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Two Methods for Measuring the Environmental Returns to Scale Using Data Envelopment Analysis Approach

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Abstract

Nowadays, the assessment of environmental performance has received considerable attention by environmental strategy advocators and decision makers. In recent years, increased emission of CO_2 into the air, water pollution, and global warming are universal problems all over the world. Therefore, development of firms with less CO_2 emission is an important issue of attention in every area of production. This paper applies data envelopment analysis (DEA) as a management technique for assessing the environmental performance of the firms. We then explore the measurement of scale economies (SE) and returns to scale (RTS) for environmental issues which have not been given the attention they deserve in the last few decades. Associated with SE and RTS for desirable outputs, the new concepts of ESE (Environmental Scale Economies) and ERTS (Environmental Returns to Scale) are proposed for both desirable and undesirable outputs. This paper presents two methods for determining the type of ERTS of efficient DMUs, and demonstrates their equivalency within a theorem. Finally, the offered models are employed to study the CO_2 emission of Japanese electric power companies. Afterwards, the type of ERTS is determined for efficient companies and based on their type of ERTS, the optimal size is suggested for them.

Keywords

Data envelopment analysis, Environmental performance, Scale economies, Returns to scale, Undesirable output.

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Introduction

Nowadays, increased emissions of CO_2 into the air, water pollution, climate change, and global warming are universal problems and have become major concerns around the world. Natural events and human industrialization and economic activities have had a significant role in the development of the above-mentioned universal issues. As one of the important means of achieving environmental protection and solving these problems, improvement of environmental efficiency is vitally important for reducing environmental risk and level of ecological scarcity (Chen et al., 2015). Therefore, the assessment of environmental performance has recently received considerable attention by environmental strategy advocators and decision makers.

Data Envelopment Analysis (DEA) initiated by Charnes et al. (1978) is a popular management tool concerned with assessing the performance of Decision Making Units (DMUs) with multiple inputs and outputs. In recent years, DEA has been widely applied as an evaluation technique to study the environmental performance of firms. In usual DEA, the gauge of efficiency is producing more desirable outputs and consuming less input resources. However, in the actual applications, pollutants are unavoidably generated along with desirable outputs. In DEA-based environmental assessment, nonetheless, the efficiency of the firms is influenced by the amounts of pollutants (called undesirable outputs or environmental outputs) that they generate.

A conventional and usual method for employing DEA in order to estimate environmental efficiency is that the undesirable outputs have been considered as inputs and the traditional DEA models have been applied. Some of the studies in this area include Dyckhoff and Allen (2001), Dyson et al. (2001), Hailu and Veeman (2001), and Sueyoshi and Goto (2011a), to name a few.

Scheel (2001) proposed another approach by inverting the undesirable output values and regarding them as desirable outputs. However, this nonlinear transformation may change the efficiency frontiers and hence lead to false efficiency scores.

Seiford and Zhu (2002) employed an alternative approach which first multiplies each undesirable output by -1 and then adds a large enough positive scalar to it so that all of the negative undesirable outputs become positive. Nevertheless, this approach is only valid under the variable returns to scale condition; moreover, it does not reflect a logical production possibility set.

Some approaches used the slacks-based DEA models to handle the undesirable outputs. For example, see Sueyoshi and Goto (2011a), Lozano and Gutiérrez (2011), Zhang and Choi (2013), and Song et al. (2013). Recently, Huang et al. (2015) applied a Meta-Frontier Directional Distance Function (MDDF) approach to manage undesirable outputs. They established that the stochastic frontier MDDF is further linked with environmental variables.

However, Färe et al. (1989, 1993) were the first publications to deal with this subject systematically. They treated undesirable outputs as outputs and tried to incorporate them into environmental DEA technologies under a new axiom. Therefore, they employed the weak disposability postulate, which had been introduced by Shephard (1974), between desirable and undesirable outputs. Later, this direction was investigated by researchers such as Färe et al. (2004, 2005), Zhou et al. (2007), Kuosmanen (2005), Kuosmanen and Podinovski (2009), Tao and Zhang (2013), Molinos-Senante et al. (2014), Khoshandam et al. (2015), Lozano (2016), and Zare Haghighi and Rostamy-Malkhalifeh (2017).

The concepts of returns to scale (RTS) and scale economies (SE) have a crucial position in economics and production theory. These concepts can be used to provide advantageous information on the optimal size of the firms (Forsund, 1996). In DEA, DMUs are classified to three categories based on their type of RTS: Constant RTS (CRS), decreasing RTS (DRS), and increasing RTS (IRS). In fact, RTS is applied to recognize whether an efficient production activity can enhance its productivity by changing the size of the scale of its operations.

Although there are many studies in the DEA publications which explore the theory and utilizations of RTS and SE (see for instance

Banker, 1984; Banker et al., 1984, 2004; Banker & Thrall, 1992; Golany & Yu, 1997; Hadjicostas & Soteriou, 2006; Soleimani-damaneh et al., 2006; Cesaroni & Giovannola, 2015), discussing these issues in the presence of undesirable outputs is really fledgling. In the only existing article doing such, Sueyoshi and Goto (2011b) studied RTS and SE (scale economies) in terms of environmental performance. Corresponding to RTS and SE for desirable (good) outputs, they introduced the new concepts of DTS (damages to scale) and SD (scale damages) for undesirable (bad) outputs, and then, combined them in a unified treatment and presented the concepts of RTS unified (RTSU) and DTS unified (DTSU). Acknowledging the contribution of their study, this research needs to mention that they treated the undesirable outputs as inputs for measuring the environmental performance, and moreover, they provided two separate indicators for each DMU (RTSU and DTSU) which may encounter the decision maker by two different strategies.

The contribution of this paper is that it treats the undesirable outputs as outputs and utilizes the extended BAM measure (Zare Haghighi & Rostamy-Malkhalifeh, 2017) which is a slacks-based DEA measure and incorporates both good (desirable) and bad (undesirable) outputs for environmental assessment in an integrated treatment. Using this model, we then explore how to measure the scale economies and the type of returns to scale in the presence of undesirable outputs and call them Environmental Scale Economies (ESE) and Environmental Returns To Scale (ERTS), respectively. The two new concepts (ESE and ERTS) for both desirable and undesirable outputs are associated with RTS and SE for desirable outputs. This paper suggests two methods for determining the type of ERTS. Also, a theorem demonstrates that the two proposed method are equivalent. The study by Sueyoshi and Goto (2011b) separated these two concepts and examined them independently. In contrast, the current paper intends to explore them in an integrated scheme between desirable and undesirable outputs. Afterwards, the proposed methods are applied to gauge the performance of nine Japanese electric power companies. To illustrate the merits of our proposed methods, the computational efficiency of the proposed approaches is compared with the existing method in Sueyoshi and Goto (2011b).

It should be noted that the subject of RTS mainly has a clear interpretation only if the DMU under evaluation is efficient. Actually, RTS is a characteristic of the frontier at a specific point, and that is why RTS is discussed only for efficient DMUs in this study.

The rest of this paper is structured as follows: The next section reviews the extended BAM model proposed by Zare Haghighi & Rostamy-Malkhalifeh (2017) that incorporates both desirable (good) and undesirable (bad) outputs for assessing the environmental performance. Using this model, the two new concepts of ESE and ERTS are defined and two methods are proposed for measuring the type of ERTS for environmental assessment. Afterwards, the results of the mentioned methods are provided and interpreted by applying them to Japanese electric power companies. The summary and conclusions of the study are supplied in the last section.

Preliminaries

In productive activities, it is supposed that there are *n* DMUs, each one of which produces a column vector of desirable (good) outputs (g_j) and a column vector of undesirable (bad) outputs (b_j) from a column vector of inputs (x_j). In addition, it is assumed that:

$x_j = (x_{1j}, x_{2j}, \dots, x_{mj})^t, x_j \geq 0, x_j \neq 0,$

$g_j = (g_{1j}, g_{2j}, \dots, g_{sj})^t, g_j \geq 0, g_j \neq 0,$

and $b_j = (b_{1j}, b_{2j}, \dots, b_{hj})^t, b_j \geq 0, b_j \neq 0,$

where the superscript "*t*" indicates a vector transpose. Table 1 shows the nomenclatures which are used in this study.

Table 1. Nomenclatures

Symbol	Definition	Symbol	Definition
DMU_k	The DMU under evaluation	x_{ik}	*i*th input of the *k*th DMU
j=1,…,n	Number of DMUs	g_{rk}	*r*th desirable output of the *k*th DMU
i=1,…,m	Number of inputs	b_{fk}	*f*th undesirable output of the *k*th DMU
r=1,…,s	Number of desirable outputs	SE	Scale economies
f=1,…,h	Number of undesirable outputs	RTS	Returns to scale

Continue Table 1. Nomenclatures

Symbol	Definition	Symbol	Definition
x	Input	ESE	Environmental scale economies
g	Desirable output	ERTS	Environmental returns to scale
b	Undesirable output	σ^*	The intercept of the supporting hyperplane
Γ_E	The environmental efficiency score	$\overline{\sigma}$	The upper bound of σ^*
R	Reference set	$\underline{\sigma}$	The lower bound of σ^*

The BAM model, which was introduced by Cooper et al. (2011), is one of the DEA additive models with more discriminatory power. Recently, Zare Haghighi and Rostamy-Malkhalifeh (2017) extended the model of BAM to be applicable for both desirable and undesirable outputs. This extended measure is employed in the next section of this study for measuring the type of ERTS. This model is applied for two reasons. First, it is a new model and was presented in 2017 by Zare Haghighi and Rostamy-Malkhalifeh. Second, it is a non-radial efficiency measure, and hence, when calculating the efficiency score all the inefficiencies that the model can identify are accounted for in the efficiency calculations. Therefore, it can easily integrate desirable and undesirable outputs in a unified manner. The extended BAM model (Zare Haghighi & Rostamy-Malkhalifeh, 2017) is as follows:

$$\theta_1^* = \max \sum_{i=1}^{m} B_i^x s_i^x + \sum_{r=1}^{s} B_r^g s_r^g + \sum_{f=1}^{h} B_f^b s_f^b \qquad (1)$$

$$\begin{aligned}
\text{s.t.} \quad & \sum_{j=1}^{n} (\eta_j + \mu_j) x_{ij} + s_i^x = x_{ik} \qquad (i = 1, \dots, m), \\
& \sum_{j=1}^{n} \eta_j g_{rj} - s_i^x = g_{rk} \qquad (r = 1, \dots, s), \\
& \sum_{j=1}^{n} \eta_j b_{fj} + s_f^b = b_{fk} \qquad (f = 1, \dots, h), \\
& \sum_{j=1}^{n} (\eta_j + \mu_j) = 1, \eta_j \geq 0, \mu_j \geq 0 \qquad (j = 1, \dots, n), \\
& s_i^x \geq 0 (i = 1, \dots, m), s_r^g \geq 0 (r = 1, \dots, s), s_f^b \geq 0 (f = 1, \dots, h).
\end{aligned}$$

In this model, $s_i^x (i = 1, \dots, m)$, $s_r^g (r = 1, \dots, s)$, and $s_f^b (f = 1, \dots, h)$ are respectively the variables for improving inputs, desirable outputs, and undesirable outputs. The ranges which are incorporated in the objective function of Model (1) are determined as follows:

$B_i^x = \frac{1}{(m+s+h)(x_{ik}-\underline{x}_i)}\ (\forall_i), B_r^g = \frac{1}{(m+s+h)(\bar{g}_r-g_{rk})}\ (\forall_r)$, and

$B_f^b = \frac{1}{(m+s+h)(b_{fk}-\underline{b}_k)}\ (\forall_f)$,

where, $\underline{x}_i = \min\{x_{ij} \mid j=1,\dots,n\}$, $\bar{g}_r = \max\{g_{rj} \mid j=1,\dots,n\}$, and $\underline{b}_f = \min\{b_{fj} \mid j=1,\dots,n\}$.

If $x_{ik} = \underline{x}_i$ and $g_{rk} = \bar{g}_r$, there will not be an improvement for the ith input and rth desirable output of DMU$_k$, and s_i^{x*} and s_r^{g*} will be zero and by convention, B_i^x and B_r^g will be considered zero. Also, if the undesirable output f satisfies $b_{fk} = \underline{b}_f$, then, B_f^b is considered zero. After solving Model (1), an environmental efficiency score ($\varGamma_E$) for DMU$_k$ is computed on optimality of the model as follows:

$$\varGamma_E = 1 - \left(\sum_{i=1}^{m} B_i^x s_i^{x*} - \sum_{r=1}^{s} B_r^g s_r^{g*} + \sum_{f=1}^{h} B_f^b\ s_f^{b*}\right) = 1 - \theta_1^*$$

Now, consider the dual model corresponding to Model (1) as follows:

$$\theta_1^* = \min \sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \qquad (2)$$

$$\begin{aligned}
\text{s.t.}\ & \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq 0 && (j = 1,\dots,n),\\
& \sum_{i=1}^{m} v_i x_{ij} + \sigma \geq 0 && (j = 1,\dots,n),\\
& v_i \geq B_i^x && (i = 1,\dots,m),\\
& u_r \geq B_r^g && (r = 1,\dots,s),\\
& w_f \geq B_f^b && (f = 1,\dots,h).
\end{aligned}$$

Here, the variables $u_r (r = 1,\dots,s), v_i (i = 1,\dots,m)$, and $w_f (f = 1,\dots,h)$ are respectively the dual variables associated with the first, second, and the third group of the constraints in Model (1). Also, σ, which is free in sign, is the dual variable corresponding to the constraint $\sum_{j=1}^{n}(\eta_j+\mu_j)=1$.

In the two following theorems, two properties of Model (2) are demonstrated. These theorems characterize a supporting hyperplane in the model. This hyperplane helps us to estimate the amount of ESE measure and the type of ERTS in the next section.

Theorem 1. In the optimality of Model (2), at least one of the constraints of the first group for $j \in \{1,\ldots,n\}$ is active.

Proof. Let an arbitrary optimal solution of Model (2) be $(\eta^*,\mu^*,s^{x*},s^{g*},s^{b*})$**.** It is claimed that $\eta^* \neq 0,$ **,** since otherwise the desirable outputs yield $g_{rk} \leq 0\ (\forall r)$**.** Consequently, $g_{rk}=0\ (\forall r)$ while this is a contradiction. Suppose that the *l*th component of $\eta^*$is nonzero, i.e., $\eta_l^*>0$**.** Then, the complementary slackness conditions of linear programming (Bazarra et al., 2010) assert that the constraint corresponding to η_l^* in the dual problem (2) must have zero slack variable. Therefore, we have: $\sum_{i=1}^{m} v_i^* x_{il}-\sum_{r=1}^{s} u_r^* g_{rl}+\sum_{f=1}^{h} w_f^* b_{fl}+\sigma^* = 0$, where (v^*,u^*,w^*,σ^*) is an optimal solution for dual problem (2). Therefore, the *l*th constraint of Model (2) is active, and the proof is complete.

Theorem 2. Let DMU$_k$ be under evaluation and (v^*,u^*,w^*,σ^*) be an optimal solution of Model (2). If DMU$_k$ is efficient, then, it is on the Hyperplane *H*,

$$H=\left\{(x,g,b)|\ \sum_{i=1}^{m} v_i^* x_i-\sum_{r=1}^{s} u_r^* g_r+\sum_{f=1}^{h} w_f^* b_f+\sigma^* = 0\right\}.$$

If DMU$_k$ is inefficient, then its projection point is on the Hyperplane *H*.

Proof. Suppose DMU$_k$ is efficient. Therefore, all of the slack variables are zero on the optimality of Model (1), and hence, the optimal value of the objective function of Model (1) is zero. According to the strong duality theorem (Bazarra et al., 2010), the optimal value of the dual problem (2) is zero, as well. So, we have:

$$\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^* = 0,$$

Hence, (x_k, g_k, b_k) is on the Hyperplane H, and $\text{DMU}_k \in H$. Now, suppose that DMU_k is inefficient. Consider $(\eta^*, \mu^*, s^{x*}, s^{g*}, s^{b*})$ as an optimal solution of Model (1). Let R denote the reference set of DMU_k as follows:

$$R = \text{Reference set of DMU}_k = \underbrace{\{j \mid \eta_j^* > 0\}}_{R_1} \cup \underbrace{\{j \mid \mu_j^* > 0\}}_{R_2}.$$

According to Theorem 1, $\eta^* \neq 0$, and hence, R is not empty. The projection point of DMU_k is as follows:

$$(\hat{x}_k, \hat{g}_k, \hat{b}_k) = \left(\sum_{j \in R} (\eta_j^* + \mu_j^*) x_j \,, \sum_{j \in R} \eta_j^* g_j \,, \sum_{j \in R} \eta_j^* b_j \right)$$

Since for all j $(j \in R_1)$, $\eta_j^* > 0$, then, by the complementary slackness conditions, the corresponding constraint in the dual problem must have zero slack variable. Therefore, for all j $(j \in R_1)$we have:

$$\sum_{i=1}^{m} v_i^* x_{ij} - \sum_{r=1}^{s} u_r^* g_{rj} + \sum_{f=1}^{h} w_f^* b_{fj} + \sigma^* = 0.$$

Multiplying each of the above equations by η_j^*, and then summing them together, the following is found:

$$\sum_{i=1}^{m} v_i^* \left(\sum_{j \in R_1} \eta_j^* x_{ij} \right) - \sum_{r=1}^{s} u_r^* \left(\sum_{j \in R_1} \eta_j^* g_{rj} \right) + \sum_{f=1}^{h} w_f^* \left(\sum_{j \in R_1} \eta_j^* b_{fj} \right) + \sigma^* \sum_{j \in R_1} \eta_j^* = 0.$$

Similarly, for all j $(j \in R_2)$, $\mu_j^* > 0$, and then again by the complementary slackness conditions, the constraint associated with the dual problem must have zero slack. Therefore, for all j $(j \in R_2)$, we have:

$$\sum_{i=1}^{m} v_i^* x_{ij} + \sigma^* = 0.$$

Multiplying each of the above equations by μ_j^*, and then summing them together, it is obtained that:

$$\sum_{i=1}^{m} v_i^* \left(\sum_{j \in R_2} \mu_j^* x_{ij} \right) + \sigma^* \sum_{j \in R_2} \mu_j^* = 0.$$

Finally, by adding the two obtained equations, it is achieved that:

$$\sum_{i=1}^{m} v_i^* \left(\sum_{j \in R_1} \eta_j^* + \sum_{j \in R_2} \mu_j^* \right) x_{ij} - \sum_{r=1}^{s} u_r^* \left(\sum_{j \in R_1} \eta_j^* g_{rj} \right) + \sum_{f=1}^{h} w_f^* \left(\sum_{j \in R_1} \eta_j^* b_{fj} \right) + \sigma^* \left(\sum_{j \in R_1} \eta_j^* + \sum_{j \in R_2} \mu_j^* \right) = 0,$$

and then, $\sum_{i=1}^{m} v_i^* \hat{x}_{ik} - \sum_{r=1}^{s} u_r^* \hat{g}_{rk} + \sum_{f=1}^{h} w_f^* \hat{b}_{fk} + \sigma^* = 0,$. Therefore, the point$\left(\hat{x}_k, \hat{g}_k, \hat{b}_k\right) \in H$ and the proof is complete.

ESE and ERTS

This section, which is composed of three subsections, provides a new concept of scale economies in the presence of both desirable and undesirable outputs in the first subsection. In the second and the third subsections, two methods for measuring the ERTS of environmental issues are presented.

Definition of ESE

Scale economies (SE) is an economic concept which is explained as “an increase in a sum of weighted outputs due to a proportional increase in all inputs” (Baumol et al., 1982; Forsund, 1996). To discuss the measure of SE, consider a production possibility set in the case that there are one input (x) and one desirable output (g). See Figure 1.

Suppose that DMU_a is projected onto $\text{DMU}_{a'}$, and let the supporting hyperplane pass through $\text{DMU}_{a'}$ be $v^* x - u^* g + \sigma^* = 0$. The SE measure, which is called the scale elasticity (e) in the case of one input and one output, is measured by the fraction $e = \left(\frac{dg}{dx}\right) / \left(\frac{g}{x}\right)$. This fraction is the ratio of the marginal productivity with respect to the average productivity. Since the supporting hyperplane is $v^{*}x - u^{*}g + \sigma^{*} = 0$, , we have $\frac{dg}{dx} = \frac{v^{*}}{u^{*}}$ and $\frac{g}{x} = \frac{v^{*}}{u^{*}} + \frac{\sigma^{*}}{v^{*}x}$. Therefore, the scale elasticity is equal to $e = \left(\frac{dg}{dx}\right)/\left(\frac{g}{x}\right) = 1/\left(1 + \frac{\sigma^{*}}{v^{*}x}\right)$. Since $v^{*}x > 0$, the degree of the scale elasticity depends on the sign of σ^{*}. Consequently, according to Sueyoshi (1999) the type of the RTS is determined as follows:

a) $\sigma^{*} < 0 \;\; \dot{\Leftrightarrow} \;\; e > 1 \;\; \dot{\Leftrightarrow}$ Increasing RTS,
b) $\sigma^{*} > 0 \;\; \dot{\Leftrightarrow} \;\; e < 1 \;\; \dot{\Leftrightarrow}$ Decreasing RTS,
c) $\sigma^{*} = 0 \;\; \dot{\Leftrightarrow} \;\; e = 1 \;\; \dot{\Leftrightarrow}$ Constant RTS.

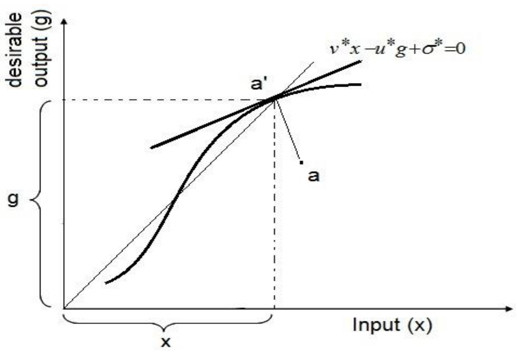

Fig. 1. The PPS of one input and one desirable output

For multiple inputs and multiple desirable outputs, the scale elasticity (e) is extended and the concept of scale economies (SE) is defined. According to Sueyoshi (1999), the SE measure can be computed for DMU_k as follows:

$$\text{SE} = \frac{v^{*}x_k}{u^{*}g_k} = \frac{v^{*}x_k}{v^{*}x_k + \sigma^{*}} = \frac{1}{1 + \frac{\sigma^{*}}{v^{*}x_k}}$$

Here, $u^{*}g_k$ has been replaced with $v^{*}x_k + \sigma^{*}$. The reason is that DMU_k is efficient, and therefore, it is on the hyperplane $v^{*}x_k - u^{*}g_k + \sigma^{*} = 0$. Based on the sign of σ^{*}, the SE measure and the type of the RTS are determined as follows:

a) $\sigma^{*} < 0 \;\; \dot{\Leftrightarrow} \;\; \text{SE} > 1 \;\; \dot{\Leftrightarrow}$ Increasing RTS,
b) $\sigma^{*} > 0 \;\; \dot{\Leftrightarrow} \;\; \text{SE} < 1 \;\; \dot{\Leftrightarrow}$ Decreasing RTS,
c) $\sigma^{*} = 0 \;\; \dot{\Leftrightarrow} \;\; \text{SE} = 1 \;\; \dot{\Leftrightarrow}$ Constant RTS.

Now the concept of SE is extended to a situation in which there are multiple inputs, multiple desirable outputs, and multiple undesirable outputs. In this case, the scale economies (SE) is called the environmental scale economies (ESE), and is defined as follows:

$$\mathrm{ESE} = \frac{v^* x_k}{u^* g_k - w^* b_k} \tag{3}$$

In the above fraction, the term $w^* b_k$was added in the denominator in order to include the undesirable outputs in SE measure along with the desirable outputs. The minus sign of this term is because of the contradictory characteristic of desirable and undesirable outputs. According to the above ratio, the environmental scale economies is defined as an increase in the sum of weighted desirable outputs plus a decrease in the sum of weighted undesirable outputs due to a proportional increase in all inputs.

In Formula (3), $(v^*, u^*, w^*, \sigma^*)$ is an optimal solution of Model (2) when $\mathrm{DMU_k}$ is efficient in the evaluation. Also, the returns to scale (RTS) in the presence of undesirable outputs is called the environmental returns to scale (ERTS), and is determined based on the value of ESE as follows:

a) $\mathrm{ESE} > 1 \overset{.}{\Leftrightarrow}$ Increasing ERTS,
b) $\mathrm{ESE} < 1 \overset{.}{\Leftrightarrow}$ Decreasing ERTS,
c) $\mathrm{ESE} = 1 \overset{.}{\Leftrightarrow}$ Constant ERTS.

The increasing ERTS implies that a unit increase in inputs increases the amount of desirable outputs with higher proportions and undesirable outputs with lower proportions to the unit increase in inputs. This means that if a company enhances its current size, it generates more proportional desirable outputs and less proportional undesirable outputs. Therefore, the suggested strategy is that the company may enhance its current size.

The decreasing ERTS means that a unit increase in inputs increases the amount of desirable outputs with lower proportions and undesirable outputs with higher proportions to the unit increase in inputs. Then, the suggested strategy is that such a company may decrease its current dimension in order to produce less pollution.

The constant ERTS means that a unit increase in inputs results in a "proportional" increase in desirable and undesirable outputs. In fact, the desirable and undesirable outputs are produced with the same previous proportions. Hence, such a company has an acceptable size, and it is encouraged that such a company maintain its current dimension.

Measurement of ERTS: First Method

This subsection attempts to examine how to estimate environmental returns to scale (ERTS) using Model (2). Here, the discussion focuses on determining the type of ERTS only for efficient DMUs, since inefficient DMUs have waste in their inputs or shortfall in their outputs, and therefore, they should first improve their inputs or outputs. Now suppose that DMU_k is efficient. According to Theorem 2, it is on the hyperplane

$$H = \left\{(x,g,b)\middle|\ \sum_{i=1}^{m} v_i^* x_i - \sum_{r=1}^{s} u_r^* g_r + \sum_{f=1}^{h} w_f^* b_f + \sigma^* \ = 0\right\},$$

where $(v^*, u^*, w^*, \sigma^*)$ is an optimal solution of Model (2) for evaluating DMU_k. Hence, we have:

$$\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^* \ = 0 \qquad (4)$$

In the previous subsection, ESE was defined as an increase in the sum of weighted desirable outputs and also a decrease in the sum of weighted undesirable outputs due to a proportional increase in all inputs. Consequently, using Formulas (3) and (4), we have:

$$\mathrm{ESE} = \frac{\sum_{i=1}^{m} v_i^* x_{ik}}{\sum_{r=1}^{s} u_r^* g_{rk} - \sum_{f=1}^{h} w_f^* b_{fk}} = \frac{\sum_{i=1}^{m} v_i^* x_{ik}}{\sum_{i=1}^{m} v_i^* x_{ik} + \sigma^*} = \frac{1}{1 + \frac{\sigma^*}{\sum_{i=1}^{m} v_i^* x_{ik}}} \qquad (5)$$

According to the sign of σ^*, the degree of ESE and the type of

ERTS are determined as follows:

a) $\sigma^* < 0 \ \dot{\Leftrightarrow} \ ESE > 1 \ \dot{\Leftrightarrow}$ Increasing ERTS,

b) $\sigma^* > 0 \ \dot{\Leftrightarrow} \ ESE < 1 \ \dot{\Leftrightarrow}$ Decreasing ERTS,

c) $\sigma^* = 0 \ \dot{\Leftrightarrow} \ ESE = 1 \ \dot{\Leftrightarrow}$ Constant ERTS.

If Model (2) has multiple optimal solutions, then

1. Increasing ERTS prevails at DMU_kif and only if $\sigma^* < 0$, for all the optimal solutions of Model (2),
2. Decreasing ERTS prevails at DMU_k if and only if $\sigma^* > 0$, for all the optimal solutions of Model (2),
3. Constant ERTS prevails at DMU_k if and only if $\sigma^* = 0$ for at least one optimal solution of Model (2).

To determine the sign of σ^* in all of the optimal solutions of Model (2), the sign of the maximum and the minimum amounts of σ^* needs to be determined. Therefore, the two following models are introduced:

$$\begin{aligned}
&\overline{\sigma} = \max \ \sigma \qquad \left(\underline{\sigma} = \min \ \sigma\right) && (6)\\
&\text{s.t.} \ \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq 0 \qquad (j = 1, \dots, n),\\
&\sum_{i=1}^{m} v_i x_{ij} + \sigma \geq 0 \qquad (j = 1, \dots, n),\\
&\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma = 0,\\
&v_i \geq B_i^x \qquad (i = 1, \dots, m),\\
&u_r \geq B_r^g \qquad (r = 1, \dots, s),\\
&w_f \geq B_f^b \qquad (f = 1, \dots, h).
\end{aligned}$$

After obtaining the two values of $\overline{\sigma}$ and $\underline{\sigma}$, which are respectively the upper and the lower bounds of the intercept of Hyperplane H, the type of ERTS is estimated as follows:

a) If $\overline{\sigma} < 0$, then increasing ERTS prevails at DMU_k.

b) If $\underline{\sigma} > 0$, , then decreasing ERTS prevails at DMU_k.

c) Under other circumstances, constant ERTS prevails at DMU_k.

Based on the above discussion, the following algorithm is provided for determining the type of ERTS of DMU_k using the first method.

Algorithm 1:

Step 1.

Solve Model (2). Assume that $(v^*, u^*, w^*, \sigma^*)$ is an optimal solution of this model for evaluating DMU_k. Go to Step 2.

Step 2.

I. If DMU_k is found to be efficient, i.e., the value of the objective function of Model (2) is zero, then, go to Step 3.
II. If DMU_k is inefficient, it should first solve its inefficiency problem.

Step 3.

I. If $\sigma^* = 0$, then, constant ERTS prevails at DMU_k, and end.
II. If $\sigma^* > 0$, , solve Model (6) and determine the amount of $\underline{\sigma}$. If $\underline{\sigma} > 0$, then, decreasing ERTS prevails at DMU_k; else constant ERTS prevails at DMU_k, and end.
III. If $\sigma^* < 0$, solve Model (6) and determine the amount of $\overline{\sigma}$. If $\overline{\sigma} < 0$, then, increasing ERTS prevails at DMU_k; else, constant ERTS prevails at DMU_k, and end.

Therefore, to determine the type of ERTS of each DMU, at most two linear programming problems need to be solved. In the next subsection the measurement of ERTS is discussed from the other viewpoint.

Measurement of ERTS: Second Method

In this part, another method is proposed for determining the type of ERTS of DMUs. Consider Model (1) again that includes the constraint $\sum_{j=1}^{n}(\eta_j + \mu_j) = 1$ with equality sign. Moreover, consider the following Models (7) and (8).

Model (7) is similar to Model (1). The only difference is that the constraint $\sum_{j=1}^{n}(\eta_j + \mu_j) = 1$ has been omitted from the model. In Model (8), the sign of the constraint $\sum_{j=1}^{n}(\eta_j + \mu_j) = 1$ has been changed to less than or equal to 1. Let θ_1^*, θ_7^* and θ_8^* denote the optimal objective function values of the models (1), (7), and (8), respectively. Theorem 3 expresses how to find the type of ERTS by means of these three optimal values.

$$\theta_7^* = \max \quad \sum_{i=1}^{m} B_i^x \, s_i^x + \sum_{r=1}^{s} B_r^g \, s_r^g + \sum_{f=1}^{h} B_f^b \, s_f^b \qquad (7)$$

$$\text{s.t.} \quad \sum_{j=1}^{n} (\eta_j + \mu_j) \, x_{ij} + s_i^x = x_{ik} \qquad (i = 1, \dots, m),$$

$$\sum_{j=1}^{n} \eta_j \, g_{rj} - s_r^g = g_{rk} \qquad (r = 1, \dots, s),$$

$$\sum_{j=1}^{n} \eta_j \, b_{fj} + s_f^b = b_{fk} \qquad (f = 1, \dots, h),$$

$$\eta_j \geq 0 \, , \, \mu_j \geq 0, \qquad (j = 1, \dots, n),$$

$$s_i^x \geq 0 \;\; (i = 1, \dots, m), \;\; s_r^g \geq 0 \; (r = 1, \dots, s), \; s_f^b \geq 0 \; (f = 1, \dots, h).$$

$$\theta_8^* = \max \quad \sum_{i=1}^{m} B_i^x \, s_i^x + \sum_{r=1}^{s} B_r^g \, s_r^g + \sum_{f=1}^{h} B_f^b \, s_f^b \qquad (8)$$

$$\text{s.t.} \quad \sum_{j=1}^{n} (\eta_j + \mu_j) \, x_{ij} + s_i^x = x_{ik} \qquad (i = 1, \dots, m),$$

$$\sum_{j=1}^{n} \eta_j \, g_{rj} - s_r^g = g_{rk} \qquad (r = 1, \dots, s),$$

$$\sum_{j=1}^{n} \eta_j \, b_{fj} + s_f^b = b_{fk} \qquad (f = 1, \dots, h),$$

$$\sum_{j=1}^{n} (\eta_j + \mu_j) \leq 1 \, , \quad \eta_j \geq 0 \, , \mu_j \geq 0 \qquad (j = 1, \dots, n),$$

$$s_i^x \geq 0 \;\; (i = 1, \dots, m), \;\; s_r^g \geq 0 \; (r = 1, \dots, s), \; s_f^b \geq 0 \; (f = 1, \dots, h).$$

Theorem 3. Let DMU_k be efficient under Model (1), i.e. $\theta_1^* = 0$.

Case 1: If $\theta_1^* = \theta_7^* = \theta_8^* = 0$, then, constant ERTS prevails at DMU_k.

Case 2: If $\theta_1^* < \theta_7^*$, , then, if $\theta_1^* = \theta_8^*$, decreasing ERTS prevails at DMU_k.

Case 3: If $\theta_1^* < \theta_7^*$, then, if $\theta_1^* < \theta_8^*$, , increasing ERTS prevails at DMU_k.

Proof. Let S_1, S_7 **,** and S_8 be the feasible regions of models (1), (7), and (8), respectively. It is evident that $S_1 \subseteq S_8 \subseteq S_7$, , and therefore,

$\theta_1^* \leq \theta_8^* \leq \theta_7^*$**.** Consider Model (2) and the following Models (9) and (10) as the dual problems of Models (1), (7), and (8), respectively.

$$\theta_7^* = \min \sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} \tag{9}$$

$$\begin{aligned}
\text{s.t.} \quad & \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} \geq 0 && (j = 1, \dots, n), \\
& \sum_{i=1}^{m} v_i x_{ij} \geq 0 && (j = 1, \dots, n), \\
& v_i \geq B_i^x && (i = 1, \dots, m), \\
& u_r \geq B_r^g && (r = 1, \dots, s), \\
& w_f \geq B_f^b && (f = 1, \dots, h).
\end{aligned}$$

$$\theta_8^* = \min \sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \tag{10}$$

$$\begin{aligned}
\text{s.t.} \quad & \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq 0 && (j = 1, \dots, n), \\
& \sum_{i=1}^{m} v_i x_{ij} + \sigma \geq 0 && (j = 1, \dots, n), \\
& v_i \geq B_i^x && (i = 1, \dots, m), \\
& u_r \geq B_r^g && (r = 1, \dots, s), \\
& w_f \geq B_f^b && (f = 1, \dots, h), \\
& \sigma \geq 0.
\end{aligned}$$

According to the duality theorem (Bazarra et al., 2010), the optimal value of the objective function of Model (1) is equal to that of Model (2). By similar demonstrations, $\theta_7^* = \theta_9^*$ an$\theta_8^* = \theta_{10}^*$d, as well.

Case 1: Let $E = (v^*, u^*, w^*)$ be an optimal solution of Model (9). As a result, $E' = (E, 0)$ is a feasible solution of Model (2) with zero objective function value. The objective function value of Model (2) is greater than or equal to zero. Since, $E' = (E, 0)$ has the best objective function value in Model (2), then, $E'$is the optimal solution of Model

(2) with $\sigma^* = 0$. According to the first method, it can be concluded that DMU_k has constant ERTS.

Case 2: Let $E = (v^*, u^*, w^*, \sigma^*)$ be an optimal solution of Model (10). Then, E is a feasible solution of Model (2), as well. The objective function values of Models (10) and (2) for feasible solution E is equal to zero. The objective function value of Model (2) is greater than or equal to zero; therefore, E has the best objective function value in Model (2). It shows that E is the optimal solution of Model (2) with $\sigma^* \geq 0$.. Also, it is claimed that $\sigma^* \neq 0$. If $\sigma^* = 0$, then, E is the feasible solution of Model (9) with the objective function value equal to zero, and therefore, E is the optimal solution of Model (9). This shows that $\theta_7^* = 0$, which is a contradiction. Therefore, $\sigma^* > 0$. According to the first method, DMU_k cannot have increasing ERTS, because in all optimal solutions of Model (2) σ^* is not less than zero. It is also claimed that DMU_k cannot have constant ERTS. If DMU_k has constant ERTS, according to the first method, there exists an optimal solution for Model (2) with $\sigma^* = 0$. This optimal solution is also optimal in Model (7). This indicates that $\theta_1^* = \theta_7^* = \theta_8^* = 0$, which is a contradiction. Therefore, it can be concluded that DMU_k has decreasing ERTS.

Case 3: Let $E = (v^*, u^*, w^*, \sigma^*)$ be an optimal solution of Model (2) with the objective function value equal to zero. It is claimed that $\sigma^* < 0$. If $\sigma^* \geq 0$, then, E is an optimal solution of Model (10), and the optimal value of Model (10) is zero, which is a contradiction. According to the first method, DMU_k cannot have decreasing ERTS because $\sigma^*$is not greater than zero in all optimal solutions of Model (2). Also, DMU_k cannot have constant ERTS. If DMU_k has constant ERTS, according to the first method, there exists an optimal solution for Model (2) with $\sigma^* = 0$. This optimal solution is also optimal in Model (9). This indicates that $\theta_1^* = \theta_7^* = \theta_8^* = 0$, which is a contradiction. Therefore, DMU_k has increasing ERTS.

In the algorithm below, the procedure of the second method is shown in an easy understanding way.

Algorithm 2:

Step 1.

Solve Model (1). If $\theta_1^* = 0$, DMU_k is efficient. Go to Step 2.

Step 2.

Solve Model (7). If $\theta_7^* = 0$, DMU_k has constant ERTS and end. Otherwise, go to Step 3.

Step 3.

Solve Model (8).

I. If $\theta_8^* = 0$, DMU_k has decreasing ERTS, and end.

II. If $\theta_8^* > 0$, DMU_k has increasing ERTS, and end.

The next section will show the applicability of the two proposed methods for evaluating the status of environmental returns to scale of Japanese electric power companies.

Numerical Example

To illustrate the efficacy of the above mentioned methods, this section employs the proposed methods to assess the environmental performance and determine the type of environmental returns to scale of nine Japanese electric power companies. The data of these companies were applied by Sueyoshi and Goto (2011a) for a period of 3 years from 2006 to 2008. In our paper, only the data set of nine companies for the year 2008 has been used.

These nine companies consume two inputs in order to produce two desirable outputs and one undesirable output. The data set of these companies is given in Table 2. For the ease of comparison, the companies are labeled D1 to D9, displayed in the second column of Table 2. The inputs and outputs, which are considered in the evaluation, are as follows:

Input 1 (TA): The total amount of assets

Input 2 (TLC): The total amount of labor cost

Desirable output 1 (TS): The total amount of sales

Desirable output 2 (NC): The number of customers

Undesirable output (CO_2): The total amount of CO_2 emission

Table 2. Data set of nine electric power companies

Electric power company	DMU	TA (100 Billion JPY)	TLC (100 Billion JPY)	TS (100 GWh)	NC (100 Thousand)	CO_2 (100 Thousand ton)
Hokkaido	D1	15.6	0.5	318.4	39.4	167.8
Tohoku	D2	36.8	1.5	811	76.8	397.9
Tokyo	D3	129.9	4.8	2889.6	284.9	1265
Chubu	D4	51.1	1.9	1297.3	104.6	646.7
Hokuriku	D5	14.2	0.5	281.5	20.8	185.2
Kansai	D6	62.4	2.4	1458.7	134	549.9
Chugoku	D7	26.1	1.1	612.2	51.9	430.7
Shikoku	D8	13.5	0.7	287	28.3	114.6
Kyushu	D9	38.3	1.4	858.8	84	341

Table 3 summarizes the environmental efficiency scores of the companies and their type of ERTS along with the upper and lower bounds of σ^*, using the first method. The third column of Table 3 denoted by Γ_E, shows the results of the environmental efficiency scores computed under Model (1). This column reveals that the companies of Tohoku and Chugoku have obtained $\Gamma_E \neq 1$ and are identified as environmentally inefficient companies. The other seven companies (D1, D3, D4, D5, D6, D8, and D9) are identified as the environmentally efficient industries and attain full efficiency, i.e., $\Gamma_E = 1$ Thus, it is concluded that these seven DMUs have been fully concerned about the management of their undesirable output while attempting to achieve their commercial targets.

The other columns of Table 3 from left to right depict the amounts of σ^*, $\underline{\sigma}$and $\overline{\sigma}$, respectively. The column denoted by $\sigma^*$is obtained by solving Model (2) and the columns denoted by $\underline{\sigma}$ and $\overline{\sigma}$ are obtained by solving Model (6). These amounts have been calculated only for the efficient companies, since the type of ERTS is only being discussed for efficient DMUs. In the last column of Table 3, I, C, and D stand for increasing, constant, and decreasing ERTS, respectively.

Table 3. The environmenal efficiency scores and the type of ERTS using the first method

Electric power company	Γ_E	σ^*	$\underline{\sigma}$	$\overline{\sigma}$	ERTS
Hokkaido	1	0			C
Tohoku	0.90561				
Tokyo	1	0.00947	0.00946		D
Chubu	1	-0.02666		$+\infty$	C
Hokuriku	1	-5.0962		-3.13767	I
Kansai	1	0			C
Chugoku	0.86913				
Shikoku	1	-1.0927		$+\infty$	C
Kyushu	1	0.04735	$-\infty$		C

The empirical results in Table 3 imply that most of the electric power companies belong to constant ERTS. There are only two DMUs that one of which exhibits decreasing ERTS (Tokyo), and the other one shows increasing ERTS (Hokuriku). However, five DMUs belong to the constant ERTS.

Table 4 shows the type of ERTS which is obtained for the Japanese electric power companies using the second method. The columns denoted by θ_1^*, θ_7^*, and θ_8^* in Table 4, are the optimal objective function values of the models (1), (7), and (8), respectively.

As evident from Tables 3 and 4, the two methods produce the same type of ERTS for the environmentally efficient companies.

The results of Table 4 reveal that one company (Hokuriku) belongs to increasing ERTS and one company (Tokyo) belongs to decreasing ERTS. The other five electric power companies, Hokkaido, Chubu, Kansai, Shikoku, and Kyushu achieve constant ERTS. These five companies have the highest performance and the most desirable size. It is recommended that these electric power companies maintain their current size, because a unit increase in their inputs results in a "proportional" increase in their desirable and undesirable outputs. As a result, they have an acceptable size and may retain their current size.

Table 4. The type of ERTS using the second method

Electric power company	θ_1^*	θ_7^*	θ_8^*	ERTS
Hokkaido	0	0	0	C
Tohoku	0.094394	0.105939	0.105939	
Tokyo	0	0.023994	0	D
Chubu	0	0	0	C
Hokuriku	0	1.017658	1.017658	I
Kansai	0	0	0	C
Chugoku	0.130873	0.170339	0.170339	
Shikoku	0	0	0	C
Kyushu	0	0	0	C

Although, the efficiency score of the Tokyo is equal to one and the company has the best performance, however, the size of this company is not optimal, and therefore, it is economical for this company to diminish its current dimension. It is because a unit increase in its inputs generates desirable outputs with a lower proportion and undesirable outputs with a higher proportion than the unit increase in its inputs. Thus, it is suggested that such a company may decrease its current size to avoid producing more pollution.

Hokuriku electric power company shows increasing ERTS. This means that a unit increase in its inputs yields desirable outputs with a higher proportion and undesirable outputs with a lower proportion than the unit increase in its inputs. Then, the suggested strategy is that it may enhance its current size. In this situation, the company can increase its operational size by using advanced technology or managerial effort to produce less CO_2 emission.

Since Tohoku and Chugoku electric power companies are inefficient, the type of ERTS is not computed for them. The reason is that these companies have waste in their inputs, shortfall in their desirable outputs, or excess in their undesirable outputs. They first need to improve their performance by increasing the amount of their desirable output or decreasing the amount of their inputs or undesirable output.

Table 5. The results of Sueyoshi and Goto (2011b)

Electric power company	RTS	DTS	RTS(U)	DTS(U)
Hokkaido	C	I	C	I
Tohoku	I	I	D	I
Tokyo	C	I	I	I
Chubu	I	I	D	I
Hokuriku	I	I	C	I
Kansai	I	I	I	I
Chugoku	I	I	D	I
Shikoku	I	C	I	I
Kyushu	I	I	D	I

Note: This table is reported from Sueyoshi and Goto (2011b)

Now consider Table 5 which reports the results of Sueyoshi and Goto (2011b) for measuring returns to scale of environmental issues. They introduced the new concepts of damages to scale (DTS) and scale damages (SD) to undesirable outputs, associated with RTS and SE on desirable outputs. Then, they combined these concepts in a unified treatment and presented the concepts of RTS unified (RTSU) and DTS unified (DTSU). Acknowledging the contribution of their study, this research needs to mention that they treated the undesirable outputs as inputs for measuring the environmental performance, and moreover, they provided two separate indicators for each DMU (RTSU and DTSU) which may encounter the decision maker by two different strategies.

For example, consider Tohoko in Table 5. It shows increasing RTS which implies that a unit increase in inputs increases desirable outputs with higher proportions. Therefore, it is logical for Tohoko to increase its current size in order to make more profits. However, the increasing DTS of Tohoko does not allow it to increase its current size. Since, its increasing DTS indicates that a unit increase in inputs increases its undesirable output (CO_2 emission) with higher proportion. Therefore, increasing the size of Tohoko is equal to producing more pollution in the environment. This contradictory condition, increasing RTS and increasing DTS, is also held for the other five companies (Chubu, Hokuriku, Kansai, Chugoku, Kyushu). A similar situation occurs in the interpretation of RTS(U) and DTS(U). In fact, the problem is that Sueyoshi and Goto separated desirable and undesirable outputs, however, we considered both of them together as outputs and combined them in the ESE and ERTS measures for returns to scale evaluation.

Summary and Conclusion

In recent years, the assessment of environmental performance has received considerable attention by decision makers and environmental strategy advocators. Nowadays, increased emission of CO_2 into the air, water pollution, climate change, and global warming are universal problems all over the world. Therefore, development of firms with less CO_2 emission and various types of pollutants is an important issue of attention in every area of production.

In this paper, data envelopment analysis (DEA) was applied as a management tool for evaluating the environmental performance of firms. Afterwards, a non-radial DEA efficiency measure, extended recently by Zare Haghighi and Rostamy-Malkhalifeh (2017) was employed for assessing the environmental performance. This model includes both desirable and undesirable outputs within an integrated model for efficiency evaluation.

The concepts of returns to scale (RTS) and scale economies (SE) have been discussed extensively in the DEA literature. However, investigating these issues in the presence of undesirable outputs has not been given the deserved attention in the last few decades. Then, this study presented two approaches to measure RTS for environmental assessment within the computational framework of DEA. Associated with SE and RTS for desirable outputs, the new concepts of environmental scale economies (ESE) and environmental returns to scale (ERTS) were proposed for both desirable and undesirable outputs.

Thereafter, the proposed approaches were employed to analyze the environmental performance of nine Japanese electric power companies. It is obvious that the electric power companies generate undesirable outputs like CO_2 emission, along with desirable outputs within their operative activities. In fact, a main contribution of this paper is that it has included the amount of CO_2 emission as an environmental output in the returns to scale measurement.

Then, environmental efficient DMUs were identified by solving Model (1). Afterwards, the type of ERTS was determined for the efficient ones using the two proposed methods. According to our DEA results, five DMUs belonged to constant ERTS, one DMU belonged to increasing ERTS, and one DMU belonged to decreasing ERTS. Based on the type of ERTS, increasing, decreasing or maintaining the size of the companies was suggested. Also, the computational efficiency of our proposed approaches was compared with the existing method in Sueyoshi and Goto (2011b) in order to illustrate the merits of the proposed methods.

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