Original scientific paper
UDC 620.9:330.44

Total-factor energy efficiency in the EU countries[*,1]

Nela Vlahinić-Dizdarević,[2] Alemka Šegota[3]

Abstract

The purpose of this research is to examine the economy-wide energy efficiency changes in the EU countries in the period from 2000 to 2010 and to compare the results with the traditional energy efficiency indicator. The DEA CCR multiple input-oriented model is applied in order to analyse the efficiency of the use of three inputs (capital stock, labour and energy consumption) in producing GDP as the output. In order to obtain the dynamics of data as to avoid the use of only a single year in calculating energy efficiency the extended DEA method - window analysis - is adopted. The empirical results confirm that the traditional one-factor energy efficiency indicator is too simplifying and could be misleading. The findings on total-factor energy efficiency scores reflect the possibility of substitution among factors in a medium run and changes in the composition of energy use. Projection values of inputs on efficiency frontier identify the amounts of relative inefficiency and, in that context, suggest improvements for all inefficient countries. The results reveal that all inefficient countries could improve their efficiency by reducing some of the inputs.

Key words: *total-factor energy efficiency, EU countries, DEA, windows analysis*

JEL classification: *Q43, C33, C61, O49*

---

* Received: 24-09-2012; accepted: 14-12-2012

1 The presented results are part of research projects (Economic impacts of regulatory reforms in electricity sector, No. 081-0361557-1455), supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

2 *Full Professor, University of Rijeka, Faculty of Economics, Ivana Filipovića 4, 51000 Rijeka, Croatia. Scientific affiliation: macroeconomics, energy economics. Phone: +385 51 355 111. E-mail: nela@efri.hr*

3 *Assistant Professor, University of Rijeka, Faculty of Economics, Ivana Filipovića 4, 51000 Rijeka, Croatia. Scientific affiliation: mathematics, decision theory. Phone: +385 51 355 161. E-mail: alemka.segota@efri.hr*

1. Introduction

As a result of considerable increase in energy prices and concerns about sustainable development, the issue of energy efficiency gained much of the attention, public as well as scientific, during the last two decades. An important focus of these studies is how to improve energy efficiency without harming economic growth. There is a growing body of the research in the field of total-factor energy efficiency but most of it focuses China and Japan which are the biggest energy consumers. As far as is known, there has been no study measuring total-factor energy efficiency in the European Union. However, energy saving is an important issue in the EU because of its strong energy-dependence. The EU's national energy policy aims to achieve three underlying goals till 2020 known as the "20-20-20" targets: the 20% reduction in primary energy use to be achieved by improving energy efficiency, the reduction in EU greenhouse gas emissions of at least 20% below 1990 levels and 20% of EU energy consumption to come from renewable energy sources. Therefore the issues of measuring and improving energy efficiency have become crucial energy and economic policy topics in era of costly energy.

Assessing energy efficiency in macro-level policy analysis is usually done by two indicators: energy intensity and energy efficiency. While these traditional energy efficiency indexes take only energy into account as a singe input to produce output (GDP) while other inputs like labour and capital are ignored, a new approach known as total-factor energy efficiency (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. This total-factor energy efficiency index provides a useful alternative to the traditional energy efficiency indicators mentioned above. It combines all three production factors as inputs and measures single-factor efficiency in a total-factor environment. Moreover, Boyd and Pang (2000) concluded that energy-efficiency improvement relies on total-factor productivity improvement. The TFEE concept includes substitution effects between energy and other production factors. And substitution happens: capital goods are activated by energy and on the other hand, energy has no economic use without capital goods. Although the substitutability of the inputs is limited in a short period of time, in the medium and especially long term, substitution among factors does occur by capital investments.

Therefore the aim of the paper is to evaluate the economy-wide energy efficiency changes in the EU countries in the period from 2000 to 2010 and to compare the results with the traditional energy efficiency indicator. The efficiency frontier is constructed by using Data envelopment analysis (DEA) based on data on three production factors (labour, capital stock and energy) and GDP as the only output.

This paper provides new empirical evidence on trends in energy efficiency of chosen countries and, consequently, it contributes to the existing energy efficiency literature by presenting an assessment of energy efficiency applying the DEA methodology.

The hypothesis is that traditional one-factor energy efficiency approach, tested in the case of EU economies, can be misleading because it disregards the substitution among energy consumption and other production factors (labour and capital) that happens in the medium run.

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

2. Literature review

Since the first oil crisis (1973/1974) there has been a growing body of research in the field of energy studies and the issue of energy efficiency has become crucial component of energy strategy in many countries and regions for the last two decades. Zhou et al. (2008) gave an extensive review of 100 studies published from 1983 to 2006 that have used DEA methodology in energy and environmental studies. According to that survey, 72 of these publications were made between 1999 and 2006, which indicates a rapid increase in using DEA methodology. However, the concept of total-factor energy efficiency has been proposed for the first time in 2006 by Hu and Wang and since then a number of papers have been published.

Generally, there are two strands in the research dealing with total-factor energy efficiency using DEA. The first one is older and it includes the studies measuring total-factor productivity change by using DEA Malmquist index. This approach was first introduced by Caves et al. (1982) and implemented in many energy studies. For example, Førsund and Kittelsen (1998) applied DEA efficiency scores to calculate the Malmquist productivity index in Norwegian electricity distribution companies for the period 1983-1989. Edvardsen and Førsund (2003) calculated Malmquist productivity index to analyze the performance of 122 electricity distributors in Denmark, Finland, Norway, Sweden and the Netherlands in the year 1997. Abbott (2006) used DEA Malmquist approach in order to estimate total factor productivity of the Australian electricity supply industry over the period 1969 to 1999. Barros (2008) applied this approach to analyze changes in total productivity of the hydroelectric energy generating plants of the Portugal Electricity Company for the period 2001-2004, breaking this down into technically efficient change and technological change.

The second strand applies index of total-factor energy efficiency (TFEE), the approach that has been used in this paper. Following the Hu and Wang's approach, during the last six years some interesting papers have been published. Honma and Hu (2008) investigated the total-factor energy efficiency (TFEE) of 47 regions in Japan for the period 1993-2003. They used 14 inputs (labour, capital stock and 11 energy sources) and a single output (GDP). In another paper the same authors (2011) computed and analyzed the TFEE of 11 industries in 14 developed countries during the period of 1995-2005 by using four inputs: labour, capital stock, energy and intermediate inputs other than energy, and GDP as the only output. 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 total-factor energy efficiency and change trends by applying data envelopment analysis (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. The model considered capital, labour and total R&D expenditure as non-energy inputs, oil, gas, solid fuels, nuclear energy and renewable energy consumption as energy inputs, and GDP as the desirable output and green house gases emissions as the undesirable output. 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.

As it is obvious from the previous analysis, the most of the studies dealing with total-factor energy efficiency examined the industry level, while only a few papers focused the economy-wide performance. One of the important reasons is the fact that the data on capital stocks are often unavailable, especially in transition and developing countries. Still, developing the appropriate performance indicators for monitoring energy efficiency trends over time in a country or region and comparing the economy-wide energy efficiency performance among countries is the crucial tool in energy and economic policy.

3. Description of data and the model

A panel dataset of 26 EU countries (except for Romania due to the capital stock data unavailability) from 2000 to 2010 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

(Cullinane, 2004:189). 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 are: capital stock in Euro at 2005 constant prices obtained from the European Commission's AMECO database, labour employment annual series in thousands persons employed, energy consumption in thousands tons of oil equivalent and real GDP at 2005 constant prices, all collected from the EUROSTAT. Capital as the factor of production statistically covers capital stock. The capital stock in a specific year equals the capital stock in the previous year plus capital formation in the current year minus capital depreciation in the current year. The energy consumption data are in thousand tones of oil equivalent (Toe) and represent the final energy consumption as the sum of the energy supplied to the final users for all energy uses. Final energy consumption measures the consumption of electricity and heat, fuels for space heating, transport fuels and fuels for industrial processes. It differs from total consumption because energy transmission and distribution losses have been removed from it. Thus, it represents the final amount of energy left at the disposal of households and other consumers.

Table 1 presents the summary statistics of the inputs and output used in the DEA model. In our model three production factors (labour-employment, capital-capital stock and energy-energy consumption) produce one output (GDP). The correlation matrix is shown in the Table 2.

Table 1: Statistics on input and output variables in 2010

Value of variable	Capital	Employment	Energy	GDP
Max	9021822	38737.8	158771	23322.03
Min	970725	164.2	451	55.15
Average	4978986	7967.915	33350	4366.517
SD	2309734	10212.48	44466.42	6459.458

Source: Authors' calculation

Table 2: Correlation coefficients of input and output variables

Variable	Capital	Employment	Energy	GDP
Capital	1	0.256414	0.273210	0.261605
Employment	0.256414	1	0.987062	0.967475
Energy	0.273210	0.987062	1	0.990224
GDP	0.261605	0.967475	0.990224	1

Source: Authors' calculation

As it is shown in the Table 2, all inputs have positive correlation coefficients with the output, implying that all inputs satisfy the isotonicity property with the output for the DEA model.

A great number of modelling techniques has been developed to address energy efficiency dilemmas because energy efficiency is a difficult concept to define. It is often confused with energy conservation, although conservation indicates the use of less energy, while efficiency implies reaching a given output with a lower use of resources (Gunn, 1997). Evaluating energy efficiency is a very important tool in energy and economic policy and it is usually done by two indicators: energy intensity and energy efficiency. Energy intensity is defined as the energy consumption divided by the economic output (GDP). It is the most commonly used basis for assessing trends in energy efficiency since a truly technical definition of energy efficiency can only be obtained through measurements at the level of a particular process or plant. Energy intensity is thought to be inversely related to efficiency, the less energy required to produce a unit of output or service, the greater the efficiency. A logical conclusion, then, is that declining energy intensities over time may be indicators of improvements in energy efficiencies (Nanduri, 1998: 10). Trends in energy intensities are influenced by changes in the economic and industrial activities of the country (structural changes), the energy mix and the efficiency of the end-use equipment and buildings. The second indicator - energy efficiency, sometimes called energy productivity - is the reciprocal value of energy intensity and is measured as the economic output divided by the energy input (consumption). The energy efficiency is in fact more an indicator of “energy productivity” than a true indicator of efficiency from a technical viewpoint. Its level reflects the nature of the economic activity (the economic structure), the structure of energy mix and the technical energy efficiency. In order to overcome these problems, data envelopment analysis (DEA) as a relatively new non-parametric approach to efficiency evaluation 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.

Compared to traditional parametric methods (such as the Cobb-Douglas function and translog production function), the advantage of using the DEA method is that this method avoids model misspecification. Moreover, the DEA-Luenberger index can easily compute total-factor productivity change, efficiency change, and technical change. However, DEA as a nonparametric mathematical programming approach has some disadvantages when comparing with the parametric frontier approach, especially stochastic frontier analysis (SFA). For example, DEA does not consider statistical noises, while SFA include statistical noises in energy efficiency analysis. For the comparison purpose, Zhou et al. (2012) computed the Shephard energy distance function DE (K,L,E,Y) and therefore economy-wide energy efficiency index in the case of OECD countries in the parametric (SFA) and nonparametric (DEA) framework. The results show that the top performer based on the SFA models, i.e. Italy, still has the highest EEI score based on the DEA models. Also, Canada has the lowest EEI score no matter which model is used. However, for most other countries the choice between SFA and DEA will affect not only the EEI scores but also the ranks. The authors conclude that SFA models often have higher discriminating power than DEA models, which might be considered as an advantage of SFA over DEA in benchmarking energy efficiency performance.

DEA is a mathematical programming-based technique for measuring the efficiency of DMU relative to other DMUs and estimating the best practice of efficient frontier. Each DMU uses *m* different inputs to produce *s* different outputs. The efficiency is defined as ratio of weighted sum of outputs and weighted sum of inputs. The mathematical programming problem for the CCR ratio is (Luptačik, 2010:18) to

$$\text{maximize} \quad h_0(u,v) = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

$$\text{subject to} \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \qquad (j = 1, 2, \ldots, n)$$

$$u_r \ge 0 \qquad (r = 1, 2, \ldots, s)$$

$$v_i \ge 0 \qquad (i = 1, 2, \ldots, m)$$

where u_r is the weight given to output *r* $(r = 1, 2, \ldots, s)$, v_i is the weight given to input *i* $(i = 1, 2, \ldots, m)$. Weights u_r i v_i are unknown and they will be chosen so as to maximize the efficiency of particular DMU subject to efficiencies of all DMUs in the set. If the efficiency h_0 is less than 1 DMU is relatively inefficient.

This mathematical programming model has been proven as a valuable performance evaluation method when homogeneous decision-making units operate in similar conditions. As far as countries are concerned, they can be regarded as uniform decision-making units, with regard to both input and output components. The DEA model is also useful in indicating sources and amounts of relative inefficiencies in order to improve the performance of DMU.

There are two basic types of DEA models with respect to envelopment surfaces referred to as constant returns-to-scale (CRS) and variable returns-to-scale (VRS). The DEA-CCR model assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. The DEA-BCC model, on the other hand, allows for variable returns to scale and is graphically represented by a piecewise linear convex frontier (Cooper et al., 2000). In this paper the input-oriented DEA-model is used since the frontier is an input-reducing focus and the efficiency of energy as input is considered. A majority of studies dealt with the intput-oriented DEA models rather than the output-oriented ones. It could be related to the characteristic of energy sector where the higher priority has been given to the goal of meeting demand (Färe et.al, 1994) and therefore the usual approach is oriented toward input conservation. As in the most studies, this paper also applies DEA with constant returns to scale (CRS) because it is not meaningful for overall economy to be operating under increasing or decreasing returns to scale. In order to capture the dynamics of total-factor energy efficiency and changes during the 2000-2010 period, the windows analysis is also employed. According to Mantri (2008:309), conventional DEA is static, i.e. the analysis does not consider the time frame to which the input consumption and output production refers. However, multi-period efficiency measurement is possible through window analysis that represents a time-dependent version of DEA. The input/output data of the DMUs for a number of consecutive periods (i.e. windows) are used to assess the efficiency of each DMU in each period. The basic idea of window analysis is to regard each DMU as if it were different DMU in each of the reporting dates: a DMU is compared to itself over time. Therefore it is useful for detecting efficiency trends of DMU over time (Cook and Seiford, 2009).

4. Empirical results and discussion

After selecting input and output variables, in the first stage the efficiency scores of countries in 2010 are analysed. This is followed by identifying sources and amounts of relative inefficiency. In the second stage, the window analysis is proceeded in order to provide trend information on the relative efficiency scores over the eleven-year period 2000-2010. Table 3 contains the summary efficiency score results from the DEA analysis using model with constant returns to scale.

According to the efficiency scores for 2010, the countries with the highest energy efficiency scores are United Kingdom, Sweden, Netherlands, Luxemburg, France, Germany and Ireland, while the worst performers in energy efficiency are transition economies: Czech Republic, Poland, Slovakia, Estonia, Lithuania, Latvia and Bulgaria. These findings can be related to the possibility of substitution among factors in a medium (11 years) run and to changes in the composition of energy use. Schurr and Netschert (1960) were the first who emphasized the importance of energy quality. Since the composition of energy use is changing significantly over time, Schurr and Netschert argued that the general shift to higher quality fuels reduces the amount of energy required to produce a dollar's worth of GDP.

In the case of US, Cleveland et al. (1984) and Kaufmann (1992) concluded that the decline in US energy intensity is significantly influenced by structural shifts in the economy and shifts from lower quality fuels to higher quality fuels.

Table 3: Rank and efficiency scores for the EU countries in 2010

Rank	Country	DMU	Rank	Country	DMU
1	United K.	1	14	Slovenia	0.590806
1	Sweden	1	15	Greece	0.559855
1	Netherlands	1	16	Hungary	0.475168
1	Luxemburg	1	17	Cyprus	0.46472
1	France	1	18	Malta	0.450903
1	Germany	1	19	Portugal	0.431223
1	Ireland	1	20	Czech R	0.334302
8	Denmark	0.944354	21	Poland	0.277075
9	Italy	0.888608	22	Slovakia	0.247929
10	Belgium	0.873544	23	Estonia	0.229153
11	Finland	0.832764	24	Lithuania	0.209527
12	Austria	0.771834	25	Latvia	0.162152
13	Spain	0.757546	26	Bulgaria	0.112807

Source: Authors' calculations

Although these results are more or less expected, the paper tempts to test the differences between the total-factor and one-factor traditional energy efficiency approach. Therefore the above listed results are compared with the traditional energy intensity indicator as the reciprocal value of energy efficiency (Table 4). Countries are ranked in ascending order according to their energy intensity. Consequently, the first rank means the lowest energy intensity i.e. the highest energy efficiency.

Table 4: Energy intensity* of the EU economies in 2010**

Rank	Country	Energy intensity	Rank	Country	Energy intensity
1	Ireland	928,150	14	Malta	1,692,020
2	Denmark	937,350	15	Cyprus	1,775,580
3	UK	1,118,650	16	Belgium	1,908,260
4	Italy	1,236,450	17	Finland	2,253,330
5	Austria	1,318,200	18	Slovenia	2,313,510
6	Spain	1,370,240	19	Hungary	2,954,940
7	Luxembourg	1,402,530	20	Lithuania	3,110,550
8	Germany	1,418,860	21	Poland	3,305,470
9	Greece	1,474,590	22	Latvia	3,633,370
10	France	1,516,040	23	Slovakia	3,713,410
11	Portugal	1,545,470	24	Czech Rep,	3,745,870
12	Netherlands	1,577,880	25	Estonia	5,458,710
13	Sweden	1,594,180	26	Bulgaria	6,711,010

Note: * Gross inland consumption of energy divided by GDP (reference year 2005)
** kilogram of oil equivalent/1000 euro of GDP

Source: European Commission, 2012

Comparing the above presented data on traditional one-factor energy efficiency with the results on total-factor energy efficiency shown in Table 3, one could note many inconsistencies. Only the least efficient countries (Bulgaria, Estonia, Czech Republic, Slovakia, Latvia, Poland and Lithuania) are similarly ranked by both methodologies, while there are some striking differences among the efficient countries according to total-factor framework methodology. Only Ireland and UK are ranked among the first seven most efficient economies, while some countries like Sweden, Netherlands and France are ranked as 13th,12th and 10th according to traditional energy efficiency concept. The biggest deviations in two methodologies are occurred in the mentioned case of Sweden, Netherlands, and France where all of them are considerably less energy efficient (or more energy intensive) regarding one factor framework. Since only Ireland, Poland and Bulgaria reach the same rank in both methodologies, one could conclude that the traditional concept is too simplifying and could be misleading.

The useful insight for the policy makers is provided by projections (Table A1). Projections on efficiency frontier are necessary improvements required in making inefficient countries efficient. As seen in Table A1, results suggest that all

Table 5: Average values of total-energy efficiency through window

Country	2000-2001-2002	2001-2002-2003	2002-2003-2004	2003-2004-2005	2004-2005-2006	2005-2006-2007	2006-2007-2008	2007-2008-2009	2008-2009-2010
Belgium	0.9	0.89	0.89	0.89	0.9	0.89	0.88	0.88	0.85
Bulgaria	0.16	0.1	0.1	0.11	0.15	0.15	0.15	0.16	0.12
Czech R	0.29	0.31	0.35	0.36	0.74	0.54	0.75	0.55	0.36
Denmark	0.99	0.95	0.95	0.96	0.98	0.99	0.99	0.97	0.93
Germany	0.9	0.93	0.93	0.93	0.89	0.87	0.87	0.86	0.9
Estonia	0.24	0.2	0.21	0.23	0.27	0.28	0.28	0.27	0.23
Ireland	0.98	0.97	0.99	1	1	0.98	0.98	0.99	0.97
Greece	0.64	0.55	0.56	0.58	0.65	0.66	0.66	0.66	0.57
Spain	0.84	0.78	0.75	0.74	0.75	0.7	0.72	0.74	0.73
France	1	0.99	0.99	0.98	0.99	0.98	0.97	0.96	0.96
Italy	0.97	0.94	0.92	0.9	0.91	0.87	0.87	0.86	0.85
Cyprus	0.53	0.47	0.47	0.48	0.52	0.53	0.54	0.53	0.47
Latvia	0.2	0.14	0.15	0.16	0.21	0.22	0.23	0.22	0.17
Lithuania	0.28	0.17	0.18	0.19	0.27	0.28	0.28	0.29	0.22
Luxembourg	0.99	0.99	1	1	0.99	0.98	0.99	0.99	0.97
Hungary	0.38	0.3	0.31	0.32	0.37	0.36	0.37	0.37	0.33
Malta	0.87	0.47	0.47	0.48	0.72	0.75	0.71	0.69	0.47
Netherlands	0.95	0.94	0.92	0.92	0.93	0.91	0.91	0.91	0.91
Austria	0.8	0.78	0.79	0.79	0.8	0.79	0.79	0.78	0.76
Poland	0.33	0.25	0.25	0.25	0.3	0.29	0.3	0.31	0.28
Portugal	0.64	0.43	0.42	0.42	0.54	0.53	0.53	0.54	0.43
Slovenia	0.42	0.36	0.37	0.38	0.42	0.43	0.44	0.44	0.39
Slovakia	0.21	0.19	0.2	0.21	0.24	0.26	0.28	0.29	0.25
Finland	0.8	0.8	0.81	0.82	0.83	0.84	0.84	0.83	0.81
Sweden	0.93	0.94	0.96	0.96	0.98	0.99	0.97	0.96	0.94
United K.	0.99	1	0.98	0.98	1	0.97	0.98	1	0.97

Source: Authors' calculations

inefficient countries could improve their efficiency on all input variables, i.e. these countries might reduce some of the inputs to become relatively efficient. Having this information, policy makers should concentrate their efforts in enhancing the performance. The results show that Bulgaria, Latvia, Estonia and Slovakia should reduce the consumption of energy for more than 70% in order to reach the same GDP comparing with the referent efficient country in the analysis (Ireland in all cases). On the other hand, some countries like Greece, Cyprus, Malta and Portugal should reduce other inputs, mostly labour, more than energy itself in order to produce the same output.

In order to capture the dynamics of the total-factor energy efficiency, the windows analysis has been applied for period 200-2010. For illustration, the first window incorporates years 2000, 2001 and 2002. Generally, when a new period is introduced into window, the earliest period is dropped. In next window year 2000 will be dropped and year 2003 will be added to the window. The analysis is over when the window analyses years 2008, 2009 and 2010. It can be observed that Luxembourg achieved the best average score and equals 0.988. Results indicate that the overall average total-factor efficiencies of analyzed countries haven`t shown considerable fluctuations over the eleven-year period analyzed. Table 5 contains the averages through a window.

It can be observed that all analyzed countries except Malta and Czech Republic have stabile score of total-factor energy efficiency. We can also note that Belgium, Bulgaria, Denmark, Spain, France, Italy, Malta, Netherlands, Austria, Poland and Portugal (approximately 40% of all analyzed countries) have the best average efficiency scores during the 2000-2001-2002 period.

5. Conclusion

The results of the research show that the hypothesis on considerable differences in measuring energy efficiency between traditional one-factor and total-factor approach is confirmed. The comparison with the traditional one-factor energy efficiency indicator shows many inconsistencies, so it could be concluded that the traditional concept is too simplifying and could be misleading. The findings on TFEE scores reflect the possibility of substitution among factors in a medium (11 years) run and the changes in the composition of energy use. Countries with the higher share of high quality fuels like electricity and natural gas have reached the best scores, while economies with the lower quality energy sources (wood, coal) are the worst energy efficiency performers. Projection values identify the amounts of relative inefficiency and, in that context, suggested improvements for all inefficient countries. The results reveal that all inefficient countries could improve their efficiency by reducing some of the inputs. These findings imply that policy makers should take this information into consideration when creating energy policy and development policy. Since this is, as far as it knows, the first total-factor energy efficiency analysis for the EU economies, the obtained results allow us to conclude that these research results are appropriate scientific contribution to economic literature, respectively economic science.

The limitation of this study is that economy-wide energy efficiency is estimated within a traditional production function framework without considering undesirable outputs. It would be worthwhile to extend this analysis by incorporating undesirable outputs like CO_2 emissions. 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 important consequences in implementing measures for improving energy efficiency in the EU in the light of the ongoing desire to reduce energy consumption.

References

Abbott, M. (2006) "The productivity and efficiency of the Australian electricity supply industry", *Energy Economics*, 28, pp. 444-454.

Barros, C.P. (2008) "Efficiency analysis of hydroelectric generating plants: A case study for Portugal", *Energy Economics*, 30, pp. 59-75.

Boyd, G.A., Pang, J.X. (2000) "Estimating the linkage between energy efficiency and productivity", *Energy Policy*, 28, pp. 289-296.

Caves, D.W., Christensen, L.R., Diewert, W.E. (1982) "The economic theory of index numbers and the measurement of input, output and productivity", *Econometrica*, 50, pp. 1393-1414.

Ceylan, D., Gunay, E.N.O. (2010) "Energy efficiency trends and policies: Cross-country comparison in Europe", paper presented at International Conference of Economic Modelling (ECOMOD), July 7-10, Istanbul.

Cleveland, C. J., Costanza, R., Hall, C.A.S., Kaufman, R. (1984) "Energy and the U.S. economy: A biophysical perspective", *Science,* 225, p.p. 890-897.

Cook, W.D., Seiford, L.M. (2009) "Data envelopment analysis (DEA) – Thirty years on", *European Journal of Operational Research*, 192, pp. 1-17.

Cooper, W. W., Seiford, L.M., Tone, K. (2000): *Data Envelopment Analysis*, Boston: Kluwer Academic Publishers.

Cullinane, K., Song, D., Ji, P., Wang, T. (2004) "An Application of DEA Windows Analysis to Container Port Production Efficiency", *Review of Network Economics,* Vol.3, Issue 2, pp. 184-205.

Edvardsen, D.F., Førsund, F.R. (2003) "International benchmarking of electricity distribution utilities", *Rosource and Energy Economics*, 25, pp. 353-371.

European Commission (2012) *Eurostat*, Statistics Database.

Färe, R., Grosskopf, S., Lovell, C.A.K. (1994) *Production frontiers,* Cambridge: Cambridge University Press.

Førsund, F.R., Kittelsen, S.A.C. (1998) "Productivity development of Norwegian electricity distribution utilities", *Resource and Energy Economics*, 20, pp. 207-224.

Gunn, C. (1997) "Energy efficiency vs economic efficiency", Energy Policy, Vol. 25, 2, pp. 241-254.

Honma, S., Hu, J.L. (2008) "Total-factor energy efficiency of regions in Japan", *Energy Policy*, 36, pp. 821-833.

Honma, S., Hu, J.L. (2009) "Total-factor productivity growth of regions in Japan". *Energy Policy*, 37, pp. 3941-3950.

Honma, S., Hu, J.L. (2011) *Industry-level Total-factor Energy Efficiency in Developed Countries*, Discussion Paper No. 51, Kyushu Sangyo, Japan: Faculty of Economics.

Hu, J.L., Wang, S.C. (2006) "Total-factor energy efficiency of regions in China", *Energy Policy*, 34, pp. 3206-3217.

Kaufmann, R. K. (1992) "A biophysical analysis of the energy/real GDP ratio: implications for substitution and technical change", *Ecological Economics,* 6, pp. 35-56.

Luptačik, M. (2010) *Mathematical Optimization and Economic Analysis*, New York: Springer Science and Business Media.

Mantri, J. K. (2008) *Research Methodology on Data Envelopment Analysis (DEA)*, Boca Raton, Florida: Universal-Publishers.

Nanduri, M. (1998) *An assessment of energy intensity indicators and their role as policy-making tools,* Report No. 232, Simon Fraser University.

Schurr, S., Netschert, B. (1960) *Energy and the American Economy, 1850-1975*, Baltimore: Johns Hopkins University Press.

Zhou, P., Ang, B.W., Poh, K.L. (2008) "A survey of data envelopment analysis in energy and environmental studies", *European Journal of Operational Research*, 189, pp. 1-18.

Zhou, P., Ang, B.W., Zhou, D.Q. (2012) "Measuring economy-wide energy efficiency performance: A parametric frontier approach", *Applied Energy,* 90, pp. 196-200.

Ukupna faktorska energetska efikasnost u zemljama Europske unije[1]

Nela Vlahinić-Dizdarević[2], Alemka Šegota[3]

Sažetak

Cilj je ovog istraživanja utvrditi promjene u energetskoj efikasnosti na makroekonomskoj razini u zemljama EU u razdoblju od 2000. do 2010. i usporediti dobivene rezultate s tradicionalnim pokazateljem energetske efikasnosti. Korišten je DEA CCR-inputu usmjereni model kako bi se analizirala efikasnost korištenja tri inputa (kapital, rad i energija) u ostvarivanju outputa (BDP). Kako bi se izbjegla statičnost metode te unijela dinamika, korištena je proširena metoda analize omeđivanja podataka – analiza prozora. Empirijski rezultati podupiru hipotezu da je uobičajeni pokazatelj energetske efikasnosti temeljen na jednom faktoru prejednostavan i može upućivati na pogrešne zaključke. Rezultati ukupne faktorske energetske efikasnosti odražavaju mogućnost supstitucije među faktorima u srednjem roku i promjene u strukturi potrošnje energije. Projicirane vrijednosti inputa na efikasnu granicu određuju količine relativne neefikasnosti i, u tom kontekstu, sugeriraju poboljšanja za sve neefikasne zemlje. Rezultati upućuju na zaključak da bi sve neefikasne zemlje mogle unaprijediti svoju efikasnost smanjenjem nekih od inputa.

***Ključne riječi**: ukupna faktorska energetska efikasnost, zemlje EU, DEA, analiza prozora*

***JEL klasifikacija:** Q43, C33, C61, O49*

[1] Prikazani rezultati proizašli su iz znanstvenog projekta (Ekonomski učinci regulatornih reformi elektroenergetskog sektora, br. 081-0361557-1455), provođenog uz potporu Ministarstva znanosti, obrazovanja i sporta Republike Hrvatske.

[2] *Redoviti profesor, Sveučilište u Rijeci, Ekonomski fakultet, Ivana Filipovića 4, 51000 Rijeka, Hrvatska. Znanstveni interes: makroekonomija, energetska ekonomija. Tel: +385 51 355 111. E-mail: nela@efri.hr.*

[3] *Docent, Sveučilište u Rijeci, Ekonomski fakultet, Ivana Filipovića 4, 51000 Rijeka, Hrvatska. Znanstveni interes: matematika, teorija odlučivanja. Tel: +385 51 355 161. E-mail: alemka.segota@efri.hr.*

Appendix

Table A1: Efficient level of input values for EU countries

No.	DMU I/O	Score			
		Data	Projection	Difference	%
1	Belgium	0.873544			
	Capital	8522784	7445028	-1077756	-12.65
	Employment	4488.7	3921.077	-567.6227	-12.65
	Energy	36396	24709.06	-11686.94	-32.11
	GDP	3186.85	3186.85	0	0.00
2	Bulgaria	0.206389			
	Capital	6638716	905579.6	-5733136	-86.36
	Employment	3052.8	285.3978	-2767.402	-90.65
	Energy	8842	1824.893	-7017.107	-79.36
	GDP	258.81	258.81	0	0.00
3	Czech R	0.341772			
	Capital	3496223	1194911	-2301312	-65.82
	Employment	4885.2	1669.624	-3215.576	-65.82
	Energy	25616	8754.83	-16861.17	-65.82
	GDP	1174.77	1174.77	0	0.00
4	Denmark	0.959018			
	Capital	4967588	4764007	-203580.9	-4.10
	Employment	2717.6	2592.028	-125.5719	-4.62
	Energy	15535	14898.35	-636.653	-4.10
	GDP	2063.12	2063.12	0	0.00
5	Germany	0.903605			
	Capital	7098710	6414427	-684283.4	-9.64
	Employment	38737.8	35003.65	-3734.148	-9.64
	Energy	217530	196561.1	-20968.9	-9.64
	GDP	23322.03	23322.03	0	0.00
6	Estonia	0.270024			
	Capital	3375012	388320.5	-2986692	-88.49
	Employment	570.9	122.3811	-448.5189	-78.56
	Energy	2898	782.53	-2115.47	-73.00
	GDP	110.98	110.98	0	0.00

No.	DMU I/O	Score			
		Data	Projection	Difference	%
7	Ireland	1			
	Capital	5850140	5850140	0	0.00
	Employment	1843.7	1843.7	0	0.00
	Energy	11789	11789	0	0.00
	GDP	1671.94	1671.94	0	0.00
8	Greece	0.726998			
	Capital	7590098	5517990	-2072108	-27.30
	Employment	4388.6	2297.488	-2091.112	-47.65
	Energy	19027	13832.6	-5194.4	-27.30
	GDP	1936.27	1936.27	0	0.00
9	Spain	0.779997			
	Capital	3670580	2863040	-807539.7	-22.00
	Employment	18456.5	14261.65	-4194.851	-22.73
	Energy	90599	70666.92	-19932.08	-22.00
	GDP	9412.19	9412.19	0	0.00
10	France	1			
	Capital	5690620	5690620	0	0.00
	Employment	25692.3	25692.3	0	0.00
	Energy	158771	158771	0	0.00
	GDP	17699.65	17699.65	0	0.00
11	Italy	0.894654			
	Capital	4586587	4103410	-483177.1	-10.53
	Employment	22872.3	20462.8	-2409.498	-10.53
	Energy	124769	111625.1	-13143.87	-10.53
	GDP	13733.7	13733.7	0	0.00
12	Cyprus	0.554691			
	Capital	3672145	528770.9	-3143374	-85.60
	Employment	385.1	166.6447	-218.4553	-56.73
	Energy	1921	1065.561	-855.4392	-44.53
	GDP	151.12	151.12	0	0.00
13	Latvia	0.20767			
	Capital	2528844	440140.9	-2088703	-82.60
	Employment	940.9	138.7125	-802.1875	-85.26
	Energy	4271	886.9567	-3384.043	-79.23
	GDP	125.79	125.79	0	0.00

No.	DMU I/O	Score			
		Data	Projection	Difference	%
14	Lithuania	0.325885			
	Capital	4307691	768313.3	-3539378	-82.16
	Employment	1343.7	242.1377	-1101.562	-81.98
	Energy	4751	1548.278	-3202.722	-67.41
	GDP	219.58	219.58	0	0.00
15	Luxemburg	1			
	Capital	6886245	6886245	0	0.00
	Employment	220.8	220.8	0	0.00
	Energy	4302	4302	0	0.00
	GDP	313.36	313.36	0	0.00
16	Hungary	0.378421			
	Capital	1934865	732192.8	-1202672	-62.16
	Employment	3781.2	1224.819	-2556.381	-67.61
	Energy	16660	6304.487	-10355.51	-62.16
	GDP	848.73	848.73	0	0.00
17	Malta	0.862234			
	Capital	991348	192970.6	-798377.4	-80.53
	Employment	164.2	60.81561	-103.3844	-62.96
	Energy	451	388.8676	-62.13237	-13.78
	GDP	55.15	55.15	0	0.00
18	Netherlands	0.978458			
	Capital	1527276	1494375	-32900.61	-2.15
	Employment	8370.2	8189.889	-180.311	-2.15
	Energy	53890	47219.05	-6670.948	-12.38
	GDP	5453.33	5453.33	0	0.00
19	Austria	0.771834			
	Capital	8760759	6761852	-1998907	-22.82
	Employment	4096.3	3161.664	-934.6361	-22.82
	Energy	27933	19978.68	-7954.322	-28.48
	GDP	2625.66	2625.66	0	0.00
20	Poland	0.341836			
	Capital	6023053	2058895	-3964158	-65.82
	Employment	15960.5	4461.871	-11498.63	-72.04
	Energy	66324	22671.91	-43652.09	-65.82
	GDP	3041.29	3041.29	0	0.00

No.	DMU I/O	Score			
		Data	Projection	Difference	%
21	Portugal	0.624825			
	Capital	4571632	2856468	-1715164	-37.52
	Employment	4978.2	2047.978	-2930.222	-58.86
	Energy	18136	11331.82	-6804.18	-37.52
	GDP	1554.7	1554.7	0	0.00
22	Slovenia	0.446631			
	Capital	7598021	1101524	-6496497	-85.50
	Employment	966	347.1507	-618.8493	-64.06
	Energy	4970	2219.754	-2750.246	-55.34
	GDP	314.81	314.81	0	0.00
23	Slovakia	0.295315			
	Capital	9021822	1698911	-7322911	-81.17
	Employment	2317.5	535.42	-1782.08	-76.90
	Energy	11593	3423.586	-8169.414	-70.47
	GDP	485.54	485.54	0	0.00
24	Finland	0.832764			
	Capital	4301912	3582477	-719434.5	-16.72
	Employment	2447.5	2038.19	-409.3101	-16.72
	Energy	26484	12822.96	-13661.04	-51.58
	GDP	1635.31	1635.31	0	0.00
25	Sweden	1			
	Capital	970725	970725	0	0.00
	Employment	4545.8	4545.8	0	0.00
	Energy	34436	34436	0	0.00
	GDP	3112.44	3112.44	0	0.00
26	United K.	1			
	Capital	4870228	4870228	0	0.00
	Employment	28941.5	28941.5	0	0.00
	Energy	142951	142951	0	0.00
	GDP	19022.32	19022.32	0	0.00

Source: Authors' calculations