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Measuring eco-efficiency based on green indicators and potentials in energy saving and undesirable output abatement

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ABSTRACT

Nowadays, majority of organizations are seeking to achieve sustainable development with respect to "green" concept. One of the main criteria for assessing green performance is eco-efficiency. To identify all aspects of the eco-efficiency, inputs should be divided into energy and non-energy and outputs should be divided into good and bad outputs. To deal with this issue, a data envelopment analysis (DEA) model is developed to divide inputs into both energy and non-energy and outputs into both desirable (good) and undesirable (bad) outputs. Likewise, variables are separated into both discretionary and non-discretionary factors. Accordingly, a bounded adjusted measure (BAM) based on green indicators is developed to calculate the eco-efficiency of decision making units (DMUs). Besides, energy saving potentials and undesirable output abatement potentials are calculated to show correlation coefficient between energy consumption and undesirable output. Finally, proposed model is validated by assessing the eco-efficiency of some selected members of organization for economic cooperation and development (OECD). Australia, Finland, Ireland, New Zealand, and Switzerland are recognized as eco-efficient countries and the rest of countries are inefficient in terms of the eco-efficiency. High and positive Spearman correlation coefficient between energy consumption and undesirable outputs addresses that the more use of energy inputs, the more undesirable outputs.

1. Introduction

Generally, sustainable development has two components; "development" and "essentials of sustainability" (Mitlin, 1992). The World Commission on Environment and Development defined sustainable development as follows: "to ensure that development meets the needs of the present without compromising the ability of future generations to meet their own needs" (Picazo-Tadeo et al., 2011). This definition was a start point for many authors. Nowadays, defining and measuring sustainability of production systems have become a popular issue. It is important to take into account both economic and environmental factors in decision making. As Coli et al. (2011) addressed, entities should not only maximize their economic aims but also they need to minimize their environmental concerns.

Competitive advantage in environmental efficiency will be a norm for any entity. Considering economic, environmental, and social factors may lead to sustainability (Koplin et al., 2007). To reach sustainable development, entities seek to achieve higher environmental efficiency. On the other hand, governments force organizations to follow sustainability issues more seriously (Schaltegger and Burrit, 2005).

One of the widely-applied tools for measuring sustainable performance of decision making units (DMUs) is the eco-efficiency measure (Wang et al., 2011). The eco-efficiency measure is a main criterion to assess abilities of DMUs in terms of economic and environmental objectives (Huppes and Ishikawa, 2009). Sustainability can be evaluated by the eco-efficiency. Meanwhile, experts can determine to what extent DMUs follow environmental rules (Lee and Farzipoor Saen, 2012). World Business Council for Sustainable Development (WBCSD) defined the eco-efficiency as follows:

"Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to the level at least in line with the Earth's estimated carrying capacity".

In short, the eco-efficiency is concerned with creating more value with less impact (World Business Council for Sustainable Development, 2000). Therefore, reducing environmental impact of

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a product and increasing its economic value can promote the eco-efficiency (Huppes, 2009).

Eco-efficiency assessment is a complicated and multidisciplinary task (Zhao et al, 2006). There are numerous approaches to deal with this problem. However, most of them assign subjective weights to criteria. Indeed, this is a kind of personal judgment which may lead to inaccurate results. One of the popular techniques to deal with this difficulty is data envelopment analysis (DEA) which allocates optimal weights to criteria (Azadi et al., 2012; Azadi and Farzipoor Saen, 2012; Farzipoor Saen, 2009). DEA is a managerial technique for measuring relative efficiency of DMUs. In previous studies, the eco-efficiency has been measured in the presence of only undesirable outputs or energy efficiency has been calculated with respect to only energy inputs. In this paper, for the first time, the eco-efficiency is measured by considering outputs (desirable and undesirable), inputs separation (energy and non-energy), discretionary, and non-discretionary factors. To illustrate linkage between energy inputs and undesirable outputs, energy saving potential (ESP) and undesirable output abatement potential (UOAP) are calculated. We calculate these potentials to determine how much each DMU can save energy inputs and reduce undesirable outputs. In this paper, bounded adjusted measure (BAM) model is extended to assess the eco-efficiencies of organization for economic cooperation and development (OECD) members in the presence of green factors. Then, ESP and UOAP are measured for inefficient DMUs. Spearman correlation coefficient is calculated to identify the relationship between energy consumptions and emissions. Furthermore, a green index is proposed to evaluate pure eco-performance. Finally, DMUs are ranked with respect to ESPs and UOAPs. In summary, contributions of this paper are as follows:

- For the first time, we calculate the eco-efficiency of some of OECD members based on BAM model in the presence of green indicators.
- For the first time, we measure the potentials of inefficient DMUs to become efficient based on their slacks.
- For the first time, we introduce a green index to assess the pure eco-performance with only energy inputs and undesirable outputs.
- For the first time, we compare inefficiencies of inefficient DMUs based on the calculated potentials.

The rest of this paper is organized as follows: Literature review is presented in Section 2. New models are extended in Section 3. Section 4 provides a case study, managerial implications, and data analysis. Finally, concluding remarks are given in Section 5.

2. Literature review

Färe et al. (1989) stated that considering undesirable outputs as inputs contradicts assumptions of production theory. They considered weak disposability assumption in modeling the undesirable outputs. Weak disposability means that it is possible to reduce undesirable outputs by decreasing the level of production activity. Korhonen and Luptacik (2004) treated undesirable outputs as inputs. They increased desirable outputs by decreasing inputs and undesirable outputs. This concept of measuring the eco-efficiency is strong disposability assumption. In this paper, we treat undesirable outputs as inputs and increase desirable outputs.

Korhonen and Luptacik (2004) assessed the eco-efficiency of 24 power plants in Europe. They dealt with undesirable outputs as inputs. They proposed two approaches for measuring the eco-efficiency. The first approach estimated the technical and ecological efficiencies, separately. In the second approach different variants of DEA models were applied for estimating eco-efficiency in which the inputs, undesirable outputs, and desirable outputs were considered. Kuosmanen and Kortelainen (2005) measured the eco-efficiency of road transportation in three cities of eastern Finland. They incorporated weight restrictions into a radial DEA model and also focused on the environmental pressures rather than specific undesirable outputs. Zhang et al. (2008) analyzed the eco-efficiency of industrial parks in China. They considered undesirable outputs in their DEA model. Barba-Gutiérrez et al. (2009) proposed a simple DEA model to assess the eco-efficiency of appliances. They considered retail price as a measure of product's economic value and life cycle assessment (LCA) score as a proxy for environmental impact. Yang et al. (2011) used ecological Shannon DEA procedure to calculate eco-efficiency score for each DMU. They incorporated undesirable outputs into the eco-efficiency evaluation of 32 paper mills in China. To improve environmental performance, Avadi et al. (2014) identified differences in the eco-efficiencies of different fleet segments. To this end, they integrated LCA and DEA to obtain desirable operational benchmarks. They used slacks-based measure model to evaluate the eco-efficiency. Egilmez and Park (2014) employed two-step hierarchical methodology to determine the amount of energy, carbon, and water footprint of nation's manufacturing sectors. They integrated economic input–output LCA (EIO-LCA) and DEA to evaluate environmental performance.

Most of the papers on eco-efficiency measurement deal with simple indicators. As discussed above, some authors have incorporated undesirable outputs and weight restrictions into the eco-efficiency measurement. However, these contributions are not sufficient for the eco-efficiency measurement. Furthermore, previous models cannot evaluate the eco-efficiency precisely. Some of them use simple radial DEA models to evaluate the eco-efficiency which are unable to consider neither slacks variables nor simultaneous reduction in inputs and expansion in outputs. There is no comprehensive model to compute the eco-efficiency measurement.

On the other hand, most of the eco-efficiency indicators have focused only on firms or products. However, governments and international organizations are also interested in measuring eco-efficiencies in macro-levels. Zaim and Taskin (2000a, 2000b) developed an environmental efficiency index for the OECD countries. They applied cross-sectional comparisons to show change of production processes of countries in multiple periods. Zofio and Prieto (2001) defined environmental efficiency and regulatory standards for OECD industries based on CO_2 emissions. They evaluated desirable output losses in the presence of environmental standards. Färe et al. (2004) proposed an index for assessing environmental performance of OECD countries based on DEA. Their environmental performance index is obtained from distance functions. Arcelus and Arocena (2005) applied DEA to minimize emission level and to maximize desirable outputs. Zhou et al. (2008) reviewed environmental DEA technologies including non-increasing returns to scale and variable returns to scale. They suggested pure measures for evaluating environmental performance. Finally, they computed carbon emission performance of OECD countries. Rashidi et al. (in press) calculated the eco-efficiency of 25 OECD countries based on slacks-based measure (SBM) and range adjusted measure (RAM). The SBM model cannot determine lower and upper bounds for inputs and outputs. Also, the RAM model has no discriminating power to calculate the eco-efficiencies. Moreover, to the best of our knowledge, there is no reference for evaluating the eco-efficiency of OECD countries based on a comprehensive DEA model which considers the adjusted bounds for inputs and outputs.

Now this question is raised: Is there any comprehensive framework for evaluating the eco-efficiency of OECD countries by a non-radial DEA model with high discriminating power and adjusted measures for inputs and outputs? Or is there any approach to measure the eco-performance of OECD countries considering the relationship between energy inputs and undesirable outputs? With respect to the above literature the main purpose of this study is to develop a non-radial model for calculating the eco-efficiency of OECD countries based on both inputs and outputs' separations in the presence of non-discretionary factors. Besides, we wish to analyze relationship between energy inputs and