Energy efficiency trends and policies: Cross-country comparison in Europe[1]

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Abstract

Energy efficiency has become a much more important concept being one of the "twin pillars" along with renewable energy and sustainable energy policy. Improvements in energy efficiency can reduce the need for investment in energy infrastructure, cut fuel costs, increase competitiveness, increase energy security by decreasing the reliance on imported fossil fuels while at the same time help save the environment by reducing greenhouse gases emissions and local air pollution. Being an energy deficient developing country whose import reliability reached almost 75% in 2008 and whose current account deficit is based primarily on energy imports, Turkey is in great need of an accurate energy efficiency strategy. The study aims to analyze economy wide energy efficiency performance and energy saving potential of Turkey by means of cross-country comparison and benchmarking with the EU countries for the period of 1995-2007. The model takes capital, labor and total R&D expenditure as non-energy inputs, oil, gas, solid fuels, nuclear energy and renewable energy consumption as energy inputs, and considers GDP in purchasing power parity as the desirable output and green house gases emissions as the undesirable output. The paper aims to trace energy efficiency changes over time by evaluating the contributing factors such as activity mix of the economy, sources of primary energy-use, share of renewables, changes in energy prices and the implemented policy and regulations across multiple entities and to determine the saving potential and illustrate its benefits to the economy if to be realized. Our results indicate an improvement in energy efficiency over the years but show that environmentally aware energy efficiency performance and its improvement pace is much lower in all countries. The more noticeable improvement in energy efficiency takes place in the last five years which coincides with accelerated energy efficiency measures and policies both in Turkey and in the EU.

Beginning with the world energy crisis in 1993, energy efficiency has been brought into the policy agenda of many countries as a top priority issue. With the more recent understanding of the need to act against global warming and climate change, it has become a much more important concept. Energy efficiency is said to be one of the "twin pillars" along with renewable energy, of sustainable energy policy. Improvements in energy efficiency can reduce the need for investment in energy infrastructure, cut fuel costs, increase competitiveness, increase energy security by decreasing the reliance on imported fossil fuels while at the same time help save the environment by reducing greenhouse gases emissions and local air pollution.

Energy efficiency is one of six broad focus areas of the International Energy Agency's G8 Gleneagles Programme. The International Energy Agency (IEA) has submitted 25 policy recommendations to the G8 for promoting energy efficiency that, if implemented, could

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reduce global CO_2 emissions by 8.2 gigatonnes by 2030. But there are some important barriers to energy efficiency namely, financial and market barriers such as high investment costs, uninformed investors with little familiarity with energy efficient products, principal agent problems; political and regulatory obstacles such as underfunded R&D, bureaucracy and cultural and behavioral barriers. As a result, it is important for governments to coordinate policies in a way to address all of these barriers across all sectors. Establishing and maintaining sound policy requires accurate assessment of energy efficiency trends and accurate assessment of the reflections of these policies.

Most of the recent analyses confirm that current energy consumption trends lead to an unsustainable energy future. From 1990 to 2006, global final energy consumption increased by 26% where the highest rate of growth was in the transport sector with 40%. Electricity consumption increased by 60% on the global scale as well. The associated carbon dioxide emissions rose by 31% during the same period. The IEA projects global primary energy demand could grow by 55% from 2005 to 2030 and the resulting carbon dioxide emissions will increase by 57%. On the other hand, in most world regions the amount of energy use per unit GDP is decreasing steadily: 1.6% per annum on average at the world level between 1990 and 2006. Energy productivity improvements throughout this period resulted in 4.4 Gtoe energy savings and avoided 10 Gt of carbon dioxide. The European Union (EU) plays a leading role in improving energy efficiency and it has the lowest energy intensity among all world regions. To illustrate, the average power plant efficiency of the world is 34%, whereas this number is 40% in the EU, and 46% in Spain, the EU best practice. This corresponds to 420 Mtoe of fuel saving and avoiding 1.3 Gt of carbon dioxide only in the year 2006, if the world had the same performance as the EU average. The EU member states have made a commitment to reduce consumption of primary energy by 20% by the year 2020.

Being an energy deficient emerging country whose import reliability reached almost 75% in 2008 and whose current account deficit is based primarily on energy imports, Turkey is in great need of an accurate energy efficiency strategy. Turkey's energy demand has grown 4.3% per annum throughout the period 1990 - 2008. This is three times that of the world average, and it is one of the highest growth rates among the OECD countries for the last decade. Likewise, since 2000, Turkey's electricity and natural gas demand growth rate has been the second highest worldwide, after China. However, Turkey has started adopting an energy efficiency strategy very late relative to the EU. The first draft of Energy Efficiency Strategy Paper was published in 2003. Turkish Energy Efficiency Law numbered 5627 came in force on 2007 and the Turkish government declared 2008 to be energy efficiency year. According to a study of The General Directorate of Electrical Power Resources, Turkey has a minimum saving potential of 20% in manufacturing, 35% in buildings and 15% in transportation. If Turkey can take determined and successful steps towards improving energy efficiency, the realized level of the predicted consumption level in 2020 can be reduced by 20% corresponding to 45 Mtoe of energy saving. This amount is about 2.5 times Turkey's electrical energy production capacity and is enough to cover around 30 million households' annual energy need.

This paper aims at calculating economy wide energy efficiency performance and energy saving potential of Turkey by means of cross-country comparison and benchmarking with the EU countries for the period of 1995-2007. For measuring economy-wide energy efficiency performance, we use a non-parametric frontier approach, in order to make benchmarking of energy efficiency performance across multiple entities. We use energy consumption data of 32 European countries, namely, EU27, Switzerland, Norway, Iceland and the candidate countries Turkey and Croatia over the period 1995-2007. We take into account green house gases emissions as the undesirable output of energy usage and compare efficiency scores with and without the environmental concerns. We believe that comparison of energy efficiency levels of the EU countries with an emerging country whose membership to the union is a great debate and also incorporating environmental factors will help provide crucial policy implications.

The majority of energy studies conducted in Turkey is either on Turkey's scarce energy resources, policies on energy trade and energy security issues, or they are associated with Turkey's foreign politics. The study on energy efficiency in Turkey, however, is very restricted and none at the economy-wide level. The major contribution of this study is to provide economy-wide energy efficiency performance analysis and energy saving potential of Turkey by taking into account green house gases emissions and environmental concerns. The second contribution of the study is to compare Turkey's energy efficiency performance across the EU countries and derive crucial policy implications by incorporating environmental factors and policies of the EU. A new application from an emerging market, Turkey, will contribute to the portfolio of emerging economies literature. Therefore, this paper could be of interest to academicians, practitioners, policy makers and regulatory authorities who are interested in energy efficiency.

The rest of the paper is organized as follows. Section 2 provides a brief energy efficiency literature including definitions and energy efficiency measures. Data envelopment analysis (DEA) and few efficiency models are shortly described in Section 3. Section 4 presents the main findings and analyzes the results. Section 5 concludes.

2. Review of energy efficiency literature

Energy efficiency is a difficult concept to define. It is often confused with energy conservation but conservation simply means using less energy, whereas efficiency implies meeting a given demand with a lower use of resources (Gunn, 1997). In the Directive 2006/32/EC of the European Council and the Parliament on energy end use efficiency and energy services, energy efficiency is defined as ''a ratio between an output of performance, service, goods or energy, and an input of energy''(EU, 2006). According to the Energy Information Administration (EIA) of US Department of Energy "increases in energy efficiency take place when either energy inputs are reduced for a given level of service or there are increased or enhanced services for a given amount of energy inputs."(EIA, 1995)

What is even more difficult than to define energy efficiency is to measure it. For measuring energy efficiency changes over time at the economy-wide level, and to be able to make cross-country comparisons and benchmarking, a rich body of research has emerged. On one hand, various efficiency - related indicators have been developed, the ratio of total national primary energy consumption to GDP (energy intensity) being one of the most popular. A number of national energy agencies and international organizations have developed their energy efficiency measurement and monitoring systems such as International Energy Agency (IEA, 1997,a,b, 2004, 2007a,b), Energy Efficiency and Conservation Authority of New Zealand (EECA, 2006), Natural Resources Canada (NRC, 2006), Office of Energy Efficiency and Renewable Energy of the US (OEERE, 2005) and ODYSSEE (2009). On the other hand, most of the research focused on developing methods to accurately decompose the aggregate energy intensity into the true change in intensities at the disaggregated sectoral levels and to understand the effects of structural changes in the economy. A comprehensive survey of index decomposition analysis in energy and environmental studies is provided by Ang and Zhang (2000). Various decomposition methods such as Laspeyres type index (Howarth et al., 1993), arithmetic mean divisia index (Boyd et al.,1988), log mean Divisia index (Ang and Liu, 2001) and the Fisher ideal index (Boyd and Roop, 2004) have been introduced by researchers in order to decompose energy intensity.

Another line of study examines energy efficiency within a framework where energy is one of the many inputs of production, and one of the most widely used techniques is data envelopment analysis. A recent literature survey by Zhou et al. (2008a) lists a total of 100 studies published from 1983 to 2006 using DEA in the area of energy and environmental analysis. According to the survey, 72 of these publications were made between 1999 and 2006, which shows a rapid increase in the number of studies using DEA methodology.

Hu and Wang (2006) and Hu and Kao (2007) developed a total-factor energy efficiency index by using DEA, which provides a useful alternative to the traditional energy efficiency indicators such as aggregated energy intensity. Zhou et al.(2008b) presented several DEA-type linear programming methods for measuring economy – wide energy efficiency performance that take labor, capital stock and energy consumption as inputs and GDP as the desirable output. DEA analysis has also been widely used in energy efficiency studies at sector, sub-sector or plant level. Boyd and Pang (2000) used DEA to discuss the relationship between productivity and energy efficiency. Ramanathan (2000) used DEA to compare the energy efficiencies of alternative transport modes in the Indian transport sector and found a gradual improvement in energy efficiency of rail transport while a decrease in the efficiency of road transport. Lam and Shiu (2001) applied data envelopment analysis approach to measure the technical efficiency of China's thermal power generation based on cross-sectional data for 1995-1996. Wei et al. (2007) investigated the energy efficiency change of China's iron and steel sectors by using DEA-based Malmquist Index Decomposition (MPI) approach. R&D has been considered as an additional input in the DEA model proposed by Conrad (2000) and it was found that an increase in R&D expenditure improves energy efficiency when the technological change is embodied.

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3. Methodology and Data

Data Envelopment Analysis (DEA), proposed by Charnes, Cooper and Rhodes (CCR, 1978), is a well-established non-parametric frontier approach to evaluating the relative efficiency of a set of comparable entities featured with multiple inputs and outputs. Since its introduction, DEA has been used extensively to study efficiency in a wide range of sectors including banking, manufacturing, and health care. It has also been used to evaluate performance of universities, cities, regions, and countries.

Consider an industry producing a single output y from a vector of m inputs $x=(x_1,x_2,\ldots, x_m)$. Let y_j represent output and the vector x_j represent the input bundle of the j-th decision-making unit (DMU). Suppose that input–output data are observed for n DMUs. Then the technology set can be completely characterized by the production possibility set

S={(x, y): y can be produced from x} based on a few regularity assumptions:

1. Feasibility: all observed input–output combinations are feasible. $(x_j, y_j) \in S$; (j=1,2,…n).

2. Free disposability with respect to inputs. $(x_0, y_0) \in S$ and $x_1 \geq x_0 \rightarrow (x_1, y_0) \in S$.

3. Free disposability with respect to outputs. $(x_0, y_0) \in S$ and $y_1 \leq y_0 \rightarrow (x_0, y_1) \in S$.

4. Convexity. $(x_0, y_0) \in S$ and $(x_1, y_1) \in S \rightarrow (\lambda x_0+(1-\lambda) x_1, \lambda y_0+(1-\lambda) y_1) \in S$; $0 \leq \lambda \leq 1$.

Within the DEA method, input-oriented technical efficiency is defined as the ratio of the optimal (i.e., minimum) input bundle to the actual input bundle of a DMU, for a given level of output, holding input proportions constant. Technical efficiency can also be measured based on output-orientation where efficiency is defined as the ratio of the observed output to the optimal (i.e., maximum) achievable output.

The CCR DEA model for measuring the input-oriented technical efficiency of a DMU with the input–output bundle (x_0, y_0) can be written as:

$$\theta^* = \text{Min } \theta$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{i0} \quad i = 1, 2, \ldots, m$$

$$\sum_{j=1}^{n} y_j\lambda_j \geq y_0$$

$$\lambda_j \geq 0 \quad j = 1, 2, \ldots, n \tag{1}$$

An efficient DMU will have $\theta^*=1$, implying that no equi-proportionate reduction in inputs is possible, whereas an inefficient DMU will have $\theta^*<1$.

Model 1 is the most basic input oriented DEA-model with constant returns to scale and is an appropriate measure when energy input has strong complementarities with other inputs. But if there is no such assumption and if our primary interest is the efficiency of energy input usage, then we would be interested in knowing what is the possible maximum reduction in energy input, that will allow the same level (observed level) of output without requiring additional amounts of other inputs. In this case we employ a different CCR-type DEA model to measure the energy use efficiency. Instead of the input vector x_0, inputs capital (K), labor (L) and energy (E) are stated explicitly.

$$\beta^* = \min \beta$$

Subject to

$$\begin{aligned}
&\sum_{j=1}^{n} K_j \lambda_j \leq K_0 \\
&\sum_{j=1}^{n} L_j \lambda_j \leq L_0 \\
&\sum_{j=1}^{n} E_j \lambda_j \leq \beta E_0 \\
&\sum_{j=1}^{n} y_j \lambda_j \geq y_0 \\
&\lambda_j \geq 0 \qquad\qquad j = 1, 2, \ldots, n
\end{aligned} \tag{2}$$

Both of the previous models assume that inputs are used to produce good or desirable outputs. In accordance with the global environmental conservation awareness, undesirable outputs of productions and social activities such as air pollutants and hazardous wastes are being increasingly recognized as dangerous and undesirable. Energy use also results in the generation of some undesirable outputs such as green house gas emissions as by-products of producing desirable outputs. In economy-wide energy efficiency studies, making comparisons and benchmarking of energy efficiency without taking into account the environmental aspects seem to be insufficient.

Consider a production process in which desirable and undesirable outputs are jointly produced by consuming both energy and non-energy inputs. Assume that x, e, y and u are, respectively, the vectors of non-energy inputs, energy inputs, desirable outputs and undesirable outputs, where energy inputs consist of L different energy sources. Then the production technology can be described as T={(x; e, y u) : (x, e) can produce (y,u)}with the following two conditions in addition to the previous disposability assumptions:

1. Outputs are weakly disposable, i.e., if (x,e,y,u) Є T and $0 \leq \theta \leq 1$, then (x,e, θy, θu) Є T.

2. Desirable outputs and undesirable outputs are null-joint, i.e., if (x,e,y,u) Є T and u = 0, then y = 0.

The first condition implies that the reduction of undesirable outputs is not free but the proportional reduction in both desirable and undesirable outputs is feasible. The second condition implies that the only way to eliminate all the undesirable outputs is to cease the production process.

Assuming there are K entities whose energy efficiency are to be measured, N non-energy inputs, L energy inputs, M desirable outputs and J undesirable outputs, then the related model for computing energy efficiency is stated as:

$$\theta^* = \text{Min } \theta$$

Subject to

$$\begin{aligned}
&\sum_{k=1}^{K} z_k x_{nk} \leqslant x_{n0}, \quad n = 1,\dots,N \\
&\sum_{k=1}^{K} z_k e_{lk} \leqslant \theta e_{l0}, \quad l = 1,\dots,L \\
&\sum_{k=1}^{K} z_k y_{mk} \geqslant y_{m0}, \quad m = 1,\dots,M \\
&\sum_{k=1}^{K} z_k u_{jk} = u_{j0}, \quad j = 1,\dots,J \\
&z_k \geqslant 0, \quad k = 1,2,\dots,K
\end{aligned} \tag{3}$$

We use two different DEA-models in order to analyze energy efficiency in Turkey with respect to the EU countries, one of which takes into account environmental aspects. The first model is a single output model, with GDP in purchasing power parity as the only output. The second model on the other hand is a two-output model which assumes greenhouse gases emissions as the second and undesirable output which is an inevitable product of energy consumption. In our empirical analysis, both our models have eight inputs; capital, labor and R&D expenditure as non-energy inputs and solid fuels, crude oil and petroleum products, gas, nuclear energy and renewables as the five energy inputs. We treat different energy sources as individual inputs in order to make interpretations on the effects of the energy mix on energy efficiency.

For the empirical analysis, we use annual time series data for 32 countries over the period 1995 and 2007. The countries included are the EU-27, Switzerland, Norway, Iceland, Hungary and Turkey. We gathered the energy consumption, green house gases emissions, capital and labor data from Eurostat, and the GDP in purchasing power parity from OECD.

GDP is millions of current prices and current PPP in USD**.** Gross capital formation consists of gross fixed capital formation, plus changes in inventories plus acquisition less disposal of valuables and it is in millions of purchasing power standard (The purchasing power standard (PPS) is the name given by Eurostat to the artificial currency unit in which the PPPs and real final expenditures for the EU 25 are expressed – namely, euros based on the EU 25). Labor is in thousands of workforce and R&D expenditure is again in purchasing power standard. The energy consumption data are all in thousand tones of oil equivalent (Toe) and represent the gross inland consumption of each energy source**.** Gross inland consumption represents the quantity of energy necessary to satisfy inland consumption of the geographical entity under consideration. It is calculated as follows: primary production + recovered products + total imports + variations of stocks - total exports – bunkers. It corresponds to the addition of consumption, distribution losses, transformation losses and statistical differences.

There are three types of frontiers that can be used in DEA: (i) the contemporaneous frontier constructed from only the cross section data from a given period, (ii) the sequential frontier that treats all current and past observations as feasible, and (iii) an intertemporal frontier based on observations from all the periods in the sample (Tulkens and Vanden Eeckaut, 1995). If changing technology has caused performance to improve over time then the later years in the sample would have a higher measured efficiency than the earlier years and this information would be masked from an analysis using contemporaneous frontiers since the benchmark would be changing from year to year (Bhattacharyya et al., 1997). In this study, we use time series data of 32 different DMU's to measure energy efficiency over time and we use an intertemporal frontier where the input-output bundles of each country for each year is considered a distinct DMU.

In both of our applications we use input-oriented DEA-models since we are interested in efficiency of energy as inputs and they assume constant returns to scale since it is not meaningful for overall economy to be operating under increasing or decreasing returns to scale.

4. Empirical Results and Discussion

Table 1 and Table 2 contain the summary efficiency score results from the DEA analysis using Model (2) without incorporating the undesirable output and with only one useful output, namely GDP. The overall assessment is that efficiency has improved in all of the countries over the time period 1995-2007 and 17 countries came to be efficient in 2007. While the average energy efficiency score was 0,720 in 1995, it reached 0,909 in 2007. But as we are measuring efficiency based on an intertemporal frontier, this finding reflects the technological progress as well as efficiency improvement. The countries with the highest energy efficiency scores in almost all years are Greece, Turkey, Malta, Iceland, United Kingdom and Luxemburg and the countries with the lowest efficiency scores are Finland, Belgium, Estonia, Slovenia and Romania. Most of the EU-15 countries have continuously increasing efficiency scores such as Austria, Belgium, France, Germany, Spain, Sweden and UK. The most notable increase is seen in the efficiency score of Slovakia which reached to 1 from 0,453 in 1995. Norway is another country that improved its energy efficiency drastically from 0,499 to 1 over the years.

Table 1. Efficiency scores from the single-output model (Model (2))

DMU	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Ave.
AUSTRIA	0,651	0,630	0,647	0,656	0,693	0,754	0,718	0,772	0,750	0,786	0,804	0,859	0,927	0,742
BELGIUM	0,556	0,537	0,562	0,555	0,569	0,621	0,623	0,691	0,650	0,662	0,687	0,730	0,804	0,634
CZECH REP.	0,758	0,780	0,750	0,732	0,733	0,801	0,802	0,789	0,763	0,760	0,783	0,841	0,934	0,787
DENMARK	0,672	0,644	0,666	0,680	0,725	0,783	0,799	0,859	0,877	0,925	0,982	0,965	1	0,814
FINLAND	0,489	0,472	0,432	0,411	0,487	0,528	0,579	0,570	0,561	0,574	0,571	0,587	0,615	0,529
FRANCE	0,677	0,706	0,790	0,725	0,736	0,777	0,811	0,906	0,915	0,908	0,953	0,982	1	0,837
GERMANY	0,651	0,644	0,661	0,661	0,698	0,720	0,748	0,811	0,828	0,867	0,914	0,934	1	0,780
GREECE	1	0,990	1	0,907	0,862	0,848	0,912	0,953	0,946	0,986	1	1	1	0,954
HUNGARY	0,696	0,803	0,807	0,879	0,922	0,932	1	0,901	0,933	1	0,955	0,943	1	0,906
ICELAND	0,926	0,928	0,860	0,849	0,888	0,907	0,962	1	0,986	1	1	1	NA	0,942
IRELAND	0,853	0,827	0,795	0,701	0,707	0,782	0,863	0,923	1	0,933	0,962	0,973	1	0,871
ITALY	0,762	0,829	0,831	0,844	0,840	0,863	0,898	0,882	0,883	0,889	0,955	0,941	1	0,878
LUXEMBURG	0,880	0,914	0,865	0,896	0,976	0,776	0,988	1	0,855	0,828	0,868	1	1	0,911
NETHERLANDS	0,670	0,662	0,679	0,668	0,687	0,756	0,804	0,901	0,884	0,908	0,931	0,970	0,953	0,806
NORWAY	0,499	0,850	0,552	0,855	0,517	1	0,893	1	1	0,830	0,692	1	0,954	0,819
POLLAND	0,768	0,724	0,733	0,761	0,794	0,802	0,859	0,959	0,983	0,968	1	0,986	1	0,872
PORTUGAL	0,942	1	0,957	0,818	0,705	0,755	0,772	0,771	0,836	0,824	0,860	0,946	0,964	0,858
SLOVAKIA	0,453	0,523	0,532	0,594	0,649	0,719	0,699	0,686	0,824	0,834	0,847	0,947	1	0,716
SPAIN	0,693	0,683	0,679	0,695	0,710	0,718	0,716	0,772	0,729	0,737	0,753	0,809	0,858	0,735
SWEDEN	0,654	0,809	0,776	0,880	0,755	1	0,768	1	0,944	1	1	1	1	0,891
SWITZ.	0,655	0,705	0,797	0,924	0,944	0,776	0,761	0,865	1	0,890	0,915	0,942	1	0,860
TURKEY	0,915	0,915	0,954	0,967	0,895	0,915	0,952	0,887	0,887	0,968	1	1	1	0,943
UK	0,751	0,833	0,857	0,835	0,842	0,889	0,985	0,996	1	1	1	1	1	0,922
CROTIA	0,853	0,731	0,632	0,670	0,682	0,758	0,674	0,655	0,647	0,682	0,768	0,862	0,920	0,733
BULGARIA	0,840	1	1	0,893	0,990	0,525	0,571	0,561	0,539	0,592	0,581	0,624	0,719	0,726
ESTONIA	0,649	0,652	0,762	0,396	0,427	0,543	0,551	0,606	0,646	0,672	0,731	0,840	0,889	0,643
CYPRUS	0,688	0,663	0,708	0,703	1	0,680	0,718	0,724	0,689	0,785	0,827	0,835	0,848	0,759
LATVIA	0,670	0,615	0,733	0,532	0,700	0,839	0,858	0,980	1	1	1	1	1	0,841
LITHUNIA	0,693	0,698	0,754	0,457	0,535	0,717	0,679	0,699	0,787	0,815	0,861	0,911	0,996	0,739
MALTA	0,851	0,935	0,825	0,981	1	1	0,955	1	0,920	0,901	0,899	0,992	1	0,943
ROMANIA	0,728	1	0,851	0,481	0,625	0,582	0,536	0,584	0,636	0,714	0,752	0,758	0,841	0,699
SLOVENIA	0,487	0,443	0,485	0,514	0,528	0,563	0,577	0,640	0,658	0,665	0,721	0,774	0,869	0,610
Average	0,720	0,755	0,748	0,722	0,744	0,770	0,782	0,823	0,830	0,841	0,862	0,905	0,909	

Most of the Eastern Europe countries such as Croatia, Bulgaria, Romania, and Estonia along with Portugal have experienced deterioration in their efficiencies in the years 1998 to 2002. This might be due to declining oil prices in the period 1997-1999 resulting from the Asian crisis and the relatively low prices in the following few years which encourages energy consumption.

When we consider Turkey's position in this frame, it emerges as one of the highest energy efficient countries in almost every year. Although this is a surprising result considering that Turkey is a highly populated emerging country, some of the reasonable factors behind this could be lower capital stock and lower industrialization rate relative to most of the developed European countries considering the logic of DEA. The efficiency score of Turkey increases from 1995 to 1998 but undergoes a decline in the year 1999 as with many other, mostly Eastern European, countries. The efficiency rises again in years 2000 and 2001, but decreases again in 2002 and 2003. The economic crises of 2001 and 2002 of Turkey, seems to have a negative effect on energy efficiency levels in terms of the deteriorating GDP. According to our results, Turkey's energy efficiency level rises notably after 2004, being efficient in the years 2005, 2006 and 2007. A few developments coincide in the same period; namely, increasingly high energy prices, high economic growth in Turkey as in most emerging countries due to foreign investment and the start of energy efficiency policy and measure implementations in Turkey.

Table 2. Efficiency scores of Turkey and EU average with Model (2)

	TURKEY		EU-15 AVERAGE	EU-27 AVERAGE	NEW MEMBERS AVERAGE
Year	**Score**	**Rank**	**Score**	**Score**	**Score**
1995	0,915	130	0,660	0,740	0,055
1996	0,915	134	0,679	0,742	0,057
1997	0,954	102	0,680	0,746	0,057
1998	0,967	89	0,668	0,702	0,056
1999	0,895	151	0,675	0,742	0,056
2000	0,915	132	0,715	0,753	0,060
2001	0,952	105	0,738	0,770	0,062
2002	0,887	160	0,790	0,814	0,066
2003	0,887	159	0,781	0,816	0,065
2004	0,968	87	0,789	0,834	0,066
2005	1	1	0,816	0,858	0,068
2006	1	1	0,846	0,894	0,071
2007	1	1	0,875	0,934	0,073

Table 2 shows a comparison of energy efficiency scores of Turkey with the average scores of EU-15, EU-27 and the new member countries. It is evident that the energy efficiency level of Turkey is higher than the EU average and the new member states have the lowest energy efficiency among the considered groups. All groups experience energy efficiency improvement over time. As we considered each input-output bundle of each year of every country as a distinct DMU, our DEA-model compared 416 DMU's. The rank column shows Turkeys' each year performance rank among the 416, and it shows that Turkey has been in the 100-160 range most of the years.

Tables 3, 4 and 5 summarize the results of the second DEA model which adds an undesirable output, green house gas emissions, to the input-output bundle. The inputs of the model are the same but this time there are two outputs, one desirable, GDP, and the other undesirable, GHG emissions. We make use of three versions of the model, by employing different weights to the good and bad outputs, namely, the ratio of good to bad outputs are (5:1), (1:1) and (1:5). This means that as weight moves from good to bad, the emphasis of the DEA changes from enlargement of the good output to reduction of the bad output. The results given in Table 3 are the results of the (1:1) model, in other words it assumes that reduction of GHG emissions, the environmental target, is of equivalent importance to enlargement of GDP, the economical target.

The first noticeable fact is that the efficiency scores are much lower when environmental factors are involved. This shows that all considered countries are less environmentally efficient even if in terms of productivity they perform well. Although on the average the efficiency scores increase from 0,453 in 1995 to 0,815 in 2007, the uptrend is not as fast and as continuous compared to the previous model. The more developed countries emerge as the countries with the highest efficiency scores, such as Sweden, United Kingdom, Norway, Switzerland and Italy. Turkey and Greece are again among the most efficient countries. Malta appears as the most efficient country with average efficiency score of 0,936, but this result is predictable considering its very low energy consumption levels being a very small country. One of the most industrialized countries, Germany, while among the least efficient in 1995 with an efficiency score 0,298, improved its energy efficiency very effectively throughout the years to reach an efficiency score of 1 by 2007. Although some of this improvement can be accounted for technological progress, this situation is not as valid in all countries. Hence it can be considered as a policy success. The new member Eastern European countries such as

Romania, Lithuania, Slovenia, Czech Republic and Bulgaria have been among the least energy efficient countries almost in all years, and moreover have experienced little improvement over the years.

Table 3. Efficiency scores from the undesirable-output model (Model (3))

DMU	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Ave.
AUSTRIA	0,501	0,489	0,493	0,504	0,546	0,604	0,568	0,614	0,578	0,639	0,657	0,726	0,820	0,595
BELGIUM	0,250	0,234	0,248	0,249	0,264	0,294	0,312	0,458	0,411	0,385	0,376	0,419	0,514	0,340
CZECH REP.	0,339	0,346	0,346	0,337	0,349	0,358	0,371	0,383	0,385	0,385	0,380	0,377	0,416	0,367
DENMARK	0,436	0,420	0,431	0,441	0,496	0,521	0,551	0,602	0,594	0,697	0,777	0,678	0,770	0,571
FINLAND	0,271	0,263	0,250	0,252	0,287	0,314	0,331	0,342	0,332	0,351	0,361	0,365	0,383	0,316
FRANCE	0,401	0,423	0,474	0,436	0,431	0,450	0,483	0,635	0,641	0,639	0,681	0,693	0,800	0,553
GERMANY	0,298	0,314	0,322	0,320	0,344	0,352	0,435	0,548	0,580	0,633	0,698	0,704	1	0,504
GREECE	1	0,810	1	0,572	0,541	0,605	0,674	0,761	0,757	0,848	0,846	0,937	1	0,796
HUNGARY	0,336	0,406	0,418	0,459	0,503	0,538	1	0,603	0,649	1	0,663	0,652	1	0,633
ICELAND	0,519	0,564	0,473	0,470	0,475	0,477	0,555	0,59	0,547	1	0,610	0,500	1	0,598
IRELAND	0,433	0,414	0,399	0,401	0,400	0,446	0,469	0,571	0,65	0,580	0,766	0,874	1	0,569
ITALY	0,575	0,641	0,647	0,681	0,693	0,727	0,807	0,762	0,797	0,819	0,885	0,908	1	0,765
LUXEMBURG	0,679	0,559	0,554	0,644	0,878	0,411	1	1	0,419	0,412	0,430	0,720	1	0,670
NETHERL.	0,274	0,287	0,296	0,315	0,329	0,367	0,415	0,528	0,527	0,603	0,697	0,776	0,868	0,483
NORWAY	0,431	0,721	0,484	0,705	0,500	1	0,745	1	1	0,767	0,808	1	1	0,782
POLLAND	0,485	0,472	0,488	0,507	0,522	0,558	0,614	0,755	0,842	0,851	1	0,911	1	0,693
PORTUGAL	0,515	0,57	0,433	0,395	0,400	0,445	0,456	0,485	0,614	0,609	0,661	0,768	0,756	0,547
SLOVAKIA	0,251	0,269	0,280	0,313	0,343	0,375	0,340	0,362	0,464	0,483	0,505	0,741	1	0,441
SPAIN	0,351	0,376	0,387	0,374	0,372	0,391	0,412	0,452	0,443	0,464	0,494	0,573	0,630	0,440
SWEDEN	0,460	0,621	0,564	0,720	0,608	1	0,656	1	0,867	1	1	1	1	0,807
SWITZ.	0,593	0,504	0,666	0,994	0,708	0,598	0,703	0,778	1	0,695	0,846	0,883	1	0,767
TURKEY	0,744	0,744	0,790	0,793	0,745	0,775	0,879	0,804	0,810	0,906	1	1	1	0,845
U.K.	0,452	0,509	0,560	0,523	0,559	0,637	0,737	0,866	1	1	1	1	1	0,757
CROTIA	0,401	0,428	0,415	0,420	0,418	0,482	0,486	0,492	0,483	0,530	0,634	0,741	0,775	0,516
BULGARIA	0,326	1	1	0,364	0,428	0,238	0,268	0,274	0,269	0,297	0,279	0,291	0,366	0,415
ESTONIA	0,401	0,403	0,447	0,262	0,287	0,372	0,391	0,412	0,425	0,444	0,473	0,493	0,504	0,409
CYPRUS	0,579	0,573	0,590	0,482	1	0,384	0,474	0,889	0,432	0,411	0,424	0,431	1	0,590
LATVIA	0,450	0,364	0,428	0,345	0,473	0,606	0,628	0,735	1	1	1	0,89	1	0,686
LITHUNIA	0,248	0,255	0,255	0,155	0,209	0,299	0,288	0,302	0,338	0,357	0,401	0,448	0,466	0,309
MALTA	0,868	0,907	0,935	0,984	1	1	1,000	1	0,799	0,857	0,862	0,961	1	0,936
ROMANIA	0,352	0,349	0,317	0,230	0,297	0,327	0,331	0,356	0,392	0,454	0,499	0,509	0,533	0,381
SLOVENIA	0,285	0,232	0,251	0,273	0,279	0,311	0,324	0,348	0,375	0,372	0,398	0,416	0,471	0,333
Average	0,453	0,483	0,489	0,466	0,490	0,508	0,553	0,616	0,607	0,640	0,660	0,700	0,815	

When we compare the efficiency scores over the years of Turkey and EU-15, EU-27, and the new members, the same results from the previous model holds for Turkey. The results show that Turkey's energy efficiency is higher then that of EU's in all years and its efficiency has relatively deteriorated in the years 1999 and 2002-2003 again. Energy efficiency performance of the EU has continuously risen over the years, but this time efficiency performance of EU15 is the highest and has experienced the highest improvement (Table 4).

Table 4. Comparison of efficiency scores of Turkey and EU average with Model (3)

	TURKEY(1-3)		EU-15 AVERAGE	EU-27 AVERAGE	NEW MEMBERS AVERAGE
	Score	Rank	Score	Score	Score
1995	0,744	120	0,460	0,438	0,410
1996	0,744	119	0,462	0,463	0,465
1997	0,790	103	0,471	0,475	0,480
1998	0,793	102	0,455	0,427	0,392
1999	0,745	117	0,476	0,475	0,474
2000	0,775	108	0,504	0,479	0,447
2001	0,879	77	0,554	0,531	0,502
2002	0,804	98	0,642	0,594	0,535
2003	0,810	95	0,614	0,577	0,531
2004	0,906	71	0,645	0,614	0,576
2005	1	1	0,689	0,637	0,574
2006	1	1	0,743	0,677	0,594
2007	1	1	0,836	0,789	0,730

The previous results were from the model that attained equal weights to good and bad outputs. Table 5 shows the differences in efficiency scores when we employ different weights to the undesirable output GHG emissions and the desirable output GDP. We can see that as the weight to the undesirable output increases, giving more emphasis on environmental performance, the efficiency scores decrease for Turkey. This implies that although energy consumption performance in terms of generating GDP is increasing, not only Turkey but almost all other countries are falling back on environmentally stable energy usage.

Table 5. Efficiency score results for Turkey with different weights

Weights to Good and Bad Outputs						
Turkey	**1 : 5**		**1 : 1**		**5 : 1**	
Year	Score	Rank	Score	Rank	Score	Rank
1995	0,730	116	0,744	120	0,744	129
1996	0,721	119	0,744	119	0,751	126
1997	0,769	108	0,790	103	0,802	105
1998	0,774	105	0,793	102	0,807	104
1999	0,703	123	0,745	117	0,769	119
2000	0,735	114	0,775	108	0,802	106
2001	0,873	77	0,879	77	0,879	84
2002	0,773	107	0,804	98	0,820	98
2003	0,780	101	0,810	95	0,834	95
2004	0,892	73	0,906	71	0,917	72
2005	1	1	1	1	1	1
2006	1	1	1	1	1	1
2007	1	1	1	1	1	1

5. Conclusion

Energy efficiency has become one of the top priority policy issues of many countries considering its crucial effects on attaining a sustainable energy future along with the search for environmental sustainability that came into the world's agenda with global warming and climate change debates. Energy efficiency measurement is more and more important for effective policymaking and assessment of implemented policies. DEA has recently been widely applied to measure energy efficiency performance by modeling energy consumption as an input within a production framework. This paper has calculated economy wide energy efficiency performance of 32 European countries for the period of 1995-2007 using DEA analysis for the purpose of understanding Turkey's standpoint by comparison and benchmarking. Our DEA models investigates the efficiency performances by also taking into account GHG emissions as the undesirable output of energy consumption along with the desirable output, GDP. Our results suggest an improvement in energy efficiency in all countries over the years, especially after 2002, but the environmental efficiency measurement yields much lower results in all countries. The new member countries, mostly Eastern Europe countries resulted in the lowest energy efficiency in both our measurements. Turkey appears as one of the most energy efficient countries among the considered countries but the highest increase takes place after 2004 which coincides with a period of high energy prices, high economic growth and the introduction of energy efficiency policy, measures and regulations. But our finding that later years of our sample are more efficient also implies that there has been technical progress as well as efficiency progress.

This study could be further widened to consider the effects of the energy mix of the economy, energy prices and measures and regulations to provide more insights on the aspects of energy efficiency and prove useful in drawing policy implications.

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