Economy & Business
ISSN 1314-7242, Volume 8, 2014

Journal of **International Scientific Publications**
www.scientific-publications.net

ENERGY EFFICIENCY ANALYSIS FOR THE EUROPEAN COUNTRIES

Fazıl Gökgöz[1], Ercem Erkul[2]

[1]Associate Professor Dr. at Ankara University, Faculty of Political Sciences,
Department of Management, Quantitative Methods Division,
06600 Cebeci, Ankara, Turkey

[2]Research Assistant at Hacettepe University, Faculty of Economics and Administration,
Department of Social Work
06100 Beytepe, Ankara, Turkey

Abstract

The energy sector receives considerable attention from both developed and developing countries. European countries, in addition to the fossil energy resources, are dependent on external energy resources, which pose a threat, as well. In addition, energy efficiency has played a significant role in the European countries' economic growth, policy and export. Data envelopment analysis (DEA), a popular and useful mathematical method for decision makers, is used to analyze the efficiency levels of the decision-making units. The goal of this empirical study is to make a comparative energy efficiency analysis for the European countries. On the basis of the DEA analyses, CCR and BCC approaches have been applied to the European energy sector for the period of 2011-2012. In this regard, we have established an efficiency model that includes employment, the gross fixed capital formation (GFCF) and the primary energy consumption as the inputs, and gross domestic product (GDP) has been selected as the output. According to our results, Denmark, Ireland and Norway have demonstrated full efficiency for each year. In addition, the average efficiency scores in 2012 for the European countries have been demonstrated to be higher than those of 2011. We can conclude that the DEA technique could offer significant results to the analysis of the energy efficiency levels for the European countries.

Key words: *Energy Efficiency, European Energy Sector, Data Envelopment Analysis*

1. INTRODUCTION

Throughout the world, people shall have to come to terms with a new situation in the future: the increasingly difficult access to the planet's mineral resources. Oil will be much more expensive, much more difficult to extract, and the stocks of fossil fuels (*oil, gas and coal*) will not last forever. While new oil and gas reserves (e.g., *shale oil and gas*) may well exist, the production of which the energy sector is directly involved in as over 80% of its output is derived from fossil fuels, there are many environmental and climate constraints (*especially the* CO_2 *and greenhouse emissions*) on their extraction. More and more energy will be needed to mine raw materials, as the mineral content of mines will continue to decrease. They need to be judiciously managed while mankind seeks new sources of energy (European Commission 2012b).

Energy changes and transformations prompt developments in society as a whole and are also a motive for economic activity that includes the natural resources that can be used after refining (Lee, Hu & Kao 2011). In this context, efficient energy consumption is a top priority in the environmental field in terms of both resource conservation and combating climate change. In general, accepting the declining economic growth as a consequence of decreased energy consumption is not acceptable. Therefore, improving energy efficiency without impairing economic performance is important for every economy (Honma & Hu 2014).

The countries that signed (*without the United States of America*) the Kyoto Protocol have been advised to decrease anthropogenic CO_2-emissions and greenhouse gas emissions and to increase the renewable energy intensity in 1998. In January 2007, the European Commission (*EC*) proposed a new energy policy designated as the 20/20/20 goals.

Therefore, as international concerns on climate change and sustainable economic growth increase, the global cooperation on environmental regulations, such as the Bali Roadmap in 2007, has significantly increased (Oh 2010).

On the other hand, production costs of energy rise, and this raises manufacturing costs. For the consumer, the price of energy becomes higher, leading to reduced consumer confidence and spending, higher transportation costs, and general price increases. To satisfy sustainable economic development, social advancement, population growth, and increased energy demand, the energy supply must suffice the energy demand. Therefore, energy-saving targets are very important for all economies (Lee, Hu & Kao 2011).

Looking at the world economy today, we observe that the security and importance of the energy sector has been increasing. In addition to the developments in the energy sector, studies and the literature on how to use the produced energy efficiently have improved. In this regard, the EU's 20/20/20 goals, the Kyoto Protocol and the Bali Roadmap indicated that both developed and developing countries desire to improve energy efficiency alongside decreasing fossil fuel energy consumption and increasing renewable energy.

Along with the high demand for energy, the efficiency of energy use should be of concern especially under the EU's energy policy. At the economy-wide level, because there is no single meaningful measure for energy services across the energy-consuming sectors, various approaches for measuring the energy efficiency performance have been proposed in the literature (Zhou and Ang 2008). However, the efficiency of energy consumption needs to be promoted simultaneously such that redundant energy consumption is eliminated. Energy alone cannot produce any output. Energy must be combined with other inputs to produce outputs. Therefore, a multiple-input model should be applied to correctly assess the energy efficiency in a region or area (Hu & Wang 2006).

The DEA has been widely used in energy efficiency and environment efficiency analysis in recent years. It can be found in the literature that the DEA has recently been widely applied to evaluate the energy efficiency and environment efficiency of different entities, namely, the decision-making units (*DMUs*). The DEA is a well-established linear programming approach for measuring the relative efficiency of peer DMUs that have multiple inputs and outputs, e.g., the CCR proposed by Charnes, Cooper & Rhodes (1978) and the BCC extended by Banker, Cooper & Charnes (1984) (Bian &Yang 2010).

This paper concentrates specifically on the energy efficiency in the European countries where further improvements can be planned and executed accordingly. This study aims to analyze and compare the DEA models of the energy markets in the European countries. In this regard, we examine the technical efficiency (*TE*) and pure technical efficiency (*PTE*) scores of the energy markets in the European countries for 2011-2012 and obtain the scale efficiency *(SE)* scores of the DMUs from the constant return of scale (*CRS*) and the variable return of scale (*VRS*) scores. The rest of the paper is organized as follows. Section 2 consists of the literature regarding energy efficiency including the DEA. In Section 3, we present the methodology and data related to the efficiency model. Section 4 clarifies an empirical application study on measuring the energy efficiency scores of the 23 European countries. Section 5 presents our empirical study's results.

2. KEY ASPECTS OF THE EUROPEAN ENERGY SECTOR

Europe is consuming, importing and increasing significant quantities of energy. European countries are well aware of the advantages of coordinated action in such a strategic field. This has led to common rules throughout Europe and a pooling of Europe's efforts to secure the energy that it needs at an affordable price, while generating the least possible pollution. Moreover, Europe's energy dependence has a great impact on their economy. Europe buys oil from OPEC (*Organization of the Petroleum Exporting Countries*) and Russia and gas from Russia, Norway and Algeria. The lesson of the January 2009 'gas crisis' is that the EU and the energy industry had to act together to address an unexpected shortage of Russian gas in the middle of winter. A lack of gas interconnections meant that countries such as Bulgaria and Romania, highly dependent on Russian gas, were completely cut off from the rest of Europe. In this context, these new circumstances will make it impossible to delay a radical rethink of Europe's energy supply security, and Europe has to be effective, to set ambitious goals and to work together if it is to diversify the energy sources and the channels of supply (European Commission 2012b)

In addition, energy has a social dimension as well as an economics dimension. Global energy markets have become more interdependent, and the ongoing EU energy situation will be directly influenced by its neighbors and by the global energy trends. In this context, the people's well-being and industrial competitiveness as well as the overall functioning of society are dependent on safe, secure, sustainable and affordable energy. Therefore, social, technological and behavioral changes will also have significant impact on the energy system, and consequently the European Union is providing vulnerable European consumers with an unprecedented level of protection (European Commission 2012a). Moreover, the Fuel Poverty Strategy defines those vulnerable consumers as certain groups of people who are more vulnerable to being fuel poor because they have higher energy requirements (Hills 2012).

Energy efficiency appears to be the only energy item in these fundamental EU goals: the reduction of GHG emissions, the improvement of energy stability, cutting energy costs, and enhancing the economic competitiveness, and thus energy efficiency can be perceived as Europe's largest energy source (Honma & Hu 2014).

In this regard, the EU attaches importance to the energy efficiency concept. Energy efficiency is at the heart of the EU's Europe 2020. It is the strategy for smart, sustainable and inclusive growth and for the transition to a resource-efficient economy. Energy efficiency is one of the most cost effective ways to enhance security for the energy supply and to reduce emissions of greenhouse gases and other pollutants. In many ways, energy efficiency can be viewed as Europe's largest energy resource. This is the reason that the Union has set itself the target of 2020 for saving 20% of its primary energy consumption compared to the projections and that this objective was identified in the Commission's Communication on Energy 2020 as a key step towards achieving our long-term energy and climate goals (European Commission 2011)

2.1. The European Union's Energy Goals and Statistics

The EU makes policies to reduce the energy dependence rate and the emission of CO_2 and greenhouse gases. The EU have many energy policies, and energy-related topics[1] were discussed by the European Council on 20/21 March 2014 at Brussels[2]. When we look at the EU's energy policies, two of them are prominent: the "20-20-20" goal for the year 2020 and decarbonisation by 2050.

First, the EC proposed a new energy policy with the aim of reducing the emissions of greenhouse gases by 20% in 2020 compared to the 1990 levels, reaching a renewable energy share of 20% of the total EU energy consumption by 2020 and increasing energy efficiency to save 20% of EU energy consumption; these goals were designated as the **20/20/20 targets[3]** (Council of European Union 2007).

Second, the scenarios in the Energy roadmap 2050 explore the routes towards the **decarbonisation** of the energy system. A number of scenarios to achieve an 80% reduction in greenhouse gas emissions involve an 85% decline of energy-related activities. The EU is committed to reducing greenhouse gas emissions to 80 to 95% below the 1990 levels by 2050 in the context of the reductions on the part of the developed countries as a group. The commission analyzed the implications of this in its Roadmap for moving to a competitive low-carbon economy in 2050 (European Commission 2012a).

[1] More detailed EU Energy, Transport and GHG Emissions Trends to 2050 Reference Scenario 2013

[2] More detailed Council of the European Union 2014, 'Brussels European Council 20/21 March 2014' Conclusions, (EUCO 7/1/14 REV 1), Brussels.

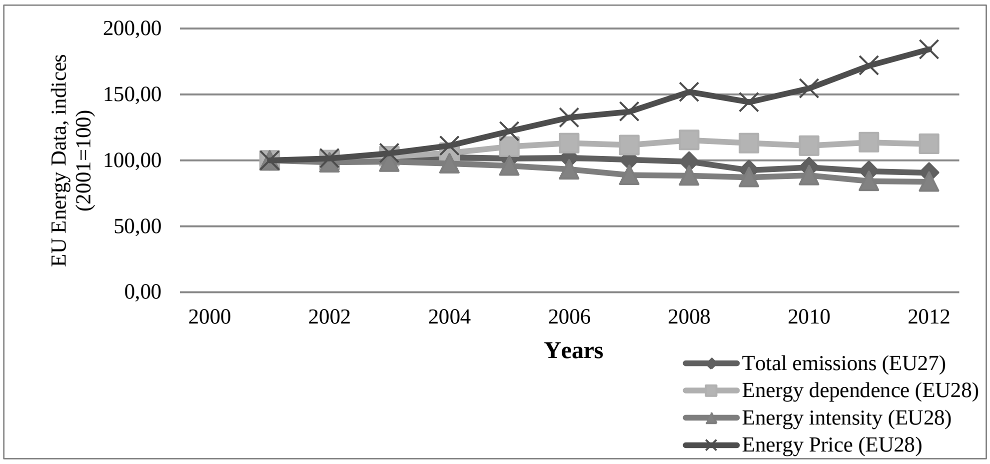
[3] 20-20-20 targets include mainly climate and energy issues.

The EU policies and measures to achieve the Energy 2020 goals and the Energy 2020 strategy are ambitious. They will continue to deliver beyond 2020, helping to reduce emissions by approximately 40% by 2050. The European Union has the powers and instruments required to implement an energy policy geared towards (European Commission 2012b):

- Securing Europe's energy supplies
- Ensuring that energy prices do not make Europe less competitive
- Protecting the environment and in particular combating climate change
- Improving energy grids

The EU countries are free to develop the energy sources they deem necessary. They must, however, take into account the European renewable energy objectives.

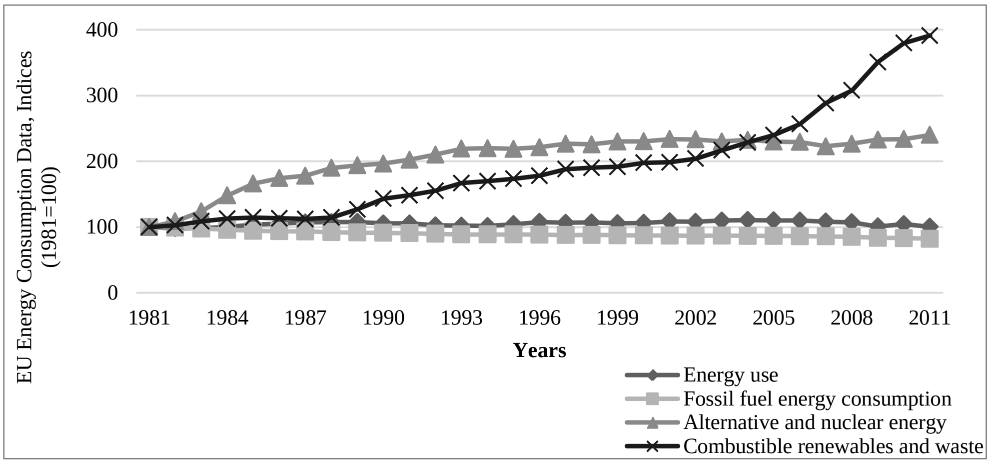
Fig. 1. Summary Energy Data at EU



Source: OECD (2014), EUROSTAT (2014), European Union (2014)

Fig. 1 presents a summary of the energy statistics for EU27-28. This summary contains Total emissions-EU27, Energy Dependence-EU28, Energy Intensity-EU28 and Energy Price-EU28, and it was measured relative to the base year 2001. It indicates that energy prices have increased from 2001 to 2012; on the other hand, the total emissions and energy intensity have decreased from 2001 to 2012. Moreover, energy dependence has increased less. As noted previously, within the framework of the EU Energy 2020 targets regarding the energy price and energy dependence, the EU aims to decrease dependence on fossil fuels, which is an ongoing problem. On the other hand, the increase in energy prices throughout the years is the expected result.

Fig. 2. Energy Consumption Data at EU



Source: Worldbank (2014)

Fig. 2 displays the summary of energy consumption data at European Union 28. The summary data contains energy use (kg of oil equivalent per capita), fossil fuel energy (*% of total energy consumption*), alternative and nuclear energy (*% of total energy consumption*) and combustible renewables and waste (*% of total energy consumption*). Moreover, it was measured relative to the base year 1981. Table 2 indicates that fossil fuel energy in total consumption decreased least. On the other hand, within the scope of the EU energy goals, the alternative and nuclear energy consumption and combustible renewables and waste energy consumption increased enormously in total energy consumption. When we observed the changes in mid-2000, the combustible renewables and waste use increased rather than alternative and nuclear energy.

2.2. What will the EU do for energy in the future?

Europe's primary focus should remain energy efficiency. Improving energy efficiency is a priority for all decarbonisation approaches and 20-20-20 goal scenarios. Higher energy efficiency in new and existing buildings is important. Investments by households and companies will have to play a major role in the energy system transformation. Greater access to capital for consumers and innovative business models are crucial. This also requires incentives to change behavior, such as taxes, grants or on-site advice by experts, including the monetary incentives provided by energy prices reflecting the external costs. An analysis of more ambitious energy efficiency measures and cost-optimal policy is required. Energy efficiency has to follow its economic potential (European Commission 2012a). In this context, the co-benefits of achieving energy efficiency in a wider resource-efficiency agenda should contribute to meeting the goals in a faster and cost-efficient manner.

The policies proposed in this plan aim at closing the gap in reaching the EU's 20% energy-saving target; in addition, they propose to help realize Europe's 2050 vision of a resource-efficient and low-carbon economy, as well as to increase energy independence and security of supply. The commission calls on the EU institutions, member states and all relevant stakeholders to endorse the new Energy Efficiency Plan, to actively engage in discussion concerning implementing measures and to cooperate closely in its implementation (European Commission 2012b).

Thus, if the EU makes the transition from fossil fuels to renewable energy sources, it will strive to stimulate the energy sector, secure Europe's energy supplies, increase energy efficiency, predict long-term energy policy, foster technological progress, engage in technological investments and make open-ended EU energy policy. In this context, the shifting process of energy in the EU should be supported with transforming other fossil fuels, smart technology, storage and alternative fuels, the increasing interaction of decentralized and centralized systems, up-to-date energy grids and energy diplomacy.

3. LITERATURE REVIEW

3.1. Data Envelopment Analysis at a Glance

During the past several decades, certain appropriate methods have been developed to monitor energy-efficiency trends and compare energy-efficiency performance across countries. These methods are generally classified as parametric and non-parametric methods (Sadjadi & Omrani 2008).

Within the wide spectrum of energy and environmental (E&E) modeling techniques, the DEA, a relatively new non-parametric approach to efficiency evaluation, has attracted much attention. Along with the wave of deregulation in the energy sectors since the late 1980s, the DEA has been accepted as a major frontier technique for benchmarking the energy sectors in many countries, particularly in the electricity industry (Jamasb & Pollitt 2001, Abbott 2006, Zhou, Ang & Poh 2008).

The DEA is a valuable mathematical programming technique that is applied to determine the technical and pure efficiencies of similar DMUs. Similar DMUs have been chosen in the empirical study. The inputs and outputs have been carefully selected to assess the DMUs as accurately as possible (Gökgöz 2010).

In an article that represents the inception of the DEA, Farrell (1957) claimed that what had been widely used to measure "Debreu-Koopmans" efficiency and productivity was motivated by the need for developing better methods and models for evaluating productivity. He argued that while attempts to solve the problem usually produced careful measurements, they were also very restrictive because they failed to combine the measurements of multiple inputs into any satisfactory overall measure of efficiency. Moreover, the secondary DEA model, i.e., the BCC model, was derived from the contribution of Banker, Charnes and Cooper to the CCR model (Cooper, Seiford & Zhu 2011).

The DEA, based on relative efficiency, is an efficiency evaluation method for the same type of DMUs. Because of the lack of a uniform energy efficiency concept and the significant differences in the input-output data, the energy efficiency calculated by many researchers is quite different (Hailiang & Dechun 2010).

A DMU that can produce the same amount of the same type of output as another DMU at a lower cost is said to be more productively efficient than the other DMU. Typically, a DMU is a firm or plant. It must be noted, however, that the non-stochastic DEA methodology makes no allowance for shocks or statistical errors (Pollitt 1996).

The DEA has advantages to other mathematical approaches. An advantage of the DEA is that the inefficient DMUs are compared to actual DMUs rather than to a statistical measure. In addition, the DEA does not require the specification of a cost or production function. However, the efficiency scores tend to be sensitive to the choice of input and output variables. Furthermore, the results (scores) are sensitive to measurement errors in the frontier DMUs as these comprise the best practice frontier. In addition, the method does not allow for stochastic factors and measurement errors. Finally, as more variables are included in the models, the number of DMUs on the frontier increases; therefore, it is important to examine the sensitivity of the efficiency scores and rank the order of the DMUs to the model specification (Jamasb, Nillsen & Pollitt 2004). One of the major advantages of the DEA efficiency measures is that it is possible to obtain the frontier-efficient plants to which an individual firm is being compared (Pollitt 1996).

The DEA has certain constraints, such as the homogeneity and input/output selection. The DEA makes a series of homogeneity assumptions about the units that are understood to be similar in a number of ways. First, the units are assumed to be engaged in similar activities and producing comparable products or services so that a common set of outputs can be defined. Second, a similar range of resources is available to all the units. Last, there is an unwritten assumption that the units are operating in similar environments because the external environment generally impacts upon the overall performance of the units (Dyson et al. 2001).

Moreover, there are four key assumptions of the input/output selection that are suggested by Dyson et al. (2001): First, it covers the full range of resources used; second it captures all activity levels and performance measures; third, the set of factors is common to all units; and finally, the environmental variation has been assessed and captured if necessary. Moreover, Dyson et al. (2001) suggest that a *"rule of thumb"* is that to achieve a reasonable level of discrimination, the number of units must be at least $2m * s$, where $m * s$ is the product of the number of inputs and the number of outputs. To illustrate, in a case with three inputs and two outputs, there would be on the order of twelve DMUs.

We define the characters which are used in DEA. We assume that there are n DMUs to be evaluated. Each DMU uses varying amounts of m diverse inputs to demonstrate diverse outputs. Moreover, we use the "ratio-form" of the DEA. There are data on N inputs and M outputs for each of I DMUs. N inputs and M outputs are illustrated by the column vectors x_i and $y_{i,}$ respectively for the i-th DMU. Both the *NxI* input matrix X and the *MxI* output matrix Y denote the data for all I DMUs. Thus, the proportion of outputs to inputs is used to calculate the relative efficiency of the $DMU_J = DMU_o$ to be demonstrate reference to the ratios of all of the $j = 1,2, \ldots, n$ DMU_J (Cooper, Seiford & Zhu 2011).

3.1.1. Constant Returns of Scale (CRS)

According to Coelli et al. (2005) CCR model is a part of the DEA, which is a non-parametric linear programming method. The efficiency score obtained by the application of the CCR model to the DMUs is called *"Technical Efficiency" (TE_{CCR})*. Coelli et al. (2005) and Cooper, Seiford & Tone (2006) have formulated the input-oriented CCR model as Equation (1):

$$(LP_0) \quad Max_{\mu,v}\,(\mu' y_i), \tag{1}$$

Subject to

$$\text{v}' x_i = 1 \tag{2}$$

$$\mu' y_j - \text{v}' x_j \leq 0, \;\; j = 1,2,\dots,I, \tag{3}$$

$$\mu, v \;\geq 0, \tag{4}$$

Here, v represented an Nx1 vector of input weights, and u is an Mx1 vector of output weights. Moreover, the change of notation from u and v to μ and y is used. The dual of this linear program is given in Equation (5) (Coelli et al. 2005, Cooper, Seiford & Tone 2006):

$$min_{\theta,\lambda}\,\theta, \tag{5}$$

Subject to;

$$-y_i + Q\lambda \geq 0, \tag{6}$$

$$\theta x_i - X\lambda \geq 0, \tag{7}$$

$$\lambda \geq 0, \tag{8}$$

Here λ is a $Ix1$ vector constant and θ is a scalar. The DEA model contains lesser constraints than the multiplier form ($N+M < I+1$) and that's why is normally the chosen the DEA model to solve. The value of θ attained is the efficiency score for the i. DMU. If $\theta < 1$, it will be a value of 1 indicating a point on the frontier and therefore a technically efficient DMU, according to the Farrell (1957) definition. Until each DMU in the sample is accounted, the linear programming problem must be solved I times.

3.1.2. Variable returns of scale (VRS)

Banker et al. (1984) contributed the CCR model with the constant returns to scale assumption to have a variable returns assumption, and they named this modified CCR model as the BCC model. The CCR linear programming issue can be readily adapted to explain the VRS model to attach the convexity constraint $I1'\lambda = 1$ (Coelli et al. 2005, Cooper, Seiford & Tone 2006):

$$min_{\theta,\lambda}\,\theta, \tag{9}$$

Subject to

$$-y_i + Q\lambda \geq 0, \tag{10}$$

$$\theta x_i - X\lambda \geq 0, \tag{11}$$

$$I1'\lambda = 1, \tag{12}$$

$$\lambda \geq 0, \tag{13}$$

Therefore, these are known as the CCR (Charnes, Cooper & Rhodes 1978) model. If the constraint $\sum_{j=1}^{n} I\lambda_j = 1$ is adjoined, they are known as BCC (Banker, Cooper & Charnes 1984) model. So, the convex shape of VRS of coinciding planes that envelope the data points more firmly than the conical shape of CRS. Therefore, pure technical efficiency scores are greater than or equal to technical efficiency scores.

In this regard, it makes possible to influence the return-to-scale evolutions. So, the BCC model is distinguished from the CCR model, which is mentioned to as the CRS model and called the VRS model (Cooper, Seiford & Zhu 2011). Although any DMUs may both technically and pure technically efficient, the scale of activity of the DMU may not be optimal. It is supposed that the DMU is holding a VRS technology. Then, the DMU covered may be too large in its scale of activity, which take part the DRS, whereas a DMU may be too small, and it may come in on the DRS. Hence, the efficiency of the DMUs might be advanced by shifting their scale of activities, i.e., to hold the same input mixed but shift the size of activity (Coelli et al. 2005).

3.1.3. Scale Efficiency

For a BBC-efficient in terms of DMU with CRS features, i.e., in the most productive scale size, its SE is 1, and thus the SE is not greater than one. The CCR score is called the TE because it does not take the scale influence as separated from the PTE into consideration. On the other hand, the BCC states the *(local)* PTE under VRS conditions. Using these notions, it shows an analysis of efficiency as (Coelli et al. 2005):

$$Scale\ Efficiency\ (SE) = \frac{Technical\ Efficiency\ (TE)}{Pure\ Technical\ Efficiency\ (PTE)} \qquad (14)$$

The SE score is calculated by dividing the technical efficiency by the pure technical efficiency. The aim of computing the scale efficiency is to verify what percentage of their capacity the DMUs are used efficiently.

In this context, a particular DMU is not scale efficient if SE is bigger than “0” and smaller than “1”. *(0<SE<1).* Besides, a DMU is scale efficient when SE is equal to “1”.

3.2. Energy Efficiency with the DEA approach

Because any economic production activity is a joint-production process, it utilizes resources related to energy (*e.g., energy, water*), and other non-resource inputs (*e.g., capital, labor*) to produce the desirable outputs (*e.g., GDP*) along with the emission of pollutants as undesirable outputs (*e.g., waste water, dust, solid waste*). Given this situation, decline in energy-use performance will cause more energy waste and more pollutant emissions (Bian &Yang 2010). In this context, the energy efficiency influences the factors research such as economic structure, energy structure, social factors, technical factors and price factors which are considered the main factors affecting energy efficiency (Dongxiou, Xin & Huanhuan 2011).

Among various definitions of energy efficiency ‘‘the ratio of energy services to energy input’’ is widely use. The definition provided by the Directive 2006/32/EC of the European Council and Parliament on the energy end-use efficiency and energy services is a general one, namely, energy efficiency is ‘‘a ratio between an output of performance, service, goods or energy, and an input of energy’’ (Zhou & Ang 2008). Since the 1973/1974 world oil crisis, energy researchers’ enthusiasm in formulating and applying analytical/modeling techniques in energy studies has increased tremendously (Loken 2007, Zhou, Ang & Poh 2008).

The traditional evaluation models of energy efficiency usually involve only the energy consumption and economic outputs, but leave out the environmental impact of energy and the substitution effect between energy and related factors (Wang, Wang & Wang 2009). On the other hand, the use of the energy-efficiency indicator in conjunction with labor and capital can provide useful insights into whether energy inputs act as complements or substitutes to other inputs designated as the economic and economic-thermodynamic indicators (Patterson 1996). In addition, there has been a growing interest on the use of nonparametric DEA in the E&E studies in recent years. In the methodological aspect, Honma & Hu (2014) found that the CRS reference technology and the radial efficiency measures are still the most widely used specifications. In contrast, the DEA has recently been widely applied to evaluate the energy efficiency performances of different entities.

Energy efficiency measurement and monitoring has evolved as an important topic in E&E studies (Ang 2006). The literature indicates that the recent survey by Jamasb & Pollitt (2001) and Zhou, Ang & Poh (2008) found a rapid increase in the number of studies using the DEA in the broad area of E&E analysis. To illustrate, Hu & Wang (2006), Hu & Kao (2007), Honma & Hu (2008), Zhang et al. (2011), Xiali, Rui & Qian (2014) and Honma & Hu (2014) developed a total-factor energy efficiency index by using the DEA.

Moreover, Zhou, Poh & Ang (2008), Zhou & Ang (2008), Bian & Yang (2010), Guo et al. (2011), Yang, Yang & Chen (2011) and Wang, Zhou & Zhou (2012) present DEA models measuring the energy efficiency with undesirable outputs.

The other energy research studies that Pollitt (1996) and Chitkara (1999) discussed measured the productive efficiency and the operational performance of nuclear power plants in the U.S and U.K and India. On the other hand, Raczka (2001), Sueyoshi & Goto (2001, 2011) and Korhonen & Luptacik (2004) measure the energy efficiency of power plants in Poland, the U.S, Japan and Norway. Moreover, Hjalmarsson & Veiderpass (1992), Bagdadioglu, Price & Jones (1996), Forsund & Kittelsen (1998), Chen (2002), Pacudan & Guzman (2002), Hawdon (2003), Savolainen & Svento (2008) proposed an integrated DEA approach to finding the efficiency score of the electric-energy distribution sectors. In addition, Golany, Roll & Rybak (1994), Yunos & Hawdon (1997), Park & Lesourd (2000), Jha & Shrestha (2006), Yang & Pollitt (2009), Liu, Lin, & Lewis (2010), Yadav, Padhy & Gupta (2009) and Fallahi, Ebrahimi & Ghaderi (2011) used the DEA to measure the efficiency of electric-energy power plants.

More efficient production processes and advanced technologies have played a positive role on the national level and in three areas of energy efficiency improvement. Using energy, capital and labor as the three elements of the economic growth model has been adopted by many scholars, and here the idea is followed, and the gross domestic product (GDP) is set as the output data (Hu & Wang 2006, Hu & Kao 2006, Zhang et al. 2011).

4. EMPIRICAL RESULTS

4.1. Data and Methodology

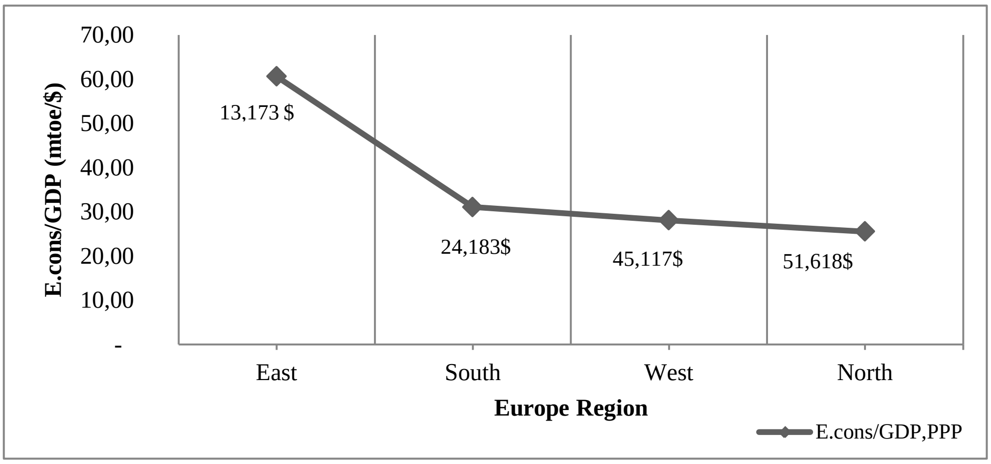
The goal of this paper is to analyze the energy efficiency levels for the European countries with the DEA approach. In this regard, the CCR and BCC efficiencies of the DMU’s have been investigated. The energy efficiency of 23 European countries has been studied during the period 2011-2012. The inputs and outputs have been determined in accordance with Dyson et al. (2001).

We use the annual data on the labor force (in thousands), the GFCF *(in billions of US dollars as valued in the year 2000 and using the PPP)* and premier energy consumption *(PEC-million tons of energy-mtoe)* as the three input variables, while GDP is the single output in this study. The data on the labor force, GDP and GFCT were collected from the EUROSTAT web site, while the energy consumption data were collected from the BP Statistical Review of World Energy 2013. The FCT was derived by multiplying GDP by *“GFCT as a percentage of real GDP”*. The data in the Eurostat are calculated by the Euro currency, and thus we have converted from the euro to the American dollar in terms of the International Exchange Rate. Table 1 presents the summary statistics and correlations matrix belonging to the energy efficiency model for the below four variables in 2011-2012. Table 1 indicates that high correlation exists between these inputs and the output.

Table 1. Summary statistics and correlation matrix for the variables used as inputs and outputs for 23 European countries, 2011-2012

Years	Tools	Labor (Input-1) (x million)	GFCF (Input-2) (x billion)	PEC (Input-3) (x mtoe)	GDP (Output) (x billion)
2011-2012	Mean	10.24	142.01	79	791.93
	Std. Dev.	10.46	165.99	80.5	947.98
	Min	1.29	7.23	6	42.61
	Max	39.12	616.49	309.50	3,526.495
	Range	37.82	609.26	303.5	3,483.888
Correlation Matrix	Labor	1.000			
	GFCF	0.915	1.000		
	PEC	0.963	0.978	1.000	
	GDP	0.921	0.989	0.977	1.000

Fig. 3. Relationship between Per Capita Income and Energy Consumption



Moreover, 23 European countries are categorized based on the United Nations Statistics Division-Standard Country and Area Codes Classifications (M49) under four regions:

- Eastern Europe (*Bulgaria, the Czech Republic, Hungary, Poland, Romania and Slovakia*)
- Southern Europe (*Greece, Italy, Portugal, Spain, Turkey*)
- Western Europe (*Austria, Belgium, France, Germany and the Netherlands*)
- Northern Europe (*Denmark, Finland, Lithuania, Norway, Sweden and the United Kingdom*)

We tested the relationship between energy consumption/GDP (E.cons/GDP) and per capita income with a simple regression analysis[4]. Fig. 3 indicates that the per capita income actually represents the economic development level in the region. In addition, the E.cons/GDP ratio indicates how much energy is consumed to produce a unit of GDP. The highest E.cons/GDP ratio (21.45 mtoe/$) is in Eastern Europe, and the lowest E.cons/GDP ratio (9.04 mtoe/$) is in Northern Europe. On the other hand, the highest per capita income (51,168$) is in northern Europe, and the lowest per capita income

[4] The regression result presents that the R-squared value is 0.70 and the p-value of 0.04 (The result is statistically at the 0.05 level).

(13,173$) is in Eastern Europe. We compared the regions that have the highest per capita income, and at the same time the lowest E.cons/GDP level is the most developed region, northern Europe.

In general, input-orientated DEA models might be suitable for most E&E issues in which the outputs are decided by the requirement of demand. The incorporation of radial efficiency measures with the ordinary CRS and VRS reference technologies, e.g., the CCR and BCC models, would be appropriate because such a setting can provide the information on not only the technical efficiency but also the scale efficiency. As to the selection of the inputs and outputs, the first step is to establish a list of possible inputs and outputs that may be related to the study. These inputs and outputs can be further examined by certain screening procedures such as the preliminary judgment and statistical analysis to retain only the most relevant ones (Zhou, Ang & Poh 2008).

4.2. Results

In the energy efficiency model using the input-oriented DEA model (the CCR and BCC) efficiency scores of the DMUs, the European countries with $TE_{CCR,}$ PTE_{BCC}, and SE scores equal to 1 are exactly efficient. Moreover, we computed the TE scores using the formula given in equation 5; we calculated the PTE scores using the formula given in equation 9; and we attained the SE scores using equation 14.

Table 2. Energy Efficiency Scores of 23 European Countries

Country	TE Score		PTE Score		SE Score	
	2011	2012	2011	2012	2011	2012
Austria	0.773	0.751	0.825	0.800	0.936	0.940
Belgium	0.733	0.747	0.814	0.827	0.900	0.903
Bulgaria	0.494	0.499	0.755	0.719	0.654	0.695
Czech Republic	0.441	0.463	0.444	0.467	0.993	0.990
Denmark	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Finland	0.725	0.733	0.766	0.766	0.948	0.957
France	0.759	0.755	**1.000**	**1.000**	0.759	0.755
Germany	0.710	0.708	**1.000**	**1.000**	0.710	0.708
Greece	0.702	0.813	0.760	0.861	0.924	0.944
Hungary	0.594	0.614	0.657	0.673	0.905	0.912
Ireland	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Italy	0.753	0.745	**1.000**	**1.000**	0.753	0.745
Lithuania	0.588	0.642	**1.000**	**1.000**	0.588	0.642
Netherlands	0.720	0.734	0.897	0.905	0.802	0.812
Norway	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Poland	0.527	0.558	0.638	0.680	0.826	0.820
Portugal	0.591	0.667	0.602	0.668	0.982	0.997
Romania	0.424	0.463	0.437	0.469	0.970	0.987
Slovakia	0.460	0.530	0.626	0.628	0.735	0.845
Spain	0.611	0.623	0.807	0.803	0.757	0.775
Sweden	0.780	0.803	0.886	0.897	0.880	0.895

Turkey	0.490	0.529	0.620	0.678	0.790	0.780
United Kingdom	0.746	0.745	**1.000**	**1.000**	0.746	0.745
Average Score	**0.679**	**0.701**	**0.806**	**0.819**	**0.850**	**0.856**

As can be observed in Table 2, according to the CCR input-oriented analysis results of the period 2011-2012, the three European countries that have technical efficiency are Denmark, Ireland and Norway. With reference to the BCC input-oriented analysis results of the period 2011-2012, Denmark, France, Germany, Ireland, Italy, Lithuania, Norway and the United Kingdom are fully efficient among the 23 European countries measured. It is observed that the average CCR-efficiency results of the energy efficiency model are above 65%, whereas the average BCC-efficiency results of the energy efficiency model are above 80%.

Moreover, the SE results of the periods 2011-2012 indicate that the European countries that reflect a fully efficient use of their capacity are Denmark, Ireland and Norway. Moreover, the average SE efficiency results of the model are above 85%. This demonstrates that the European countries have achieved highly efficient use of their capacities. On the other hand, Table 2 presents a summary of the information prepared with regard to the four-variable ratio, which is developed the most among the input and output variables both in the CCR and the BCC models as a result of the DEA. In addition, the pure technical efficiencies have exhibited higher efficiency scores rather than the technical for the European countries in the period 2011-2012.

Table 3. Distribution of the European Countries' DEA scores

Score Value	TE		PTE		SE	
	2011	2012	2011	2012	2011	2012
Below 0.49	5	3	2	2	0	0
0.50-0.59	4	3	0	0	1	0
0.60-0.69	1	4	5	5	1	2
0.70-0.79	10	8	3	2	7	6
0.80-0.89	0	2	5	5	3	4
0.90-0.99	0	0	0	1	8	8
1.00	3	3	8	8	3	3

We observe that 20 European countries operate at a suboptimal level of production. However, the distribution of the SE scores in Table 3 indicates that 8 European countries *(35% of the European countries)* are very close to the optimum level of production in the period 2011-2012. There are three plants that operate at the optimum scale *(13% of European countries)*. Moreover, as we compared between the European countries' SE scores for the period 2011-2012, some European countries are raised in the rank-score value.

Table 4. Ratios of Improvement for Each Measurement of European Countries for the period 2011-2012

Input and Output	CCR Model Improvement Ratios		BCC Model Improvement Ratios	
	2011	2012	2011	2012
Labor	-0.424	-0.415	-0.271	-0.274
Fixed Capital Formation	-0.321	-0.299	-0.201	-0.181
Primer Energy Consumption	-0.404	-0.403	-0.281	-0.283
GDP	-	-	-	-

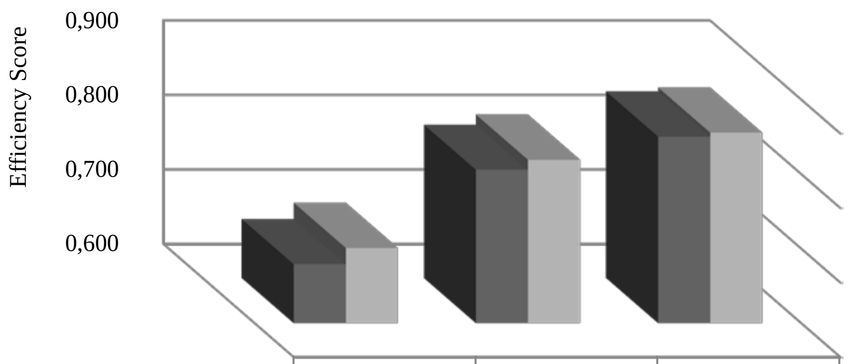
Table 4 displays the potential improvement ratios of the input and output elements according to the CCR and BCC model results. In addition, the practical application of the improvement ratios given is important for increasing the efficiency levels of the European countries that will become efficient when any of the inputs are reduced. Because the GDP and GFCF rely upon many factors in the economy, the EU is unlikely to step in on these factors. Additionally, the labor force would experience a decrease in the prosperity of society, and this would cause unrest; thus, this input not be changed. In the course of events, the European countries that will reduce their primary energy consumption reach a realistic efficient frontier. The average improvement ratios of the European countries indicate that they were not on the efficient frontier in the CCR and BCC model in the period 2011-2012.

To improve the efficiency levels in 2011 and 2012 in the CCR energy efficiency model, any of the following targets should be achieved: lessen the workforce by 42.2% and 41.5%, reduce the GFCF by 32.1% and 29.9%, decrease the PEC by 40.4% and 40.3%, respectively, and maintain the GDP. The European countries are not able to decrease the labor, GFCF or GDP; therefore, they should try to achieve efficiency by reducing energy consumption. The results indicate that the European countries did not reduce primary energy consumption in 2011 to the efficient frontier, and unfortunately they maintained the same level in 2012. On the other hand, the European countries should attempt to become fully efficient by decreasing the measures to 28.1% and 28.3%, respectively, in the BCC model. In addition, we observe no change in the average improvement ratios of primary energy consumption in the period 2011-2012.

5. CONCLUSIONS

We make allowances for the literature in this paper by establishing total power energy consumption, fixed capital investment and labor forces as the input indicators and GDP as the output indicator; then we adopt the DEA models to make an empirical analysis of the energy efficiency of 23 European countries. In this context, the inputs and outputs required for a DMU to be efficient can be computed by an input-oriented DEA approach. An efficiency frontier is established by the DEA composed of those European countries with the best energy efficiency, with the energy input considered. The energy efficiency is measured in each European country based on the distance from this efficiency frontier.

Fig. 4. Energy Efficiency Scores of European Countries



	TE	PTE	SE
2011	0,679	0,806	0,850
2012	0,701	0,819	0,856

In Fig. 4, a comparison of the CCR and BCC models for the period 2011-2012 is presented with regard to the TE, PTE, and SE. All efficiency scores obtained from the model are high according for the period. The European countries have demonstrated a 2.2% rise in efficiency in 2012 with regard to the CCR analysis and a 1.3% efficiency increase in 2012 in terms of the BCC analysis. In addition, the scale efficiency score increases 0.6% in 2012. Within the context of the number of countries that are above the average efficiency score in the model:

- According to the CCR model based on the year 2011, 56.52% of the countries are above average, and for the BCC model, 65.21% of the countries are above average
- According to the CCR model based on the year 2012, 56.52% of the countries are above average, and for the BCC model, 62.51% of the countries are above average
- According to the SE model based on the year 2011 and 2012, 56.52% and 56.52% of the countries, respectively, are above average.

Therefore, the average scores of the TE, PTE and SE of the European countries in 2012 are higher than in 2011. This indicates that the energy efficiency of European countries has improved at minimum. Thus, there are three crucial points to make.

First, observing the energy sector in the world, we have observed that the security and significance of the energy market has been increasing more and more. As a result of the crucial developments that are generated by the energy sector, our results are optimistic. Although the European countries' average scale efficiency scores are high *(closed by 1)*, only 56.52% of the countries have a performance above the averages. Moreover, the improvement ratios of the European countries indicate that the technical efficiency levels increase when the premier energy consumption is reduced enormously *(40.4)*. Thus, this indicates that energy efficiency continues to be a problem throughout the European zone.

Second, northern Europe is formed by Denmark, Finland, Ireland, Lithuania, Norway, Sweden and the United Kingdom. Moreover, Denmark, Ireland and Norway have demonstrated a full technical, pure technical and scale efficiency score for the period 2011-2012. In this regard, northern Europe possesses the majority of the per capita income, the lowest E.cons level among the European regions, and also the SE score is the highest *(0.866 for 2011 and -0.873 for 2012)*. Eventually, the performance of northern Europe should be taken as an example by the other parts of Europe.

Finally, we suggest that the European countries should obey the internal energy policies *(the 20-20-20 targets and decarbonization)* and the external energy policies (Kyoto and Bali Roadmap) to improve energy efficiency alongside decreasing fossil fuel energy consumption, fossil fuel energy dependence and CO_2 gas emissions and increasing renewable energy and energy security.

Consequently, empirical studies which were carried out via *data envelopment approach* have shown significant results for the decision makers in analyzing the energy efficiency levels of the European energy markets.

REFERENCES

1. Abbott, M 2006, 'The productivity and efficiency of the Australian electricity supply industry', Energy Economics, vol 28, no. 4, pp. 444-454.
2. Ang, BW 2006, 'Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index', Energy Policy, vol 34, no. 5, pp. 574-582.
3. Bagdadioglu, N, Price, CMW & Weyman-Jones, TG 1996, 'Efficiency and ownership in electricity distribution: A non-parametric model of the Turkish experience', Energy Economics, vol 18, no. 1-2, pp. 1-23.
4. Banker, RD, Charnes, A & Cooper, WW 1984, 'Some Models For Estimating Technical and Scale Inefficiencies Data Envelopment Analysis', Management Science, vol 30, no. 9, pp. 1078-1092.
5. Bian, Y & Yang F 2010, 'Resource and environment efficiency analysis of provinces in China: A DEA approach based on Shannon's entropy', Energy Policy, vol 38, no. 4, pp. 1909-1917.
6. BP 2013, 'Statistical Review of World Energy', viewed 10 May 2014, <http://www.bp.com/statisticalreview>.
7. Charnes, A, Cooper, WW & Rhodes, E 1978, 'Measuring the efficiency of decision making units', European Journal of Operational Research, vol 2, no. 6, pp. 429-444.
8. Chen, T-Y 2002, 'An assessment of technical efficiency and cross-efficiency in Taiwan's electricity distribution sector', European Journal of Operational Research, vol 137, no. 2, pp. 421-433.
9. Chitkara, P 1999, 'A Data Envelopment Analysis Approach to Evaluation of Operational Inefficiencies in Power Generating Units: A Case Study of Indian Power Plants', IEEE Transactions on Power Systems, vol 14, no. 2, pp. 419-425.
10. Coelli, TJ, Rao, PDS, O'Donnell, CJ & Battese, GE 2005, An Introduction to Efficiency and Productivity Analysis, 2nd edn, Springer Science+Business Media, Inc., New York.
11. Council of the European Union 2007, 'Brussels European Council 8/9 March 2007', Presidency Conclusions, (7224/1/07), Brussels.
12. Council of the European Union 2014, 'Brussels European Council 20/21 March 2014' Conclusions, (EUCO 7/1/14 REV 1), Brussels.
13. Cooper, WC, Seiford , LM & Tone, K 2006, Introduction to Data Envelopment Analysis and Its Uses , Springer Science+Business Media, Inc., New York.
14. Cooper, WW, Seiford, LM & Zhu, J 2011, Handbook on Data Envelopment Analysis, 2nd edn, Springer Science+Business Media,LLC, New York.
15. Dongxiao, N,Xin, L & Huanhuan, Q 2011, 'Empirical Analysis on Shanxi electric energy efficiency by DEA model', Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, IEEE, Harbin, pp. 1184-1187.
16. Dyson, RS, Allen, R, Camanho, AS, Podinovski, VV, Sarrico, CS & Shale, EA 2001, 'Pitfalls and protocols in DEA', European Journal of Operational Research, vol 132, no. 2, pp. 245-249.
17. European Commission 2011, 'Energy Efficiency Plan 2011', COM (2011) 109/4, Communication From The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions, European Commission, Brussels.
18. European Commission 2012a, 'Energy Roadmap 2050', ISBN 978-92-79-21798-2, Publications Office of the European Union, Luxembourg.
19. European Commission 2012b, 'The European Union Explained', European Commission General for Communication, ISBN 978-92-79-24116-1, European Union, Luxembourg.
20. European Union 2014, 'EU Energy, Transport and GHG Emissions Trends to 2050 Reference Scenario 2013', ISBN: 978-92-79-33728-4, Publications Office of the European Union, Luxembourg.
21. EUROSTAT 2014, viewed 10 May 2014, <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

22. Fallahi, A, Ebrahimi, R & Ghaderi, S.F. 2011, 'Measuring efficiency and productivity change in power electric generation management companies by using data envelopment analysis: A case study', Energy, vol 36, no. 11, pp. 6398-6405.
23. Førsund, FR & Kittelsen, SAC 1998, 'Productivity development of Norwegian electricity distribution utilities', Resource and Energy Economics, vol 20, no. 3, pp. 207-224.
24. Gökgöz, F 2010, 'Measuring The Financial Efficiencies and Performances Of Turkish Funds', Acta Oeconomica, vol 60, no. 3, pp. 295-320.
25. Golany, B, Roll, Y & Rybak, D 1994, 'Measuring Efficiency of Power Plants in Israel by Data Envelopment Analvsis', IEEE Transactions on Engineering Management, vol 41, no. 3, pp. 291-301.
26. Guo, X-D, Zhua, L, Fan, Y & Xie, B-C 2011, 'Evaluation of potential reductions in carbon emissions in Chinese provinces based on environmental DEA', Energy Policy, vol 39, no. 5, pp. 2352-2360.
27. Hailiang, M & Dechun, H 2010, 'Total-factor Energy Efficiency of Jiangsu Province Based on DEA', E-Product E-Service and E-Entertainment (ICEEE), 2010 International Conference on, IEEE, Henan, pp.1-5.
28. Hawdon, D 2003, 'Efficiency, performance and regulation of the international gas industry—a bootstrap DEA approach', Energy Policy, vol 34, no. 11, pp. 1167-1178.
29. Hills, J 2012, 'Getting the measure of fuel poverty Final Report of the Fuel Poverty Review', Department of Energy and Climate Change (DECC), Centre for Analysis of Social Exclusion, ISSN 1465-3001, London School of Economics and Political Science, London.
30. Hjalmarsson, L & Veiderpass, A 1992, 'Efficiency and ownership in Swedish electricity retail distribution', Journal of Productivity Analysis, vol 3, no. 1-2, pp. 7-23.
31. Honma, S & Hu, J-L 2008, 'Total-factor energy efficiency of regions in Japan', Energy Policy, vol 36, no. 2, pp. 821-833.
32. Honma, S & Hu, J-L 2014, 'Industry-level total-factor energy efficiency in developed countries: A Japan-centered analysis', Applied Energy, vol 119, pp. 67-78.
33. Hu, J-L & Wang, S-C 2006, 'Total-factor energy efficiency of regions in China', Energy Policy, vol 34, no. 17, pp. 3206-3217.
34. Jamasb, T, Nillesen, P & Pollitt, M 2004, 'Strategic behavior under regulatory benchmarking', Energy Economics, vol 26, no. 5, pp. 825-843.
35. Jamasb, T & Pollitt, M 2001, 'Benchmarking and regulation: international electricity experience', Utilities Policy, vol 9, no. 3, pp. 107-130.
36. Jha, DK & Shrestha, R 2006, 'IEEE TRANSACTIONS ON POWER SYSTEMS, vol 21, no. 4, pp. 1502-1511.
37. Kopsakangas-Savolainen, M & Svento, R 2008, 'Estimation of cost-effectiveness of the Finnish electricity distribution utilities', Energy Economics, vol 30, no. 2, pp. 212-229.
38. Korhonen, PJ & Luptacik, M 2004, 'Eco-efficiency analysis of power plants: An extension of data envelopment analysis', European Journal of Operational Research, vol 154, no. 2, pp. 437-446.
39. Lee, Y-C, Hu, J-L & Kao, C-H 2011, 'Efficient saving targets of electricity and energy for regions in China', International Journal of Electrical Power and Energy Systems, vol 33, no. 6, pp. 1211-1219.
40. Liua, C.H, Lin, J.S & Lewis, C 2010, 'Evaluation of thermal power plant operational performance in Taiwan by data envelopment analysis', Energy Policy, vol 38, no. 2, pp. 1049-1058.
41. Løken, E 2007, 'Use of multicriteria decision analysis methods for energy planning problems', Renewable and Sustainable Energy Reviews, vol 11, no. 7, pp. 1584-1595.
42. OECD 2014, viewed 10 May 2014, < http://www.oecd.org/statistics/>
43. Oh, D-H 2010, 'A metafrontier approach for measuring an environmentally sensitive productivity growth index', Energy Economics, vol 32, no. 1, pp. 146-157.
44. Pacudan, R & de Guzman, E 2002, 'Impact of energy efficiency policy to productive efficiency of electricity distribution industry in the Philippines', Energy Economics, vol 24, no. 1, pp. 41-54.
45. Park, S-U & Lesourd, J-B 2000, 'The efficiency of conventional fuel power plants in South Korea: A comparison of parametric and non-parametric approaches', International Journal of Production Economics, vol 63, no. 1, pp. 59-67.

46. Patterson, MG 1996, 'What is energy efficiency? Concepts, indicators and methodological issues ', Energy Policy, vol 24, no. 5, pp. 377-390.
47. Pollitt, MG 1996, 'Ownership and Efficiency in Nuclear Power Production', Oxford Economic Papers, vol 48, no. 2, pp. 342-360.
48. Raczka, J 2001, 'Explaining the performance of heat plants in Poland', Energy Economics, vol 23, no. 4, pp. 355-370.
49. Sadjadi, S.J & Omrani, H 2008, 'Data envelopment analysis with uncertain data: An application for Iranian electricity distribution companies', Energy Policy, vol 36, no. 11, pp. 4247-4254.
50. Sueyoshi, T & Goto, M 2001, 'Slack-adjusted DEA for time series analysis: Performance measurement of Japanese electric power generation industry in 1984–1993', European Journal of Operational Research, vol 133, no. 2, pp. 232-259.
51. Sueyoshi, T & Goto, M 2012, 'Environmental assessment by DEA radial measurement: U.S. coal-fired power plants in ISO (Independent System Operator) and RTO (Regional Transmission Organization)', Energy Economics, vol 34, no. 3, pp. 663-676.
52. Wang, Q, Zhou, P & Zhou, D 2012, 'Efficiency measurement with carbon dioxide emissions: The case of China', Applied Energy, vol 90, no. 1, pp. 161-166.
53. Wang, Q, Wang, S & Wang, X 2009, 'Research on Total Factor Energy Efficiency in China based on super Efficiency Grey DEA Model', Proceedings of 2009 IEEE International Conference on Grey Systems, IEEE, Nanjing, pp.1542-1547.
54. Worldbank 2014, viewed 10 May 2014, < http://data.worldbank.org/>
55. Xiaoli, Z, Rui, Y & Qian, M 2014, 'China's total factor energy efficiency of provincial industrial sectors', Energy, vol 65, pp. 52-61.
56. Yadav, VK, Padhy, NP & Gupta, HO 2011, 'Performance evaluation and improvement directions for an Indian electric utility', Energy Policy, vol 39, no. 11, pp. 7112-7120.
57. Yang, H & Pollitt, M 2009, 'Incorporating both undesirable outputs and uncontrollable variables into DEA: The performance of Chinese coal-fired power plants', European Journal of Operational Research, vol 197, no. 3, pp. 1095-1105.
58. Yang, M, Yang, F-X & Chen, X-P 2011, 'Effects of substituting energy with capital on China's aggregated energy and environmental efficiency', Energy Policy, vol 39, no. 10, pp. 6065-6072.
59. Yunos, JM & Hawdon, D 1997, 'The efficiency of the National Electricity Board in Malaysia: An intercountry comparison using DEA', Energy Economics, vol 19, no. 2, pp. 255-269.
60. Zhang, X-P, Cheng, X-M, Yuan, J-H & Gao, X-J 2011, 'Total-factor energy efficiency in developing countries', Energy Policy, vol 39, no. 2, pp. 644-650.
61. Zhou, & Ang, W 2008, 'Linear programming models for measuring economy-wide energy efficiency performance', Energy Policy, vol 36, no. 8, pp. 2911-2916.
62. Zhou, , Ang, & Poh, L 2008, 'A survey of data envelopment analysis in energy and environmental studies', European Journal of Operational Research, vol 189, no. 1, pp. 1-18.