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The Effectiveness of New Power Generation and Energy Demand Reduction to Achieve Greenhouse Gas Reduction Goals in Building Area

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Abstract Since the massive power outages that hit across the nation in September 2011, a growing imbalance between energy supply and demand has led to a severe backup power shortage. To overcome the energy crisis which is annually repeated, a policy change for deriving energy supply from renewable energy sources and a demand reduction strategy has become essential. Buildings account for 18% of total energy consumption and have great potential for energy efficiency improvements; it is an area considered to be a highly effective target for reducing energy demand by improving buildings' energy efficiency. In this regard, retrofitting buildings to promoting environmental conservation and energy reduction through the reuse of existing buildings can be very effective and essential for reducing maintenance costs and increasing economic output through energy savings.

In this study, we compared the energy reduction efficiency of national power energy consumption by unit production volume based on thermal power generation, renewable energy power generation, and initial and operating costs for a building retrofit.

The unit production was found to be 13,181GWh/trillion won for bituminous coal-fired power generation, and 5,395GWh/trillion won for LNG power generation, implying that LNG power generation seemed to be disadvantageous in terms of unit production compared to bituminous coal-fired power generation, which was attributable to a difference in unit production price. The unit production from green retrofitting increased to 38,121GWh/trillion won due to the reduced energy consumption and benefits of greenhouse gas reduction costs. Renewable energy producing no greenhouse gas emissions during power generation and showed the highest unit production of 75,638GWh/trillion won, about 5.74 times more effective than bituminous coal-fired power generation.

Keywords: Energy Reduction Efficiency, Renewable Energy, Power Generations, Building Retrofit

1. INTRODUCTION

As the government has recently committed to adopting a long-term strategy of reducing greenhouse gas emissions 37% by 2030 from current greenhouse gas emission projections (BAU, 851 million tons), highly intensified measures to reduce greenhouse gas emissions are needed in the transportation, industrial and building sector (Ministry of Environment, 2015). The building sector, accounting for 18% of total energy consumption, is recognized as having a high potential for energy savings (Korea Energy Agency, 2015).

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A number of studies are actively ongoing to improve the energy performance of buildings associated with the heating and cooling loads of passive houses and zero-energy buildings, however most of the component technologies can only be applied to newly built buildings which correspond to about 2% of total domestic 6.8 million buildings (Korea Institute of Construction Technology, 2013). Accordingly, related research and the retrofitting of existing buildings that can be expected to effectively reduce greenhouse gases in the building sector are gradually attracting attention. In this regard, aligned with the activation of the energy performance improvements of existing buildings, the Ministry of Land, Infrastructure, and Transport set out to provide support and management plans for green retrofit target buildings through the partial revision of the Act, and newly established 'green building compositions Act' and 'green area planning division' to promote phased green building activation plans.

Meanwhile, South Korea specifies new and renewable energy in "new and renewable energy, development, use and diffusion promotion Act" as 9 items of renewable energy (solar radiation, solar heat, bio, wind power, hydro power, ocean, wastes, geothermal, hydrothermal) and 3 items of new energy (fuel cells, coal liquefaction / gasification, hydrogen energy). Renewable energy is generally defined as infinite energy that comes from resources which are naturally replenished. Whereas it is clean energy with virtually no emissions of greenhouse gases, and high value-added energy with high potential from technology advances, the development and diffusion of related renewable technologies have progressed slowly so far due to its low economic efficiency.

In September 2011, sudden massive power outages hit across the country except Jeju Island; including Gangnam in Seoul, Gyeonggi province, Gangwon province, and Chungcheong province. In consideration of further blackout crisis and economic growth; a discussion about further power supply was held, establishing a construction plan for additional 29,570MW power plant capacity by 2027 in the 6th power supply and demand basic plan (Ministry of Trade, Industry and Energy, 2013). The plan is focused on adding generational capacity by 4,560MW from renewable energy and by 15,300MW from thermal power, corresponding to about 15% and 52% of the planned capacity respectively. But the plan seems to be somewhat contradictory to the present situation which aims to reduce greenhouse gas emissions by 37% from the BAU levels mentioned above, since the greenhouse gas reduction process can be a more reasonable approach by virtue of the fact that reducing energy use in buildings leads to a reduction in power generation.

In this regard, advanced research (Song et al., 2014) reviewed the cost-effectiveness of energy based on cost and the amount of power generation needed for thermal power generation, the associated costs and energy gained savings through building energy retrofit. The study concluded that the effectiveness of a building retrofit increased by about 37% to reach 1.37 times of the effectiveness of thermal power generation.

This study, as a follow up to the above study, further examined the amount of power generation and associated costs of renewable energy excluded from the existing comparison items. The study intended to compare power generation by renewable energy to thermal power generation using fossil fuels, and energy savings by building energy retrofits at the same level to quantitatively derive an optimal plan for achieving the national greenhouse gas reduction target.

In the study, we also reasonably recalculated construction costs for a thermal power plant using the materials that were not available at the time of writing the relevant paper and fully updated the costs associated with thermal power generation in consideration of labor costs and expenses to promote objectivity utilizing the literature of energy consumption of existing buildings applied with conservative values.

2. REVIEW OF GREEN RETROFITTING

2.1 Green Retrofit Policy Projects

"Energy retrofit of existing buildings" mentioned above is hereinafter referred to as green retrofit. Green retrofit is a policy project organized by the Ministry of Land, Infrastructure, and Transport that supports energy waste prevention and creating a pleasant environment for existing buildings, divided into public buildings pilot projects and private sector support projects.

The public buildings pilot project intends to primarily support green retrofitting of existing public buildings to activate the composition of green buildings, improving public awareness for green buildings so it can be applied in the private sector (Ministry of Land, Infrastructure and Transport, 2014). This mainly includes project-phased customized technical support, construction cost support, design and planning support aimed at improving the energy performance from the initial stage.

The private sector support project (Ministry of Land, Infrastructure and Transport, 2013) is based on the Article 25 of the green building compositions Act on a support for green building promotion project, and the Article 26 on financial support and activation. It is to provide financial support for building owners to participate in the performance improvement of buildings without the burden of initial expenses. The project is focused on building insulation improvement, energy management devices, renewable energy construction, energy performance enhancement related construction work and the related ancillary works in a way that a building owner takes out a loan for necessary expenses and repays the installment loan with reduced energy costs after construction. At this time, the government supports for the interest paid on construction costs for performance improvement to reduce the initial financial burden on building owners,

2.2 Green Retrofit Costs and Effectiveness

Son et al. (2015) examined case studies on the costs and benefits of green retrofits. The retrofit cost for a business facility with the total floor area of 40,000m^2 appeared to be 2.2 billion won, corresponding to 55 thousand won/m^2, resulting in 129,000MWh annual energy savings and about a 20% cost reduction. In another green retrofit related report (K Assets Trust Company, 2013), the benefit of spending 0.44 billion Won on a green retrofit by replacing the boiler and refrigerator of an office building with a total floor area of 33,000m^2 is found to be 13 thousand won/m^2, reducing the existing energy use cost of 0.47 billion won by 31.9%.

In this study, the energy saving rate by a green retrofit was assumed to be 25 % drawn from using the median value in the above cases, and the cost was assumed to be 300 thousand won/m^2, equivalent to one quarter of new construction costs by a conservative calculation. In addition, the construction of green retrofit was limited to the areas that affect the energy use of buildings, including envelope insulation, windows and doors performance improvement, the replacement of and efficiency improvements of heat source equipment, replacement of lighting equipment, and BEMS.

Energy consumption by the energy source is specified in the first green building basic plan (Ministry of Land, Infrastructure and Transport, 2014) according to the building application; the per unit area energy consumption of a business facility is found to be 27.156kgOE/m^2, which can be converted to 126.8kWh/m^2 using an energy calorie conversion factor (The Ministry of Trade, Industry and Energy, 2013). Accordingly, applying a 25% energy savings rate the green retrofit can produce an annual reduction of 31.7kWh/m^2, and energy savings of 10.57MWh per 100 million won, when applying a cost of 300 thousand won/m^2. Since the implementation of a green retrofit is generally determined by business feasibility analysis undertaken by the building owners, in this study, it is assumed to support 20% of the cost in effort to induce the activation of green retrofit by supporting a portion of the cost. Therefore, using the support rate we can derive 52.83MWh/100 million won, which means that it is possible to expect energy consumption reduction of 52.83MWh from a building if a green retrofit support of 100 million won is committed.

3. POWER GENERATION AND COSTS BY SECTOR

3.1 Thermal Power Generation: Construction and Operating Costs

Thermal power generation has been operating in South Korea typically by bituminous coals, LNG and nuclear power; however nuclear power is excluded from this study due to not only the difficulty of selecting a new site, but also there is a social disagreement on the exact calculation of waste disposal costs and compensation costs in the event of a disaster.

While 2004 based inflation rate data was employed in previous studies for calculating the construction costs of thermal power plants, while in this study 2014 data (Korea Power Exchange, 2014) was directly utilized to ensure the validity of the research content. In the study, the construction of a bituminous coal-fired power plant is estimated to cost approximately 1,500 thousand won/kW, and that of a LNG power plant to cost approximately 2,800 thousand won/kW.

The unit cost of power generation appears to be 53.91 won/kWh for bituminous coals and 166.7 won/kWh for LNG. The unit cost of power generation includes operating costs, labor costs, and overhead costs, such as maintenance and depreciation costs.

To get a grasp the operating rates of power plants by energy source, we identified the facility capacity and power generation of plants. As of 2014 (Ministry of Trade, Industry and Energy, 2015), the facility scale of a bituminous coal-fired power plant amounts to 26,274MW and that of a LNG power plant to 26,742MW. The power generation capacities of a bituminous coal-fired power plant and LNG power plant correspond to 203,765GWh and 111,705GWh, respectively. The respective operating rates are 88.5% and 47.7%, which are calculated by dividing the annual power generation by the maximum power generation. Table 1 summarizes the contents mentioned above.

Table 1. Thermal Power Generation(2014)

Type	Bituminous Coal	LNG
Construction unit cost (thousand won/kW)	1,500	930
power generation unit cost (won/kWh)	53.91	166.7
Annual power generation (GWh)	203,765	111,705
Power generation capacity (MW)	26,274	26,742
Power plant operating rate (%)	88.5	47.7

The calculation results show that in case of building a 1,000MW power plant, a bituminous coal plant is estimated to cost 1.5 trillion won and a LNG plant 0.93 trillion won. By substituting the operating rates by energy source, shown in Table 2, into the values above one obtains a respective power generation capacity and cost for a bituminous coal-fired power plant of 7,756GWh and 420.3 billion won, and 4,205GWh and 700.9 billion won for a LNG power plant.

Table 2. Construction and Operating Costs of Thermal Power Generation(1,000MW)

Type	Bituminous coal	LNG
Construction cost (trillion won)	1.5	0.93
Annual power generation (GWh)	7,756	4,205
Annual power generation cost (100 million won)	4,203	7,010

3.2 Renewable Energy Power Generation and Costs

The amount of power generated by renewable energy in South Korea has increased by an annual average of 9.6% over the last five years to reach 8,851 thousand TOE, which corresponds to approximately 3.18% of primary energy consumption as of 2012 (Korea Energy Agency, 2014). Among the 34 OECD countries, South Korea ranks low in the ranking relative to other countries including Iceland (89.8%), Germany (11.9%) and USA (6.3%). As a result, the government is making an effort to respond to domestic power demand by announcing various policies for the aggressive diffusion of renewable energy; such as subsidies, incentives, financial support, and regulations.

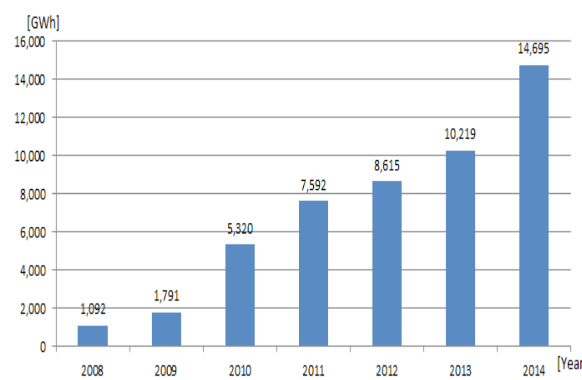

Figure 1. Renewable Energy Generation of The Last Seven Years

Figure 1. shows the power generation trends of the last seven years by renewable energy (Korean Statistical Information Service, 2014). The amount of power generated in 2014 is estimated to be 14,695GWh, an increase of 1,246% compared with 2008. This is attributable to a year-on-year increase in power generation capacity by renewable energy, resulting from the government's various support systems which are mentioned above. For an accurate evaluation of renewable energy generation, it is necessary to grasp the amount of support set by the government, except for net capital investment.

The support systems and amounts set by the government for renewable energy diffusion are as follows:

First, the support amount from the "housing support project" which supports a portion of the cost of installing renewable energy facilities in houses for the widespread use of renewable energy in housing, between 2008 and 2013 spending on solar power generation reached 418.4 billion won.

Second, in the "building support project" the government supports a portion of the cost of installing renewable energy facilities in general buildings such as offices and shopping malls, a total of 232.81 billion won was supported from 1993 to 2013 for generation from major energy sources including photovoltaic, solar thermal, geothermal and fuel cells.

A total of 721.63 billion won was formulated from 1996 to 2013 in the 'community support project' to support the projects being promoted by municipalities. The support was used to enhance the energy supply and demand situation, and promote regional economic development through the diffusion of renewable energy while taking into account regional characteristics.

Next is the 'convergence support project', which supports a portion of the installation costs arising from the convergence and partial combination of energy sources. The project has been in place since 2014 and its financial support for that year amounted to 10 billion won.

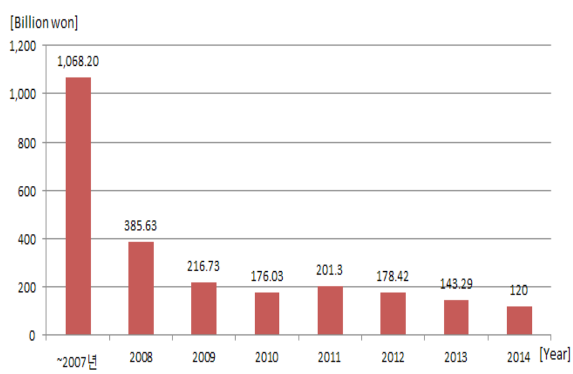

Figure 2. Costs of Support for Renewable Energy-related Projects

Lastly the 'finance support project', which supports long-term low-interest loans for utilization and production facilities of renewable energy, in order to reduce initial investment costs and cultivate related businesses. The project has cost 740.68 billion won from the start of the project to 2007, and a total of 790.77 billion won from 2008 to 2014. Figure 2 shows the amount of support for renewable energy-related projects graphically, it indicates that the total amount of support from 1990 to 2013 (early 2014) was 2 trillion and 914.29 billion won.

4. REVIEW OF OPTIMAL GREENHOUSE GAS REDUCTION MEASURES

4.1 Costs of Reducing Greenhouse Gas Emissions

After the Kyoto protocol entered into force, carbon markets have been designed and operated in many parts of EU, North America and Asia. South Korea also opened a carbon market on January 12, 2015. Since thermal power generation using fossil fuels generates greenhouse gases, the cost of reducing greenhouse gas emissions must be taken into account to estimate the exact cost.

However, the emissions trading market trades KAU (Korean Allowance Unit) and KCU (Korean Credit Unit). KAU is the government's greenhouse gas emission allowances granted to companies, and KCU allows its reductions to be certified and converted to emission credits in case of reducing greenhouse gas emissions in discharge facilities outside the organizational boundaries, in a manner consistent with international standards.

Table 3(KRX, 2015) shows the emissions trading market status in Korea, taken from January 12, 2015 to October. The average traded price of an Allowance Unit (KAU) amounts to 9,550 won/tCO2, and that of an Offset Credit (KCU) to 10,100 won/tCO2. The total traded volumes of Allowance Unit and Offset Credits are 13,800tCO2 and 779,658tCO2, respectively.

The difference in total traded volume between the Allowance Units and Offset Credits is attributable to the fact that with Offset Credits companies with less gas emissions can trade excess gas emission permits with companies with more gas emissions, unlike Allowance Units which have mandatory allocation.

Table 3. Emissions Trading Market Status in Korea

Type	KAU15 (Allowance Unit)	KCU15 (Offset Credit)
Average traded price (won/tCO2)	9,550	10,100
Total traded volume (tCO2)	13,800	779,658
Total traded amount (million won)	124.2	8,019.8
Average amount of allowance unit and offset credit (won/tCO2)	9,775	

Table 4. Greenhouse Gas Emissions Cost of Thermal Power Generation

Type		Bituminous Coal	LNG
Emission reduction costs (won/kWh)	25,000 won/tCO2	23.28	9.99
	9,775 won/tCO2	9.10	3.92
Annual power capacity (GWh)		7,796	4,205
Annual reduction costs of greenhouse gas emissions (100 million won)		709	165

In this study, the average value of 9,775 won for Allowance Units and Offset Credits was used for the greenhouse gas reduction cost to estimate the costs of greenhouse gas reduction by green retrofit, thermal power generation and renewable energy.

In the study by Lee et al. (2012), the greenhouse gas reduction cost was estimated to be 23.28 won/kWh for bituminous coal-fired generation and 9.99 won/kWh for LNG generation at a carbon credit price of 25,000won/tCO2. All cost estimates have been adjusted to the 2015 costs and listed in Table 4 where annual power capacity was obtained by the 1,000MW thermal power generation, using the values calculated in Table 2. The reduction cost of greenhouse gas emissions per kWh by bituminous coals and LNG appeared to be 9.1won and 3.92 won, respectively, estimating the annual reduction cost of greenhouse gas emissions to be 70.9 billion won for bituminous coal-fired generation and 16.5 billion won for LNG generation.

Also, renewable energy power generation was assumed to produce no greenhouse gases, and greenhouse gas reduction costs were considered to be a negative value since a reduction in the energy consumption of a building by green retrofit caused a reduction in the overall power consumption. Here, the power used in buildings was generated from nuclear power and petroleum, in addition to bituminous coals and LNG, considering that carbon dioxide was not emitted by nuclear power. Table 5 summarizes the proportions of power generation by energy source and greenhouse gas reduction costs for the year 2014. As a result of calculating the weighted average of the proportions and scales of power generation by energy source, excluding nuclear power, the greenhouse gas reduction cost from a reduction in energy consumption by a green retrofit was estimated to be -6.45 won/kWh.

Table 5. The Proportions of Power Generation by Energy Source and Greenhouse Gas Reduction Costs for the year 2014

Type	Nuclear Power	Bituminous Coal	LNG	Petroleum
Scale of power generation by energy source (GWh)	146,779	134,892	57,962	16,385
Proportion of power generation by energy source (%)	30	39.1	21.4	1.5
Greenhouse gas emission reduction cost (won/kWh)	-	9.10	3.92	7.89

4.2 Costs by Energy Source

Table 6 summarizes annual energy production, reduction amounts, costs, and greenhouse gas reduction costs for bituminous coal and LNG-fired thermal power generation, green retrofit, and renewable energy, based on the contents above. The support amount for a green retrofit was the average construction cost of building a bituminous coal and LNG power plants, and an average production cost of 93.5 won/kWh was used for calculating the annual energy production costs, being the average value of general-purpose power rates in the middle of the winter and summer periods.

Table 6. Annual Costs and amount of Energy by Energy Source

Type	Bituminous Coal	LNG	Retrofit	Renewable Energy
Construction costs and support amounts (trillion won)	1.5	0.93	1.215	2.91
Annual energy production or reduction amounts (GWh)	7,796	4,205	641.9	14,695
Annual energy production costs (100 million won)	4,203	7,010	-600.2	-
Annual greenhouse gas reduction costs (100 million won)	709.4	164.8	-41.4	-

4.3 Effectiveness Comparison using Unit Production Indices

Considering the lifespan of renewable energy facilities and the timing of a building retrofit, in addition to the annual costs and power capacity calculated in the previous section, The estimates for 15-year costs and amounts of energy are given in Table 7.

Since the above costs and amounts of energy by source were calculated with different references, an index of 'unit production' for comparison was calculated with the formula defined in Equation(1).

$$\text{Unit Production} = \frac{Energy\ Production\ or\ Total\ Reduction\ Amount\ [GWh]}{Total\ Investment\ Cost\ [Trillion\ won]}$$

Equation(1)

That is, unit production is an increase or decrease in the amount of energy obtained for the same cost, and represents power generation from thermal and renewable energy, and the amount of energy savings from a green retrofit. In Table 8, all estimates are represented in unit production for easy comparison of each source, and unit production ratios are calculated by substituting 1 for bituminous coal-fired power generation considering the cost of reducing greenhouse gas emissions.

When greenhouse gas reduction costs are excluded or included, the unit production was found to be 14,984GWh/trillion won or 13,181GWh/trillion won for bituminous coal-fired power generation, and 5,511GWh/trillion won or 5,395GWh/trillion won for LNG power generation, implying the exclusion of the greenhouse gases reduction costs appeared to be highly effective. When the costs of reducing greenhouse gases were included, the unit production decreased by 14% for bituminous coals and 1% for LNG, the energy source differences were attributable to more power generation by bituminous coals than by LNG, and the high greenhouse gas reduction cost.

In case of a green retrofit with a higher unit production than thermal power generation, the unit production was found to be 30,597GWh/trillion won or 38,121GWh/trillion won respectively when excluding or including greenhouse gas reduction costs, showing that including the greenhouse gas reduction costs appeared to be highly effective. Additionally, the unit production of renewable energy was 75,638GWh/trillion won, making it the most effective among the compared items and greenhouse gas reduction costs had no effect on the result.

5. CONCLUSIONS

In this study, we used unit production indices to examine the cost-effectiveness of thermal power generation by bituminous coals and LNG, renewable energy power generation, and green retrofit as a way to achieve the greenhouse gas reduction targets in South Korea. When greenhouse gas reduction costs are taken into account, the following results were obtained:

The unit production was found to be 13,181 GWh/trillion won for bituminous coal-fired power generation, and 5,395GWh/trillion won for LNG power generation, implying that LNG power generation seemed to be disadvantageous in terms of unit production compared to bituminous coal-fired power generation,

Table 7. Estimates for Initial Costs, 15-year Costs and Amounts of Energy

Type	Bituminous Coal	LNG	Retrofit	Renewable Energy
15-year energy production and reduction amounts (GWh)	116,940	63,075	9,629	220,425
15-year energy production and reduction costs (trillion won)	6.30	10.51	-0.90	-
15-year greenhouse gas reduction costs (trillion won)	1.06	0.25	-0.06	-
Total cost without greenhouse gas reduction costs (trillion won)	7.80	11.44	0.31	2.91
Total cost with greenhouse gas reduction costs (trillion won)	8.87	11.69	0.25	2.91

Table 8. Unit Production Costs in Accordance with Greenhouse Gas Reduction

Type		Bituminous Coal	LNG	Retrofit	Renewable Energy
Unit Production (GWh/trillion won)	CO2 cost excluded	14,984	5,511	30,597	75,638
	CO2 cost included	13,181	5,395	38,121	75,638
Unit Production Ratio	CO2 cost excluded	1.14	0.42	2.32	5.74
	CO2 cost included	1	0.41	2.89	5.74

which was attributable to a difference in unit production price.

The unit production from green retrofitting increased to 38,121GWh/trillion won due to the reduced energy consumption and benefits of greenhouse gas reduction costs.

Renewable energy producing no greenhouse gas emissions during power generation and showed the highest unit production of 75,638GWh/trillion won, about 5.74 times more effective than bituminous coal-fired power generation.

By reconsidering the scale of support to maximize energy savings by green retrofitting, therefore increasing the efficiency of renewable energy power generation, its cost-effectiveness is projected to increase further, contributing to greenhouse gas reduction and helping to obtain national emission targets.

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