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Total-factor Energy Efficiency in EU: Do Environmental Impacts Matter?

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ABSTRACT

The concept of total-factor energy efficiency (TFEE) measures energy efficiency in a more superior and complex way within the total-factor framework, but takes only gross domestic product (GDP) as the only output. A new approach that includes desirable (GDP) and undesirable outputs (greenhouse gas [GHG] emissions) has been developed recently and is applied in our research. The aim of our paper is to assess economy-wide energy efficiency in EU countries in a total-factor framework and compare these results with the environmental TFEE (ETFEE) that takes into account undesirable outputs like CO2 and SOx emissions. Our analysis is based on 2008-2014 panel data for 28 EU countries. The efficiency frontier is constructed by using DEA and modified slack-based model model based on data on three production factors (labor, capital and energy), GDP as desirable output and CO2 and SOx emissions as undesirable outputs. Our research results show that energy efficiency that does not incorporate environmental pollution is overestimated in 20 out of 28 EU countries. When analyzing environmental TFEE during time, results show that in 2014 there are more countries that have reached efficient frontier than in 2008, which could imply that EU countries pay a lot of attention to reduction of GHG emissions and sustainable development.

Keywords: Total-factor Energy Efficiency, EU Countries, DEA, Undesirable Outputs, Environmental Pollution
JEL Classifications: Q43, Q56, C32, C61

1. INTRODUCTION

Energy efficiency plays an important role in economic development and therefore attracts growing academic research efforts. These research evaluations are based on two different methods: One is partial-factor energy efficiency and the other one is total-factor energy efficiency (TFEE). Assessing partial energy efficiency is usually done by two indicators: Energy intensity and energy efficiency. While these traditional energy efficiency indexes take only energy into account as a single input to produce output gross domestic product (GDP) while other inputs like labor and capital are ignored, a new approach known as TFEE has been developed by Hu and Wang (2006) in order to overcome the disadvantages of the traditional partial-factor energy efficiency. Some researchers (Honma and Hu, 2009) concluded that the partial-factor energy efficiency estimation is misleading and cannot give the appropriate benchmark. Therefore this TFEE index provides a useful alternative to the traditional energy efficiency indicators mentioned above. It combines three production factors as inputs and measures single-factor efficiency in a total-factor environment. Boyd and Pang (2000) concluded that energy-efficiency improvement relies on total-factor productivity improvement. This total-factor efficiency model is more realistic because it includes substitution effects between energy and other production factors. This substitution really happens: Capital goods are activated by energy and at the same time, energy has no economic use without capital goods. Substitution among factors occurs during time, in the medium and long-time period, while the substitutability of the inputs is limited in a short term.

However, TFEE measures energy efficiency in a total-factor framework, but takes only GDP as the only output. A new approach that takes into account undesirable outputs as well, has been developed recently due to the growing concern of the importance of environmental protection. GDP has been produced from the use of energy and other production factors, with environmental pollution as additional undesirable output. Therefore sustainable framework should be proposed to measure energy efficiency.

The aim of our paper is to assess economy-wide energy efficiency in EU countries in a more superior total-factor framework and compare these results with the ecological TFEE that takes into account undesirable outputs like CO2 and SOx emissions. The analysis is based on 2008-2014 panel data. The efficiency frontier is constructed by using Data envelopment analysis (DEA) based on data on three production factors (labor, capital and energy) and GDP as desirable and CO_2 and SO_2 emissions as undesirable outputs. It should be noted that most studies assessing the energy efficiency at the macroeconomic level using a total factor structure adopt the DEA method, as it provides an appropriate mechanism for dealing with multiple inputs and multiple outputs to measure the efficiency ratio of each decision making unit (DMU) under evaluation (Camioto et al., 2016). So, the analysis tool used in this study is the DEA, through the slack-based model (SBM) Bad output model, incorporating multiple inputs and two kinds of multiple outputs: Desirable and undesirable as the result of input utilization. Undesirable outputs are often occur in the environmental context, and represent an anomaly, which should not be ignored when measuring TFEE. In contrast to the "desirable" outputs which should have as high as possible value, "undesirable" outputs, or environmentally unfavorable outputs, achieve as low as possible value. Also, in case of emissions or pollution, regulatory standards define the maximum amount of undesirable outputs as a result of the production process.

The remainder of the paper is organized as follows: The second section explains the concept of TFEE as a new approach in measuring economy-wide energy efficiency performance and gives the literature review relevant for our research. The third section describes the data and the model, the fourth section presents the empirical results and discussion, while the last section gives the concluding remarks.

2. LITERATURE REVIEW

During the last decade there has been a growing number of papers dealing with the issue of energy efficiency because increasing energy efficiency has become an important goal of energy strategy in many countries and regions. However, the concept of TFEE has been proposed for the first time in 2006 by Hu and Wang and since then a number of papers have been published.

Following the Hu and Wang's approach, during the last 10 years some interesting papers have been published. Honma and Hu (2008) investigated the TFEE of 47 regions in Japan for the period 1993-2003. In another paper the same authors (Honma and Hu, 2011) computed and analyzed the TFEE of 11 industries in 14 developed countries during the period of 1995-2005. Zhang et al. (2011) used a total-factor framework to investigate energy efficiency in 23 developing countries during the period of 1980–2005. They explored the TFEE and change trends by applying DEA window, which is capable of measuring efficiency in cross- sectional and time-varying data. Ceylan and Gunay (2010) applied TFEE in order to analyze energy efficiency performance and energy saving potential in Turkey by means of cross-country comparison and benchmarking with the EU countries for the period of 1995-2007. Shu et al. (2011) calculated total-factor electricity consumption efficiency for 4 districts in China from 2001 to 2007 and econometrically tested the related influencing factors to explain the difference of electricity consuming efficiency of different districts. Li and Hu (2012) measured the ecological TFEE of 30 regions in China for the period 2005-2009 through the SBM with undesirable outputs. Their results showed that there are significant regional differences and China's regional energy efficiency is extremely unbalanced.

Due to the rising awareness of global warning and other serious environmental problems, the research on TFEE has been amended by introducing environmental impacts. One of the early studies on environmental efficiency, which was conducted in 1995, involved 19 OECD countries during the period from 1970 to 1990. Initially, the study included the following variables: Real GDP Per Capita, Inflation Rate, Unemployment Rate and the Balance of Trade. Additional two variables were eventually included (nitrous oxide [N_2O] and carbon dioxide [CO_2] emissions as undesirable outputs) and further analysis was carried out to determine changes in the efficiency trend. The study focused on the comparison of efficiency among 14 European and 5 non-European OECD countries. The expanded additive model approach revealed that European countries have lower relative efficiency after including the environmental issues (Lovell et al., 1995). Färe et al. (1996) were the first authors to include the variable of pollution in the DEA methodology at the microeconomic level, involving electricity industry. They analyzed environmental efficiency of the U.S. electricity companies that produce electricity from fossil fuels, including total world emissions of SO_2, NO_x and CO_2 (in tonnes) as undesirable outputs. The study was based on two different sets of data comprising of 49 respectively 90 DMUs.

Since then a considerable number of researches on electricity production have been conducted using DEA methodology involving various variables of environmental pollution (Zhou et al., 2008; Ramli and Munisamy, 2013). In 2003, a survey was conducted across 103 Italian regions, divided into four groups based on the geographic zones, to evaluate relative environmental efficiency. The study included three sets of factors or variables: Number of employees as input, GDP as desirable output, with ambient concentrations of nitrogen dioxide and particulates as undesirable output. The findings revealed that only a few regions have a significantly low environmental efficiency (Nissi and Rapposelli, 2006).

By using the input-oriented DEA approach with the assumption of a variable returns-to-scale, Fang et al. (2013) computed the pure technical efficiency and energy-saving target (EST) of Taiwan's service sectors during 2001–2008. Besides the analyzing the effects of industry characteristics on the EST by applying the DEA method, they also calculated the pre-adjusted and environment-adjusted TFEE scores in service sectors. Results showed that the most energy efficient service sector was finance, insurance and real estate, which has an average TFEE of 0.994 and an environment-adjusted TFEE of 0.807. The study also utilized the panel-data, random-effects Tobit regression model with the EST as the dependent variable.

Zhang et al. (2015) proposed a meta-frontier SMB approach to model ecological TFEE. They conduct an empirical analysis of regional ecological energy efficiency by incorporating carbon dioxide (CO_2) and sulfur dioxide (SO_2) emissions and the chemical oxygen demand of China during 2001-2010. Their results indicated that most of the provinces were not performing at high ecological energy efficiency. One of the most recent research is the one from Zhang et al. (2016). They analysed the panel data of 30 provinces in China from 2000 to 2012 by using the super-efficiency DEA model. Their results showed that energy efficiency can be improved by promoting environmental regulation and they proposed a mechanism and mathematical model of environmental regulation and energy efficiency.

A new research on environmental TFEE in EU countries (Šegota et al., 2017) shows significant differences in efficiency scores. In order to solve their environmental problems, inefficient countries should aim to change their energy structure and consumption behaviour.

3. DATA AND THE MODEL

A panel dataset of 28 EU countries from 2008 to 2014 is collected for the analysis. Panel data enable a DMU to be compared with other counterparts, but also because the movement of efficiency of a particular DMU can be tracked over a period of time. Therefore the panel data are more likely to reflect the real efficiency of a DMU than cross-sectional data. Annual series used in the analysis as inputs are: Gross fixed capital formation in current prices in million euro as a proxy for capital, labor employment annual series in thousands persons employed and energy consumption in thousands tons of oil equivalent, all obtained from EUROSTAT (European Commission, 2017). Annual series used as outputs are: GDP at market prices in million euro and two undesirable outputs: Carbon dioxide and sulphur oxides emissions in tonnes, all collected from the EUROSTAT.

Table 1 presents the correlation matrix of the inputs and outputs used in the DEA model. As it is shown in the Table 1, inputs and outputs are highly positive correlated. The highest coefficient of correlation between inputs and outputs is between capital and GDP (0.99) while the lowest coefficient of correlation is between capital and SO_x emissions (0.63). High values of coefficients of correlation between inputs and outputs have approved their choice, implying that increasing values of inputs result with increasing values of outputs.

We apply DEA as a relatively new non-parametric approach to efficiency evaluation, which has been applied very often for benchmarking energy performance that is capable of handling multiple inputs and outputs. It is also applied in order to compare the energy efficiency performance of different countries/regions from the viewpoint of production efficiency. DEA is linear programming method for measuring the relative efficiency of DMUs in converting multiple inputs into multiple outputs. Let us suppose that n DMUs having three factors: Inputs, good outputs and bad (undesirable) outputs as represented by three vectors $x \epsilon R^m$, $y^g \epsilon R^{s1}$ and $y^b \epsilon R^{s2}$ and, respectively. In the presence of undesirable outputs, efficiency can be defined as "capacity" of DMU to produce more desirable outputs and less undesirable outputs with less input resources or, more precisely, by following definition (Cooper et al.,2004):

Definition: A DMU_o (x_o, y_o^g, y_o^b) is efficient in the presence of undesirable outputs if there is no vector (x, y^g, y^b) element production possibility set such that $x_o \geq x$, $\leq y^g$, $\leq y^g$ with at least one strict inequality.

Bad-output model, as modified SBM model (Tone, 2001), is used to estimate relative efficiency of 28 EU countries in converting three selected inputs into selected desirable output and two undesirable outputs:

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{S_{io}^-}{x_{io}}}{1 + \frac{1}{s}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b} + \right)} \quad (1)$$

s.t. $X_0 = X\lambda + S^-$

$y_o^b = Y\lambda - s^g \quad y_o^b = Y\lambda - s^b \quad L \leq e\lambda \leq US^- \geq 0, \quad S^g \geq 0, \ S^b \geq 0 \lambda \geq 0$

Where λ is intensity vector, L and U are the lower and upper bounds of the intensity vector, s^- and s^b excesses in inputs and bad outputs, s^g expresses shortages in good outputs while s_1 and s_2 denote the number of elements in s^b and s^g with equality $s=s_1+s_2$. If the above program has the optimal solution (ρ^*, s^{-^*}, s^{g^*}, s^{b^*}) the DMU is efficient in the presence of undesirable outputs if and only if $\rho^*=1$, $s^{-^*}=0$, $s^{g^*}=0$, $s^{b^*}=0$. If the DMU is not efficient, it can become $\leftrightarrow$ efficient by following projections: x_0 $x_o \Leftarrow x_o - s^{-^*}$ $y_o^g \Leftarrow y_o^g + s^{g^*}$ $y_o^b \Leftarrow x_o - s^{b^*}$

It follows that Bad-output model is useful in indicating sources and amounts of relative inefficiencies for each inefficient country under estimation. In order to capture the dynamics of efficiency and changes during the 2008-2014 periods in EU we have conducted DEA for each year using DEA- Solver- Pro 13.0.

Table 1: Correlation coefficients of input and output variables

Variable	Capital	Employment	Energy	CO_2 emissions	SOx emissions	GDP
Capital	1	0.971566	0.988942	0.903501147	0.6291712	0.9918128
Employment	0.971566	1	0.984658	0.956703296	0.7618548	0.9767951
Energy	0.988942	0.984658	1	0.931836383	0.7028478	0.9797972
CO_2 emissions	0.903501	0.956703	0.931836	1	0.8114032	0.9136125
SOx emissions	0.629171	0.761855	0.702848	0.811403179	1	0.6333703
GDP	0.991813	0.976795	0.979797	0.913612549	0.6333703	1

Source: Authors' calculation. GDP: Gross domestic product

4. RESULTS AND DISCUSSION

As it has been indicated, the aim of our paper is to test the differences between TFEE with and without environmental impacts. Therefore, after selecting input and output variables, in the first stage the efficiency scores of countries without undesirable outputs in each year of the period 2008-2014 are analyzed. This is followed by identification of sources and amounts of relative inefficiency. Table 2 contains the summary efficiency score results without environmental impacts (CO2 and SOx emissions), while Table 3 contains the summary efficiency score results with undesirable outputs using Bad-output model with constant returns to scale.

According to presented results, one could conclude that energy efficiency can be overestimated without including environmental impacts. Regarding efficiency scores in 2014, EU countries can be divided into three groups. The first group consists of Denmark, Greece, Luxembourg and UK. There are no gaps between TFEE (without greenhouse gas [GHG] emissions) and environmental TFEE because they stay on efficient frontier for both TFEE and ETFEE. The second group includes Cyprus, France, Germany, Hungary, Ireland, Italy, Portugal and Sweden. These countries have reached higher ETFEE scores in 2014 than TFEE without CO2 and SOx emissions. Most of them are developed countries with high environmental standards and strong awareness of the importance of environmental protection and sustainable development. The third group includes most of the countries (16 of them) where efficiency scores are higher comparing with the efficiency results that incorporate environmental impact. These results indicate that measurement of energy efficiency without including environmental impacts as undesirable outputs, can be overestimated and cannot give a clear picture.

When analyzing environmental TFEE during time, results show that in 2014 there are more countries that have reached efficient frontier than in 2008, which could imply that EU countries pay a lot of attention to reduction of GHG emissions and sustainable development. European Union advocated the ambitious targets, so-called 20/20/20 goals: (1) Reduce GHG emissions by 20% in 2020 compared to 1990 levels; (2) increase energy efficiency so as to achieve the objective of saving 20% of the EU's energy consumption compared to projections for 2020; (3) a binding target of a 20% share of renewable energies in overall EU energy consumption by 2020. Energy efficiency appears to be the only energy item in these fundamental EU goals; the improvement of energy efficiency not only that can lead to reduction of GHG emissions, but also it can increase the renewable energy share without new investment. Measures to ensure energy efficiency have become a priority for all EU countries, but their success differs among EU Members. The worst performers in TFEE that takes into account the level of harmful emissions are transition economies. In 2014 the worst relative efficiency was obtained by Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia. These worst performers are countries with relatively strong industrial basis and their level of CO2 and SOx emissions are relatively high in comparison with the level of inputs and GDP. As one could expect, the

Table 2: Efficiency scores for the EU countries in the period 2008-2014 without CO_2 and SOx emissions

Country	2008	2014
Austria	0.8742	0.7997
Belgium	0.8132	0.7466
Bulgaria	0.5249	0.3675
Croatia	0.6168	0.6219
Czech Republic	0.5973	0.485
Cyprus	0.7022	0.9766
Denmark	1	1
Estonia	0.5558	0.4674
Finland	0.7937	0.7854
France	0.829	0.7878
Germany	0.8828	0.8335
Greece	0.8252	1
Hungary	0.7453	0.549
Ireland	1	0.9836
Italy	0.9416	0.9868
Latvia	0.561	0.5834
Lithuania	0.6657	0.6505
Luxembourg	1	1
Malta	0.883	0.8884
Netherlands	0.8639	0.8873
Poland	0.7505	0.5553
Portugal	0.7732	0.8698
Romania	0.4514	0.5276
Slovak Republic	0.6785	1
Slovenia	0.5858	0.662
Spain	0.7274	0.8256
Sweden	0.8083	0.7802
United Kingdom	1	1

Source: Authors' calculations

Table 3: Efficiency scores for the EU countries in the period 2008-2014 with CO_2 and SOx emissions

Country	2008	2014
Austria	0.663516	0.67018
Belgium	0.534928	0.541386
Bulgaria	0.213054	0.265181
Croatia	0.373642	0.455309
Czech Republic	0.320896	0.296302
Cyprus	0.463317	1
Denmark	1	1
Estonia	0.269233	0.277539
Finland	0.498689	0.634009
France	1	1
Germany	0.668043	0.551806
Greece	0.550205	1
Hungary	0.384389	1
Ireland	1	1
Italy	0.727997	1
Latvia	0.355637	0.373536
Lithuania	0.333581	0.404398
Luxembourg	1	1
Malta	0.503298	0.590428
Netherlands	0.596302	0.651691
Poland	0.35756	0.348336
Portugal	0.517744	1
Romania	0.259823	0.310934
Slovak Republic	0.341339	0.409593
Slovenia	0.376174	0.420429
Spain	0.523972	0.558316
Sweden	1	1
United Kingdom	1	1

Source: Authors' calculations

results for Croatia are similar to other new EU Member States, although there is a positive change in 2014. Findings for Croatia could be related to decrease in inputs, especially employment and energy consumption, while undesirable outputs (emissions) have been reduced. On the other hand, developed countries with highest energy efficiency that experienced the strongest growth of renewable energy like Denmark, UK and Luxembourg are countries that are graded as the most efficient.

5. CONCLUSIONS

The aim of the paper is to measure TFEE with and without environmental (bad) impacts. This approach known as environmental TFEE inherits total-factor framework based on DEA, taking energy consumption with capital and employment as multiple inputs. In measurement of environmental TFEE, the SBM model with desirable output (GDP) and undesirable outputs (CO2 and SOx emissions) has been adopted. Under this framework, our paper analyzes energy efficiency in 28 EU countries from 2008 to 2014.

Our research results confirm that most of the EU countries have higher efficiency scores when the model does not include CO2 and SOx emissions. Except for Cyprus, France, Germany, Hungary, Ireland, Italy, Portugal and Sweden, in all other countries (20 out 28) efficiency scores for TFEE in 2014 are higher or the same comparing with ETFEE in the same year. Obviously measurement of energy efficiency can be overestimated and misleading when it doesn't incorporate environmental (bad) impacts.

This study could be further widened to consider the effects of the energy mix of the EU economies and energy prices in order to provide more insights on the aspects of energy efficiency, especially the possibility of energy sources' substitutability, which could significantly alter policy measures and their implications. The obtained results have consequences in implementing measures for improving energy efficiency in the EU in the light of the ongoing desire to reduce greenhouse gas emissions.

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