The Analysis of Security Cost for Energy Sources in Korea

Younghwan Kim
Researcher, Ph.D.
KAIST (Korea Advanced Institute of Science and Technology),
Center for Science-based Entrepreneurship,
335 Gwahangno, Yuseong-gu, Daejeon 305-701, Republic of Korea,
Phone: +82-42-350-4346
/Fax: +82-42-350-4340
/Email: younghwankim@kaist.ac.kr

Wonjoon Kim
KAIST, Graduate School of Innovation and Technology Management

Eunju Jun
Korea Atomic Energy Research Institute (KAERI)

Soon Heung Chang
KAIST, Department of Nuclear and Quantum Engineering

Abstract

With the rising global concern for energy security, the increasingly unstable supply of fossil fuels, and the massive energy demand of developing countries, urgent policy responses for national energy security are required. However, few attempts have been made to define energy security and measure the cost of energy security. This study classifies energy security into supply security, economic security, and climate change mitigation effects and calculates the security cost of the different energy sources used to produce electricity in Korea, such as coal, oil, liquefied natural gas (LNG), nuclear, as well as photovoltaic and wind sources, which are regarded as new energy sources. Through an analysis of the security cost of the six energy sources, we find that the security cost of nuclear, photovoltaic, and wind energy is much cheaper than that of traditional fossil fuels. Especially in terms of the economic security cost, we find that photovoltaic and wind energy types are superior to fossil fuels as well as nuclear energy. Therefore, in order to enhance the energy security of Korea, we suggest an expansion of electricity generation from photovoltaic and wind resources as new types of energy.

1. Introduction

In the aftermath of the 1970s oil shock, energy security has become a major political issue all over the world. Unfortunately, most oil producing countries in the Middle East and Latin America, which have dominant positions in the world's oil market, are politically unstable, while oil consumption by major developing countries, such as China and India, is rapidly increasing. This is especially true when considering the past decade. However, only a few studies have attempted to define and measure energy security in order to meet policy requirements (Turton and Barreto, 2006).

Jun et al. (2009) examined and defined energy security by calculating the energy security cost of different energy sources, such as oil, coal, liquefied natural gas (LNG), and nuclear fuel, classifying the facets of energy security into supply security, economic security, and climate change mitigation effects. However, they did not consider any sources of new and renewable energy.

Therefore, following the methodology used in the study of Jun et al. (2009) for more accurate energy security cost calculations, this study compares the energy security cost of fossil fuels, in this case coal, oil, and LNG, along with nuclear energy, which has received increased attention recently as a low-carbon energy source, and photovoltaic and wind sources as new eco-friendly energy sources. Through a comparison of the energy security costs associated with these sources, we suggest a new energy policy that can reduce nations' energy security costs.

2. Cost of energy security

2.1. Definition of energy security

Energy security refers to a reliable and adequate supply of energy that fully meets the needs of the global economy that is available at a reasonable price (Bielecki, 2002). The definition has physical, economic, social, and environmental dimensions (European Commission (EC), 2000). A *physical disruption* occurs when an energy source is exhausted or when production is terminated temporarily or permanently. *Economic disruptions* refer the case when the market price of energy fluctuates and consequently causes serious disturbances in the regular economic activities and systems associated with the market price. *Social disruption* is associated to geographical instability that can be caused by political, ideological, and/or religious differences. *Environmental disruption* refers to disruption that is caused by polluting emissions such as greenhouse gasses and urban pollution (Costantini et al., 2007).

Among the four types of disruption, physical and economic disruptions have a direct effect on energy security, while social and environmental disruptions have an indirect effect on energy security. In this study, we consider physical and economic disruptions, which have direct effect on energy security, as the main components of the cost of energy security, as collecting and calculating data related to the indirect costs is difficult and because direct factors incorporate indirect effects inherently. However, the climate change mitigation effect is included in our analysis of the cost of energy security owing to its important link to energy security.

2.2. Climate change mitigation effect

Climate change has become an important global issue for the future of humans. The emission of hazardous materials can occur at all the steps of the energy chain, from the extraction of resources, the building of facilities, and the transport of the materials through to their final conversion to useful energy services. In order to measure the climate change mitigation effect of energy sources, we consider the environmental cost of CO_2, which is the main component causing global warming. Also considered are the other environmental pollutants SO_2 and NO_2 as well as the TSP (total suspended particles). With the information about the amount of emitted environmental pollutants, i.e., the amounts of CO_2, SO_2 and NO_2 as well as the TSP per unit of electricity generated from each energy source, we calculate the overall environmental cost of each energy resource by adding the costs of six types of environmental damage: *the damage from dust*, *the damage to visibility*, *the damage in agricultural production*, *the mortality risk*, *the risk of disease*, and *global warming*.

2.3. Cost of supply security

Consistent with the definition from the study of Jun et al. (2009), we define the cost of supply security as the opportunity cost that a country should pay in electricity generation when the supply of a certain energy source is disrupted for a specific period (e.g., for one year). On the other hand, energy reserves can reduce the cost of supply security due to a supply disruption. Therefore, the cost reduction by reserves should be reflected in the calculation of the supply security cost. The cost of supply security (C_{Si}) can be calculated as follows:

$$C_{Si} = \pi_i \cdot (G_i - R_i)$$

Here, π_i is the supply disruption probability of energy i. π_i can be derived by the inverse of the period in which the relevant energy source will be exhausted in the world. G_i is the total amount of GDP induced by the generation of electricity. We assume that the contribution of one unit of generated electricity to GDP is identical across various energy sources. R_i is the amount of GDP which can be generated from the reserve of energy *i* in the event of a supply disruption.

2.4. Cost of economic security

The calculation of the economic security cost is more complex than that of the supply security cost. According to the concept of the economic security cost as applied in the study of Jun et al. (2009), the cost of economic security in this study is based on the price volatility of the energy. In other words, economic security cost of an energy source with a wider range of market price is higher than that of an energy source without variation in its market price. In addition, for a precise definition of the cost of economic security, we consider the supply and demand concentration, the portion of the fuel price, and the unit cost to produce electricity with the specific energy source as the components of the economic security cost. Consequently, economic security is defined as the opportunity cost that a country should pay for the generation of one unit of electricity from a certain energy source when other energy sources are selected for the generation of electricity. The cost of supply security (C_{Ei}) can be calculated as follows:

$$C_{Ei} = \omega_i \cdot \varphi_{pi} \cdot \nu_{pi} \cdot c_i = H_i^* \cdot \varphi_{pi} \cdot \sqrt{\frac{1}{\tau(n-1)} \sum_{t=1}^{\tau} (\nu_t - \overline{\nu})^2}$$

where $\nu_t = p_t - p_{t-1}$, and where

$$H_i^* = \frac{(H_i - \frac{1}{n})}{(1 - \frac{1}{n})}$$

In these equations, ω_i denotes the degree of supply and demand concentration for the energy i. In order to calculate the value of ω_i, we use the *normalized Hirschman-Herfindahl Index* (H_i^*), where n is the number of energy sources in the country. The Hirschman-Herfindahl Index is defined as the sum of the squares of the market shares of firms (energy sources in this study). φ_{pi} is the portion of the fuel price in the generation of electricity using the energy i. On the other hand, ν_{pi} refers to the price volatility of energy source *i* within the country. To calculate the price volatility, we use the standard deviation of price differences during specific periods. Lastly, c_i is the unit cost of generating electricity from each energy source (Slade, 1991).

3. Security cost of energy sources in Korea

With electricity generation data from 2007, we calculated the security costs of various energy sources in Korea. The total amount of electricity generated in Korea generated in 2007 was 403,125 GWh. The portions of the different energy sources were 38.4%, 35.5%, 19.5%, and 4.5% for coal, nuclear, LNG, and oil, respectively. As of 2008, photovoltaic and wind among new energy sources account for 0.05% and 0.11% of all of electricity generated in Korea. Following the methodology suggested in the previous section, this study compares the energy security cost (supply security cost, economic security cost, and environment cost from the climate change mitigation effect of fossil fuels) of the energy from coal, oil, LNG, nuclear, photovoltaic and wind sources in Korea.

First, for the supply security cost, the fossil fuels coal, oil and LNG have higher probabilities of supply disruption compared to the other energy sources due to limited stocks or reserves, whereas the disruption probability of nuclear energy is relatively low. Photovoltaic and wind sources are unaffected by supply disruption or exhaustion issues due to their characteristics. On the other hand, the reserve of LNG is 15 days, that of coal is 30 days, and that of oil is 100 days in Korea. These limited reserves of fossil fuels lead to significant losses in terms of GDP in the event of a supply disruption lasting one year. However, in the case of nuclear energy, uranium reserves can last for more than 2 years, and photovoltaic and wind sources do not require any reserves. Therefore, nuclear, photovoltaic, and wind energy do not incur a supply security cost for one year. However, if we suppose the time period in the security cost analysis to more than 2 years, the supply security cost of nuclear energy increases sharply, and the relatively low supply security costs of the new energy sources of photovoltaic and wind become more attractive (see Table 1).

Table 1. Supply security cost of energy sources in Korea

	Disruption probability (π)	GDP loss from supply disruption (trillion won)	GDP gain from reserve (trillion won)	Net GDP loss from supply disruption (trillion won)	Cost of supply security (C_{Si}) (won/KWh)
Coal	5.208×10^{-3}	374.100	30.748	343.352	11.562
Oil	2.439×10^{-2}	44.087	12.079	32.008	42.829
LNG	1.493×10^{-2}	189.686	7.795	181.891	34.616
Nuclear	2.778×10^{-4}	354.713	354.713	0.000	0.000
Photovoltaic	0	0.489	0.489	0.000	0.000
Wind	0	1.028	1.028	0.000	0.000

Second, regarding the economic security cost, we find that the fossil fuels of coal, oil, and LNG have greater price volatility compared to the new energy sources of photovoltaic and wind power. Photovoltaic and wind power also have no fuel cost for electricity generation; thus, they do not add to the cost of economic security. On the other hand, in the case of nuclear energy, the unit cost for generation (40.28 Korean won for 1

KWh) is much lower than that of oil and LNG (123.05 won/KWh and 159.00 won/KWh, respectively). Moreover, the portion of the fuel cost (11 percent) of nuclear energy is also much lower than that of the fossil fuel energy sources. Consequently, photovoltaic and wind energy do not cause incur an economic security cost, and nuclear energy (0.371 won/KWh) and coal (2.037 won/KWh) has lower costs of economic security than oil (11.058 won/KWh) and LNG (28.791 won/KWh) (see Table 2).

Table 2. Economic security cost of energy sources in Korea

	Price volatility (ν_{pi})	Portion of fuel cost (φ_{pi})	Unit cost (c_{pi})	H_s^*	H_d^*	Cost of economic security (C_{Ei}) (won/KWh)
Coal	0.120	0.470	42.690	0.846	1.000	2.037
Oil	0.155	0.730	123.050	0.871	0.912	11.058
LNG	0.278	0.780	159.000	0.885	0.943	28.791
Nuclear	0.107	0.110	40.280	1.000	0.783	0.371
Photovoltaic	0.050	0.000	716.400	0.616	0.372	0.000
Wind	0.020	0.000	107.700	0.616	0.372	0.000

Note: H_s^* and H_d^* represents the normalized *Hirschman-Herfindahl Index* in the dimension of supply and demand. The data of price volatility of photovoltaic and wind energy is obtained from the 'German law of new and renewable energy'.

Finally, regarding the climate change mitigation effect (environmental cost), we find that coal, oil, and LNG emit large amounts of CO_2 as well as SO_2, NO_2 and TSP, while nuclear, photovoltaic and wind energy sources emit relatively small amounts of CO_2 only. Nuclear energy has the lowest environmental cost, followed by wind power, photovoltaic, LNG, oil and coal in that order (see Figure 1). However, the cost of nuclear waste disposal was excluded from our analysis. It should be considered for an exact calculation of the environmental cost in a future study.

Figure 1. Climate change mitigation effect of energy sources in Korea (environmental cost, won/KWh)

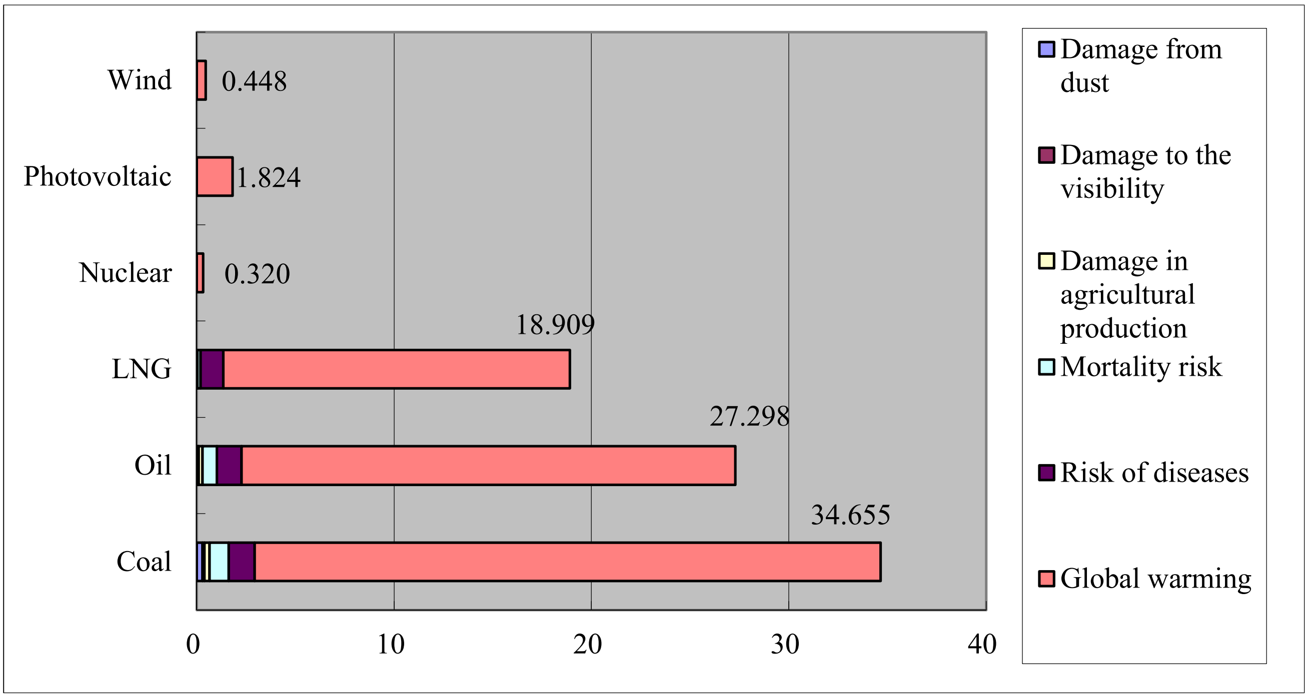

Table 3 shows the total cost of energy security integrating the supply cost and the cost of economic security for the six major energy sources in Korea given a one-year supply disruption period. If we do not consider the environmental cost of each energy source, the most secure energy sources are photovoltaic and wind, followed by nuclear, coal, oil and LNG, in that order. Specifically, the supply security cost of oil and the economic security cost of LNG are higher than those costs of the other energy sources. The supply and economic security cost of photovoltaic, wind power, and nuclear energy are nearly zero, and their environmental costs are much lower than these costs for fossil fuels. However, the total cost of electricity generation from coal is higher than that from oil due to the difference in the amount of electricity generation per energy source.

On the other hand, considering the environmental cost of each energy source, the rankings of nuclear energy and photovoltaic are reversed in terms of the unit cost to generate electricity. This fact may stem from the higher level of CO_2 emitted when generating photovoltaic power or from the aforementioned omission of the cost of nuclear waste disposal in the generation of nuclear energy. However, because nuclear energy overwhelms photovoltaic energy in terms of the amount of electricity generated, the total cost of nuclear energy including the environmental cost is much higher than that of the new energy sources.

Table 3. Energy security cost of energy sources in Korea (1 year)

	Cost of supply security (C_{Si}) (won/KWh)	Cost of economic security (C_{Ei}) (won/KWh)	Energy security cost (C_i) (won/KWh)	Energy security cost (C_i^*) (won/KWh)	Total cost (billion won)
Coal	11.562	2.037	13.599	48.254	2103.436
Oil	42.829	11.058	53.887	81.186	982.260
LNG	34.616	28.791	63.407	82.315	4972.783
Nuclear	0.000	0.371	0.371	0.691	53.075
Photovoltaic	0.000	0.000	0.000	1.824	0.000
Wind	0.000	0.000	0.000	0.448	0.000

Note: C_i^* represents the energy security cost that includes climate change mitigation effect (environmental cost). Total cost does not include climate change mitigation effect.

4. Conclusion

In this study, we compared the energy security cost of four major energy sources of electricity generation – coal, oil, LNG, and nuclear energy – and two new energy sources – photovoltaic and wind in Korea. We classified energy security into supply security, economic security, and the climate change mitigation effect and calculated the security cost of different energy sources for producing electricity in Korea, in this case coal, oil, liquefied natural gas (LNG), nuclear fuel, and photovoltaic and wind, which are major new energy sources.

Through an analysis of the security costs pertaining to the six energy sources, we found that, in Korea, photovoltaic, wind, and nuclear energy are more competitive energy sources than traditional fossil fuels – coal, oil, and LNG – in terms of energy security. Photovoltaic and wind energy are more attractive sources than nuclear energy in terms of the supply and economic security costs for one unit of electricity generation (1 KWh). Specifically, in terms of the economic security cost, we found that photovoltaic and wind sources are superior to fossil fuels as well as nuclear energy. Although the rankings of nuclear energy and photovoltaic were reversed in terms of the unit cost to generate electricity when we considered the environmental cost of each energy source, the amount of electricity generation from new energy sources is much smaller than that from nuclear fuel. Therefore, electricity generation from new energy sources – photovoltaic and wind – should be greatly expanded in Korea.

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