero Sum Gains DEA CCR models). Pesquisa Operacional, Vol. 25, 2005, pp. 261–277.

[7] CHANG, M. Carbon Emission Allocation and Efficiency of EU Countries. Modern Economy, Vol. 3, No. 5, 2012, pp. 590-596.

[8] CHIU Y-.H., LIN J.-C., SU W.-N., LIZ J.-K. An Efficiency Evaluation of the EU's Allocation of Carbon Emission Allowances. Energy Source, Part B, Vol. 10, No. 2, 2015, pp. 192-200.

[9] LINS M.P.E., GOMES E.G., SOARES DE MELLO J.C.C.B., SOARES DE MELLO A.J.R. Olympic ranking based on a zero sum gains DEA model. Journal of the Operational Research Society, Vol. 148, 2003, pp. 312-322.

[10] SIJM J.P.M., BECK M.M., DEN ELZAN M.G.J., VAN DEN WIJNGGARRT R.A. Options for Post-2012 EU Burden Sharing and EU ETS Allocation. Netherlands Environment Assessment Agency. Bilthoven, 2007.