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Energy Efficiency in Electricity Production: A Data Envelopment Analysis (DEA) Approach for the G-20 Countries

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ABSTRACT: Factors such as global warming, increased energy prices, decreased security of energy supply and the vision of sustainable development have inspired researchers to focus on energy efficiency. In this context, this study adopts input oriented DEA based on the Charnes, Cooper and Rhodes (CCR) model and estimates technical and super efficiency scores of G-20 countries in terms of electricity production for the periods 1990, 1995, 2000, 2005 and 2011. Findings reveal that China and Russia appear at the top of energy efficiency rankings. On the other hand, France and the European Union are inefficient in four of five periods. Besides, the way that the United States follows for recent electricity production seems inefficient. This implies that the world has been experiencing an important transformation in terms of efficient electricity production and policy makers should be aware of this progress in order to avoid unexpected outcomes for the energy future.

Keywords: Energy efficiency; Data Envelopment Analysis; G-20 countries
JEL Classifications: C14; O13; O57

1. Introduction

The most popular topic in energy economics is the contribution that energy consumption makes to economic growth. Thus, ever since the pioneering study of Kraft and Kraft (1978), energy consumption and economic growth nexus has become a vast field of interest that is constructed around the *growth*, *conservation*, *feedback* and *neutrality* hypotheses (Ozturk, 2010). However, the contribution that energy consumption makes to economic growth is first determined by its technical efficiency (Mukherjee, 2008; Shi et al., 2010; Zhang et al., 2011; Khademvatani and Gordon, 2013). In this sense, even if the consumption level is relatively high, it will not contribute much to growth under a situation in which it is produced in an inefficient way. From this point of view, investigating energy efficiency is at least as substantial as investigating the impact of energy consumption on economic growth.

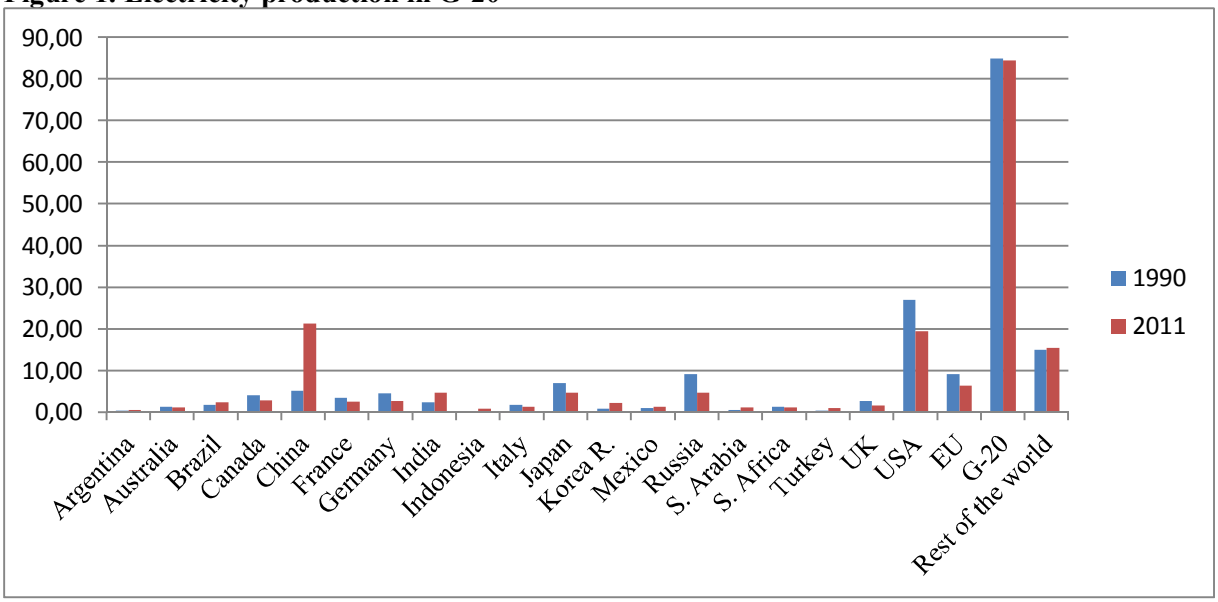
There are numerous factors that strengthen the importance of energy efficiency. Zhou et al. (2012) state that higher energy prices, global warming and perception of sustainable development have made energy efficiency the vital component of energy strategy in many countries. And also, energy efficiency is beneficial for reducing CO2 emissions, increasing security of energy supply and promoting industry competitiveness. According to the Mukherjee (2008), since the energy demand from emerging economies is rising and the projections about the energy supply indicate a shortage in the near future, the goal of achieving increased energy efficiency has attracted a greater level of interest. Besides, from the standpoint of cost minimization, it is also important to supply and sustain efficient energy production.

Although there is no consensus on the appropriate method for defining and measuring energy efficiency (Khademvatani and Gordon, 2013), many of the researchers have adopted the DEA for the assessment of energy efficiency in different countries (Hu and Wang, 2006; Chang and Hu, 2010; Zhang et al., 2011; Zhou et al., 2012). Following these studies, the present study adopts the DEA and aims to compare the energy efficiency performances of G-20 countries in electricity production for the periods 1990, 1995, 2000, 2005 and 2011.

For assessing the efficiency in electricity production, the G-20 seems as one of the most appropriate samples in the world. According to the World Bank statistics, electricity production of the world has doubled from 1990 to 2011. In 1990, total electricity production in the world was 11,8 trillion kWh and the production share of G-20 countries was 85%. In 2011, world's total electricity production has increased to 22,2 trillion kWh and the G-20 have produced 84.6% of the total. On the other hand, the scene is almost the same for electricity consumption. In 1990, total electricity consumption in the world was 10,8 trillion kWh and the consumption share of G-20 countries was 86.3%. In 2011, world's total electricity consumption has increased to 20,3 trillion kWh and the G-20 have consumed 85.6% of the total.

Figure 1 clearly illustrates the shares of G-20 countries in total electricity production for the periods 1990 and 2011. It is evident from the plots that Argentina, China, Brazil, India, Indonesia, Korea Republic, Mexico, Saudi Arabia and Turkey are the countries that have experienced an improvement in the electricity production from 1990 to 2011. On the other hand, the USA that was ranked 1st in electricity production in 1990 has faced a decline and has lost its ground to China whose electricity production share in 2011 is approximately five times bigger than the one in 1990.

Figure 1. Electricity production in G-20

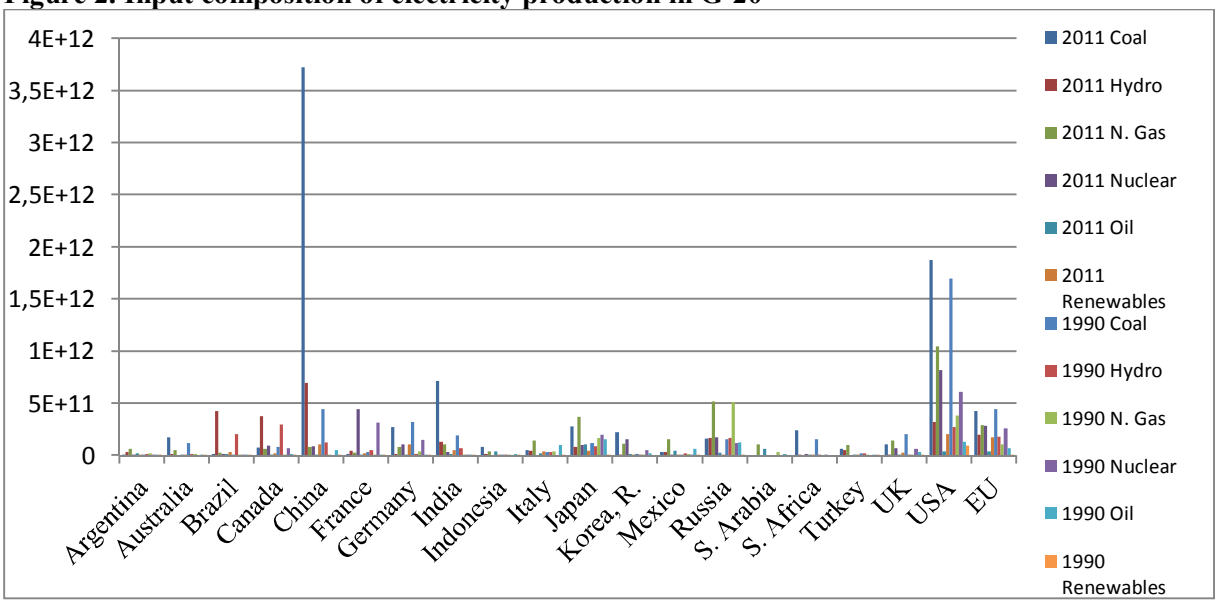


Source: The World Bank, World Development Indicators

Finally, the Figure 2 decomposes the inputs of electricity production in G-20 countries for the periods 1990 and 2011. It is evident that coal is the most used input in electricity production either in 1990 or in 2011, whereas the renewable sources are among the least used ones. Although it is one of the least, compared to 1990, the share of renewable sources in electricity production has experienced a rapid growth towards 2011. On the other hand, changes in the usage of energy sources in electricity production in China between two periods are spectacular. By 2011, China's electricity production from coal sources is 8.4 times; from hydroelectric sources is 5.5 times; from natural gas sources is 30 times; from nuclear sources is 86350000000 times; from oil sources is 0.2 times and from renewable sources is 26132 times bigger than they are in 1990. In addition, the progress experienced in the composition of inputs in electricity production by India is also noteworthy. By 2011, India's electricity production from coal sources is 3.7 times; from hydroelectric sources is 1.8 times; from natural gas

sources is 10.8 times; from nuclear sources is 5.4 times; from oil sources is 1.2 times and from renewable sources is 1645.7 times bigger than they are in 1990.

Figure 2. Input composition of electricity production in G-20



Source: The World Bank, World Development Indicators

Rest of the paper is organized as follows: The next section reviews the literature and describes novelty. Section 3 presents the data, methodology and results. Finally, Section 4 concludes.

2. Literature Review

The literature related to energy efficiency can be classified under two lines. The first one is composed of studies that take the issue into account in an industry-based perspective (Boyd and Pang, 2000; Worrell et al., 2003, Wei et al., 2007; Azadeh et al., 2007; Mukherjee, 2008; Martinez, 2013; Martinez, 2015). The common result from these studies is that increased energy intensity is the factor that decreases energy efficiency.

The second line includes studies that deal with energy efficiency problem in regional and/or (inter)national perspectives. In this context, Hu and Wang (2006) estimate the index of total-factor energy efficiency and analyze energy efficiencies of 29 administrative regions in China for the period 1995-2002 by employing the DEA. Findings illustrate that the central area of China has the worst energy efficiency and its total adjustment of energy consumption amount is over half of China's total. On the other hand, except for the western part, the regional index of total-factor energy efficiency in China generally improved from 1995 to 2002. Chien and Hu (2007) analyze the effects of renewable energy on the technical efficiency of OECD and non-OECD countries during the 2001-2002 periods through the DEA and state that increased use of renewable energy improves an economy's technical efficiency, whereas increasing the input of traditional energy decreases. In addition, compared to non-OECD countries, OECD countries have higher technical efficiency scores due to the higher share of geothermal, solar, tide, and wind fuels in renewable energy. Chang and Hu (2010), by using 29 provincial level data from 2000 to 2004, evaluate the energy productivity change of regions in China with a total-factor framework. Findings of the data envelopment analysis show that average total-factor energy efficiency improves about 0.6% per year, whereas energy productivity and total-factor energy technical change decline 1.4% and 2% per year, respectively. Shi et al. (2010), by considering undesirable outputs and minimization of energy consumption in measuring Chinese industrial energy efficiency, investigate the maximum energy-saving potential in 28 administrative regions in China for the period 2000-2006 and conclude that industries in the east area have the best average energy efficiency, followed by the central area. In addition, the level of pure technical efficiency and the massive use of energy in order to support the industrial-based economy are the two basic factors that cause the wastage of a large amount of energy during the industrial production process. Zhang et al.

(2011) use a total-factor framework and investigate energy efficiency in 23 developing countries during the period of 1980–2005 by employing the data envelopment analysis. Results indicate that Botswana, Mexico and Panama perform the best in terms of energy efficiency, whereas Kenya, Sri Lanka, Syria and the Philippines perform the worst. Besides, seven countries show little change in energy efficiency over time and eleven countries experienced continuous decreases in energy efficiency. Finally, among five countries witnessing continuous increase in total-factor energy efficiency, China experienced the most rapid rise. Finally, Zhou et al. (2012) estimate economy-wide energy efficiency performance from a production point of view by focusing on energy efficiency measurement at a macro-level and proposing a parametric frontier approach for 21 OECD countries and found that Ireland, Italy and Norway are the most efficient countries, whereas the lowest efficiency scores belong to Canada, New Zealand and Belgium, respectively.

The present study as a complement to the second line of the literature differs from the previous studies in several aspects. First, the study estimates the super efficiency score as well as technical efficiency and indicates which countries are the most efficient in terms of electricity production. Second, by considering five different time periods from 1990 to 2011, this study clearly states any changes experienced and compares energy efficiency performances of the countries in consideration. Third, to the best of our knowledge, no other papers using the same data set have been published. Hence, this paper aims to fulfill this gap and contribute to the empirical literature.

3. Data, Methodology and Results

3.1. Data

Electricity is a type of energy and it is generated using different energy sources such as coal, hydroelectric, natural gas, nuclear, oil or renewable energy. In this study G-20 countries are analyzed and their efficiency in electricity production is measured in five different time periods. Saudi Arabia and South Africa are excluded from the analyses due to missing data on some input variables. The sample constituted from 17 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Turkey, United Kingdom, United States, as well as the European Union[1]. Five input variables and a single output variable (in kWh) are considered. The inputs are coal sources (CS), hydroelectric sources (HS), natural gas sources (NGS), oil sources (OS), and renewable energy sources (RS), excluding hydroelectric. The output is the electricity generated (EG). Data were obtained from the World Development Indicators Database of World Bank.

3.2. Methodology

Production is simply the process of transforming inputs into outputs. Generally, the inputs are the resources of a production unit and the outputs are the value added things created, such as products or services. It is important to determine how these resources are being used while generating these outputs. Efficiency is measured to determine the usage of the inputs in a production process.

Data envelopment analysis is one of the most important methods used for efficiency measurement. It is introduced by Charnes et al. (1978) and it enables to measure the efficiency of the decision making units (DMUs) and to rank them according to their efficiency scores. The DEA is a linear programming method and it has the ability of handling multiple inputs and multiple outputs simultaneously without the need of specifying a cost or a production function.

One of the basic models of the DEA, the input oriented Charnes, Cooper and Rhodes (CCR) model which takes into account the constant returns to scale (CRS), is used in this study. Suppose we have a set of n DMUs. Each DMU_j ($j=1,...,n$), produces s different outputs y_{rj} ($r=1,...,s$) using m different inputs x_{ij} ($i=1,...,m$). The input oriented CCR model is as follows Zhu (2001:445):

[1] In order to avoid double counting, the European Union does not contain the data of France, Germany, Italy and the United Kingdom.

$$\begin{aligned} &\min\ \theta_0 \\ &s.t. \\ &\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_0 x_{i0},\ \ i = 1,...,\ m \\ &\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0},\ \ r = 1,...,\ s \\ &\lambda_j \ge 0,\ \ j = 1,...,\ n \end{aligned} \tag{1}$$

where, x_{i0} and y_{r0} are respectively the ith input and rth output for DMU_0 under evaluation.

In Model (1), the efficiency score of DMU_0 is shown as Θ_0. The efficient DMUs take score 1 and the inefficient ones take scores less than 1. Model (1) has some shortcomings in ranking the efficient DMUs since it attains the efficiency score of 1 to all efficient DMUs. Andersen and Petersen (1993) proposed the super-efficiency DEA model to overcome this problem.

The input oriented CCR super-efficiency model is expressed as follows Xu and Ouenniche (2012:580):

$$\begin{aligned} &\min \theta_0 \\ &s.t. \\ &\sum_{\substack{j=1 \\ j\neq j_0}}^{n} \lambda_j x_{ij} \le \theta_0 x_{i0},\ \ i = 1,...,m \\ &\sum_{\substack{j=1 \\ j\neq j_0}}^{n} \lambda_j y_{rj} \ge y_{r0},\ \ r = 1,...,s \\ &\lambda_j \ge 0,\ \ j = 1,...,n \end{aligned} \tag{2}$$

The efficiency score from Model (2) is obtained by eliminating the data on the DMU to be evaluated (e.g. DMU_k) from the solution set Sadjadi et al. (2011:10876). In other words, the main difference between Model (2) and Model (1) is that DMUk is excluded from its own reference set, which make it possible to obtain efficiency scores that exceed 1 Xu and Ouenniche (2012:580).

3.3. Results

Efficiency measurement is made using Model (1) and Model (2), respectively. Table 1 shows the efficiency measurement results. ES is the "*efficiency score*" and SES is the "*super-efficiency score*" and their values are given for each period and country. ES and SES are derived from solving Models (1) and (2), respectively.

As mentioned in the previous section; the only difference between Model (1) and Model (2) is the ranking ability of efficient units of Model (2). It can be seen from Table 1 that among 18 samples in 1990, 16 countries are efficient and only 2 of them are inefficient. The inefficient samples are France and the European Union. The most efficient country in 1990 is China; followed by Brazil, Argentina, United Kingdom, Russia and so on. It is evident that China and Brazil are extreme efficient countries with their SES values.

Table 1 shows that in 1995, similar to 1990, 2 samples are inefficient: France (99.74 %) and the European Union (98.41 %). Despite the presence of inefficiency, France and the European Union are so close to the efficiency frontier. The rest of the countries are efficient and ranked in order of decreasing SES values as follows: Russia, Brazil, China, Argentina, Korea, United Kingdom, India, Australia, Italy, Germany, Canada, Japan, Mexico, Indonesia, Turkey, and the United States.

In 2000, 5 countries are found to be inefficient. The inefficiency of France and the European Union still continues. The other inefficient countries are India, Indonesia, and the United States. 13 countries are efficient and their rankings in order of decreasing SES values are as follows: China, Brazil, Korea, Russia, Australia, United Kingdom, Argentina, Mexico, Canada, Germany, Italy, Japan, and Turkey.

In 2005, France, India and the United States are inefficient. The rest of the countries are efficient. China is the most efficient country with its extreme SES value (1049,24 %) and it is followed by Korea, Brazil, United Kingdom, Argentina, Russia, Australia, Indonesia, Canada, Mexico, Germany, Italy, Turkey, Japan, and the European Union.

Table 1. Efficiency estimates

	1990		*1995*		*2000*		*2005*		*2011*	
Country	**ES**	**SES**	**ES**	**SES**	**ES**	**SES**	**ES**	**SES**	**ES**	**SES**
Argentina	100,00	464,84	100,00	425,04	100,00	241,50	100,00	224,39	100,00	273,73
Australia	100,00	113,14	100,00	158,55	100,00	279,23	100,00	177,02	100,00	112,92
Brazil	100,00	1362,32	100,00	1462,96	100,00	650,88	100,00	510,20	100,00	462,53
Canada	100,00	114,69	100,00	126,18	100,00	145,77	100,00	118,57	100,00	146,70
China	100,00	1460,26	100,00	552,57	100,00	763,87	100,00	1049,24	100,00	682,88
France	99,60	99,60	99,74	99,74	99,74	99,74	99,40	99,40	100,00	111,29
Germany	100,00	175,43	100,00	127,61	100,00	122,36	100,00	118,19	100,00	149,80
India	100,00	213,92	100,00	196,29	99,39	99,39	99,50	99,50	99,17	99,17
Indonesia	100,00	159,72	100,00	107,62	99,91	99,91	100,00	130,19	100,00	119,82
Italy	100,00	115,59	100,00	145,39	100,00	114,47	100,00	113,06	100,00	110,03
Japan	100,00	117,29	100,00	112,02	100,00	104,43	100,00	104,12	100,00	105,65
Korea, R.	100,00	158,11	100,00	265,61	100,00	614,28	100,00	756,36	100,00	499,12
Mexico	100,00	162,52	100,00	108,03	100,00	146,34	100,00	118,35	100,00	131,08
Russia	100,00	230,95	100,00	1665,50	100,00	511,55	100,00	202,11	100,00	1234,91
Turkey	100,00	111,23	100,00	106,85	100,00	101,14	100,00	104,39	100,00	170,20
UK	100,00	398,27	100,00	223,64	100,00	247,00	100,00	237,70	100,00	165,14
USA	100,00	101,80	100,00	103,83	98,85	98,85	99,16	99,16	99,92	99,92
EU	96,98	96,98	98,41	98,41	99,95	99,95	100,00	101,04	99,11	99,11

The last two columns of Table 1 show the ES and SES values of G-20 countries in 2011. Accordingly, India, the United States and the European Union are inefficient. 15 countries are found to be efficient and they are ranked in order of decreasing SES values as follows: Russia, China, Korea, Brazil, Argentina, Turkey, United Kingdom, Germany, Canada, Mexico, Indonesia, Australia, France, Italy, and Japan. Different from other periods, France is efficient in 2011.

4. Conclusion

In this study energy efficiency of G-20 countries were measured in terms of energy use in electricity production by using cross-section data for 1990, 1995, 2000, 2005, and 2011 periods. For this purpose, classical and super-efficiency input oriented CCR models of the DEA were used.

Results show that, among the entire sample; in 1990 and 1995, 16 countries are efficient and 2 of them are inefficient. In 2000, 13 countries are efficient and 5 countries are inefficient. Finally, in 2005 and 2011, 15 countries are efficient and 3 countries are inefficient. In this sense, China is the most efficient country in 1990, 2000, 2005 and Russia in 1995 and 2011. It is also remarkable that Brazil and Korea appear among the top 5 of the efficiency ranking in all five periods. On the other hand, France and the European Union are inefficient in four of five periods. France is inefficient in 1990, 1995, 2000 and 2005, and the European Union is inefficient in 1990, 1995, 2000 and 2011. In addition, India and the United States are the inefficient countries in 2000, 2005, and 2011. Indonesia is found to be inefficient in 2000.

Estimates imply that the G-20 has been experiencing a transformation from monopolar structure to multipolar one in terms of efficient energy production. Since the G-20 either produces or consumes approximately 85% of the world's total electricity, this transformation is also important for the world economy. In this context, China, Brazil and India should be taken into account when designing national and/or international energy policies. Otherwise, it may be inevitable to face with some unexpected results.

This study has some limitations. First, two of the countries are excluded from the data set due to lack of some input data. This exclusion is made in order to make robust analyses and obtain more consistent results. The second limitation is that since nuclear sources are not available for the entire

sample, it is not considered as one of the inputs in electricity production. This study only deals with the technical efficiency of the G-20 countries. This can be considered as the third limitation of the study. There is potential for future researches to focus more on economic dimensions of energy efficiency by measuring the Malmquist index. Another subject for future researches may be to compare G-20 countries with other countries or to deal with the efficiency of other types of energy production. Furthermore, similar studies can be performed by using more comprehensive methods like the fuzzy DEA.

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