Energy Policy 88 (2016) 100–112

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

An evaluation of energy-environment-economic efficiency for EU, APEC and ASEAN countries: Design of a Target-Oriented DFM model with fixed factors in Data Envelopment Analysis

Soushi Suzuki [a,*], Peter Nijkamp [b,c]

[a] Hokkai-Gakuen University, Department of Life Science and Technology, 1-1, South26 West 11, Chuo-ku, 064-0926 Sapporo, Japan
[b] VU University Amsterdam, Department of Spatial Economics, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands
[c] A. Mickiewicz University, Poznan, Poland

HIGHLIGHTS

- We examine energy-environment-economic efficiency in European and A&A countries.
- We present an operational efficiency improvement strategy using DEA.
- European countries tend to have higher energy efficiency than A&A countries.
- The study provides efficiency-enhancing strategic paths for inefficient countries.

ARTICLE INFO

Article history:
Received 22 June 2015
Received in revised form
5 October 2015
Accepted 10 October 2015

Keywords:
Data Envelopment Analysis (DEA)
Distance Friction Minimisation (DFM)
Target-Oriented (TO) method
Fixed factor (FF)
Energy-environment-economic efficiency
EU
APEC
ASEAN countries

ABSTRACT

This paper aims to offer an advanced assessment methodology for sustainable national energy-environment-economic efficiency strategies, based on an extended Data Envelopment Analysis (DEA). The use of novel efficiency-improving approaches based on DEA originates from the so-called Distance Friction Minimisation (DFM) method. To design a feasible improvement strategy for low-efficiency DMUs, we develop here a Target-Oriented (TO) DFM model. However, in many real-world cases input factors may not be flexibly adjusted in the short run. In this study, we integrate the TO-DFM model with a fixed (inflexible) factor (FF) approach to cope with such more realistic circumstances. Super-efficiency DEA is next used in our comparative study on the efficiency assessment of energy-environment-economic targets for the EU, APEC and ASEAN (A&A) countries, employing appropriate data sets from the years 2003 to 2012. We consider two inputs (primary energy consumption and population) and two outputs (CO_2 and GDP), including a fixed input factor (viz. population). On the basis of our DEA analysis results, EU countries appear to exhibit generally a higher efficiency than A&A countries. The above-mentioned TO-DFM-FF projection model is able to address realistic circumstances and requirements in an operational sustainability strategy for efficiency improvement in inefficient countries in the A&A region.

1. Introduction

Balanced economic growth has to be accompanied simultaneously by resource and environment conservation in a sustainable world. In 2014, the 'International Energy Efficiency Scorecard', published by ACEEE (American Council for an Energy-Efficient Economy, 2014), pointed out: 'Countries can preserve their resources, address global warming, stabilize their economies, and reduce the costs of their economic outputs by using energy more efficiently—an eminently achievable goal.' This report analysed the world's 16 largest economies (countries/regions). The report looked at 31 criteria, divided roughly in half-between policies and quantifiable performance in order to evaluate how efficiently these economies use energy. The scores for the policy criteria were based on the presence in a country/region of a best-practice policy. However, this evaluation relied heavily on rather subjective policy criteria. Therefore, the actual conditions of energy efficiency for each country/region were not evaluated in an appropriate or

* Corresponding author.
E-mail addresses: soushi-s@lst.hokkai-s-u.ac.jp (S. Suzuki), p.nijkamp@vu.nl (P. Nijkamp).

http://dx.doi.org/10.1016/j.enpol.2015.10.007
0301-4215/

testable manner.

A standard tool by which to judge efficiency among different actors is Data Envelopment Analysis (DEA), proposed by Charnes et al. (1978) (hereafter CCR: see Appendix A1). This has become over the past decades an established quantitative assessment method in the evaluation literature. Seiford (2005) mentions even more than 2800 published articles on DEA in various fields and this number is nowadays already much higher. Nowadays, there are also in a sustainability context several assessment studies that have applied DEA models to measure aggregate energy-environment-economic efficiency among countries or regions, regarded as Decision Making Units (DMUs). For example, Zhou et al. (2008) presented a literature survey on the application of DEA to energy and environmental (E&E) studies, followed by a classification of 100 publications in this field. This study argues that all this research which provides lists of DMUs is confined to just one country or major region, such as the OECD, APEC, and the EU, or developing countries, but without a rigorous cross-regional comparison, for example, the EU vs. APEC and ASEAN (hereafter A&A). The A&A countries are regions where remarkable economic development is taking place, but comparing them from the viewpoint of energy-environment-economic efficiency with the performance of EU countries brings to light often contrasting findings. Martínez (2011) measures energy-efficiency development in non-energy-intensive sectors (NEISs) in both Germany and Colombia, based on a DEA model. And Wu et al. (2014) apply a DEA model – and calculate related Malmquist indices – for an efficiency evaluation of regions in China. The above list of studies shows that comparative efficiency analysis in the energy-environment sector using DEA models has increasingly become an important research topic in recent years (see also Suzuki et al. (2011)).

It should be noted that DEA was originally developed to analyse the relative efficiency of a DMU by constructing a piecewise linear production frontier and projecting the performance of each DMU onto that frontier. A DMU that is located on the frontier is efficient, whereas a DMU that is off on the frontier is inefficient. The wealth of DEA studies has demonstrated that an inefficient DMU can become efficient by reducing its inputs, or by increasing its outputs. In the standard DEA approach, this is achieved by a uniform reduction in all inputs (or a uniform increase in all outputs). However, in principle, there are an infinite number of possible improvements that could be implemented in order to reach the efficient frontier, and, hence, there are many solutions should a DMU plan to enhance its efficiency. We refer to the standard textbook of Cooper et al. (2006) for a full exposition.

It is noteworthy that in the past few decades, the existence of many possible efficiency improvement solutions has prompted a rich literature on the methodological integration of Multiple Objective Linear Programming (MOLP) and DEA models. We will offer a concise overview here (see also Suzuki et al. (2010)). One of the first contributions was offered by Golany (1988) who proposed an interactive MOLP procedure, which aimed at generating a set of efficient points for a DMU. This model allows a decision maker to select a preferred set of output levels, given the input levels. Likewise, Thanassoulis and Dyson (1992) developed adjusted models, which can be used to estimate alternative input and output levels, in order to render relatively inefficient DMUs more efficient. These models are able to incorporate preferences for a potential improvement of individual input and output levels. The resulting target levels reflect the user's relative preference over alternative paths to efficiency. Later on, Joro et al. (1998) demonstrated the analytical similarity between a DEA model and a Reference Point Model in a MOLP formulation from a mathematical viewpoint. In addition, the Reference Point Model offers suggestions which make it possible to search freely on the efficient frontier for good solutions, or for the most-preferred solution (MPS), based on the decision maker's preference structure. Furthermore, Halme et al. (1999) developed a Value Efficiency Analysis (VEA), which includes the decision maker's preference information in a DEA model. The foundation of VEA originates from the Reference Point Model in a MOLP context. Here, the decision maker identifies the MPS, such that each DMU could be evaluated by means of the assumed value function based on the MPS approach. A further development of this approach was made by Korhonen and Siljamäki (2002), who dealt with several practical aspects related to the use of a VEA. In addition, Korhonen et al. (2003) developed a multiple objective approach, which allows for changes within the time frame concerned. Next, Lins et al. (2004) proposed two multi-objective approaches that determine the basis for the incorporation of a posteriori preference information. The first of these models is called Multiple Objective Ratio Optimization (MORO), which optimizes the ratios between the observed and the target inputs (or outputs) of a DMU. The second model is called Multiple Objective Target Optimization (MOTO), which directly optimizes the target values. Washio et al. (2012) suggested four types of improvements for making inefficient DMUs efficient in the CCR framework, by introducing a decision-maker's policy model with a minimal change of input and output values. More recently, Yang and Morita (2013) utilised DEA and Nash bargaining game (NBG) theory to help improve inefficient banks in the financial sector, in order to: (i) make an inefficient bank Pareto-optimal from multiple perspectives, which could avoid being dissatisfied with some particular management or market perspectives; and (ii) change its attributes and provide various improvement schemes for decision makers. Furthermore, Suzuki et al. (2010) proposed a Distance Friction Minimization (DFM) model that is based on a generalized distance function and serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. The DFM model is able to calculate either an optimal input reduction value or an optimal output increase value in order to reach an efficiency score of 1.000, even though in reality this might be hard to achieve for low-efficiency DMUs. And finally, Susuki et al. (2015) presented a newly developed adjusted DEA model, emerging from a blend of the DFM and the Target-Oriented (TO) approach based on a Super-efficiency model, for generating an appropriate efficiency-improving projection model. The TO approach specifies a target-efficiency score (TES) for inefficient DMUs. This approach can compute an input reduction value and an output increase value in order to achieve a higher TES. However, in many cases, the input factor may not be flexible or adjustable due to the indivisible nature or inertia in the input or output factor. Usually, the DEA model does not allow for such a non-controllable or a fixed input factor.

In the present study we propose a newly developed TO-DFM model in combination with a fixed factor (FF) model (see Suzuki et al. (2011)) which has an advantage in that policy implications by the approach can be more realistic than given in any other DEA approaches. A comparative assessment of real-world choices in which fixed factors beyond a DMU's control exist and data for a DEA efficiency analysis are wide-ranging, calls for a new research approach. In this sense, the proposed approach serves to improve defects of DEA approaches so far developed.

We will present empirical results from a comparative assessment on energy-efficiency in various countries, by our TO-DFM-FF model in order to cope with realistic choice conditions in our search for a feasible efficiency improvement projection. After the description of the methodology adopted here, a Super-efficiency model (Anderson and Petersen, 1993; see Appendix A2) for DEA is used in our comparative study on the efficiency assessment of energy-environment-economic goals for EU and A&A countries, using appropriate data sets ranging from 2003 to 2012. As