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A Study on Recalculating Nuclear Energy Generation Cost Considering Several External Costs

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Abstract: Nuclear energy issues such as safety and social acceptance can not only influence the production costs of generating nuclear power, but also the external costs that are not reflected in market prices. Consequently, the social issues affiliated with nuclear power, beyond a severe accident, require some form of financial expense. The external social issues considered here are accident risk and realization, regulatory costs, and nuclear energy policy costs. Through several calculations and analyses of these external costs for nuclear power generation, it is concluded that these costs range from 7 to 27 ₩/kWh. Considering external costs are required for making energy plans, it could have an influence on generation costs.

Key Words : Nuclear energy costs, Nuclear energy, External costs, Nuclear power plant

1. Introduction

For sustainable economic development, stable and efficient energy supplies are required. Many countries including South Korea are using nuclear power under the assumption that nuclear power is safe. Nuclear power is widely used since it is economical compared to renewable forms of energy as well as coal power, which has a high dependence on imported fuel.[1)] Nuclear power has a low percentage of fuel costs in the generation costs. But after the Fukushima nuclear disaster, which halted the nuclear renaissance, each country has sought to enhance the safety of its nuclear power plants (NPPs) and has reviewed nuclear energy policies for its own energy environment. Additionally, the Fukushima disaster resulted in a hostile social acceptance environment in South Korea.

Nuclear energy production issues such as safety and policy can not only influence the direct costs of generating nuclear power, but also the external costs that are not reflected in market prices which distributors and consumers are involved in. Consequently, the social issues affiliated with nuclear power, beyond a severe accident, require some form of financial expense. Thus, it is necessary to review a variety of costs incurred throughout the NPP life cycle.

This study attempts to estimate the external costs associated with nuclear power generation by analytically reviewing cost items that are not considered during power generation. These analyses are based on costs which are related to new NPPs, in particular the APR1400.

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2. Nuclear Generation Costs

The South Korean government establishes an Energy Master Plan every five years and a Basic Plan for Electricity Supply and Demand every two years. Because economics is an important factor when choosing power generation, the government estimates the cost of generating electricity by assuming construction costs, lifetime, capacity factor, and discount rate. This value is named generation cost for planning, and is calculated by dividing all expenditures into the plant lifetime. Note that all energy sources have their own cost types and methods of calculations.[2)]

The generation cost that is calculated based on the cost incurred in the process of operating plants is called annual generation cost. Since Korea Hydro and Nuclear Power Corporation (KHNP) is the only operator of NPPs in South Korea, annual generation costs are calculated from annual expenditures from the KHNP balance sheet and the energy actually sold. As an example, Table 1 presents annual generation cost for three years. The electricity sold from KHNP includes nuclear, hydro power, and pumped storage (using electricity during off-peak times, water is pumped into a reservoir and stored for generating electricity later on).[3)]

In 2013, total sales of electricity from nuclear sources were 132,465 GWh, which was about 96% of total power generation. According to recent data in South Korea, nuclea rpower generation cost is estimated inherange of 42 to 49 ₩/kWh based on the APR1400 (Shin-Kori 3 and 4) with a discount rate of 6%.[3)]

According to the IEA/NEA report, the cost of generating electricity in South Korea is estimated to be about 31 US$/MWh at a discount rate of 5%. This is the lowest in countries which operate more than 10 NPPs. Generally, construction costs account for more than 50 percent of generation costs, and is a main factor for the low generation cost.

Table 1 Example annual generation costs.[3)]

Year	2011	2012	2013
Sales cost (million ₩)	5,425,127	6,180,514	6,007,111
Selling and administrative expenses (million ₩)	107,320	119,345	130,312
Corporation tax expenses (million ₩)	165,010	35,103	52,850
Other cost (million ₩)	252,264	257,394	502,111
Total cost (million ₩)	5,949,721	6,592,356	6,692,384
Generation (GWh)	151,836	145,526	138,021
Nuclear generation (GWh)	147,167	140,557	132,465
Generation cost (₩/kWh)	39.2	45.3	48.5

It is reasonable to choose a power source of the least expense by calculating all the costs to produce the same amount of electricity. Since nuclear energy generation costs may differ depending on how to define the cost items, this study considers the cost items and generation costs that are released by international organization or research centers in several countries to present expenses as objectively as possible.

The International Energy Agency (IEA) and the Organization for Economic Co-operation and Development's (OECD) Nuclear Energy Agency (NEA) releases estimations of generating costs by power source for member countries.[4)] This report compares the various types of power generating plants within each of the countries represented and also provides a basis for comparing generating costs between different countries for similar types of power plant. The calculations are based on the simple levelized average lifetime cost approach, using the discounted cash flow method. According to this report, the levelized cost of electricity for nuclear power is in the range of 29 to 78 US$/MWh (34 to 90 ₩/kWh) considering country-by-country

differences at a discount rate of 5%. The cost items consist of construction costs, operation and maintenance (O&M) costs, fuel costs, and decommissioning costs.

3. External Nuclear Generation Costs

In economics, an externality is the cost that affects a party who did not choose to incur that cost. In other words, external costs are the costs that are not included in the market price. Typically, pricing of electricity from various energy sources may not include all external costs since it is hard to quantify. In the case of nuclear power, external costs are normally assumed to be zero. Interestingly, costs for managing a serious accident are usually taken up by insurance, however if the costs exceed the insurable amount, the government generally intervenes. In this study, external costs are classified into three sections; accident risk costs, safety regulation costs, and policy costs.

Accident risk costs are defined here as the costs for evading risk or addressing accidents. It is associated with damage compensation, decontamination of contaminated area, and decommissioning of a damaged or expiring plant. In order to estimate the accident risk cost for NPPs in South Korea, case studies on accidents are needed.

According to official announcements, the frequency of a severe accident is extremely low at one in 100,000 years, however, in the case of a severe accident, the extent of the damage would be immense.[5,6,7,8] South Korea has large populations surrounding areas near NPPs, so accident costs are expected to be higher than other countries. The accident risk costs typically translate to expected costs associated with damage compensation, decontamination of contaminated areas, and decommissioning of damaged plants. The method used for analysis here is estimation of NPP accident risk cost based on accident frequency.

Table 2 shows damage costs for major nuclear accidents

Event	TMI	Chernobyl	Fukushima
Occurrence year	1979	1986	2011
Damaged plants	1 unit	1 unit	4 units
Lifetime of NPP	4 months	8 years	30~40 years
Damage restoration costs	US $1 billion	US $235 billion	Minimum 5.8 trillion yen
Based on exchange rate 2013	1.1 trillion ₩	257 trillion ₩	Minimum 50.5 trillion ₩

For the method based on accident frequency, premise of damage costs, accident frequency, and annual generation amount at a model plant are needed. The relationship is taken as Accident Damage costs = Damage costs × Accident Frequency / Annual nuclear power plant generation.

Table 2 Extent of damage for three nuclear accidents.[9,10,11)]

Average exchange rate in 2018. (US $1 ~ 1100 ₩, ¥ 100 = 1100 ₩)

The accident frequency summarized as below is based on IAEA safety standards, U.S. Nuclear Regulatory Commission, and Japanese Atomic Energy Commission.

1) 1×10^{-5}/reactor year: Frequency is early large release frequency of existing reactors depicted in the IAEA safety standard.[5,6)]

2) 3.5×10^{-4}/reactor year: Frequency is calculated based on the operation years of commercial reactors in the world and five accidents at TMI-2, Chernobyl-4 and Fukushima Daiichi NPPs by regarding the incidents in units 1 to 3 as three separate events.[7)]

Table 3 Accident damage costs by frequency

		Accident Damage Costs (₩/kWh)			
Standard	Frequ-ency	TMI	Cherno-byl	Fuku-shima	Aver-age
IAEA	0.00001	0.0010	0.23440	0.0461	0.0938
World Nuclear	0.00035	0.0351	8.20411	1.6121	3.2838
Japan	0.0020	0.2007	46.8806	9.2120	18.7644

3) 2×10^{-3}/reactor year: Frequency is calculated based on the operation years of commercial reactors in Japanand by regarding the incident sinunits 1 to 3 at the Fukushima Daiichi NPS as three separate events.[7)]

Annual electricity production of a model plant is based on APR1400 (Capacity 1400 MW), and calculated by applying the average capacity factor of 89.4 from 2004~2013. This leads to an annual electricity production of 10.964 TWh. The accident risk costs based on the premise outlined above are shown in Table 3.

Safety regulation costs signify the expected costs in accordance with additional safeguards reinforcement and growth in management expenses by new safety standards and regulations. As a result of the Fukushima disaster, long and short term improvements were derived from the safety review.

South Korea spend ₩7.5 trillion for reinforcing safety equipment up to 2018. Most countries are also planning for upgrading safety equipment. U.S. NPP operators are spending $3.6 billion on modifications to their 102 nuclear plants and France is planning to invest €10 billion by 2018. The cost for upgrading safety facilities is supposed to be ₩7.5 trillion for 6 years. From a careful analysis of the available data, the regulation costs are estimated to be 4.96 ₩/kWh by applying annual generation as stated previously.

In the case of applying stronger regulations than current levels, safety regulation costs could increase. However, accident risk costs could be offset by safety regulation costs, since the risks reduce by increasing required safety measures. Therefore, the relationship between safety regulation costs and accident occurrence probability requires further examination

Policy costs are expenses to the government to maintain nuclear energy, including the costs to support the areas adjacent to NPPs, public relation costs to improve social acceptance, and operation costs for nuclear energy-related organizations as well. These expenses have been supported from general accounts, nuclear research and development (R&D) funds, electric power industrial infrastructure fund, and radioactive waste funds. Nuclear R&D funds and radioactive waste funds are included in private costs, since NPP owners cover all of the expenses for them. Thus, such expenses for supporting nuclear energy are the sum of public expenditures from general accounts and electric power industrial infrastructure fund. As an example, Table 4 shows the amount of financial support for nuclear energy in South Korea.

Table 4 Example of status of financial aid related to nuclear energy.[12)]

Classification	2010	2011	2012	2013	2014
General accounts (million ₩)	71,124	106,953	153,511	197,227	221,422
Electric power industrial infrastructure funds (million ₩)	139,492	173,503	162,733	189,187	152,107
Special accounts of energy and resources business (million ₩)	96,964	115,744	124,561	130,528	135,723
Total (million ₩)	307,580	396,200	440,805	516,942	509,252

General accounts have been supporting fundamental R&D projects and international cooperation activities for nuclear energy and operation expenses for nuclear public institutions such as the Korea Institute of Nuclear Safety and the Korea Institute of Nuclear Safety

Nonproliferation and Control. Electric power industrial infrastructure funds are used for technical development of commercial nuclear plants, assistance program of neighboring area, public relations, and nuclear exportation industrialization, and manpower training programs. Special accounts of energy and resources business have been spending for operation expenses for the Korea Atomic Energy Research Institute. Table 5 presents the estimated policy costs of nuclear power in this study.

Policy costs are not only for nuclear energy in that the other power sources have been supported similar costs. However, it is included in external costs since policy costs are vital in providing nuclear power.

External costs are estimated in the range of 7 to 27 ₩/kWh. It means nuclear generation cost could increase when considering external costs. However, other power sources have their own external costs as well. Therefore, external costs are required to consider when estimating generation cost for all generation sources.

Table 5 Policy costs of nuclear energy

Classification	2010	2011	2012	2013
Policy costs (million ₩)	307,580	396,200	440,805	516,942
Nuclear generation (GWh)	148,596	154,723	150,327	138,796
Unit cost (₩/kWh)	2.07	2.56	2.93	3.72

4. Summary of Costs Analysis

External costs, which are paid by the government or the public instead of nuclear power operators, were classified into three parts: accident risk costs, safety regulation costs, and policy costs.

Accident risk costs are the potential costs associated with damage compensation for nuclear accidents. Nuclear accidents can cause extensive damages to local residents and people. However, accident risk costs are poorly considered because the maximum coverage of nuclear power owners is established by law. A careful analysis of the available data suggests 0.1~18.8 ₩/kWh.

Safety regulation costs are the prevention costs for accidents risk by tightening regulations. The need for prevention of nuclear accidents and safety assurance has grown as awareness of how dangerous nuclear accidents are has been spreading following the Fukushima disaster. KHNP planned to spend ₩7.5 trillion for safety regulation reinforcements and safety regulation costs are estimated to be 4.96 ₩/kWh. However, construction costs or O&M costs could also increase by extending the construction period or adding more safeguards. However, as stronger regulations are applied, there is lower risk of accidents. Therefore, more research on the relationship between level of regulation and accident risk is needed.

Policy costs are the expenses to the government for nuclear energy. It is estimated to be from 2.1 to 3.7 ₩/kWh based on recent performance and is expected to rise. Since other generation resources have been supporting these costs, policy costs should be considered for all types of energy.

5. Conclusions

This study attempted to understand the economical feasibility of nuclear power by taking

into account external costs including sufficient safety and social acceptance. The external costs of nuclear power are defined as potential costs that are not reflected to the generation costs directly.

External costs are not reflected in market prices. Form this study, these additional external costs amount to approximately 7 to 27 ₩/kWh.

Furthermore, since NPPs are regarded as a low-carbon means of generating electricity, it could be in a better position for climate change issues. It is clear that additional work is required for a better understanding of the external costs related to nuclear power generation.

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