A CRITICAL STUDY ON RELATION BETWEEN PUBLIC AND PRIVATE OWNERSHIP USING DEA MODEL IN KOREAN ELECTRICITY GENERATION INDUSTRY

By

Kiwook Kim

THESIS

Submitted to

KDI School of Public Policy and Management

in partial fulfillment of the requirements

for the degree of

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Committee in charge:

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ABSTRACT

A CRITICAL STUDY ON RELATION BETWEEN PUBLIC AND PRIVATE OWNERSHIP USING DEA MODEL IN KOREAN ELECTRICITY GENERATION INDUSTRY

By

Kiwook Kim

This paper investigates efficiency relationship between efficiency and ownership structures in case of power generation companies in Korea. The efficiency level of each of generation companies is analyzed with 5 year empirical data based on energy sources, coal and LNG, using DEA model. The result indicates that private ownership generally has a higher average efficiency level compared to public ownership. However, in specific, there is a polarization of efficiency among public generators. 3 out of 5 publicly owned generation companies demonstrate similar or better efficiency level with private generators. On the other hand, other 2 public owned generators are inefficient in both energy sources. Therefore, to increase the efficiency level of the Korean electricity market, an intensive reformation or privatization of those two inefficient generators is required. In addition, the monopolized LNG market works as an obstacle to reduce fuel cost, introduction of competition in LNG supply market would bring efficiency improvement in the Korea electricity market.

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When I decided to further my education, my surrounding people were a tower of strength. They listened to my concerns and encouraged me in my choice. While I was studying in KDI School, my surrounding people were my comrades to take part in a war to chase the value of wisdom and knowledge. We, together, enlightened my ignorance as well as lightened the library and public houses all the night through. Without them, I cannot imagine how I would pass through this arduous journey. Especially, Prof. Nam, Il-Chong led me to the consilience of my undergraduate background, work experience and knowledge that I leant in KDI School. With my people's contribution, I could leave this thesis as the evidence of my life.

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Introduction

In the past, electric power industry all around the world is generally managed by a vertical monopoly over generation, transmission, distribution and retail. In some regions of U.S., a private enterprise has the ownership of the vertical monopoly. In the greater part of the world, however, the ownership of the vertical monopoly belongs to a government which has either 100% or majority of shares.

Behind the decision to have one single monopoly integrating all four components of electricity industry, there is an underlying acceptance that the electric power industry is one of natural monopoly industries so that the vertical integrated structure would be more efficient.

However, the paradigm for electric power industry shifts to a combination of monopoly in transmission and distribution and competition in generation and retail. Developed countries realize the possibility of disbursement of the four components and to introduce competition in generation and retail is more efficient since the two components do not have a characteristic of natural monopoly as contrasted with transmission and distribution which are known as network stages in the electricity industry. As a result, starting with England in 1990, developed countries prosecute reformation of their electricity industries.

When four components are vertically integrated into one government enterprises, the disbursement is conducted with a certain level of privatization. In the case of England, all four stages in the electricity industry are privatized. On the other hand, Australian government limits private participation. The government turns over some portion of generation parts and maintains government ownership for the other portion. In addition, the government enables private firms to participate in the electricity industry. For the transmission and distribution, a regulated monopoly is introduced.

South Korea is one of the countries which follows the trend and accepts the background economic theories of reformation. In 1999, the government announces the basic plan for structural reform that includes 4 stages to introduce competition gradually. As the first step to process the plan, the generation part of the Korea Electricity Power Cooperation(KEPCO) is split into 6 generation companies in 2001, each of which than is allowed private participation in the generation sector.

In 2004, however, the discussion related to reformation has been halted after the two sequential events. The first one is the failure of privatization of Korea Southeast Power Corporation. In addition, with the fear for price uncertainty and supply instability, Economic and Social Development Commission recommends the government halt the reformation process

Due to the halt of the reformation process, the Korean electricity industry is operating under the unplanned structure which the generation part is the only part to introduce competition. Therefore, the effect of the reformation is directly linked to outcomes from the introduction of competition in the generation part and it becomes a critical issue whether or not the efficiency improves after the reformation.

In Korea’s power generation part, private and government ownership is doing business in coexistence. Private companies strongly pursue financial gain for shareholders so that it tends to achieve higher efficiency. On the contrast, the government as a majority shareholder has lower interest to seek profits and higher interest to achieve public policy objectives so that government ownership has more possibility to have a lower efficiency level.

Government owned firms have an unparalleled power business experience compared to privately owned firms in the business operation point of view. Even though the portion of private participation in generation part keeps increasing, it is still relatively small and limited. The operational efficiency of government firms attributed to accumulated experience is reckoned with. In addition, cost reduction from economies of scale such as fuel cost, especially coal, and maintenance cost is incapable for private firms.

These strengths of government owned generation companies in Korea make it hard to determine private generation companies perform better. In addition, to evaluate relative efficiency among private and government generation companies is useful to prevent reckless management for government companies. Although the government carries out public enterprise performance evaluation every year, only government owned companies are subject of the appraisal. Determining a ranking of efficiency among only government firms reminds possibility that the group itself has low efficiency. In that case, ranking among them is not so useful.

Efficiency level of electricity industries around the world are influenced by tremendous factors. A significant number of researches have been conducted to find out significant factors which affect efficiency. Malcolm Abbott(2005) indicates a few major issues which consistently discussed such as environmental control, economies of scale and ownership structure.

The conclusions of previous studies to establish relation between efficiency and ownership structure provoke controversy. Pollitt(1995) argues that there is no clear evidence of relation. However, Kwoka(1995) and Kim, Dae-Wook and Lee, Yoo-Soo(2010) find relation even though two conclusions are conflicting. Kim, Dae-Wook and Lee, Yoo-Soo(2010) concludes that efficiency of private ownership is higher than public ownership in Korea. A number of studies related to ownership and efficiency is very limited and conclusions show different directions according to the design or range of research. This situation emphasizes the necessity of additional researches for Korean electricity market.

Therefore, this paper will carefully evaluate relative efficiency based on the type of ownership after the reformation when the participation of private firms is allowed. In order for this, DEA(Data Envelopment Analysis) model developed by Charnes, Cooper, and Rhodes(1978) and modified by Banker, Charnes and Cooper(1984) is applied to investigate efficiency based on 5 year empirical data for each subject.

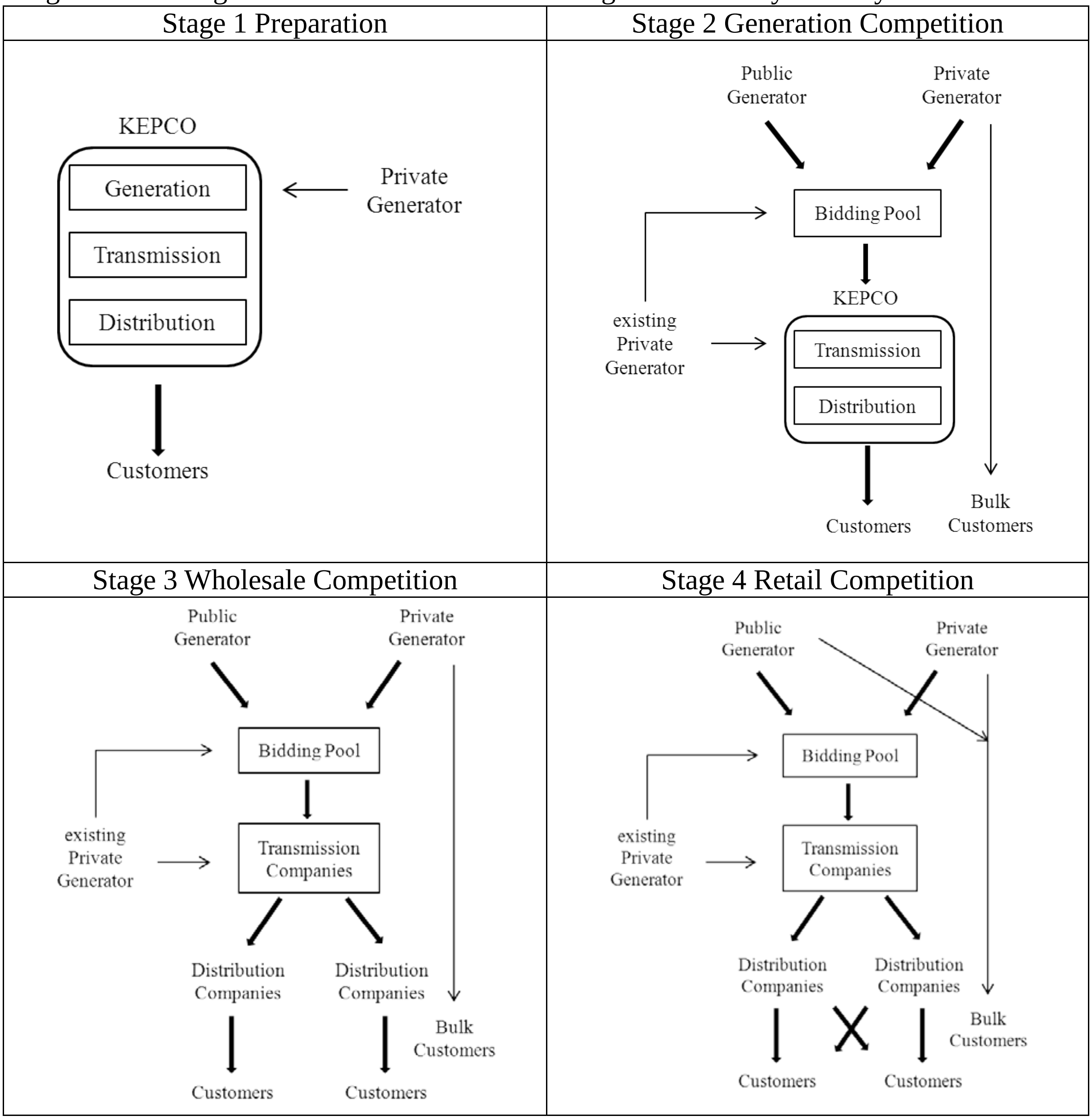
This paper consists of 7 chapters including an introduction. In chapter 2, it provides a basic overview of the Korean electricity market focusing on a role of private generation companies after the reformation. Chapter 3 explains the DEA model as an efficiency measurement tool and reasons to choose the method. In chapter 4, it reviews preceding studies which apply the DEA model to analyze efficiency of Korea electricity market and introduces results of previous studies discussing the relationship between ownership and efficiency. Chapter 5 gives a detailed explanation of subject and input output variable selection. Chapter 6 analyzes the result and explains possible causes of efficiency difference. This paper concludes that private ownership has generally better efficiency proposes several policy implications which may improve efficiency of Korea electricity market in the last chapter.

II. Korean Electricity Market Overview

In the Basic Plan for Restructuring the Electricity Industry, 4 stages are planned in order to introduce competition in each sectors in the electricity market. The plan aims to increase efficiency by the introduction of market mechanism and give more choices of electricity for customers.

In the preparation stage, KEPCO monopolizes the whole electricity market from generation to retail including transmission and distribution. To introduce competition in power generation, generators of KEPCO are split into 6 companies. Distribution and Transmission still belongs to KEPCO. In addition, the two organizations are established. Korea Power Exchange is the one in charge of system operation and management of the market. The other one is Electricity Regulatory Commission. The commission carries out a role to approve electricity business and set a policy on the electricity market structure. For the next step, distribution part of KEPCO is separated into several distribution companies and all transmission lines are open to them in order to introduce competition in the distribution sector. Finally, in the last stage, all distribution lines are open to public so that consumers can choose electricity producers that they are willing to use.

Table 1
Diagrams of 4 Stages in Basic Plan for Restructuring the Electricity Industry



Source : Basic Plan for Restructuring the Electricity Industry, Ministry of Trade, Industry and Energy in Korea, 1999

Through 4 stages, the electricity market is planned to introduce competition step by step. However, the reformation has been ceased in the second stage. In 2003, privatization of the Korea South-east Power Corporation becomes failure due to missing tender with a huge difference between bidding and reservation price. Moreover, economic and social development commission recommends the government stop the reformation process based on possibility of price hikes and unstable supply in 2004. After the two events, the discussion related to privatization has been halted.

After the reformation, the Korean electricity market grows steady both capacity and generation volume as Korea economy develops. Below table 2 shows the annual numbers of capacity and volume and its growth rates. After 2001 when the reformation conducts, the average growth rate of capacity is 5.1%. It tends to be slower as time goes by.

Table 2
Changes in Korean electric power generation capacity(MW) and volume(GWh)

Year	Capacity (Growth rate, %)	Volume (Growth rate, %)
2001	47,959	199,027
2002	51,467 (7.3)	281,871 (41.6)
2003	56,925 (10.6)	299,509 (6.3)
2004	58,943 (3.5)	318,045 (6.2)
2005	61,554 (4.4)	338,861 (6.5)
2006	65,357 (6.2)	354,869 (4.7)
2007	68,443 (4.7)	374,384 (5.5)
2008	71,256 (4.1)	392,323 (4.8)
2009	73,335 (2.9)	405,692 (3.4)
2010	77,361 (5.5)	440,868 (8.7)

2011	78,827 (1.9)	462,343 (4.9)
2012	82,527 (4.7)	471,795 (2.0)

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Power mix changes in Korea show that the portion of nuclear power plants decrease. The capacity of nuclear power plants slowly changes seem to be the outcomes of a long period of construction and safety problems of nuclear. Coal, LNG and oil power plants maintain its portion. Each group hugely expands approximately 10GW while nuclear power plants increase only 4GW.

Fuel mix also indicates a similar tendency with power mix. The generation volume of nuclear power plants decreases while coal, LNG and oil power plants increase its generation. Since private companies do not have any coal power plants, the increment of coal power plants is originated from public investment. Private companies more concentrates on LNG combined cycle power plants which require less capital investment and a short time of construction.

Table 3
Power mix in Korean electricity market (MW)

Year	Nuclear	Coal	LNG & Oil	Hydro & Pumping-up	Etc.	Sum
2001	14,716 (30.7)	15,531 (32.4)	14,628 (30.5)	3,075 (6.4)	10 (0.0)	47,959
2002	15,716 (30.5)	15,931 (30.9)	15,705 (30.5)	3,094 (6.0)	1,021 (2.0)	51,467
2003	16,716 (29.4)	16,813 (29.5)	17,696 (31.1)	3,099 (5.4)	2,602 (4.6)	56,925
2004	17,716 (30.1)	17,620 (29.9)	17,850 (30.2)	3,104 (5.3)	2,655 (4.5)	58,943
2005	17,716 (28.8)	18,717 (30.4)	19,334 (31.4)	3,109 (5.0)	2,679 (4.4)	61,554
2006	17,716 (27.1)	19,719 (30.1)	19,612 (30.0)	5,483 (8.4)	2,828 (4.3)	65,357
2007	17,716 (25.9)	21,603 (31.5)	20,622 (30.1)	5,492 (8.0)	3,010 (4.4)	68,443

2008	17,716 (24.9)	24,023 (33.7)	20,654 (29.0)	5,502 (7.7)	3,361 (4.7)	71,256
2009	17,716 (24.2)	24,924 (34.0)	21,449 (29.3)	5,515 (7.5)	3,733 (5.1)	73,335
2010	18,716 (24.2)	25,050 (32.4)	23,847 (30.8)	5,521 (7.1)	4,227 (5.5)	77,361
2011	18,716 (23.7)	25,379 (32.2)	23,760 (30.2)	6,412 (8.2)	4,560 (5.8)	78,827
2012	20,716 (25.1)	25,437 (30.9)	25,158 (30.5)	6,438 (7.3)	4,778 (5.8)	82527

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Table 4
Fuel mix in Korean electricity market (GWh)

Year	Nuclear	Coal	LNG & Oil	Hydro & Pumping-up	Etc.	Sum
2001	80,528 (40.5)	83,309 (41.9)	32,625 (16.4)	2,559 (1.3)	6 (0.0)	199,027
2002	114,684 (40.7)	114,578 (40.7)	48,722 (17.2)	3,838 (1.3)	47 (0.0)	281,871
2003	124,412 (41.5)	116,754 (39.0)	53,319 (17.8)	4,416 (1.5)	608 (0.2)	299,509
2004	125,142 (39.3)	122,891 (38.6)	65,332 (20.5)	3,909 (1.2)	771 (0.2)	318,045
2005	140,367 (41.4)	129,231 (38.1)	64,985 (19.1)	3,632 (1.0)	645 (0.2)	338,861
2006	142,114 (40.0)	134,480 (37.9)	72,556 (20.5)	4,847 (1.4)	872 (0.2)	354,869
2007	136,599 (36.5)	149,113 (39.9)	82,222 (21.9)	4,989 (1.4)	1,460 (0.4)	374,384
2008	144,254 (36.8)	166,728 (42.5)	74,120 (18.9)	5,487 (1.4)	1,732 (0.4)	392,323
2009	141,123 (34.8)	186,137 (45.9)	70,424 (17.4)	5,577 (1.4)	2,430 (0.6)	405,692
2010	141,894 (32.2)	191,008 (43.3)	97,014 (22.0)	6,400 (1.4)	4,551 (1.0)	440,868
2011	147,763 (32.0)	193,555 (41.9)	105,573 (22.9)	7,698 (1.7)	7,753 (1.7)	462,343
2012	143548 (30.4)	192,623 (40.8)	119,701 (25.4)	7,488 (1.6)	8,435 (1.8)	471,795

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Table 5

Korean electric power generation capacity (MW)

Year	Public Ownership		Private Ownership		Total	
	Capacity	Proportion	Capacity	Proportion	Capacity	Proportion
2001	47,629	99.3	331	0.7	47,959	100%
2002	49,869	96.9	1,598	3.1	51,467	100%
2003	52,829	92.8	4,095	7.2	56,925	100%
2004	54,719	92.8	4,224	7.2	58,943	100%
2005	56,293	91.5	5,260	8.5	61,554	100%
2006	59,102	90.4	6,256	9.6	65,357	100%
2007	60,975	89.1	7,468	10.9	68,443	100%
2008	63,357	88.9	7,899	11.1	71,256	100%
2009	64,489	87.9	8,846	12.1	73,335	100%
2010	66,361	85.8	11,000	14.2	77,361	100%
2011	66,801	84.7	12,026	15.3	78,827	100%
2012	69,187	83.8	13,340	16.2	82,527	100%

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Table 6

Korean electric power generation volume (GWh)

Year	Public Ownership		Private Ownership		Total	
	volume	Proportion	volume	Proportion	volume	Proportion
2001	198,841	99.9	186	0.1	199,027	100%
2002	280,789	99.6	1,081	0.4	281,871	100%
2003	294,195	98.2	5,314	1.8	299,509	100%
2004	313,365	98.5	4,680	1.5	318,045	100%
2005	334,621	98.7	4,240	1.3	338,861	100%
2006	346,756	97.7	8,113	2.3	354,869	100%
2007	363,731	97.2	10,653	2.8	374,384	100%
2008	377,606	96.2	14,717	3.8	392,323	100%
2009	388,590	95.8	17,102	4.2	405,692	100%
2010	416,395	94.4	24,473	5.6	440,868	100%
2011	423,945	91.7	38,398	8.3	462,343	100%
2012	428,781	90.9	43,014	9.1	471,795	100%

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Since the introduction of private generators in the generation market, they have expanded their participation. The growth rate of private participation is notably high. Compared to 2001, the capacity of private companies increases by 40 times in 2012. Even though the portion is relatively small compared to public generators which have 84% of the total generation capacity in the end of 2012, the role of private sectors dramatically becomes important and is expected to be more.

Table 7
A data set on public and private power mix in 2011(MW)

	Hydro	Coal	Oil	LNG	Nuclear	Etc.
Public	6,293	24,534	4,175	13,973	18,716	135
Private	-	-	647	7720	-	3,149

Sources : 1. Electricity Market Trends and Analysis 2013 Annual Report, Korea Power Exchange 2. Electric Power Statistic 2005-2012, Korea Power Exchange 3. Electric Power Statistic System

Table 7 shows the power mix of public and private generators at the end of 2011. As the table clearly shows, the power mix of private generators is very limited compared to public owned generation companies. However, some of private firms have started constructing coal fired power plants nowadays and even submitted a letter of intent for nuclear power plants construction for the 6th Basic Plan of Long-term Electricity Supply and Demand. In addition, there is additional credit for private generators to invite more investment from private sectors in a process of evaluation of letter of intent for power plants. Therefore, it is expected that the portion of private generators is going to be expanded and the power mix is also going to be diverse even though the participation of private companies is very limited for now.

III. Methodology

A. Techniques for measuring efficiency

Efficiency as a term in economics indicates how a firm or an organization well uses its resources to produce intended goods and services. In other words, efficiency demonstrate how well production structure is optimized either to operate limited resources to produce maximized intended outputs or to minimize resources to produce a certain level or volume of outputs. Efficiency can be applied to evaluate an organization or a policy to decide a degree of success or failure. In addition, the result of the evaluation can provide policy or strategy directions.

Techniques of measuring efficiency have been developed such as regression, ratio and frontier analysis. Two traditional approaches, regression and ratio analysis, have disadvantages when they deal with multiple variables. Frontier analysis is suggested as an alternative option to control a variety of variables. Data Envelopment Analysis model is one of frontier analysis and suitable to analyze multiple subjects with variety of inputs and outputs.

(1) Regression analysis

Regression analysis calculates an average efficiency by using a regression equation. The equation is derived from the selected dependent and independent variables that a conductor chooses. The result of the calculation applies the average efficiency as an efficiency criterion to separate between efficient and inefficient subjects. Subjects which have efficiency above the average efficiency are classified as the efficient group, and vice versa.

The difference between the calculated input and the actual input volume or the difference between the calculated output and the actual output volume for each subject demonstrates a level of efficiency. In case of input, if the difference has a negative number, the subject is efficient. In contrast, if the difference between the calculated output and the actual output volume has a positive number, the subject is efficient.

Regression analysis can statically investigate correlation or independence among variables. On the other hand, the analysis has difficulties to consider multiple inputs and outputs. Because the calculations in the analysis are conducted based on one single regression equation, either input or output should be a single variable. (Sykes, Alan, 1993)

(2) Ratio analysis

To select variables which can affect the efficiency and calculate the input-output ratio of them are the concept of ratio analysis. The ratio of the estimated monetary value of inputs and outputs is calculated for each alternative and compared. By doing so, this analysis selects the best one among alternatives. Because of the simple calculation, ratio analysis is known as the simplest efficiency measurement method.

However, a limitation appears when the ratio analysis deals with multiple inputs and outputs. If the method is applied to multiple variables, the analysis treats the multiple variables as one single combined monetary value. Each variable has different characteristic so that in the process of conversion into one single value may not be accurate. In addition, it has a high possibility to ignore some of particular variables.

These limitations make it difficult to apply the analysis on industry with complicated production stages. Therefore, it is insufficient to apply this analysis to evaluate the efficiency of the electricity generation companies which have complex inputs and outputs. (Laurent, Clinton R, 1979)

(3) Frontier analysis

Frontier analysis consists of DEA and SFA(Stochastic Frontier Analysis). DEA is non-parametric method which estimation of production or cost function is not required(Charnes & Cooper, 1978). In contrast, SFA assumes a particular equation to estimate parameters(Aigner et al., 1977).

In 1957, Farrell suggests that the measure of relative efficiency which is defined with weighted sum of inputs and outputs. DEA model is developed by Charnes, Cooper, and Rhodes to measure the relative efficiency among the Decision Making Unit(DMU) which is a group of subjects which have a similar input-output structure.

DEA model has several strengths and weaknesses. As a tool for relative efficiency evaluation, it cannot provide any absolute efficiency level of each subject. It may provide some indicators to be improved for low efficiency level subjects. However, it does not give any ideas to 100% efficiency companies for further improvement. In addition, other combinations of input and output selection may derive a totally different result of analysis. Even with these shortcomings, DEA model is widely applied for evaluation of many industries. It has strengths that it is suitable to deal with an organization with a large number inputs and outputs. Inputs and outputs are not required to have one single unit. This aspect, no requirement of unit conversion, makes more convenient to apply this model. In addition, it is an effective alternative to parametric methods which requires an accurate production function because the estimation of the actual production function often is difficult.

Based on these strengths, this paper determines DEA model to apply to efficiency evaluation of generation companies in Korea based on consideration of characteristic of the electricity generation industry. The output of the generation industry may have only one variable, however, the industry has multiple and different kind of inputs. Moreover, it is hard to calculate an accurate estimation of production cost. As a result, regression and ratio analysis are not suitable. In case of DEA model, it can take multiple variables with dissimilar units into account and provide notions for causes of inefficiency. (Cullinane, et al., 2006)

B. Theoretical background of DEA model

Farrell defines relative efficiency as below equation which consists of weighted inputs and outputs(Farrell, 1958).

$$\text{Relative efficiency of i} = \frac{v_1 y_{1i} + v_2 y_{2i} + v_3 y_{3i} \cdots\cdots + v_l y_{li}}{u_1 x_{1i} + u_2 x_{2i} + u_3 x_{3i} \cdots\cdots + u_m x_{mi}} \qquad [1]$$

In [1], m number of inputs and l number of outputs of i are represented by x_m and y_l. Each of x_m and y_l has a different weight, u_m and v_l. These weigh factors are multiplied to the same input and output for every i. However, the determination of fair weights for each input and output is difficult. The absolute value of weights is hard to calculate and to adjust a small value of weights can affect the relative efficiency of a group.

To find out the fair weight value, Charnes, Cooper, and Rhodes suggest a DEA model. In the model, each subject chooses the weight value to maximize its own efficiency.

$$\text{Max } e_j = \frac{\sum_{r=1}^{l} v_r y_{rj}}{\sum_{i=1}^{m} u_i x_{ij}} \quad [2]$$

Subject to

$$\frac{\sum_{r=1}^{l} v_r y_{rj}}{\sum_{i=1}^{m} u_i x_{ij}} \leq 1 \quad j = 1,2,3, \ldots\ldots, n \text{ (every j)}$$

$$v_r \geq \varepsilon > 0 \ , \ u_i \geq \varepsilon > 0$$

ε should have a value bigger than 0 in order to prevent removing any input and output by multiplying 0. e_j indicates relative efficiency. It has a value between 0 from 1. If e_j is equal to 1, it means that subject j is efficient compared to other subjects in the group. In the case of that e_j is less than 1, the subject j is less efficient than other subjects. Even though the subject j selects and applies the weight value u_m and v_l which maximize the efficiency of the subject j, the maximized efficiency of the subject j is less than other subjects' efficiency calculated with the same weight values.

[2] has the crux of the calculation when a number of the subject is big. To make the calculation simpler, there are two ways, either making the sum of the weighed input 1(input oriented) or the sum of the weighed output 1(output oriented). The approach of input oriented type is to minimize inputs and output oriented type is to maximize outputs. In the current Korean power generation sector, the outputs cannot be decided by owners so that input oriented type is applied in this paper.

As a result, [2] is transformed a linear programming problem.

$$\text{Max } e_j = \sum_{r=1}^{l} v_r y_{rj} \qquad [3]$$

Subject to

$$\sum_{i=1}^{m} u_i x_{ij} = 1$$

$$\sum_{r=1}^{l} v_r y_{rj} - \sum_{i=1}^{m} u_i x_{ij} \leq 0$$

$$v_r \geq \varepsilon > 0 \ , \ u_i \geq \varepsilon > 0$$

In CCR model, it assumes the constant returns to scale so that it cannot separate between scale efficiency and pure technical efficiency. To overcome this limitation, Banker, Charnes and Cooper apply variable returns to scale to evaluate each efficiency level of the subjects. It has been well aware of the existence of economies of scale in electricity production. Therefore, the BCC model reflects the attribution of the electricity generation market better than the CCR model does.

In the BCC model, a scale factor v_{e_j} is introduced. [3] is transferred into another linear programming problem.

$$\text{Max } e_j = \sum_{r=1}^{l} v_r y_{rj} - v_{e_j} \qquad [4]$$

Subject to

$$\sum_{r=1}^{l} v_r y_{rj} - \sum_{i=1}^{m} u_i x_{ij} \geq 0 , \forall_j$$

$$v_r \geq \varepsilon > 0 \ , \ u_i \geq \varepsilon > 0$$

v_{e_j} has no typical sign

$v_{e_j} = 1$: Constant return to scale

$v_{e_j} < 1$: Decreasing Return to scale

$v_{e_j} > 1$: Increasing return to scale

IV. Literature Review

A. Application Examples of DEA model in Korea

DEA model as an efficiency evaluation tool for Korean electricity market has frequently been applied. Kim, Taewoong, Jo, Sunghan(2000) point out the limitations of ratio analysis such as rate of return on equity, profit margin ratio, etc. They argue that ratio analysis only considers one single input and output so that it cannot reflect an actual firm's efficiency. As an alternative, the paper suggests a DEA model as a method to evaluate the efficiency of the industry with multiple variables. The model evaluates efficiency of 51 generation firms all over the world in 1996 and derives that the technological efficiency of KEPCO is 98.78% and scale efficiency is 78.89%. Based on the result of analysis, it concludes that inefficient is partially originated from scale inefficiency and 15% of reduction in a number of the employee is required.

Seung-Chul Ko et al.(2007) evaluates the efficiency of each government generation owned companies after the disbursement of KEPCO using the DEA model. In this paper, total sales and generation volume are selected as output variables. For the inputs, it chooses two variables, generation capacity and a number of employees. One important point is that it applies two sets of input selection. Total generation capacity is one and another one is generation capacity of each energy sources. It classifies generation capacity according to fuel sources such as hydro, coal, oil and gas, and nuclear. The paper concludes that there is no significant efficiency difference among the generation companies. By considering fueled generation capacity, the result indicates potential efficiency improvements for each subject when they increase capacity of different fueled power plants.

Kim, Jong Gu(2008) also applies the DEA model to evaluate Korea’s electricity market reformation policy. The paper indicates that the efficiency of the market is generally higher in 2002 and 2003 on the morrow of the reformation and the efficiency keeps decreasing after 2004 when the reformation is halted. The paper concludes that the effect of the reformation policy is very limited and lower than expected. It indicates the incomplete reformation policy as the main cause.

These preceding studies on efficiency of Korean electricity market demonstrate appropriacy of the DEA model as a measurement method to the analyze efficiency of the market.

B. Analogous Studies

Kim, Dae-Wook and Lee, Yoo-Soo(2010) investigate efficiency difference in fuel consumption according to the ownership based on 2001 - 2008 annual data and recent 3 year monthly data for generators. This study estimates regression equation considering the monotone increasing relationship between fuel consumption and generation volume. For other inputs such as capital and labor, it applies a different equation in order to reflect the characteristic that electricity volume generated does not increase unless fuel consumption increases. The result of the analysis indicates that private generators use fuel more efficiently than public generators, 6.3~10% in annual data and 14% in the monthly data.

Pollitt(1995) takes 95 generation companies from 9 different countries in 1986 into account to compare the relative efficiency by using DEA, SFA, and Corrected Ordinary Least

Squares models. This study selects labor, capital, and fuel consumption as inputs and one single output, generation volume. The relationship between ownership and efficiency is not significant in the result.

Kwoka(1995) investigates efficiency of 396 publicly owned and 147 private owned firms in the U.S. by using a quadratic cost function. Various data including fuel cost, wage, ownership differences in 1989 are considered. The study finds a strong evidence of the ownership and efficiency relationship that public ownership performs more efficiently. In detail, the cost and the price of public ownership is 2.3%, 1.9% lower than private ownership.

Preceding studies dealing with the effect of ownership structure on efficiency approach with a various methods. The decision of superiority between public and private ownership in terms of efficiency depends upon the design of research. In other words, selections of subjects, variables and analysis method bring totally different conclusions.

The structure of the Korean electricity market differs from the other nation's market structure. The existence of difference may bring a different ownership and efficiency result. To discover the relationship offers a political direction related to a degree of privatization or reformation of government owned generators. In spite of the importance as a political criterion, researches related to that issue have rarely been conducted.

Kim, Dae-Wook and Lee, Yoo-Soo (2010) brings an attention on the relationship, however, the study has several limitations. It considers the amount of fuel consumption but not the price of fuel. The amount of fuel used to generate electricity depends on the amount of power generation and efficiency of power plants. If the amount of power generated by two power plants is identical, only technological efficiency makes a difference in fuel consumption no matter how high or low price the power plants supplies fuels in the study.

This study has three different aspects compared to the previous studies. First of all, it is the methodology, DEA model. DEA model is frequently used to measure efficiency improvement due to the reformation in the Korean electricity market. Even though the model is widely applied in various objects including the purpose to reveal the ownership and efficiency relationship in with other countries, it seems that an application case of a DEA model to evaluate the relative efficiency in generation companies according to the ownership does not exist in Korea. Second, previous studies related to the efficiency of the electricity market in Korea mainly focus on evaluation of the reformation policy whereas this study attempts to find an evidence of ownership and efficiency relationship and investigate causes of difference. Last but not the least, this paper measures the relative efficiency of each subject in each ownership group and review main causes of the difference among subjects.

V. Design of Research

A. Selection of Subjects

In order to investigate the relationship between ownership and efficiency using the DEA model, 5 companies from public ownership and 3 companies from private ownership are selected. Based on 5 year annual statistical data from 2008 to 2012 of the subjects, annual relative efficiency is calculated.

In this paper, all subjects are separated into two categories according to the fuel source, liquefied natural gas and coal. It is due to absence of coal fired power plant in private ownership. Comparing with private ownership which has only LNG power plants and public ownership which has a mixture of LNG and coal power plants would bring an incomplete analysis.

From above-mentioned reason, Korea Hydro & Nuclear Power(KHNP), one of public ownership, is excluded. KHNP operates all nuclear and hydro power plants in Korea, it does not have any LNG or coal power plants. In addition, coal fired combined heat and power plants(CHP) also are not included in the subject. The main purpose of the CHPs in Korea is to provide thermal energy, for example, steam for industrial parks. The cogeneration generators in Korea do not fully participate in the electricity market and electricity is a by-product for the CHPs.

Companies with insignificant capacity from private ownership are excluded as well. It might be meaningful to include every single private generation company. However, it also might affect the analysis in an unintended way. To analysis the difference efficiency between private and public ownership, the evenly weighted mean of the subject is required. Meaning that one subject which has a significant high or low efficiency level of the companies influences the result noticeably. Companies with limited capacity have more possibility to distort the result while others can mitigate the potential error.

The analysis result of the LNG fuel source group, it mainly focuses on private and public ownership comparison. Since there is no private ownership subject in coal, the result indicates efficiency differences among public ownership.

Table 8
List of subjects

Fuel source	Public	Private
LNG	Korea Southern Power(KOSPO)	POSCO Energy
	Korea Midland Power(KOMIPO)	GS EPS
	Korea Western Power(KOWEPO)	SK E&S
	Korea East-West Power(EWP)	
Coal	Korea Southern Power(KOSPO)	N/A
	Korea Midland Power(KOMIPO)	
	Korea Western Power(KOWEPO)	
	Korea South-East Power(KOSEP)	
	Korea East-West Power(EWP)	

B. Selection of Input and Output Variables

To derive a credible and reliable result of analysis from the DEA model, to select appropriate inputs and outputs is critical. Previous studies using the DEA model to analyze power generation companies shows similar but different input and output selections.

Table 9
Input and output set of previous studies

Author(year)	Market	Input	Output
Kim, Teawoong	Korea	Total number of employee Generation capacity	Sales Net benefit Power generation
Kim, Jong Gu	Korea	Total number of employee Investment cost	Sales EBIDTA
Seung-Chul Ko et al.	Korea	Total number of employee Generation capacity	Sales Power generation
Toshiyuki Sueyoshi	Japan	Total number of employee Generation capacity Total amount of fuel consumption	Total power generation
This paper	Korea	Annual average salary Generation capacity Fuel cost	Total power generation

In order for proper calculation related to the number of employees, it is required to know the total number of employees for power generation most part only. However, the subjects are expanding their business boundary. Not only do they power business but also other energy business such as urban gas, district heating etc. This aspect makes more difficult to gather data and identify the total number of employees who work in the power generation industry. Therefore, average annual salary data for employees is collected instead of total number of employees to reduce possibility of error.

Generation capacity is another important input. An efficient company chooses its generation capacity to maximize its capacity utilization factor. A low utilization factor means that it has a great portion of idle resources and it is directly brings down the efficiency of the firm.

For the output, some previous studies choose monetary outcomes of subjects. The reason for exclusion of any monetary outcomes such as sales, net benefit, etc., is that there is one special feature which should be considered, a system marginal price correction factor. The correction factor is applied only for public owned generators to reduce a gap between an electricity production cost and a price that KEPCO purchases from public ownership. In other words, even though each one of public generators and private generators has an identical power plant meaning that the cost of production is the same, the price that KEPCO applies for the same electricity is totally different. Because of the correction factor which distorts the monetary gains of public ownership, to use the monetary values is inappropriate. Therefore, the amount of total generation for each fossil fuel sources is considered as the output variable.

VI. Results and Analysis

A. Efficiency comparison between private and public ownership

The result of the analysis is shown below, table 10. Among 4 public owned generation companies, KOSPO and KOMIPO approximately have 100% efficiency level while SK E&S is the only one to show 100% level among private ownership. Annual average efficiencies indicate that private ownership generally has a higher efficiency than public ownership except 2011. In 2011, POSCO Energy constructs two 626MW combined power plants. The two power plants that do not operate during the full year bring the low efficiency. In this respect, the result can be concluded that there is a relationship between ownership and efficiency and private generation companies have a higher efficiency.

The cause of inefficiency for public ownership is mainly due to low generation volume. The capacity that the public owns is relatively huge compared to private. In contrast, technical efficiency of the plants is generally higher for private generators because the public owned power plants almost reaches its end of economic life. Under the current market mechanism, low technical efficient power plants are rarely operated. As a result, the public mostly owns idle power plants in Korea and brings low electricity generation compared to its capacity.

One important note is that public ownership does not always mean low efficiency. Even though the average efficiency of public ownership is lower than the average efficiency of private, at least two companies from public ownership demonstrate its competitiveness compared to private. It demonstrates that the possibility to increase efficiency even under public ownership and low efficient 2 public owned generators, KOMIPO and EWP, are required to take actions.

Table 10
DEA efficiency measure for LNG(%)

	2012	2011	2010	2009	2008
KOSPO	100	100	100	100	100
KOMIPO	81.6	96.2	97.8	81.6	79.8
KOWEPO	100	100	100	95.8	100
EWP	92.4	89.5	81.0	100	88.1
Average	93.5	96.4	94.7	94.35	92.0
POSCO Energy	100	77.2	100	100	91.7
SK E&S	100	100	100	100	100
GS EPS	100	94.8	94.8	94.8	100
Average	100	90.7	98.3	98.3	97.2

Table 11
Conclusions of foreign Studies

Author (year)	Market	Relation	Superiority
Pollitt (1995)	9 Countries	X	N/A
Kwoka (1995)	U.S.	O	Public
Kim, Dae-Wook and Lee, Yoo-Soo (2010)	Korea	O	Private
This paper (2013)	Korea	O	Private

Conclusions of foreign preceding studies related to the ownership and efficiency are inconsistency. Pollitt(1995) argues that there is no significant relation between ownership and efficiency when considering 95 generation companies from 9 different countries in 1986. On the other hands, Kwoka(1995) concludes that efficiency of public ownership is higher than private ownership.

One possible explanation for the discordance among the previous studies is a different market situation. Each government in the world, they use own price regulation scheme to control its electricity industry. According to the regulation scheme, the result of the analysis may differ when the analysis considers monetary inputs such as sales or profit. For example, Korean government applies a double standard to generation companies. The profits of the public owned companies are controlled by allowed rate of return on investment capital using a system marginal price correction factor. On the other hand, the private generators make a profit based on a system marginal price without any correction factor. In case of U.S., the government does not apply any price discrimination scheme. Each and every Regulatory authority has developed its own regulation scheme along with its philosophy. It leads to the inconsistent efficiency analysis result. (Lee, Seong-Uh, 2006)

One Korea's case study done by Kim, Dae-Wook and Lee, Yoo-Soo (2010), however, indicates the same conclusion with this paper. Even though the design of research such as methodology and selection of input and output is different, two studies are compromised that private ownership has a superior efficiency compared to public ownership in Korea.

B. Efficiency difference in private and public ownership

There is polarization among public ownership. KOSPO and KOWEPO have a high efficiency level. However, the efficiency level of KOMIPO and EWP shows significantly low and they are inefficient for 5 years. In coal power generation sector, it derives the consistent result that KOMIPO and EWP are inefficient compared to other public companies. Especially the efficiency level of the EWP is significantly low.

Table 12
DEA efficiency measure for public ownership in LNG (%)

	2012	2011	2010	2009	2008
KOSPO	100	100	100	100	100
KOMIPO	81.6	96.2	97.8	81.6	79.8
KOWEPO	100	100	100	95.8	100
EWP	92.4	89.5	81.0	100	88.1
Average	93.5	96.4	94.7	94.35	92.0

Table 13
DEA efficiency measure for public ownership in coal (%)

	2012	2011	2010	2009	2008
KOSPO	100	100	100	100	100
KOMIPO	100	100	100	100	90.1
KOWEPO	100	100	100	100	100
KOSEP	100	100	100	100	100
EWP	85.3	93.9	93.0	100	93.0
Average	95.6	97.1	97.3	95.6	93.3

The more detailed result of KOMIPO and EWP are shown in the below table 14 and 15. In the analysis of LNG generation part, both KOMIPO and EWP are required to reduce all three inputs. Because the LNG market is monopolized, to find a way to enhance efficiency in terms of capacity and salary is more appropriate. For coal, KOMIPO has no room to increase its efficiency by reducing capacity. However, it has higher salaries than other public companies. For G5, it required to reduce all three inputs largely.

Table 14
DEA efficiency improvement target in LNG (%)

	2012	2011	2010	2009	2008
KOMIPO					
Capacity	-18.38	-3.78	-2.17	-35.62	-20.15
Fuel cost	-18.38	-38.07	-19.47	-25.18	-20.15
Salary	-18.38	-11.32	-4.02	-18.43	-21.28
EWP					
Capacity	-23.51	-34.50	-41.72	-	-33.75
Fuel cost	-7.62	-32.75	-31.06	-	-13.91
Salary	-7.62	-10.54	-19.05	-	-11.87

Table 15
DEA efficiency improvement target in Coal (%)

	2012	2011	2010	2009	2008
KOMIPO					
Capacity	-	-	-	-	-9.88
Fuel cost	-2.41	-7.05	-12.69	-	-12.21
Salary	-24.08	-3.23	-0.5	-	-14.01
EWP					
Capacity	-21.06	-17.89	-18.35	-	-14.85
Fuel cost	-14.70	-6.09	-7.03	-	-6.96
Salary	-21.98	-6.09	-7.03	-	-6.96

Table 16
DEA efficiency measure for private ownership in LNG (%)

	2012	2011	2010	2009	2008
POSCO Energy	100	77.2	100	100	91.7
SK E&S	100	100	100	100	100
GS EPS	100	94.8	94.8	94.8	100
Average	100	90.7	98.3	98.3	97.2

The cause of low efficiency in 2011 comes from POSCO Energy. At that time, the capacity hugely increases due to the construction of two 626MW combined cycle power plants. The construction ends in the middle of 2011 so that the capacity increment is considered at the end of the year but generation volumes are small because the power plants do not operate one full year.

Among private ownership, SK E&S has a matchless efficiency level. It is the only company that imports LNG directly while other firms are supplied by KOGAS, so that its fuel cost is significantly lower than the other ones.

VII. Conclusion

The analysis using DEA model concludes that private generation companies generally have better efficiency than public generation companies in Korea. This conclusion, however, does not mean efficiency of private ownership always better than public ownership. At least two public companies operate its resource as efficient as the private companies do. It indicates that even efficiency of public companies have potential to be improved.

Two low efficient public companies are required to allocate its resource more efficiently. The result suggests that all three inputs should be minimized to achieve a higher efficiency level. In addition, the fact that the two companies maintain the lowest rank during 5 years represents the magnitude of inefficiency.

Among private companies, one significant company stands out. SK E&S has one special difference from other ones, fuel supply chain. In Korea, KOGAS has the exclusive competence of sales of liquefied natural gases to power generators. The government does not allow other companies to participate in the gas business. As a result, the choice of the generating companies is very limited and they should import directly from abroad if they want another source of supply. For generation companies, it is hard to import gas in a cheaper price due to a small volume of their consumption. However, the SK E&S succeeds and achieves a high efficiency. This case can be an evidence of the possibility to reduce fuel cost for other generation companies.

The conclusion from the analysis proposes a direction to make Korea's electricity market more efficient. First, the government should take an action for two inefficient public generation companies. The government conducts the public enterprise performance evaluation to improve the efficiency of the low efficient generators. However, according to 5 year data analysis, the improvement is insignificant and nonproductive. Under this situation, privatization may be a good alternative option since private ownership has superior efficiency. Second, to promote private investment is important to improve efficiency of the market. The government gives incentives to evaluate a new power plant proposal to invite more private investment. The participation is still insignificant. The more business friendly policy implication is required. Third, the government should consider the introduction of competition in LNG market. Like SK E&S's case, fuel cost is one significant factor to influence efficiency. Bringing competition in LNG market would lower the cost of LNG. It directly reduces the cost of electricity production and improves efficiency of the electricity market. Finally, including evaluation of private generation companies in the public enterprise performance evaluation as a reference is required. The public enterprise performance evaluation has several categories that private firms cannot open to the public. Nevertheless, it is worth doing since evaluations of private firms still have possibility to propose sources of efficient improvement for public ownership.

APPENDICES

APPENDIX A

DEA analysis Result

	2012		2011		2010		2009		2008	
	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC
KOSPO	100	100	100	100	100	100	100	100	100	100
KOMIPO	73.5	81.6	96.2	96.2	97.1	97.8	76.5	81.6	74.9	79.8
KOWEPO	100	100	100	100	99.5	100	82.2	95.8	88.4	100
EWP	81.1	92.4	77.8	89.5	64.1	81.0	93.0	100	83.7	88.1
Average	88.7	93.5	93.5	96.4	90.2	94.7	87.9	94.4	86.8	92.0
POSCO Energy	87.5	100	64.7	77.2	43.4	100	52.0	100	54.9	91.7
SK E&S	100	100	100	100	100	100	100	100	100	100
GS EPS	92.6	100	85.0	94.8	81.5	94.8	74.6	94.8	78.6	100
Average	93.4	100.0	83.2	90.7	75.0	98.3	75.5	98.3	77.8	97.2

	2012		2011		2010		2009		2008	
	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC
KOSPO	100	100	100	100	100	100	99.7	100	95.1	100
KOMIPO	93.5	100	98.8	100	99.6	100	95.1	100	84.6	90.1
KOWEPO	100	100	100	100	97.0	100	100	100	100	100
KOSEP	100	100	100	100	100	100	100	100	100	100
EWP	84.7	85.3	86.9	93.9	89.7	93.0	83.4	100	86.7	93.0

Data Set

Annual average salary (million won)

	2012	2011	2010	2009	2008
KOSPO	63	60	60	70	62
KOMIPO	76	62	60.3	69.2	70.4
KOWEPO	57.7	60.3	58.8	56.7	55
KOSEP	74	63	63	57	58.4
EWP	58.6	52	45	68	51
POSCO Energy	60	46	51	51.9	55.6
SK E&S	70	51	48	47	45
GS EPS	68.7	58.2	62.4	63.4	55.2

Note : For SK E&S's annual average salary 2010~ 2008 are estimated based on average wage growth rate from Employment and Labor Statistics of Korea

Generation capacity (LNG, MW)

	2012	2011	2010	2009	2008
KOSPO	4553	4553	4553	3705	3705
KOMIPO	2812.45	2362.4	2812.5	2812.5	2303.5
KOWEPO	2998	2998	2998	2280	2280
KOSEP	1800	1800	1800	1800	1800
EWP	3052	3052	1800	1800	1800
POSCO Energy	1049	1049	1049	1049	1049
SK E&S	1106	1106	1106	1106	1106
GS EPS	68.7	58.2	62.4	63.4	55.2

Generation capacity (Coal, MW)

	2012	2011	2010	2009	2008
KOSPO	4000	4000	4000	4000	3500
KOMIPO	4000	4000	4000	4000	4000
KOWEPO	4000	4000	4000	4000	4000
KOSEP	5200	5200	5200	5200	5200
EWP	6580	6580	6580	6580	6580

Fuel cost (LNG)

	2012	2011	2010	2009	2008
KOSPO	3,967,034	2,972,220	2,496,825	1,952,219	2,951,219
KOMIPO	2,506,615	2,608,272	1,951,400	1,118,300	1,564,400
KOWEPO	2,838,391	2,341,360	1,747,032	854,395	1,534,187
EWP	667,378	721,658	521,626	248,976	421,864
POSCO Energy	2,023,455	1,506,314	786,173	253,989	556,840
SK E&S	341,184	389,527	359,635	388297	208,743
GS EPS	1,381,478	1,036,431	918,702	638,385	1,046,166

Note : POSCO Energy’s 2012, 2011, 2010 and GS EPS’s all Fuel cost are estimated.

Fuel cost (Coal) million won

	2012	2011	2010	2009	2008
KOSPO	1,547,060	1,608,886	1,219,523	1,276,752	934,544
KOMIPO	1,525,590	1,730,875	1,396,800	1,204,200	1,120,200
KOWEPO	1,488,839	1,661,059	1,360,295	1,739,576	1,168,030
KOSEP	1,803,122	1,828,984	1,402,120	1,444,806	1,353,612
EWP	2,703,335	2,648,808	2,100,189	1,977,568	1,719,340

Total power generation (LNG)

	2012	2011	2010	2009	2008
KOSPO	27,015,444	24,736,608	23,947,182	19,729,358	22,946,790
KOMIPO	13,522,000	13,997,000	15,167,000	9,662,000	9,760,000
KOWEPO	19,736,948	18,472,189	16,372,372	8,077,708	11,336,186
EWP	6,953,184	7,118,606	5,793,755	3,350,006	4,519,958
POSCO Energy	13,612,000	9,882,000	4,390,000	1,909,000	3,409,000
SK E&S	6,427,000	6,440,000	6,842,000	5,615,000	3,621,000
GS EPS	6,739,388	5,790,024	5,878,956	4,416,130	5,384,190

Total power generation (Coal)

	2012	2011	2010	2009	2008
KOSPO	33,611,699	33,550,373	33,660,544	32,378,276	25,807,803
KOMIPO	31,141,000	33,309,000	33,536,000	30,805,000	26,628,000
KOWEPO	32,737,005	33,725,149	32,600,597	33,083,010	32,834,062
KOSEP	53,398,076	53,439,166	52,853,639	53,277,136	44,463,000
EWP	33,575,742	32,983,568	34,258,070	32,456,756	32,401,172

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