Measurement of Energy Use Efficiency in Lower-Middle, Upper -Middle and High Income Countries: A Data Envelopment Analysis

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ABSTRACT

The purpose of this paper is to measure the energy use efficiency in the low-middle income, the upper-middle income and the high-income countries over the period of 1991 to 2011 using the data envelopment analysis. Energy use efficiency is generally measured by energy intensity which is defined as the ratio of energy use to gross domestic product. However, this ratio or measurement is arguable in the literature and therefore, energy intensity is not a good indicator of energy use efficiency. Energy use efficiency improvements make mention of a decrease in energy used for a given service or level of activity. Hence, it can be measured by either deterministic or non-deterministic approaches within the framework of production theory. The findings of this paper show either energy is used efficiently or inefficiently between lower middle-income countries, upper middle-income countries and high income countries also help to make some policy implications on energy use, because almost all countries are implementing a broad array of policy measures for energy efficiency.

Key Words: *Energy use efficiency, total factor productivity, low and upper - middle and high-income countries, data envelopment analysis*

JEL Classification: *C6, D, D2, Q4*

Alt-Orta, Üst-Orta ve Yüksek Gelir Gruplarında Yer Alan Ülkelerin Enerji Kullanım Etkinliklerinin Ölçülmesi: Veri Zarflama Analizi

ÖZ

Bu çalışmanın temel amacı, 1991-2011 yıl aralığı için alt-orta, üst-orta ve yüksek gelir gruplarında yer alan ülkelerin enerji kullanımlarındaki etkinliklerini veri zarflama analizi yöntemini kullanarak ölçmektir. Enerji kullanımındaki etkinlik çoğu zaman, toplam enerji kullanımının gayri safi yurtiçi hasıla içerisindeki payı olarak hesaplanan enerji yoğunluğu kavramı ile ölçülmektedir. Bununla birlikte bu oran literatürde tartışmaya çok açıktır ve bu yüzden enerji yoğunluğu enerji kullanımındaki etkinliği göstermek için iyi bir ölçüm göstergesi olarak görülmemektedir. Bununla birlikte enerji yoğunluğu hesaplamaları çerçevesinde enerji kullanımındaki etkinliğin ölçümü ile ilgili gelişmeler belirli bir faaliyet düzeyinde enerji kullanımında görülen düşüşten bahsetmektedir. Bu yüzden üretim teorisi çerçevesinde enerji kullanımındaki etkinliğin deterministik ve deterministik olmayan yaklaşımlar ile ölçülmesi daha sağlıklı bulunmaktadır. Çalışmanın bulguları, alt-orta, üst-orta ve yüksek gelir gruplarında yer alan ülkeler arasında ülke gruplarına göre enerjinin etkin veya etkinsiz kullanılabildiğini göstermekte ve enerji kullanımına yönelik politika uygulamaları yapılmasının gerekliliği yönünde katkı sağlamaktadır. Çünkü hemen hemen artık tüm ülkeler enerjinin etkin kullanımı üzerine politika önlemleri almaktadırlar.

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Anahtar Kelimeler: *Enerji kullanım etkinliği, toplam faktör verimliliği, alt-orta, üst-orta ve yüksek gelir grubu ülkeleri, veri zarflama analizi.*
JEL Sınıflandırması: *C6, D, D2, Q4*

INTRODUCTION

Energy is one of the most contentious issues for all countries, regardless of their development level. The rise of the world population not only increases the economic activities, but also puts even more demand on energy and this creates a serious danger for energy resources. OECD, International Energy Agency and other important organizations have also been mentioning this challenge, for instance bias OECD Green Growth Studies and Word Energy Outlook 2016. Therefore, the terms "energy use efficiency" and "energy use inefficiency" have gained importance and in this context, the energy use efficiency has also become one of the most important strategies among countries. When evaluated in the context of development level of countries, it can be seen that, developed countries are comparatively more successful at efficient use of energy.

Hence, energy use efficiency is one of the most important targets to be achieved by countries due to scarcity of energy sources in the world. Any improvement in energy use efficiency refers to a reduction in energy used for a given service or level of activity.

In the literature, energy use efficiency is generally defined as energy intensity measured by the ratio of energy use to gross domestic product (GDP) (Eurostat Metadata). However, this ratio or measurement is traditional and thus arguable. Because, this ratio ignores some other important indicators to measure energy use efficiency. Therefore does not have any power to characterize an economy and to make energy policies (Filippini and Hunt, 2010).

To overcome the inadequacy of the traditional ratio, new approaches have been developed. And most popular approaches to measure energy use efficiency are known as decomposition analysis and frontier analysis. Decomposition analysis, which deals with the changes of energy efficiency over time in a specific decision-making units (or DMUs), include structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Zhou and Ang, 2008, 2911-2912). On the other hand, data envelopment analysis (DEA) and Stochastic frontier analysis (SFA) are mostly preferred under the frontier analysis. The DEA which is a non-parametric and the SFA which is parametric are applied widely for efficiency measurement of the DMUs. Hence, either deterministic or non-deterministic approaches within the framework of production theory have been used to measure energy use or consumption efficiency. In this case, the aggregate energy consumption function that means the best-practice frontier shows the level of energy necessity for an economy to produce any given level of activity. Therefore, in this study we obtain the best-practice frontier using non-parametric and deterministic approach, namely data envelopment analysis.

In the literature, there is a various study to measure energy efficiency levels at a country level, industry level, and firm level. Honma and Hu (2008) indicated regional energy efficiency in Japan using DEA; Zhou and Ang (2008) and

Fhillippini and Hunt (2010) studied economy –wide energy efficiency performances of selected OECD countries using frontier analysis; Zhang et al. (2011) analyzed 23 developing countries to show energy efficiency level; Alsahlawi (2013) examined the energy efficiency levels of Golf Cooperation Council countries employing the DEA;

The main purpose of this paper is to get the baseline energy consumption frontier using data envelopment analysis for lower-middle, upper-middle and high income countries over the 1991-2011 period using data envelopment analysis. This approach allows us to know whether a country is on the best-practice frontier or not (Coelli et al, 1998). If a country or a DMUs is on the frontier, it is said that it is efficient in energy use, otherwise it is inefficient with relative to the best-practice frontier. The distance from the frontier, which explains inefficiency level, measures energy consumption level above the baseline demand (Fhillippini and Hunt, 2010,7).

This paper, as far as known, is the one of the first attempts to measure energy use efficiency and total factor productivity (TFP) components in terms of aggregate energy consumption function for different level of income countries. The TFP indices show that how energy use efficiency and technology have changed over the study period (Chang and Hu, 2010, 3264). The paper also aims to make some policy implications on energy use, because policy-making about energy use efficiency is almost the most popular aim due to scarcity of energy sources.

The rest of paper includes section of data, methodology, empirical findings, and conclusion.

I. DATA

Data Envelopment Approach based on the Malmqüist Indices requires information about quantities or values of inputs and outputs, but not input and output prices which are required to measure efficiency performances of decision-making units. Therefore, this study analyzes 8 lower-middle income countries, 9 upper- middle of countries and 20 high-income countries and the data set includes energy use (kt of oil equivalent), GDP (constant 2005 US$), land area (sq. km), population in total, and roads (total network, km) for the mentioned income groups. The number of countries and time are determined according to data availability. All the data were taken from the World Development Indicators (World Bank, 2013) and Penn World Table 8.1 for the period 1991-2011. Besides that, the data set in this study is based on balanced data.

In this study, we used the energy use (kt of oil equivalent) as a dependent variable and the others are independent variables. In terms of aggregate energy consumption function, we assumed that there is an aggregate energy consumption (or use) relation for panel of different income group-countries, as follows:

$$Energy\ Use_{it}=f(GDP_{it},\ Land\ Areas_{it},\ Population_{it},\ Roads_{it})$$

It means that energy is mainly consumed or used by GDP, land area, population and road sector.

II. METHODOLOGY

This study prefers to use the Data Envelopment Approach based on the Malmqüist Totat Factor Productivity (MTFP) indices to measure energy use efficiency for different income group countries. The method of MTFP indices was put forward by Caves et al., (1982) Following studies about MTFP have improved the literature of this methodology. In addition to this, DEA methodology has been the center of interest in this area. Charnes et al., (1978); Fare et al., (1994); Charnes et al., (1994); Coelli (1996); and Seiford, (1996) make a big contribution on DEA. However, current literature possess panel data applications of DEA methodology, such as and Singh et al., (2001); Milan and Aldaz, (2004); Deliktaş and Balcilar, (2005); Chien and Hu, (2007); Song et al., (2013).

DEA methodology has many benefits. Among those are the possibility of seeing the indices of technical efficiency change and technological change, by using distance functions, which operates in input-oriented form or output-oriented form.

It is possible to define the input distance function on the input set as Coelli, Rao, and Battaese did in 1998:

$$d_i(x, y) = \max\{\rho : (x/\rho) \in L(y)\} \tag{1}$$

Where the input set L(y) shows the set of all input vectors (x), which can produce the output vector (y). That is,

$$L(y) = \{(x, y) : x \text{ can produce } y\}. \tag{2}$$

The distance function measures the technical efficiency, which calculates the distance between the observation and the frontier of technology. The technical efficiency is considered as a dynamic indicator to show the changes in the time period. The distance function can be explained via the following equations;

If (x_t, y_t) is on the frontier of the technology, Distance is $"D_0^t(x_t, y_t) = 1"$

If $(x_t, y_t) \in L(y)$, Distance is $"D_0^t(x_t, y_t) \leq 1"$ (Karadag et al. 2005, 216-218).

Add to obtain the technical efficiency, DEA based on distance functions are used to measure efficiency levels of decision making units. DEA measures the relative efficiency of the decision-making units as the ratio the sum of their weighted outputs to the sum of their weighted inputs. A relative efficiency measure can be defining as follows:

$$TE_j = \frac{u_1 y_{1j+} u_2 y_{2j+} u_3 y_{3j+} ..... + u_n y_{nj+}}{v_1 x_{1j} + v_2 x_{2j+} v_3 y_{3j+} .... + v_n x_{nj+}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_r x_{sj}}$$

$$\text{Subject to} \quad \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_r x_{sj}} \leq 1 \qquad (3)$$

and $u_r, v_j, \varepsilon > 0$

In compliance with the above formulas, where ϵ is a small constant and which compels to all inputs and outputs to possess non-zero weights (El Mahgay and Lahdelma, 1995,701);

- TE_j is the technical efficiency (score),
- x and y show input and output respectively,
- v and u indicate input and output weights, respectively,
- s and r are the number of inputs and outputs, respectively.

The methodology used in this study is based on the input-oriented DEA model for a single output. This method is parallel with Farrel (1957), Coelli et al., 1998. The situation in this model considers *i=1,2…N* industries. Each of them uses K inputs and produces a single output. In this model x_{it} and y_{it} are respectively mentioned as a column vector and a scalar for the *i-th* industry. X denotes the *K x NT* input matrix and Y denotes *1 x NT* output matrix. Under these circumstances, the input-oriented DEA model is given by;

$$\begin{aligned} & \min_{\theta,\lambda} \theta, \\ & subject..to \\ & -y_{it} + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1 \\ & \lambda \geq 0 \end{aligned}$$

(4) (Coelli, 1996).

In accordance with the above formulas, $N1'\lambda = 1$ denotes the convexity constraint in the case of variable returns to scale (VRS). This provides that an inefficient firm may only be "benchmarked" against firms of a parallel size. However, the convexity constraint is not valid for the constant returns to scale (CRS). Therefore, in the context of CRS condition, it is possible that a firm may be "benchmarked" against firms of dissimilar size (larger or smaller than it) (Coelli, et al, 1998). Add to the above formulas, the weights (λ) is a N×1 vector (where $1 \leq \theta < \infty$) and "1/θ" shows technical efficiency index (score). This index should be lie between zero and one. The value of one indicates any point on the frontier.

Besides that, analyzing productivity change between period *t* and *t+1* is possible using Malmquist index approach. When we follow Fare et al., 1994, the index of productivity change can be defined as

$$MTFP_0^{t,t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\left(\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \right) \left(\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \right) \right]^{1/2}, \tag{5}$$

where $D_0^{t+1}(x_t, y_t)$ indicates the distance between period *t* observation and *t+1* technology.

Total Factor Productivity (TFP) change has two components: efficiency and technical changes (Nishimizu and Page 1982,924). When we follow Fare et al. (1994), the definition of TFP with two components can be expressed as:

$$MTFP_0^{t,t+1}(x_t, y_t, _{t+1}, y_{t+1}) = \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} x \left[(\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_{t+1}, y_{t+1})}) x (\frac{D_0^t(x_t, y_t)}{D_0^{t+1}(x_t, y_t)} \right]^{1/2} \tag{6}$$

The equation (6) expresses the indicators of technical efficiency change (EC) and technological change (TC). $\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)}$ represents the score of EC and $(\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_{t+1}, y_{t+1})}) x (\frac{D_0^t(x_t, y_t)}{D_0^{t+1}(x_t, y_t)}$ indicates the score of TC. The EC score provides to analyze the convergence performance of the country to the best-practice frontier.

In accordance with the above information, Malmqüist TFP change can be shown as

$$MTFP_0^{t,t+1} = EC \cdot TC. \tag{7}$$

The equation (7) provides to interpret the total factor productivity, technical efficiency change and technological change. Table 1 shows the meaning of alternative scores of them.

Table 1: *Explanation of the MTFP, EC and TC Scores*

$MTFP_0^{t,t+1} > 1$	Productivity increase between the period of t and t+1.
$MTFP_0^{t,t+1} < 1$	Productivity decrease between the period of t and t+1.
$MTFP_0^{t,t+1} = 1$	No change in the productivity level between the period of t and t+1.
EC > 1	Convergence effect for countries between the period of t and t+1.
EC < 1	Divergence effect for countries between the period of t and t+1
EC = 1	No change in the position of countries between the period of t and t+1
TC > 1	Technical progress
TC < 1	Technical regress

MTFP indices can be run using the DEA linear programming programs. Therefore, under the benefits of this methodology, we prefer to use DEA based on the MTFP indices in this study.

III. EMPIRICAL RESULTS

A. Technical efficiency and total factor productivity components for the lower middle-income-countries

The efficiency levels of the different income groups are obtained by using equation (7). Technical efficiency index can be between the value of zero and one. The values of zero and one demonstrate full inefficiency and full efficiency, respectively. The equation (7) is rely on the VRS, employing DEA. The best-practice frontier (efficiency level) in this study is determined for 37 countries (in the context of 3 different income groups) between 1991 and 2011.

Add to this, the TFP change index has two components which are EC and TC. They are calculated by using equation (6). TFP change index gives information about the improvement level of productivity among countries through technical progress or a more efficient use under the existing technology. Moreover, EC and TC compensate the overall productivity growth. (Deliktas, Balcilar, 2005). The result of TFP index in this study presents whether there is a regress or progress in the productivity level. If the TFP index is bigger than one, it shows a percentage growth.

The indicator of the increasing efficiency in this study explains the power of the adaptation to technology. It means, this indicator shows the convergence effect. With the assumption of technology is constant, the increase in efficiency also presents a more efficient use.

Table II. Annual averages of efficiency levels and total factor productivity change components for the lower middle-income-countries over the 1991-2011 period

Country	Mean te *	effch	Techch	pech	sech	Tfpch
Bolivia	0.470	1.052	0.977	1.017	1.034	1.027
Georgia	0.648	0.982	0.970	0.985	0.997	0.953
India	0.907	1.029	0.982	1.000	1.029	1.011
Indonesia	0.899	1.032	0.977	1.000	1.032	1.009
Moldova	1.000	1.000	0.963	1.000	1.000	0.963
Morocco	0.348	1.047	0.977	1.047	1.000	1.023
Pakistan	0.799	1.042	0.969	1.002	1.040	1.010
Paraguay	0.557	1.033	0.965	1.000	1.032	0.997
Mean	**0.703**	**1.027**	**0.973**	**1.006**	**1.021**	**0.999**

*Mean technical efficiency level is the arithmetic mean for each country over the 1991-2011 period.

The annual average technical efficiency levels and the components of total factor productivity growth are given Table 1 to 3 for different level of income groups over the 1991-2011 period. The annual technical efficiency levels for each country are given in Appendix.

According to Table 1, Moldova appears to be a full energy efficient country. It is one of the countries that determine the-best-practice frontier for whole period. This country is followed by India and Indonesia, respectively. On the other hand, Bolivia appears to be the least energy efficient country followed Morocco and Paraguay, respectively. Average efficiency level for the lower-income countries is 0.703 or inefficiency level is 0.297 over the 1991-2011 period.

The average annual TFP change index, as given in the last column of Table 1, for the lower-middle income countries is 0.999 over the 1991-2011 period. The TFP change index is almost one that indicates no change during the study period. The efficiency change index which is one of the components of the TFP change indicates that there is an improvement in the energy consumption efficiency over the 1991-2011 period and average annual growth rate is 2.7 percent. However, there is a technical regress or shift of frontier, on average 2.7 percent. Thus, the sum of these two changes is zero, therefore, the TPF doesn't change.

The average annual pure efficiency change (pech) and scale efficiency change (sech) indices, which are the components of efficiency change, indicate an improvement. Table 1 also shows that the energy consumption efficiency has decreased in Georgia over the study period. In terms of the TFP, Bolivia and Morocco have a high growth rates which are 2.7 and 2.3 percent, respectively.

B. Technical efficiency and total factor productivity components for the upper middle-income-countries

Table 2 gives the average annual technical efficiency levels and The TFP change components for the upper-middle income countries over the 1991-2011 period. In this group, according to annual mean of efficiency levels, the most energy efficient countries are Romania and Jordan, respectively. On the other hand, the least efficient countries are Panama, Costa Rica, and Brazil, respectively. The average annual efficiency level for the upper-middle-income countries is 0.624 over the 1991-2011 period. It means that the upper-middle incomed countries have also been inefficient in energy consumption for the 1991-2001 period, on average. However, the average annual efficiency change index is bigger than one (1.022), it indicates that they are catching up the best-practice frontier from period t+1 to period t.

The average annual TFP change index is bigger than one indicating growth in the total factor productivity due to improvement in technical efficiency or energy use efficiency. Mexico and Romania have a negative growth in the TFP change. On the other hand, the average annual technological change for the upper-middle income countries is negative, with an average technical regress is 1.6 percent over the 1991-2011 period.

Table III. Annual averages of efficiency levels and total factor productivity change components for the upper middle-income-countries over the 199-2011 period

Country	Mean te *	effch	techch	pech	sech	tfpch
Brazil	0.460	1.020	0.986	1.002	1.018	1.006
Chile	0.507	1.016	1.000	1.015	1.001	1.016
Costa Rica	0.406	1.043	0.976	1.016	1.026	1.018
Jordan	0.961	1.019	0.990	1.009	1.010	1.009
Macedonia, FYR	0.855	1.034	0.971	1.019	1.015	1.004
Mexico	0.557	1.007	0.991	0.984	1.024	0.998
Panama	0.397	1.027	0.986	1.006	1.021	1.013
Romania	0.964	1.001	0.973	0.995	1.005	0.973
Turkey	0.505	1.031	0.981	1.024	1.006	1.011
Mean	**0.624**	**1.022**	**0.984**	**1.008**	**1.014**	**1.005**

*Mean technical efficiency level is the arithmetic mean for each country over the 1991-2011 period.

The multiplication of two indices gives the TFP, which is 1,005 indicating that the annual average total factor productivity growth rate is 0.5 percent over the 1991-2011 period.

C. Technical efficiency and total factor productivity components for the high-income-countries

Table 3 gives the average annual technical efficiency levels and the TFP change indices for the high-income countries over the 1991-2011 period. According to annual mean of efficiency levels, the full energy efficient countries are Saudi Arabia, Singapore, and United States. They have determined the best-practice frontier for whole countries over the 1991-2011 period. These full efficient countries are followed by Korea and Finland, respectively. On the other hand, the least efficient country is Italy followed by Austria, Switzerland and Denmark, respectively. Average annual efficiency level for the upper-middle-income countries is 0.762 for the 1991-2011 period. This score indicates that the high-income countries are more energy use efficient than both of the lower-middle and upper-middle income countries, on average.

Table III. Annual averages of efficiency levels and total factor productivity change components for the high-income-countries over the 199-2011 period

Country	Mean te *	effch	techch	pech	sech	tfpch
Australia	0.796	1.000	0.997	1.001	0.999	0.998
Austria	0.608	0.996	1.012	0.996	1.000	1.008
Denmark	0.611	0.980	1.013	0.982	0.999	0.993
Finland	0.931	1.001	1.000	1.002	0.999	1.001
France	0.684	0.986	1.012	0.988	0.998	0.998

Germany	0.724	0.978	1.016	0.986	0.992	0.994
Italy	0.511	0.991	1.013	0.989	1.002	1.004
Japan	0.710	0.980	1.020	1.000	0.980	1.000
Korea, Rep.	0.962	1.009	0.997	1.000	1.009	1.006
Latvia	0.801	0.981	0.984	0.988	0.993	0.966
Malta	0.629	0.992	0.991	1.000	0.992	0.983
Netherlands	0.848	0.983	1.017	0.990	0.993	1.001
New Zeland	0.656	0.992	1.004	0.996	0.997	0.996
Norway	0.773	1.006	1.000	1.007	0.999	1.007
Saudi Arabia	1.000	1.000	1.016	1.000	1.000	1.016
Singapore	1.000	1.000	1.013	1.000	1.000	1.013
Sweden	0.748	0.999	0.990	1.000	0.999	0.989
Switzerland	0.609	0.980	1.015	0.980	1.000	0.994
United Kingdom	0.641	0.973	1.017	0.974	0.998	0.989
United States	1.000	1.000	0.993	1.000	1.000	0.993
Mean	**0.762**	**0.991**	**1.006**	**0.994**	**0.997**	**0.997**

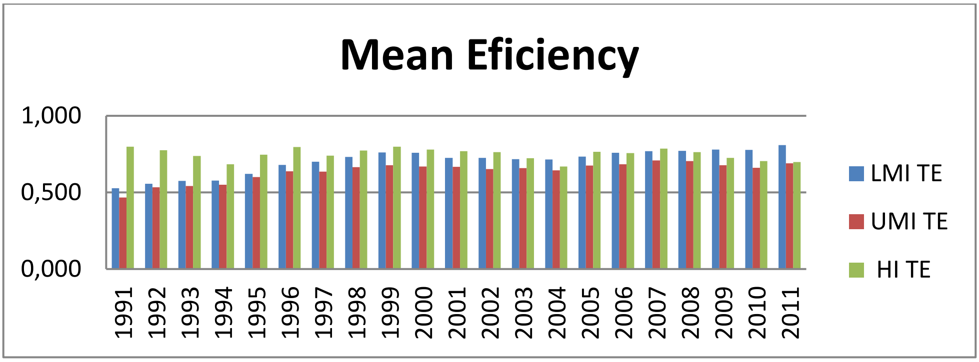
*Mean technical efficiency level is the arithmetic mean for each country over the 1991-2011 period.

Table 3 also shows that there is a slight decrease in technical efficiency change. The average annual efficiency change index is smaller than one (0.991), it indicates that this group diverges from the best-practice frontier from period t+1 to period t. The average annual TFP growth rate is negative due to a slight decrease in efficiency. However, another component of TFP change, namely technical change, shows a shift or advance in technology, but total effect on The TFP change is negative.

D. Comparison of mean technical efficiency for the income group-countries

Figure 1 shows average annual energy consumption efficiency levels of the income group countries. It is seen that the high-income countries are relatively more efficient on average than the other countries until 2003, but especially after 2007 the average annual energy use efficiency level for the high-income countries and the upper middle income countries have started to decrease. On the other hand, the average energy use efficiency level for the lower income countries has continued to increase over the 1991-2011 period. However, it is seen that for a whole period, the high-income countries are relatively more energy use efficient than the other groups. Nevertheless, the lower-income countries are relatively more energy use efficient than the upper-middle income countries, but less efficient than the high-income countries over the 1991-2011 period, on average.

Figure I. Annual mean efficiency levels of lower-middle, upper-middle and high income countries



CONCLUSION

This paper analyses energy consumption efficiency for the different level of income countries using the non-parametric method, namely the data envelopment analysis. The technical efficiency level indicates relatively whether a country is energy use efficient or inefficient for a given time. However, it does not show the overall performance or energy trilemma index, which includes energy security, energy equity, and environmental sustainability for a given country.

In this study, technical efficiency index and total factor productivity indices for the lower-middle income, upper-middle income and high income countries over the 1991-2011 period were obtained by DEAP computer program Coelli, Rao and Battese (1998).

In terms of income groups, it is seen that high-income countries are more energy efficient than both lower-middle income and upper-middle income countries, on average. Also, lower-middle income countries are more energy efficient than upper-middle income countries over the 1991-2011 period, on average.

According to total factor productivity indices, the lower-middle income countries and the upper-middle income countries have improvement in energy consumption efficiency, but high income countries have deterioration in energy consumption efficiency, on average. On the other hand, the high-income countries have technical progress, but the other two group countries have technical regress, on average. As a result, only the upper-middle income countries have growth in the TFP, on average.

The findings of the study show that energy consumer countries are not efficient in energy use. For example, Italy, Austria, Malta, Switzerland, New Zealand, France are high income countries but they use energy inefficiently. The United States which is the highest primary energy producer country, but which is also one the importer countries have the full efficiency in energy use. Australia, Denmark, and Norway are net energy exporter countries, but they are not energy efficient countries. On the other hand, Saudi Arabia is the one of energy exporting countries; it is also full efficient in energy use over the 1991-2011 period.

Bolivia, Indonesia, and Paraguay are the net energy exporter countries in the lower income group; however they are not energy use efficient countries. The full efficient country of this group is Moldova, which is in fact an energy importing country.

The main findings show that the energy consumer countries are not energy use efficient countries. It is well-known that energy is a scarce resource and it should be used efficiently. Additionally, the lower-middle income and upper-middle income countries are less efficient in energy use than the high income countries, on average. In order to explore the reasons of inefficiency for these countries the further studies should be done.

REFERENCES

Alsahlawi, M. (2013). Measuring Energy efficiency in GCC Countries Using Data Envelopment Analysis. *The Journal of Business Inquiry*, 12, 15-30. https://pdfs.semanticscholar.org/f2e8/c9e23e72d5d9cedf681a84ff72b3cba01a21.pdf.

Caves, D.W., Christensen L.R., Diwert, W.E. (1982). The Economic Theory of Index Numbers and Measurement of Input, Output and Productivity. *Econometrica*,50,1394-1414. http://www.aae.wisc.edu/aae741/Ref/Caves%20Econometrica%201982.pdf

Chang, T., Hu, J. (2010). Total-factor energy productivity growth, technical progress, and efficiency change: An empirical study of China. *Applied Energy,* 87, 3262-3270. doi:10.1016/j.apenergy.2010.04.026.

Charnes, A., Cooper, W.W., Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2, 429-444. https://www.utdallas.edu/~ryoung/phdseminar/CCR1978.pdf

Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M. (1994). Data Envelopment Analysis: Theory, Methodology and Applications, Boston, Kluwer.

Chien, T., Hu, J. L. (2007). Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. *Energy Policy,* 35, 3606-3615. doi:10.1016/j.enpol.2006.12.033.

Coelli, T.J., Rao, D.S.P., Battase, G.E. (1998). An Introduction to Efficiency and Productivity Analysis. Boston, Kluwer..

Coelli, T.J. (1996). A guide to DEAP version 2.1: A data envelopment analysis (computer) program. *CEPA Working Papers*, 96/08, Australia. http://www.owlnet.rice.edu/~econ380/DEAP.PDF.

Deliktas, E., Balcilar, M. (2005). A Comparative analysis of Productivity Growth, Catch-up and Convergence in Transition Economies. *Emerging Markets Finance and Trade*, 41-1, 6-28.

El-Mahgary, S., Lahdelma, R. (1995). Data Envelopment Analysis: Visualizing the Results. *EJOR*, 83-3, 700-710. doi.org/10.1016/0377-2217(94)00303-T.

Eurostat, http://ec.europa.eu/eurostat/web/products-datasets/-/tsdec360

Färe, R.S.G., Norris, M., Zhang, Z. (1994). Productivity Growth, Technical Progress and Efficiency Changes in Industrial Countries. *American Economic Review,* 84, 66-83. http://www.iadb.org/res/files/dev2010/1994_productivity.pdf.

Farrel, M. J. (1957). The measurement of Productive Efficiency. *Journal of Royal Statistical Society*, 120-3, 253-82. DOI: 10.12691/ajer-2-1-2

Philippini, M., Hunt, L.C. (2010). Energy Demand and energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach. *Surrey Energy Economics Discussion Paper Series*, 127, 1-30. http://www.seec.surrey.ac.uk/research/SEEDS/SEEDS127.pdf.

Groningen Growth and Development Centre, Penn World Table 8.1.

Honma, S., Hu, J. L. (2008). Total-factor energy efficiency of regions in Japan. *Energy Policy*, 36-2, 821-833. http://dx.doi.org/10.1016/j.enpol.2007.10.026.

International Energy Agency (2016), *World Energy Outlook 2016.*

Karadag, M., Deliktas, E., Onder, A.O. (2005). Growth of Factor Productivity in the Turkish Manufacturing Industries at Provincal Level. *Regional Studies*, 39-2, 213-223. DOI: 10.1080/003434005200060007

Milan, J.A., Aldaz, N. (2004). Efficiency and Technical Change in Intertemporal Intersectoral DEA. *Journal of Productivity Analysis,* 21, 7–23, 2004.

Nishimizu, M., Page, J.M. (1982). Total Factor Productivity Growth, Technical Progress and Technical Efficiency Change: Dimensions on Productivity Change in Yugoslavia 1965-78. *Economic Journal*, 368, 920-936. https://www.jstor.org/stable/pdf/2232675.pdf?refreqid=excelsior%3Aed933b821966de7139be485be922c846.

OECD (2011), *OECD Green Growth Studies: Energy*, OECD Publishing.

Seiford, L.M. (1996). Data envelopment analysis: The evolution of the state of the art (1978 1995), *Journal of Productivity Analysis,* 7, 99-138. DOI: 10.1007/BF00157037

Singh, S., Coelli, T., Fleming, E. (2001). Performance of Dairy Plants in the Cooperative and Private Sectors in India. *Annals of Public and Cooperative Economics,* 72-4, 453-479. http://onlinelibrary.wiley.com/doi/10.1111/1467-8292.00178/pdf

Song, M., Zhang, L., Liu, W., Fisher, R. (2013). Bootstrap-DEA Analysis of BRICS' Energy Efficiency Based on Small Sample Data. *Applied Energy*, 1049-1055. https://doi.org/10.1016/j.apenergy.2013.02.064.

World Bank (2013). World Development Indicators.

Zhang, X.P., Cheng, X.M., Yuan, J.H., Gao, X.J. (2011). Total-factor energy efficiency in developing Countries. *Energy Policy*, 39, 644-650. https://doi.org/10.1016/j.enpol.2010.10.037.

Zhou, P., Ang, B.W. (2008). Linear Programming Models for Measuring Economy Wide Energy Efficiency Performance. *Energy Policy*, 36-8, 2911-16. https://doi.org/10.1016/j.enpol.2008.03.041

Appendix

A1: Technical efficiency scores for the lower-middle income countries

Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Bolivia	0,274	0,244	0,256	0,307	0,358	0,438	0,486	0,525	0,545	0,476	0,347
Georgia	0,892	0,949	1,000	0,696	0,604	0,693	0,628	0,618	0,626	0,689	0,583
India	0,565	0,542	0,614	0,699	0,795	0,888	0,948	1,000	1,000	1,000	1,000
Indonesia	0,530	0,621	0,609	0,636	0,802	0,862	0,887	0,926	1,000	1,000	1,000
Moldova	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Morocco	0,190	0,233	0,232	0,260	0,287	0,307	0,333	0,333	0,373	0,370	0,379
Pakistan	0,436	0,496	0,490	0,552	0,601	0,683	0,704	0,804	0,885	0,887	0,869
Paraguay	0,323	0,360	0,401	0,468	0,521	0,571	0,624	0,644	0,661	0,652	0,631
Mean	**0,526**	**0,556**	**0,575**	**0,577**	**0,621**	**0,680**	**0,701**	**0,731**	**0,761**	**0,759**	**0,726**

A1: Continued

Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Bolivia	0,410	0,398	0,382	0,529	0,655	0,557	0,610	0,632	0,695	0,749
Georgia	0,560	0,547	0,544	0,531	0,548	0,611	0,552	0,573	0,534	0,623
India	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Indonesia	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Moldova	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Morocco	0,366	0,358	0,359	0,377	0,380	0,402	0,427	0,415	0,441	0,478
Pakistan	0,865	0,855	0,882	0,892	0,931	1,000	0,988	0,997	0,964	1,000
Paraguay	0,605	0,578	0,560	0,545	0,552	0,590	0,593	0,617	0,587	0,618
Mean	**0,726**	**0,717**	**0,716**	**0,734**	**0,758**	**0,770**	**0,771**	**0,779**	**0,778**	**0,809**

A2: Technical efficiency scores for the upper-middle income countries

Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Brazil	0,350	0,371	0,391	0,410	0,421	0,444	0,471	0,494	0,513	0,508	0,489
Costa Rica	0,222	0,307	0,319	0,315	0,319	0,315	0,314	0,320	0,371	0,400	0,396
Jordan	0,688	0,838	0,785	0,872	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Macedonia, FYR	0,494	0,628	0,706	0,680	0,736	0,937	0,874	0,977	0,970	0,902	0,886
Mexico	0,513	0,530	0,491	0,474	0,537	0,553	0,544	0,567	0,580	0,550	0,555
Panama	0,255	0,308	0,313	0,335	0,355	0,388	0,408	0,465	0,464	0,457	0,491
Romania	0,875	0,923	0,950	0,927	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Turkey	0,332	0,369	0,385	0,388	0,431	0,464	0,476	0,504	0,528	0,541	0,515
Mean	**0,466**	**0,534**	**0,543**	**0,550**	**0,600**	**0,638**	**0,636**	**0,666**	**0,678**	**0,670**	**0,667**

A2: Continued

Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Brazil	0.460	0.466	0.444	0.460	0.454	0.515	0.528	0.474	0.480	0.521
Costa Rica	0.402	0.410	0.480	0.486	0.506	0.541	0.546	0.543	0.512	0.511
Jordan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Macedonia, FYR	0.850	0.898	0.882	0.915	0.930	0.989	0.965	0.903	0.868	0.961
Mexico	0.562	0.555	0.516	0.595	0.585	0.610	0.623	0.598	0.566	0.591
Panama	0.429	0.420	0.370	0.417	0.417	0.408	0.392	0.402	0.405	0.435
Romania	1.000	1.000	0.966	1.000	1.000	1.000	0.970	0.888	0.858	0.887
Turkey	0.516	0.514	0.498	0.534	0.570	0.612	0.604	0.613	0.596	0.611
Mean	**0.652**	**0.658**	**0.645**	**0.676**	**0.683**	**0.709**	**0.704**	**0.678**	**0.661**	**0.690**

A3: Technical efficiency scores for the high income countries

Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Australia	0.787	0.783	0.803	0.738	0.773	0.873	0.822	0.825	0.819	0.810
Austria	0.642	0.592	0.53	0.473	0.556	0.633	0.548	0.609	0.639	0.624
Chile	0.387	0.416	0.427	0.447	0.460	0.495	0.563	0.567	0.609	0.588
Denmark	0.727	0.675	0.609	0.557	0.628	0.745	0.608	0.659	0.671	0.639
Finland	0.918	0.850	0.867	0.855	0.858	1.000	0.914	0.933	0.936	0.906
France	0.781	0.736	0.661	0.565	0.666	0.746	0.633	0.714	0.753	0.742
Germany	0.903	0.849	0.718	0.619	0.732	0.77	0.688	0.772	0.819	0.807
Italy	0.554	0.524	0.451	0.388	0.492	0.506	0.46	0.531	0.582	0.583
Japan	0.829	0.773	0.656	0.593	0.722	0.740	0.677	0.757	0.842	0.836
Korea, Rep.	0.841	0.867	0.852	0.781	0.979	1.000	1.000	1.000	1.000	1.000
Latvia	0.992	1.000	0.948	0.902	0.905	0.899	0.871	0.87	0.832	0.777
Malta	0.717	0.649	0.731	0.578	0.626	0.601	0.620	0.559	0.635	0.547
Netherlands	1.000	0.947	0.804	0.691	0.835	0.860	0.764	0.878	0.948	0.949
New Zealand	0.701	0.698	0.697	0.620	0.683	0.728	0.714	0.702	0.711	0.717
Norway	0.719	0.712	0.735	0.699	0.721	0.848	0.717	0.755	0.779	0.752
Saudi Arabia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Singapore	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	0.754	0.729	0.74	0.76	0.769	0.931	0.766	0.775	0.745	0.688
Switzerland	0.739	0.714	0.599	0.525	0.598	0.626	0.57	0.645	0.693	0.669
United Kingdom	0.791	0.748	0.648	0.565	0.663	0.705	0.616	0.701	0.761	0.749
United States	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	**0.799**	**0.774**	**0.736**	**0.683**	**0.746**	**0.795**	**0.740**	**0.773**	**0.798**	**0.780**

A3: Continued

Country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Australia	0.792	0.791	0.797	0.74	0.773	0.771	0.806	0.823	0.813	0.78	0.792
Austria	0.627	0.636	0.590	0.529	0.684	0.670	0.703	0.677	0.624	0.592	0.591
Chile	0.548	0.523	0.516	0.486	0.517	0.506	0.562	0.542	0.481	0.472	0.534
Denmark	0.620	0.618	0.563	0.478	0.599	0.628	0.657	0.605	0.552	0.508	0.489
Finland	0.922	0.970	0.970	0.921	0.937	1.000	1.000	0.982	0.915	0.956	0.937
France	0.724	0.728	0.641	0.571	0.727	0.700	0.738	0.705	0.647	0.588	0.592
Germany	0.769	0.761	0.637	0.553	0.739	0.731	0.779	0.739	0.653	0.592	0.583
Italy	0.544	0.552	0.483	0.422	0.570	0.556	0.593	0.547	0.485	0.451	0.463
Japan	0.753	0.763	0.624	0.55	0.759	0.734	0.803	0.717	0.639	0.577	0.557
Korea, Rep.	1.000	1.000	0.996	0.893	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Latvia	0.787	0.723	0.740	0.702	0.712	0.682	0.713	0.696	0.697	0.700	0.678
Malta	0.605	0.571	0.588	0.542	0.732	0.693	0.753	0.660	0.593	0.597	0.613
Netherlands	0.89	0.901	0.760	0.653	0.909	0.856	0.980	0.905	0.822	0.741	0.715
New Zealand	0.705	0.663	0.644	0.585	0.600	0.588	0.617	0.624	0.597	0.590	0.601
Norway	0.784	0.724	0.773	0.734	0.759	0.772	0.776	0.858	0.883	0.926	0.813
Saudi Arabia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Singapore	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	0.743	0.753	0.737	0.746	0.735	0.719	0.705	0.718	0.693	0.764	0.738
Switzerland	0.659	0.646	0.546	0.472	0.623	0.630	0.648	0.626	0.590	0.491	0.490
United Kingdom	0.693	0.684	0.580	0.495	0.672	0.639	0.671	0.614	0.54	0.473	0.456
United States	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	**0.769**	**0.762**	**0.723**	**0.670**	**0.764**	**0.755**	**0.785**	**0.763**	**0.724**	**0.706**	**0.697**