Original Research

Carbon Emission Allowances of Efficiency Analysis: Application of Super SBM ZSG-DEA Model

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Abstract

Our study analyzes the emission allowances of 24 European Union (EU) members from a sample taken from 2005-07. A Super Slacks-Based Measure Zero Sum Gains Data Envelopment Analysis (Super SBM-ZSG-DEA) model was employed to examine allocation equality. The empirical results indicated that the countries with higher efficiency would have to increase their emission allowances. The majority of investigated countries with lower rankings in the initial allowances were likely to be less developed countries. Accordingly, these less developed countries would have to decrease their emission allowances in order to be more realistic and compliant regarding allowance allocations.

Keywords: DEA, zero sum gains DEA, super efficiency

Introduction

Technology development and economic growth create a better quality of life for individuals and society as a whole. However, excessive exploitations of natural resources resulting from industrialization have led to instances of environmental degradation. Among various environmental issues, global warming is one of the primary concerns. A known contributor to global warming, greenhouse gas emissions lead to unpredictable climate changes that can be harmful for people all over the world. Therefore, how to control greenhouse gas emissions is an important issue.

Based upon the study results, the Intergovernmental Panel on Climate Change's (IPCC) 2007 report noted that the continuation of rising sea levels and the decrease of snow coverage in the world are significant indicators of global warming. Accordingly, the global temperatures are projected to be twice as warm (Fig. 1) in 2006 (from 1956 to 2006). It is estimated that the rate of greenhouse gas emissions will continue in a steady fashion and the emission of carbon dioxide (CO_2) will reach 135 Gt in 2100.

From the 2010 IPCC report, CO_2 is the largest contributor, accounting for approximately 77% of greenhouse gas emissions among a variety of greenhouse gasses. The rate of CO_2 emission has increased approximately 80% from 1970 to 2004 (IPCC, 2010) [1]. In fact, fossil fuel burning is the key to CO_2 emissions which primarily result from industrialization. Since the increase in CO_2 emissions impact the planet and has accumulated over time, being proactive to stop or, at least, slow down the process of global warming becomes a focal point for research-based action. In fact, controlling CO_2 emission is a global issue. Currently, developed countries such as Japan, France, the United Kingdom, and the United States, to name a few, have made efforts (e.g., tougher regulations, environmental

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education programs) to reduce CO_2 emissions. At the same time, economic development is important for a country as well. Therefore, balancing economic growth, while reducing CO_2 emissions, becomes a task in which global-wide involvement is necessary and essential.

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) stated that the goal of controlling greenhouse gas emissions should focus on keeping them at a level where there is a minimum impact on the earth's climate system. The passage of the Kyoto Protocol in 1997 created a mechanism for the world to deal with greenhouse gases. Six greenhouse gases were particularly addressed. They were carbon dioxide, (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF6). The Kyoto Protocol is considered an important platform toward the reduction of greenhouse gases and the provisions of the protocol were enforced in 2005. Industrialized countries and the European community are required to reduce the amount of greenhouse gas emissions over the five-year compliance span from 2008 to 2012. For example, the specific rates of greenhouse gas reduction are 8% for EU and Eastern European countries, 7% for the United States, and 6% for Japan, Canada, Poland, and Hungary.

In 2009 the 15th session of the Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change (UNFCCC) took place in Copenhagen, Demark. The actions in reducing greenhouse gas emissions were proposed. Table 1 presents a list of countries and their proposed goals for the reduction of greenhouse gas emissions.

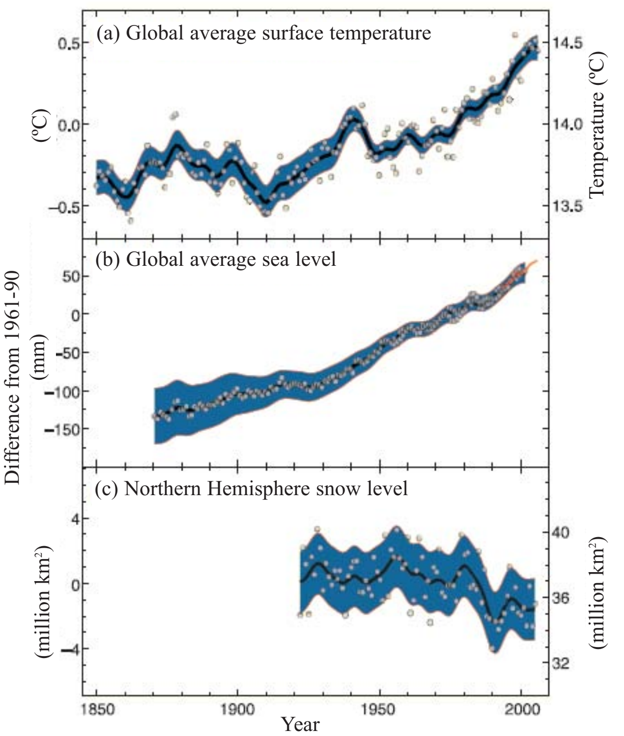

Fig. 1. Changes in global temperature, sea level, and snow coverage.
Source: The Intergovernmental Panel on Climate Change (2010).

Table 1. Proposed changes for the reduction of greenhouse gas emissions.

Country	Actions proposed to 2020	Base year
Australia	5-15% (Stabilized levels of CO_2 to 450 ppm)	2000
Russia	15-25%	1990
United States, Canada	17%	2005
Croatia	5%	1990
EU	20-30%	1990
Iceland, Monaco	30%	1990
Japan	25%	1990
Norway	30-40%	1990
New Zealand	10-20%	1990
Switzerland	20-30%	1990
Ukraine, Liechtenstein	20%	1990

Source: UNFCCC – United Nations Framework Convention on Climate Change (COP 15)

Under the Kyoto Protocol, industrialized countries (also called Annex I countries) have to meet their greenhouse gas emission obligations concerning their target allowances through national measures. The Protocol also offers three options for countries to meet the targets. They are market-based mechanisms including joint implementation (JI), clean development mechanism (CDM), and emission trading (ET).

Particularly for Annex I countries, JI is an alternative to help these countries in reducing emissions. Specifically, an Annex I country can invest in emission reduction projects of other Annex I countries. By doing so, those countries are able to comply with their Kyoto obligations in a cost effective way and, accordingly, to apply credits for their own emission reductions. Credits awarded in the JI alternative are called Emission Reduction Units (ERUS). One ERU refers to the reduction of one ton of CO_2 emissions. In addition, each country has assigned emission credits known as Assigned Amount Units (AAUs). The amount of AAUs is predetermined for each Annex I country and the acquiring of JI credits is from a host country's AAU pool.

CDM is designed to help countries that are not on the Annex I list (developing countries) achieve sustainable development and, at the same time, meet UNFCCC's goal of minimizing climate change. Such a mechanism allows the Annex I countries to purchase certified ERUS from emission reduction projects in developing countries as part of emission reduction efforts under the Kyoto Protocol. Promoting clean development in developing countries is one of the aims of CDM. The design of the mechanism permits developing countries to meet their commitments of reducing greenhouse gas emissions while benefiting from external funding and technology/knowledge transfer and, ultimately, having less negative impact on their economies.

Table 2. International trading for greenhouse gas emission allowances (2007-09).

	2007		2008		2009	
	Volume ($MtCO_2e$)	Value (US $, in millions)	Volume ($MtCO_2e$)	Value (US $, in millions)	Volume ($MtCO_2e$)	Value (US $, in millions)
Allowances markets						
EU ETS	2,060	49,065	3,093	100,526	6,326	118,474
NSW	25	224	31	183	34	117
CCX	23	72	69	309	41	50
RGGI	Na	Na	62	198	805	2,179
AAUs	Na	Na	23	276	155	2,003
Subtotal	2,108	49,361	3,278	101,492	7,362	122,822
Spot and Secondary Kyoto offsets						
Subtotal	240	5,451	1,072	26,277	1,055	17,543
Project-based transactions						
Primary CDM	552	7,433	404	6,511	211	2,678
JI	41	499	25	367	26	354
Voluntary market	53	263	57	419	46	338
Subtotal	636	8,195	486	7,297	283	3,370
Total	2,984	63,007	4,836	135,066	8,700	143,735

Source: The World Bank (2010)

Serving as a market-based mechanism, ET is characterized by offering economic incentives to achieve reductions in greenhouse gas emissions. Since each participating country is required to set a limit or cap concerning the amount of greenhouse gas emissions and is not allowed to exceed the cap, a participating country that needs more emission volumes has to purchase allowances (or permit or carbon credits) from those who do not exceed their caps. In reality, an emission trade refers to the transfer of allowances. The seller is being paid for achieving reduced emissions while the buyer is charged for being unable to reach its set emission cap.

Currently, there are several trading schemes for greenhouse gas emission allowances in the world, including Chicago Climate Exchange (CCX), UK Emissions Trading Groups (ETG), New South Wales Greenhouse Gas Reduction Scheme (NSW GGAS), and EU Emission Trading Scheme (EU ETS). It is necessary to note that the ETG is closely related to EU ETS. The organization aims at preparing UK industry for mandatory EU ETS participation. EU ETS has been in operation since 2005. Table 2 presents the volumes and values of trading schemes for greenhouse gas emission allowances from 2007 to 2009. We can see the significant increases in the volumes and values from EU ETS over the three-year span. In addition, most of the trading took place with the assistance of EU ETS.

ET is considered the most usable and beneficial option as it enables countries to make exchanges based on greenhouse gas emission allowances. Its goal centers on cost efficiency and an overall reduction in gas emissions. ET characterizes an allocation of emission allowances and as such each government is required to build a compliance system responsible for monitoring greenhouse gas emissions.

The rationale of ET, based upon the Coase Theorem [2], is that free trade can lead to an efficient result if the concept of emission rights is clearly defined, no transaction cost exists, and, finally, trade-in an externality which is generated from an economic allocation is probable. Following a similar vein, Dales [3] applied the theorem to examine a permit system where pollution emission rights can be traded in a particular market. Many researchers have embraced the concept of cost-effectiveness and made efforts to built models for the purpose of analyzing the trade-in system that focuses on the allocation of emission allowances [4-8]. For example, Montgomery [9] employed the Kuhn-Tucker theory to explore a possible equilibrium and build a model associated with a pollution permit and trading market.

Establishing the initial emission allowances is key to the success of the trading system. The current emission allowances focus on the overall emission level. That is, the total volume of greenhouse gas emissions is fixed. Being aware of the need for economic development and how to fairly portion out the emission level for each participating country becomes an important issue and an area of concern. Basically, two allowance allocation approaches are employed: auctioning and grandfathering. Auctioning is a paid allowance and simply refers to the buyer and seller relationship via auctions. Grandfathering (also known as gratis allocation) is a free allocation and is based on a condition in which a historical volume of emissions is applied.

Many researchers provide different views concerning the methods of emission allowance allocations [10-36]. For example, Burtraw et al. [21] and Palmer et al. [28] use simulation modeling to examine different approaches to emission allowance allocation for electricity and Gas sector under Cap-and-Trade programs. Carmton and Kerr [18] and Sijm et al. [23] provide the auction methods in the emission allowance allocations system. Shobe et al. [31] indicate that different auction formats can efficiently allocate emission allowances. Neuhoff et al. [22] use analytic models and a numeric simulation to illustrate the impact of the allowance allocation on price and efficiency. Rosendahl and Storrøsten [32] use analytic models to illustrate the impact of allowance allocations on entry/exit and distribution. Demailly et al. [24] use dynamics modeling to examine the impacts of market competitiveness under the EU-wide CO_2 emissions system. Badyda [27] examines the impacts of the Polish Power and Heating Industry under the EU-wide CO_2 emissions system. Benz and Truck [26] provide Markov switching and AR-GARCH models to investigate the returns of emission allowance under new EU-wide CO_2 emissions system. Zhao et al. [29] use the nonlinear complement model for investigating the long-run equilibrium under alternative systems for power market. Huw and Hutton [15], Weishaar [25], and Goulder et al. [30] employ a general equilibrium model to examine the impacts of alternative allowance allocation systems under Cap-and-Trade programs. Lu [36] indicates that the national carbon trading scheme may not be applicable in China. Heilmayr and Bradbury [34] show three important priorities: the economic efficiency of the cap and trade program, an equitable distribution of the program's allowance, and the effectiveness of the allocation when countries use allowance allocations to mitigate emissions leakage. Kockar [35] uses a mixed integer programming model to assess the linearization of generation cost and emission functions. He notes that the emission trading scheme can affect the outcome of generation scheduling. Maruyama [33] suggests that a carbon or energy tax can be imposed with imports and rebated on exports under the World Trade Organization's (WTO) existing border tax adjustment rules.

In summary, the principles of auctioning and grandfathering are widely discussed in the literature. The reality is that most countries continue to apply grandfathering as the primary principle of allocating their emission allowances.

The application of the grandfathering principle allows countries to base previously recorded volumes of emissions as their current emissions "quota." One concern related to the grandfathering principle is that some countries may obtain more allowances than actually needed, whereas other countries receive too little to fulfill their emission reduction obligations [23]. As such, countries may trade in their grandfathered allowances and result in capital transfer among these countries since the allocation of emission allowances has a direct link to economic development. Consequently, such capital transfer may have an impact on the sustainability and competitiveness of participating parties and the issue of fairness becomes considerable. How to fairly allocate emission allowances is the cornerstone of the whole emission trading system.

This study is an effort to explore the system of allocation of emission allowances. Since the sum of production (i.e., emission allowances) is fixed, it can be postulated that efficient parties are able to generate outputs more efficiently, and vice versa. In this case, having more efficient parties to allocate more emission allowances becomes desirable. As an approach to assess productivity, the application of the ZSG-DEA model enables investigators to differentiate between efficient and inefficient parties. Subsequently, the volume of emission allowances for each party can be assessed.

The purpose of this study was to analyze the emission allowances of 24 European Union (EU) members. A Super SBM ZSG-DEA model, which used Tone's [37] slacks-based measure of super efficiency in combination with the Zero Sum Gains Data Envelopment Analysis model proposed by Lin et al. [38], was employed to examine allocation equality. The results of the study provide baseline data for EU members to reconsider their optimal allocations of emission allowances. Research methodology, data collection and analysis methods, findings, and conclusions and recommendations are provided to address the purposes of this research study.

Research Methods

Assuming that the efficient production function is known, the deterministic nonparametric frontier model proposed by Farrell [39] is a pioneer approach of measuring productive efficiency. Since the production function is known and thereby an isoquant can be drawn, researchers are capable of comparing those observed performance levels with postulated efficiency. Charnes, Cooper, and Rhodes (CCR) [40] extended Farrell's model and introduced the CCR ration definition, also called a ratio definition of efficiency, as a part of their DEA approach. This method characterized multiple input/output ratios. In addition, an *a priori* weighing scheme became unnecessary when this method was employed. Later, Banker, Charnes, and Cooper (BCC) [41] modified the CCR model and introduced a separate variable that allowed researchers to determine whether efficiencies (i.e., pure technical efficiency, scale efficiency) could be reached by measuring the regions of increasing, constant, or decreasing returns to scale.

Data Envelopment Analysis (DEA) is a multi-factor productivity model to measure the relative efficiencies of a set of decision-making units (DMUs) [42]. Each DMU would have to choose input/output weights for the purpose of maximizing the efficiency score. Basically, a DMU can be considered efficient when its score reaches 1. If a score is less than 1, it indicates that the DMU is inefficient. It is, however, well documented that conventional DEA models are not effective at ranking those efficient DMUs. Anderson and Petersen [43] proposed a revised model that allowed researchers to obtain an efficiency score greater than 1. The modification, which removed the tested DMU from the constraint set, was an alternative to resolve the issue of ranking efficient and inefficient DMUs. However, several researchers determined that Anderson and Petersen's model would have an unfeasible issue under the variable returns-to-scale environment [44-46]. Based upon the slacks-based measure (SBM) of efficiency, Tone [37] proposed a super-SBM model that could resolve the unfeasible issue. In fact, under the environment of variable returns to scale, employing Tone's model can rank DMUs effectively. The super-SBM model is expressed as follows:

$$\delta^* = Min \qquad \delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\overline{x_i}/x_{i0}}{\frac{1}{s}\sum_{r=1}^{s}\overline{y_r}/y_{r0}} \tag{1}$$

$$\text{s.t.} \qquad \overline{x} \ge \sum_{i=1}^{n}\lambda_j x_j$$

$$\overline{y} \le \sum_{j=1,\neq 0}^{n}\lambda_j y_j$$

$$\overline{x} \ge x_0,\quad \overline{y} \le y_0,\quad \overline{y} \ge 0,\quad \lambda \ge 0$$

Since traditional DEA weight restrictions would have an impact on DMU rankings, Lins et al. [38] proposed a zero sum gains DEA model that presumes the sum of outputs is constant. Zero sum gain is a situation in which one or more participants' gains are offset by other participants (one or more). In this case, if a particular DMU is to increase its output and, accordingly, attempt to reach the efficient frontier, the loss of outputs of other DMUs would be generated as the result of the particular DMU's gain. In this study, Tone's [37] slacks-based measure of super-efficiency was applied by incorporating Lins et al. [38] ZSG-DEA model. The model herein proposed in this study is the Super SBM ZSG-DEA model.

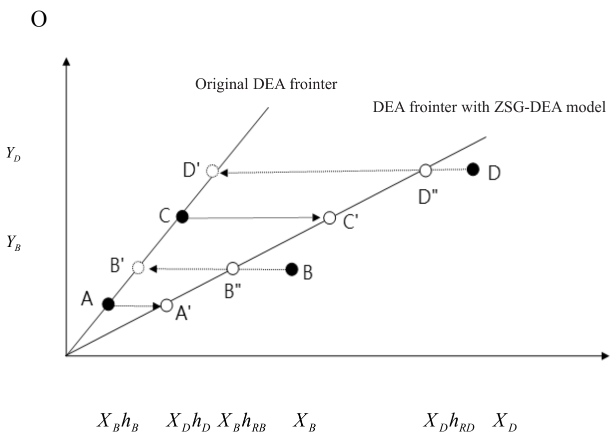

Fig. 2. Illustration of maximum efficiency frontier.

The model is shown in Formula 2. In this model, h_{RO} is the value of DMU efficiency; x_j and y_j represent the input and output of DMU$_j$; y_j is the reference set of DMU; convex analysis is under the condition of $\Sigma_j\, y_j = 1$. The production possibility set P\(X_0, Y_0) spanned by (X, Y) excluding (X_0, Y_0).

$$\text{P}\backslash(X_0, Y_0) = [(\overline{X}, \overline{Y}) \,|\, \overline{X} \ge \sum_{i\in I, i\neq 0}^{n}\lambda_i X_i,\ \overline{Y} \le \sum_{i\in I, i\neq 0}^{n}\lambda_i Y_i\ ,\ \overline{Y} \ge 0,\ \lambda \ge 0].$$

From Formula 2 we know that the degree of super-efficiency of (X_0, Y_0) under estimation is excluded from the reference set. In other words, the super efficiency ZSG-DEA models are based on reference technology constructed from all other DMUs.

The Super SBM ZSG-DEA model is formulated as the following.

$$h^* = Min \qquad h_{RO} = \frac{\frac{1}{m}\sum_{i=1}^{m}\overline{x_i}/x_{i0}}{\frac{1}{s}\sum_{r=1}^{s}\overline{y_r}/y_{r0}} \tag{2}$$

$$\text{s.t.} \qquad h_{R0}\overline{x} = \sum_{j\in I, j\neq 0}^{n}\lambda_j x_j\left[1 + \frac{x_0(1-h_{ro})}{\sum_{j\in I, j\neq 0} x_j}\right]$$

$$\overline{y} = \sum_{j\in I, j\neq 0}^{m}\lambda_j y_j$$

$$\sum_j \lambda_j = 1$$

$$\overline{x} \ge x_0,\quad \overline{y} \le y_0,\quad \overline{y} \ge 0,\quad \lambda \ge 0$$

In order to achieve the efficient frontier of ZSG-DEA, DMU$_0$ adopts competition or cooperation to maximize efficiency (Formula 2). This study mainly explores strategies based on cooperation. Using the comparison of a pair of DMUs as an example (Fig. 2), the efficiency scores are maximized (DMU$_A$ and DMU$_C$), whereas the scores of inefficient ones are minimized (DMU$_B$ and DMU$_D$). In this case, a new DEA frontier can be obtained and it becomes the maximum efficiency frontier.

We derive (2) and (3) from Targets' Assessment Theorem and Benchmarks' Contribution Equality Theorem proposed by Gomes and Lins in 2007 [47] and Gomes and Lins [48].

Formula (3) and formula (4) are the input-oriented and output-oriented expressions, respectively. hi and hj are the traditional DEA efficiency; W represents cooperative DMUs; $q_{ij} = h_i/h_j$ is the proportional adjustment factor.

$$h_{Ri} = h_i\left(1 + \frac{\sum_{j\in w}\left[x_j\left(1 - q_{ij}h_{Ri}\right)\right]}{\sum_{j\notin w} x_j}\right) \tag{3}$$

$$h_{Ri} = h_i\left(1 - \frac{\sum_{j\in w}\left[y_j\left(q_{ij}h_{Ri} - 1\right)\right]}{\sum_{j\notin w} y_j}\right) \tag{4}$$

Table 3. Summary statistics on input variable (emission allowance).

Input (emission allowance) (Unit: Tonne)	Min. Value	Max. Value	Means	Standard Deviation
2005	3,229,321	493,482,295	87,264,941.42	110,507,879.07
2006	3,229,321	495,488,263	86,164,759.46	110,335,002.30
2007	3,229,321	497,302,479	86,521,745.21	110,708,737.02

Source: Data compiled by the authors of the study.

Data Analyses and Empirical Results

Data Analysis

Data were obtained from the Community Independent Transaction Log (CITL) and Eurostat. The data concerning the volume of CO_2 emissions and emission allowances came from the CITL database. The data concerning the economy of individual countries, energy usage, and demographic profiles were from Eurostat. Currently, there are 27 countries as European Union (EU) members. However, Romania and Bulgaria joined the EU in 2007 and Malta did not have a complete data set. As a result, 24 EU countries were assessed from 2005 until 2007: Austria, Belgium, Czech Republic, Cyprus, Demark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

Employing Gomes and Lins' [38] method as the base, the Super SBM-ZSG-DEA model was employed to assess the issue associated with the fairness of the reallocation allowances. Under the assumption of having fixed emission allowance, a country would have a higher carbon emission allocation efficiency with a higher gross domestic product (GDP) and lower CO_2 emission rate. Traditionally, DEA uses labor and capital as the inputs of efficiency measures. In this study, the input of efficiency measure was replaced by CO_2 emission allowances. The output variables consisted of GDP and the emission volume of CO_2.

In this model, one of the outputs was the undesirable factor, in this case CO_2. Seiford and Zhu's [49] method of handling each undesirable output was employed. Specifically, each undesirable output was multiplied by "-1" and an appropriate translation vector would be found to transform the negative output into a positive one. The following is the modified formula: $\bar{Y}_j^h = -Y_j^h + \omega > 0$, $\omega = \max\{Y_j^h\}+1$.

The following are the definitions concerning input and output variables.

Input Variable

Emission allowance: Emission allowance also is called carbon credit or carbon asset and is a generic term that represents a permit that allows the credit possessor to emit one ton of CO_2. Such credit is allowed to be traded in the international market. In this study, the emission allowances were based upon the information released by EU ETS.

Output Variables

(1) Gross domestic product (GDP): GDP refers to "the market value of all final goods and services produced within a geographical entity within a given period of time" [47]. Considering as a positive output, the higher the GDP, the better the praxis for prosperity and progress of a country.
(2) Carbon dioxide (CO_2) emission: Fossil fuel burning is the major source of CO_2 emissions. However, changes in land use also can lead to CO_2 emissions. Such a form of CO_2 emissions primarily results from deforestation and, subsequently, utilizing the land for agriculture or built-up areas (e.g., road building). This is because when substantial areas of forest are cut down, the land often becomes less productive grasslands and the capability of storing CO_2 also becomes less effective. CO_2 emissions are in large part caused by industrialization for the pursuit of cross-country economic development and is a major source for global warming. Thus, it is considered as an undesirable output in this study.

Table 3 shows means, standard deviations, and emission allowances on inputs. Table 4 presents means, standard deviations, GDP (i.e., maximum, minimum), and the volumes of CO_2 emissions (i.e., maximum, minimum) on outputs. As shown in Tables 3 and 4, the standard deviations of emission allowances and GDP were larger than the means. This could be the result of variations among countries. The emission allowances from 2005 to 2007 were 87,264,941.42 tons, 86,164,759.46 tons, and 86,521,745.21 tons, respectively. This showed that the allowance caps fluctuated slightly during the three-year span but the differences were not significant. 2005, 2006, and 2007 GDPs were $566,240,663,694.90, $601,752,802,011.45, and $693,092,499,896.25, respectively. The growth of GDP was 6.27% from 2005 to 2006 and 15.18% from 2006 to 2007. This indicated a continuous increase in consumption and economic development. Finally, the average volumes of CO_2 emissions from 2005 to 2007 were 391,353,199.3 tons, 442,504,170.9 tons, and 401,572,168.6 tons, respectively. CO_2 emission increased by 13.07% from 2005 to 2006 and decreased by 9.25% from 2006 to 2007.

Table 4. Summary statistics on output variables (GDP and CO_2 emissions).

Output (GDP) (Unit: US Dollars)	Min. Value	Max. Value	Means	Standard Deviation
2005	13,789,968,054.16	2,791,443,850,267.38	566,240,663,694.90	798,934,481,346.80
2006	16,449,097,472.92	2,913,310,751,474.09	601,752,802,011.45	841,024,042,205.29
2007	20,958,675,439.59	3,317,365,597,284.57	693,092,499,896.25	959,628,366,892.19
Output (CO_2 Emission) (Unit: Tonne)	Min. Value	Max. Value	Means	Standard Deviation
2005	1	474,482,886	391,353,199.3	109,536,122.9
2006	1	545,062,355	442,504,170.9	442,504,170.9
2007	1	484,578,686	401,572,168.6	112,321,070.4

Source: Data compiled by the authors of the study.

Table 5. Super-SBM-V efficiency ranking (2005-07).

<table>
<tr><th colspan="2">2005</th><th colspan="2">2006</th><th colspan="2">2007</th></tr>
<tr><th>Rank</th><th>Country</th><th>Rank</th><th>Country</th><th>Rank</th><th>Country</th></tr>
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Table 6. Comparisons of emission allowances and CO_2 emissions.

	Greece		Estonia		Hungary	
	EA	CO_2	EA	CO_2	EA	CO_2
2005	71,162,432	71,267,752	16,747,054	12,621,824	30,236,166	26,161,642
2006	71,162,432	69,965,151	18,199,834	12,109,281	30,236,166	25,845,908
2007	71,162,432	72,717,011	21,343,525	15,329,934	30,236,166	26,836,758
	Slovakia		Poland		Czech Republic	
	EA	CO_2	EA	CO_2	EA	CO_2
2005	30,470,677	25,218,717	237,557,630	203,149,576	96,919,971	82,454,636
2006	30,486,877	25,530,744	237,557,630	209,616,290	96,919,971	83,624,960
2007	30,486,829	24,511,057	237,542,720	209,618,357	96,919,971	87,834,764

EA – emission allowance; CO_2 – carbon dioxide emission

Table 7. Projected input and output variable adjustments.

	2005	2006	2007
Emission Allowance	-34,515,380.88	-32,622,664.90	-32,222,996.85
GDP	3,260,712,170	3,692,069,847	3,759,127,997
CO_2 Emissions	36,612,720.46	54,535,482.39	33,016,666.56

Empirical Results

Super-SBM Input Oriented Efficiency Analysis

Using Super-SBM input-oriented efficiency analysis, the data of 24 EU countries from 2005 to 2007 was assessed. Based on the efficiency values generated, Table 5 shows the efficiency ranking of 24 EU countries for the 3-year period of analysis.

In 2005 Luxembourg was ranked first while the United Kingdom was ranked No. 1 in 2006 and 2007. Sweden was in second place in 2005 and 2006. In 2007 five countries ranked as second: Cyprus, France, Germany, Luxembourg, and Sweden. From 2005 to 2007 the bottom six consisted of Greece, Estonia, Hungary, Slovakia, Poland, and the Czech Republic. Though there were slightly interchangeable fluctuations among these countries, the overall ranking was quite consistent. In fact, the countries with lower rankings all had a similar issue – the carbon allowances possessed by these countries exceeded their actual emissions (Table 6). Because such allowances were tradable, it would lead to a drop of market prices. If the emission allocation issue could not be properly resolved, the generation of inefficiency values would be the result.

Slacks-Based Measure of Super-Efficiency

The use of a DEA model can help to determine efficient or inefficient DMUs. The employment of slacks-based measure (SBM) of super-efficiency can further enable investigators to make adjustments for those inefficient variables. Table 7 is a summary of the data concerning input and output variables. Using the year of 2005 as an example, 24 EU participant countries should each reduce 34,515,380.88 tons of allowances from their assigned "quotas." Accordingly, these countries should increase \$3,260,712,170 U.S. dollars to their respective GDPs and increase 36,612,720.46 tons of CO_2 emissions from their annual emission amounts.

Application of Super-SBM-ZSG DEA

In the EU there is an allowance cap in terms of the total quantity of CO_2 emissions. Since emission allowances are tradable, cross-country deals could be made among them. Specifically, if a country had more allowances than demanded, it could sell those remaining "quota" values to countries whose allowances were not sufficient and vice versa. Therefore, the application of the Super SBM-ZSG-DEA model can provide baseline data for the reallocation of EU emission allowances. In addition, Super-SBM would generate higher efficiency values and, therefore, offset the traditional DEA shortcoming of being unable to effectively rank order those countries with an efficiency value of 1. Based on the data compiled from 2005 to 2007, EU countries could be divided into two groups:

1) increase
2) decrease in the quantity of emission allowances (Table 8).

Seven countries would need to increase the quantity of emission allowances. In contrast, the remaining ones would have to decrease their emission allowance quantity.

Table 8. Countries with increases and decreases in emission allowances (from 2005 to 2007).

Countries w/ emission allowance increases from 2005~2007	Countries w/ emission allowance decreases from 2005~2007
Cyprus, France, Germany, Latvia, Luxembourg, Sweden, United Kingdom	Austria, Belgium, Czech Republic, Demark, Estonia, Finland, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain
Total: 7	Total: 17

Table 9. Initial and adjusted allowance comparisons in 2005.

Country	Initial Allowance (IA)	Adjusted Allowance (AA)	AA-IA
Austria	32,412,654	29,855,263.29	-2,557,390.71
Belgium	58,309,908	38,007,311.44	-20,302,596.56
Czech Republic	96,919,971	5,342,294.55	-91,577,676.45
Cyprus	5,471,353	9,051,398.61	3,580,045.61
Denmark	37,303,720	24,446,108.03	-12,857,611.97
Estonia	16,747,054	5,342,294.55	-11,404,759.45
Finland	44,665,566	17,245,877.30	-27,419,688.70
France	150,412,090	248,830,551.20	98,418,461.17
Germany	493,482,295	816,380,328.60	322,898,033.59
Greece	71,162,432	23,160,295.23	-48,002,136.77
Hungary	30,236,166	8,440,850.02	-21,795,315.98
Ireland	19,236,747	17,842,391.79	-1,394,355.21
Italy	216,150,241	204,760,310.20	-11,389,930.80
Latvia	4,070,078	5,342,294.55	1,272,216.55
Lithuania	13,499,398	5,342,294.55	-8,157,103.45
Luxembourg	3,229,321	7,188,375.14	3,959,054.14
Netherlands	86,452,491	68,651,176.12	-17,801,314.88
Poland	237,557,630	29,725,893.01	-207,831,736.99
Portugal	36,908,808	16,069,198.45	-20,839,609.55
Slovakia	30,470,677	5,790,722.25	-24,679,954.75
Slovenia	9,138,064	5,342,294.55	-3,795,769.45
Spain	172,160,788	127,790,853.40	-44,369,934.56
Sweden	22,289,169	37,684,457.88	15,395,288.88
United Kingdom	206,071,973	336,725,759.30	130,653,786.30
Total	2,094,358,594	2,094,358,594	0

Three summary tables (Tables 9-11) and figures (Figs. 3-5) were constructed to compare the differences in initial and adjusted emission allowances from 2005 to 2007. For instance, the initial emission allowance of Luxembourg was 3,229,321 tons in 2005. After the adjustment was made, Luxembourg would have to add 3,959,054.14 tons of allowances, which amounts to an approximately 123% increase. Czech Republic's initial allowances were 96,919,971 tons in 2006. The adjusted allowances would be 5,193,889.065 tons. This accounts for about a 94.49% decrease in emission allowances. In fact, the Czech Republic had a similar number in 2007 and was the country with the largest differences in the initial and adjusted emission allowances during the three-year span. In addition, highly developed countries such as France, Germany, and the United Kingdom could increase their emission

Table 10. Initial and adjusted allowance comparisons in 2006.

Country	Initial Allowance (IA)	Adjusted Allowance (AA)	AA-IA
Austria	32,649,366	28,660,075.58	-3,989,290.42
Belgium	58,309,908	36,643,975.21	-21,665,932.79
Czech Republic	96,919,971	5,193,889.06	-91,726,081.94
Cyprus	5,612,379	9,031,963.03	3,419,584.03
Denmark	27,907,569	23,513,523.36	-4,394,054.64
Estonia	18,199,834	5,196,872.17	-13,002,961.83
Finland	44,617,969	16,315,202.37	-28,302,766.63
France	149,966,891	241,340,689.10	91,373,798.10
Germany	495,488,263	797,385,863.20	301,897,600.20
Greece	71,162,432	22,693,540.43	-48,468,891.57
Hungary	30,236,166	7,906,206.74	-22,329,959.26
Ireland	19,237,593	17,356,530.44	-1,881,062.56
Italy	205,050,245	196,376,599..03	-8,673,645.97
Latvia	4,058,197	5,196,872.17	1,138,675.17
Lithuania	10,576,697	5,196,872.17	-5,379,824.83
Luxembourg	3,229,321	5,196,924.14	1,967,603.14
Netherlands	86,387,889	66,535,099.63	-19,852,789.37
Poland	237,557,630	30,622,219.16	-206,935,410.84
Portugal	36,908,808	14,722,992.24	-22,185,815.76
Slovakia	30,486,877	5,709,904.15	-24,776,972.85
Slovenia	8,691,991	5,196,872.16	-3,495,118.84
Spain	166,209,335	127,858,711.30	-38,350,623.70
Sweden	22,483,602	36,434,799.40	13,951,197.40
United Kingdom	206,005,294	357,668,030.70	151,662,736.70
Total	2,067,954,227	2,067,954,227	0

allowances. After the subsequent adjustments, Germany, for example, should increase 306,639,527.40 tons of average allowances.

Based upon the geographical locations (i.e., central, eastern, western, southern, and northern Europe), a further analysis was conducted. Western European countries should increase their emission allowances based on the data analysis for the three-year span (2005-07). Conversely, central, southern, northern, and eastern European countries should reduce their emission allowances (Tables 12-14). In fact, with more developed EU members in this region, western European countries needed more emission allowances to satisfy their economic development. In contrast, other regions of the European continent might decrease their emission allowances for the purpose of effectively allocating or reallocating emission allowances.

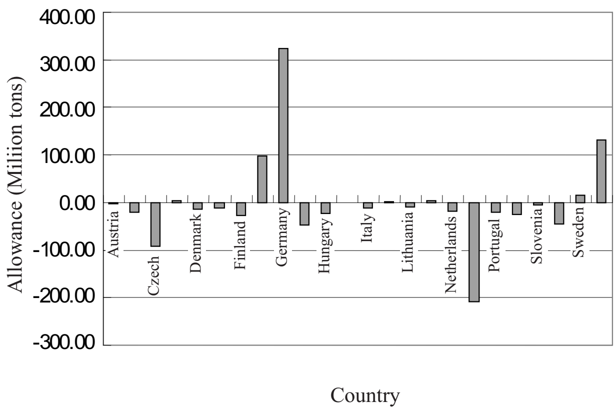

Fig. 3. Initial and adjusted allowance comparisons in 2005.

Table 11. Initial and adjusted allowance comparisons in 2006.

Country	Initial Allowance (IA)	Adjusted Allowance (AA)	AA-IA
Austria	32,649,366	28,660,075.58	-3,989,290.42
Belgium	58,309,908	36,643,975.21	-21,665,932.79
Czech Republic	96,919,971	5,193,889.06	-91,726,081.94
Cyprus	5,612,379	9,031,963.03	3,419,584.03
Denmark	27,907,569	23,513,523.36	-4,394,054.64
Estonia	18,199,834	5,196,872.17	-13,002,961.83
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France	149,966,891	241,340,689.10	91,373,798.10
Germany	495,488,263	797,385,863.20	301,897,600.20
Greece	71,162,432	22,693,540.43	-48,468,891.57
Hungary	30,236,166	7,906,206.74	-22,329,959.26
Ireland	19,237,593	17,356,530.44	-1,881,062.56
Italy	205,050,245	196,376,599..03	-8,673,645.97
Latvia	4,058,197	5,196,872.17	1,138,675.17
Lithuania	10,576,697	5,196,872.17	-5,379,824.83
Luxembourg	3,229,321	5,196,924.14	1,967,603.14
Netherlands	86,387,889	66,535,099.63	-19,852,789.37
Poland	237,557,630	30,622,219.16	-206,935,410.84
Portugal	36,908,808	14,722,992.24	-22,185,815.76
Slovakia	30,486,877	5,709,904.15	-24,776,972.85
Slovenia	8,691,991	5,196,872.16	-3,495,118.84
Spain	166,209,335	127,858,711.30	-38,350,623.70
Sweden	22,483,602	36,434,799.40	13,951,197.40
United Kingdom	206,005,294	357,668,030.70	151,662,736.70
Total	2,067,954,227	2,067,954,227	0

Conclusion

Reducing the emissions of greenhouse gases is a global issue and a collective effort and response becomes imperative. Since the quantity of emission allowances is linked to economic development, how to balance development with emissions is important both regionally as well as within the context of the European continent. It was believed that the success to the carbon trading system relied upon not just cooperation among the 24 EU countries, but also a fair share of emission allowance so that such a system could function appropriately. The aim of this paper was to examine these members' optimal allocations of emission allowances. The results of this study could serve as baseline data as a reference point for these countries.

The SUPER SBM-ZSG-DEA was employed to determine the emission allowances. The empirical results indi-

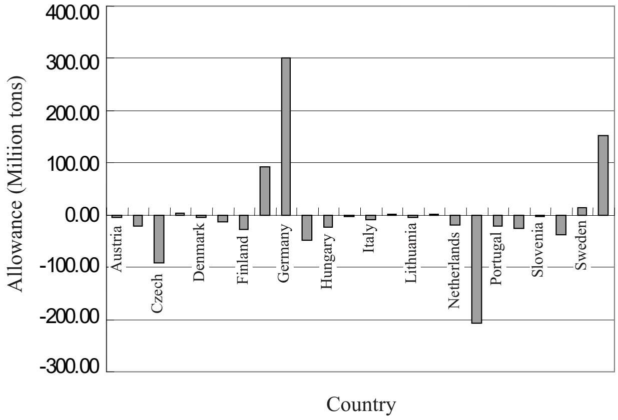

Fig. 4. Initial and adjusted allowance comparisons in 2006.

Table 12. Geographical comparisons concerning emission allowances in 2005.

	Western	Eastern	Northern	Southern	Central
TQA	193,533,034	-18,289,646	-24,882,011	-124,817,335	-25,544,041
AQA	32,255,506	-6,096,549	-8,294,004	-20,802,889	-4,257,340

TQA – Total Quantity of Emission Allowances Adjusted,
AQA – Average Quantity of Emission Allowances Adjusted.

Table 13. Geographical comparisons concerning emission allowances in 2006.

	Western	Eastern	Northern	Southern	Central
TQA	201,604,353	-17,244,111	-18,745,614	-117,754,511	-47,860,115
AQA	33,600,726	-5,748,037	-6,248,538	-19,625,752	-7,976,686

TQA – Total Quantity of Emission Allowances Adjusted,
AQA – Average Quantity of Emission Allowances Adjusted.

Table 14. Geographical Comparisons concerning Emission Allowances in 2007.

	Western	Eastern	Northern	Southern	Central
TQA	205,011,302	-20,259,743	-20,394,738	-112,425,366	-51,931,454
AQA	34,168,550	-6,753,248	-6,798,246	-18,737,561	-8,655,242

TQA – Total Quantity of Emission Allowances Adjusted,
AQA – Average Quantity of Emission Allowances Adjusted.

cated that the countries with higher carbon emission allocation efficiency would have to increase their emission allowances. These types of countries were likely to be highly industrialized (i.e., France, Germany, and the United Kingdom). In contrast, the majority of investigated countries with lower rankings in the initial allowances were likely to be less developed countries. Accordingly, these less developed countries would have to decrease their emission allowances in order to be more adequate or appropriate regarding allowance allocations. In addition, the countries with allowance shortages could make exchanges with the countries unable to consume their "quotas" completely. By doing so, the EU countries, as a whole, could be more efficient concerning the consumption of carbon credit.

Based upon the geographical locations (i.e., central, eastern, western, southern, and northern Europe), further implications can be drawn. Western European countries needed more emission allowances to satisfy their economic development and other regions of the European continent might decrease their emission allowances for the purpose of more effectively and realistically allocating emission allowances.

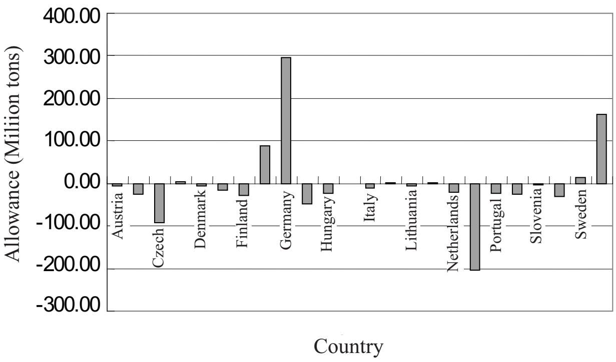

Fig. 5. Initial and adjusted allowance comparisons in 2007.

This study was an effort to assess the efficiency of emission allowance allocations. If countries received allowances beyond what was needed, they could trade in the remaining units with those countries that had too few and vice versa. The results of the study not merely provided an overview of EU countries' allocation efficiency, but also could serve as a platform for further policy analysis and assessment.

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