Energy Policy 55 (2013) 426–434

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

Technical efficiency of economic systems of EU-15 countries based on energy consumption

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HIGHLIGHTS

- ► Technical efficiency index of EU-15 countries is determined through the DEA method.
- ► Level of the TE index is determined from the energy mix used in each country.
- ► TE level depends on the maximization level of GDP without waste of energy resources.
- ► Capacity of an economy to produce more GDP for a given energy input is determined.
- ► TE differentiation before and after the integration of nuclear energy is performed.

ARTICLE INFO

Article history:
Received 31 October 2011
Accepted 5 December 2012
Available online 8 January 2013

Keywords:
Energy consumption
Technical Efficiency
DEA method

ABSTRACT

In the present study, Data Envelopment Analysis is used to determine the Technical Efficiency index of EU-15 countries from 1980 to 2008, using cross-country comparison. Technical Efficiency index represents the capacity of an economy to produce a higher level of Gross Domestic Product for a given level of total energy input. The level of the Technical Efficiency index is determined from the energy mix (fossil fuels, non-fossil fuels, nuclear energy) of each country and depends on the maximization level of the production of the Gross Domestic Product of the economic system, without waste of energy resources. The current study is applied in the case of the EU15 countries. Its scope is to highlight the differentiations of country classifications before and after the integration of nuclear energy in the energy mix of each country. The main result is that the integration of nuclear energy as an additional input in the energy mixture affects negatively the Technical Efficiency of countries. Also, when an economy achieves a decrease of the energy consumption produced from fossil fuels, and a better exploitation of renewable energy sources, clearly improves its capacity to produce more output with the given levels of inputs.

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1. Introduction

The increasing share of renewable forms of energy in a country's energy mix is a necessary but not a sufficient condition for the sustainability of economic system. This is due to the increasing energy demand, which cannot be met only from renewable resources. The maintenance of high levels of energy efficiency (EE) is essential to ensure the satisfaction of the energy needs of a country.

Based on the definition provided by the World Energy Council (WEC), EE encompasses all changes leading to a reduction in the energy used for a given energy service (heating, lighting,…) or level of activity. This reduction in the energy consumption is not necessarily associated to technological changes, since it can also result from a better management or improved economic conditions of the sector, e.g. overall gains of productivity (WEC, 2011).

Depending on the research discipline, the concept of EE can be different. In economic terms, it encompasses all changes resulting in a decrease of the amount of energy used to produce one unit of economic activity (e.g. the energy used per unit of GDP or value added) or to meet the energy requirements for a given level of comfort. In this case, energy efficiency is associated with economic efficiency and includes technological, behavioral and economic change (WEC, 2011).

In the present study the concept of Technical Efficiency index (TE), as defined by the Data Envelopment Analysis (DEA) method for constant returns to scale, is applied in the case of energy efficiency of EU-15 countries. The Data Envelopment Analysis

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0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.12.021

(DEA), developed by Charnes et al., 1978, is an alternative non-parametric approach based on a model of linear programming for assessing efficiency and comparative analysis of Decision Making Units (DMUs), in cases of constant (Charnes et al., 1978; Thanassoulis, 2001) or variable (Banker et al., 1984; Thanassoulis, 2001) returns to scale. In the DEA model of Constant Returns to Scale (CRS) the output y change is proportional to the input x (Charnes et al., 1978). In the DEA model of Variable Returns to Scale the output y increases with the increase of input x, but either less (descending returns to scale), or more (increasing returns to scale) than the increase of x (Banker et al., 1984).

The concept of TE is an output maximization linear programming problem for constant inputs (Charnes et al., 1978; Thanassoulis, 2001). The concept of TE is in line with the concept of energy efficiency, since only the energy resources (fossil fuels, non-fossil fuels, nuclear energy (NE)) are considered to be the inputs of the economic system. However, the TE index gives more complex information, since it is not limited to the energy efficiency levels of a single resource or the total energy input. On the contrary, it incorporates the specificities of the composition of the energy mixture of each country.

Moreover, the methodology of TE index determination allows the investigation of the effects of nuclear energy on efficiency levels, as the index is calculated before and after the integration of nuclear energy in the energy mix of countries. Nuclear power corresponds to 14% of the total energy consumption of European Union in 2006 (EEA, 2006). Nuclear energy is very cost effective (NEA, 2001) and emits much fewer greenhouse gases than the production of electricity from coal or other traditional power plants (NEA, 2001). However, nuclear energy has specific dangers. Though nuclear energy does not release greenhouse effect gases, it produces radioactive waste products. This radioactive waste must be stored for a long period of time in specific conditions (Ferguson, 2007; Cochran et al., 2005).

Also, no matter how sophisticated technology is used, several accidents in nuclear power plant occurred (for example, the 1979 Three Mile Island accident in Pennsylvania, the Chernobyl Disaster of 1986, in actual Ukraine, or even the recent Fukushima, Japan, accident of March 2011). The social, political, economic, psychological and health consequences of those accidents are significant.

The present study is based on a cross section data analysis of EU-15 countries. The Technical Efficiency index (TE) is used as a measure of efficiency of DMUs (which are the economic systems of EU-15 countries) based on energy consumption and is determined by taking into account the composition of the energy mixture of each country. The total input entered in the DEA model is the weighted sum of different types of energy. The disaggregation of total energy consumption into three different forms (fossil, non fossil fuels and nuclear energy) is an essential prerequisite for the classification of the countries based on TE index, before and after the integration of nuclear energy. Consequently, the degree of efficiency of each country is determined by the major shifts towards an energy-intensive mix. The degree of contribution of nuclear energy on TE levels of energy consumption is estimated for the efficiency levels of EU-15 countries before and after the integration of nuclear energy.

2. Methodology and data sources

2.1. The model (DEA formulation)

The TE index is defined, in the case of multiple input and output factors, as the ratio of the weighted sum of outputs to the weighted sum of inputs. TE index ranges from 0 to 1 for all the DMUs of the model (Charnes et al., 1978). One DMU is considered efficient if obtains a score of 1 and inefficient if the score is less than 1. The TE index is determined through the non parametric method DEA and a cross sectional analysis.

Assuming that there are n DMUs, with m inputs and s outputs each, the level of relative efficiency of one of them (even of p DMU), arises as a result of the solution of the following model, described by Charnes et al., 1978:

$$\max \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \quad \text{s.t} \ \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 \quad \forall i$$
$$v_k, u_j \ge 0 \quad \forall k, j \tag{1}$$

It is difficult to solve the above program because of its fractional objective function. By setting the denominator of the ratio equal to unity, one can obtain the following output maximization linear programming problem for constant inputs (2):

$$\max \sum_{k=1}^{s} v_k y_{kp} \quad \text{s.t} \sum_{j=1}^{m} u_j x_{jp} = 1$$
$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \le 0 \quad \forall i$$
$$v_k, u_j \ge 0 \quad \forall k, j \tag{2}$$

where $k=1–s$, $j=1–m$, $i=1–n$, y_{ki}=amount of output k produced by DMU i, x_{ji}=amount of input j utilized by DMU i, u_k=weight given to output k, and u_j=weight given to input j.

In the present study, the DEA model of CRS is applied, because it is assumed that output y is changed in direct proportion to the input x (Charnes et al., 1978). In this case, the output of the production process increases or decreases with the increase or decrease of the inputs. The TE index estimations are based on the data obtained from the Energy Information Administration and the World Bank (EIA, 2010; World Bank, 2010). Those data are the:

(i) Energy consumption indexes of hydroelectric, geothermal, solar, wind, wood and waste electric power, nuclear, petroleum, dry natural gas and coal (EIA, 2010),
(ii) GDP index (World Bank, 2010), and
(iii) Population index (EIA, 2010).

2.2. Empirical applications of the model

In order to determine the TE index, entire EU-15 and each of the individual EU-15 countries are taken as DMUs. The data of the countries used in the analysis, cover the period from 1980 until 2008 and are summarized in Figs. 1 (energy mixture per capita of fossil fuels, non-fossil fuels and nuclear energy) and 2 (evolution of the economic growth index of the countries over time).

The fossil fuel consumption index is the sum of the consumption of petroleum, coal and dry natural gas while the non-fossil fuel consumption index is the sum of the consumption of hydroelectric, geothermal, solar, wind, wood and waste electric power. However, there is an upper level of participation of non-fossil fuels (renewable forms of energy) in the energy mixture of each country due to the instability of the global electricity network of a country. This is because the production of electricity from renewable energy is neither continuous nor in phase with the time of consumption. That level determines the substitution limits between fossil and non-fossil fuels.

2.3. Steps of TE index determination

The determination process of TE index is performed before and after the integration of nuclear energy in the energy mix of countries.

At the first step (before the integration of NE), the GDP index is used as output and the indexes of energy consumption of fossil

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