COMPARISON OF ENVIRONMENTAL IMPACTS BETWEEN COAL AND NUCLEAR FUEL CYCLES IN KOREA

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Introduction

Nuclear and coal have been selected as the major electricity sources due to the insufficient domestic energy resources, and will provide 62% of total electricity generation in Korea by 2015. Up to now, environmental impact assessments between two electricity sources have been focused on the CO_2 emission or economics. And future generation would require the environment friendliness energy policy for the environmentally sound and sustainable development of energy. So it is necessary to take into account an application of a broad environmental management tool to the comparative assessment of energy systems. Therefore, the environmental impacts of coal and nuclear fuel cycles are identified and quantified with the dimensionless unit concerning various environmental categories in this study. This result will be much helpful to make a decision for the long-term electricity planning and the energy mix optimization with respect to the environmental preservation in Korea

Role of Coal and Nuclear in Korean Electricity Supply

In order to cope with the future electricity demands, the long-term power development plan has been updated bi-annually. The total installed capacity in Korea is 46,978 MWe at the end of 1999 with 29.2% from nuclear, 27.8% from coal, 26.3% from LNG, 10.0% from oil and 6.7% from hydro and others. The total generated energy at the end of 1999 was 237,194 GWh. The share between the sources was 43.5% by nuclear, 34.1% by coal, 12.7% by LNG, 7.3% by oil and 2.4% by hydro and others [1].

The long-term nuclear power development plan by the year of 2010 is fixed. Currently sixteen nuclear power plants (12 PWRs and 4 CANDUs) are in operation. The first nuclear power plant started its operation in 1978 at the Kori site. The total electricity generation capacity of nuclear in 1999 is about 13.7 GWe. Two other units of 1000 MWe Korean Standard PWRs are scheduled for commissioning by 2002. By then, 14 PWRs and 4 CANDUs will be connected to the grid in Korea. Therefore, as the Korean nuclear power program is expanded, more radioactive wastes released to environment and arising of spent fuels are expected. In the case of coal-fired power generation, thirty-three coal-fired power plants have been in operation since 1965. The total generation capacity in 1999 is as much as 13.03 GWe. Six more units of 800 MWe, two more units of 500 MWe and three more units of 300 MWe coal-fired power plants will be connected to the grid by 2015. Therefore, nuclear and coal have been the major electricity sources and will provide the 62% of total electricity generation in Korea by 2015 [1].

Necessity of Broad Comparative Assessment Tool

The reason why a new comparison of nuclear and coal power generation system is necessary are the following. First, up to now, environmental impact assessment of nuclear and non-nuclear sources of energy has been focused on the only comparative assessment of the aspects of prevention of GHG (Greenhouse Gas) emissions between nuclear and non-nuclear sources of energy and the result showed that nuclear facilities release relatively very small amounts of GHG. On this basis, the non-radiological environmental impact of nuclear energy production has been considered very limited and the claim that nuclear energy is the clean energy source has been prevalent. However, the environmental predominance of nuclear energy over other energy sources considering various environmental categories such as global warming, acidification, resources depletion, and etc. has to be assessed in more detail. Second, energy policy related with environmental issues and energy conservation has been regarded as an important element of environmental favorable policy. Recent concern for environmental preservation has increased the demand for more efficient environmental management and long term electricity supply planning. Finally, recently International Standard Organization (ISO) has prepared the standardization of Environmental Management System (EMS), and life Cycle Assessment (LCA) is adopted as the most appropriate EMS tool in ISO 14000 series. Preference of public for purchasing products or services could be concentrated on environment friendliness known as eco-labeling developed by ISO 14000 standards and this concept rapidly becomes an established part of the market place [2]. So LCA will play an important role in providing an eco-labeling program. Therefore, application of LCA to electricity generation system is essential to make a decision of energy policy in environmental aspect.

Methodology

LCA is known as an appropriate methodology for environmental management of product or processes. This is cradle-to-grave approach to evaluate and quantify the environmental burdens associated with a product, process, or service at all stages of its life cycle by identifying energy and materials used and wastes released to the environment. Procedures of LCA are based on the following framework defined by SETAC (Society of Environmental Toxicology and Chemistry) such as goal and scope, inventory analysis, impact assessment, and valuation [3].

Goal and scope is to define which system is included in LCA. Inventory analysis is called as often Life Cycle Inventory (LCI). LCI step is to construct the data set consisting of the energy and raw materials used and emissions to the environment.

Impact assessment stage ends up with a list of up to ten figures instead of hundreds of specific emissions [4]. The list of most common substances and their classification factors on various environmental themes used in this study are data prepared by R. Heijungs et al. [5]. The environmental impact categories for which data are available and non-zero are followings: Abiotic Resources Depletion Potential (ADP), Global Warming Potential (GWP: gCO_2-eq), Ozone Depletion Potential (ODP: g CFC-eq), Acidification Potential (ACP: g), Ecotoxicity through Aquatic (ECA: m^3 water), Nutrification Potential (NP: $gPO_4{}^{3-}$ -eq/yr) [6].

It is difficult to interpret the environmental impact quantitatively. So LCA expresses the environmental impact by environmental category as effect scores (E_i) in equation (1). Effect score is calculated by multiplying $Load_j$ for a pollutant j, which means the emission, by its classification factor $C_{i,j}$ for a given environmental impact category i. However because the order of magnitude and units of the various effect scores differ, normalization and weighting of effect scores are proposed. Then normalization impact is calculated by dividing the effect score by normalization reference (N_i) for a given impact category i as noted in the equation (2). Finally a weighting impact (WI_i) in equation (3) is calculated by multiplying the normalization impact by relative significance factor (W_i) used in equation according to the suggestion of K. M. Lee [7].

$$E_i = \sum_j Load_j \times C_{i,j} \tag{1}$$

$$NI_i = \frac{E_i}{N_i} \tag{2}$$

$$WI_i = NI_i \times W_i \tag{3}$$

Environmental Data

In the case of nuclear, data related to fuel cycles prior to fuel fabrication and amounts of chemicals are taken from a report of ExternE project (Externalities of Energy) [8], as no front-end fuel cycle systems before the fuel fabrication is available in Korea. KNFC (Korea Nuclear Fuel Co. Ltd.) is in charge of all the fabrication of nuclear fuels in Korea. In the process of the fuel fabrication, it is assumed that enriched UF_6 as primary materials for UO_2 fuel would have no loss in the fabrication process and 1 % of auxiliary gas appear as the effluents to air. Data for electricity generated and chemical substances used in plants first come from the annual report on nuclear power generation and radioactive waste management of KEPCO (Korean Electric Power Corporation) [9,10]. Data associated with 11 PWRs generating total electricity of 74,546 GWh in 1998 were used for inventory analysis and impact assessment.

In case of coal, it is important to know the air pollutants emission. Pollutant amounts can be measured directly or combustion and emission can be estimated using the proper emission factor. Ministry of Environment (MOE) in Korea has set up the emission factors for energy sector in 1997 based on the compilation of air pollutant emission factor provided by EPA except emission factor of CO_2. Emission factors are listed in Table 1 [11]. for emission factor of particle in Table 1 means the ash content of coal and is the sulfur content. Also these values are estimated by MOE assuming the efficiency of air pollutant control device as 90%. Emission amounts of pollutants are calculated from the product of emission factor by annual fuel usage rate. Emission amount of CO_2 is calculated by the estimation of Korea Energy and Economic Institute (KEEI) based on the estimation of IPCC [12]. Table 2 shows the emission amounts of pollutants estimated using the emission factors in Table 1. Fuel cycle of coal-fired power generation system consists of mainly coal mining, transport of fuel and waste and power generation. Data related to coal mining are cited from a report of ExternE project (Externalities of Energy) [13], as activity of domestic coal mining in Korea contributes merely to 3% of power generation. Data from 13 power plants with a production of 32,839 GWh in 1996 are used for inventory analysis and impact assessment because all data of coal-fired power plants in Korea are not available.

	Bituminous	Anthracite
Particle	5A*	5A
SOx	19S**	19.5S
CO	0.3	0.3
HC	0.04	0.04
NOx	4	2.4
CO_2	KEEI	

Table 1. Emission Factor [kg/ton]
A : ash content, S : sulfur content

	Bituminous	Anthracite	Sum
Particle	1.90	7.87	9.77
SOx	3.61	5.37	8.98
CO	0.11	0.11	0.22
HC	0.01	0.01	0.02
NOx	1.52	0.94	2.46
CO_2	257.75	166.71	424.46

Table 2. Emission Amounts of Pollutants [kg/MWh]

One of the major problems in performing the normalization and weighting steps is to obtain the normalization references and the relative significance factors. The relative significance factors may differ from country to country. To obtain this, the KAB (Korea Accreditation Board) examined normalization references and relative significance factors for each environmental category on the basis of questionnaires from experts in 1999 [14] and this study uses this result for the normalization and weighting. The normalization references and the relative significance factors are shown in Table 3.

Impact Assessment

All environmental data of nuclear and coal are calculated on the basis of 1 GWh electricity generation. The impact assessment of radionuclides is excluded in comparison because classification factors for radionuclides are not provided by previous LCA's studies and radiological impact is mainly focused on the nuclear fuel cycle.

	ADP	**GWP**	**ODP**	**HCA**
Normalization References (Unit)	2.94E+3 (-)	5.66E+6 (g CO_2-eq)	8.26E+1 (g CFC-eq)	6.67E+4 (g)
Relative Significance Factors	1.650E-1	1.668E-1	1.668E-1	1.502E-1
	HCW	**ECA**	**ACP**	**NP**
Normalization References (Unit)	6.40E+4 (g)	4.17E+4 (m^3)	5.64E+4 (g SO_2-eq)	2.83E+4 (g CO_4^--eq)
Relative Significance Factors	1.502E-1	1.416E-1	1.146E-1	1.138E-1

Table 3. Normalization References and Relative Significance

Table 4 shows the environmental impact on the basis of weighting impact (WI) for the nuclear and coal fuel cycle. Overall, electricity generation by nuclear turns out to cause less environmental impact than coal. Environmental categories selected in the comparison process are resource depletion, global warming, human toxicity, eco-toxicity, acidification and nutrification. Generally it is known that coal-fired power plants cause mostly air pollution and nuclear power plants cause environmental impact through water. This result is conform to expectations since air pollutants due to fuel combustion plays important role in coal-fired power generation while quite a number of chemicals are used in water purification system of reactor coolant in nuclear power generation system. Traditional studies of GHG emissions have emphasized the distinctions between nuclear and coal fuel cycle and insisted on the fact that nuclear facilities release very small amounts of GHG. On this basis, the non-radiological environmental impact of nuclear energy production has been considered very limited. However, through LCA of nuclear power generation system, following conclusions could be drawn. HCA from the fluorine used in nuclear fuel conversion plants and ECA due to chemicals around mining plants are the categories causing potentially significant environmental impact. GWP is associated with the fabrication and transportation processes following the assumption based on BNFL's non-radioactive discharge data that a small amount of HCFCs (hydrochlorofluorocarbons) is released to the environment during the operation of the fabrication facility [15].

	ADP	GWP	HCA	HCW
WI_Coal	1.065E+01	2.456E+01	7.359E+00	9.898E-06
WI_Nuclear	6.038E-03	1.124E-06	9.193E-05	1.289E-05
	ECA	**ACP**	**NP**	
WI_Coal	6.403E-02	3.046E+01	2.676E+00	
WI_Nuclear	4.803E-05	9.408E-06	3.433E-05	

Table 4. Environmental Impact of Coal and Nuclear

One important role of LCA is to identify the environmentally dominant stage during the manufacture or generation of a product or service with various cycles [16]. Listing the dominant stages by merit indicates the main routes for making environmental improvements of existing products. The significant environmental category of nuclear fuel cycle is ADP due to the utilization of uranium resources. ADP is the major contributor of 95.4% to total environmental impact, HCA (2.1%) and ECA (1.1%) are minor ones and the rest are environmentally negligible categories. 93% of total environmental impact of nuclear power generation system is caused during mining/milling stage and 4% is caused during the nuclear power plant operation, hence the overall environmentally most dominant stage among nuclear fuel cycle components is mining/milling. It can be suggested from this results that spent nuclear fuels be recycled for the prevention of uranium ore depletion, the chemical effluents such as NOx and F^- not be released to the environment and use of hazardous chemicals be reduced. Surprisingly GWP comes mainly from the fabrication stage rather than the transportation stage. This could be due to the assumption of the release of auxiliary gas added in the fabrication step.

Conclusion

Nuclear and coal are major electricity generation sources in Korea, so it is necessary to take a broader approach for comparative environmental assessment between two major energy resources before making long term energy planning. Previous comparative assessment of nuclear and coal has been focused on the only comparison of prevention of GHG emissions and economic advantages. On this basis, the claim that nuclear energy is a cleaner energy source is accepted. However, it might be necessary to prove objectively the environmental predominance of nuclear energy over other energy sources considering various environmental categories. For the future an overall energy policy more favorable to environmental protection would be required. So the demand for more efficient environmental management and long term electricity planning would be increased. Finally, LCA will play an important role in providing an eco-labeling program in the advent of ISO 14000 standards. Therefore, application of LCA to electricity generation system is essential to make an appropriate decision for the long-term energy planning with environmental aspect.

Emissions from coal-fired power plants are calculated using the emission factor provided by MOE and the data associated with total raw material and energy used, and corresponding emission and wastes released during the normal operation of nuclear and coal fuel cycle facilities are cited from the annual report of KEPCO. Because all necessary data are not available in Korea, proper foreign references provide good supplements of Korean data. As a result, environmental categories such as resource depletion, global warming, human toxicity, eco-toxicity, acidification and nutrification are selected for comparison of nuclear and coal. After all, electricity generation by nuclear turns out to cause less environmental impact than coal.

This study is still in progress and results are quite preliminary ones. Therefore, further study for the construction of more appropriate Korean data should be implemented. However, the results will establish and provide the extensive infrastructure of database related with power generation stages and be much helpful to make a decision for the long term electricity planning and the energy mix optimization considering the environmental aspect in Korea.

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