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Comparison of Electricity Sources in the Environmental Management Aspect

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Abstract

National energy plan is addressing environmental issues and energy conservation has come to be regarded as an important element of environmental policy. 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. According to current situation, it is necessary to compare two major electricity sources in the view of environmental management issues. Up to now, environmental impact assessment between two electricity sources has been focused on the CO_2 emission or economics. But future generation would require the environment friendliness energy policy established objectively with the comparative assessment tool 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 including global warming, acidification and so on. 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

1. Status of Korean Electricity Supply System

The total installed capacity in Korea is 43,406 MWe at the end of 1998, 27.7% from nuclear, 26.1% from coal, 24.8 % from integrated coal-gasification combined cycle, 10.0% from oil and 11.4% from hydro and others. The generated energy at the end of 1998 was 215,300 GWh. The share was 41.6% by nuclear, 35% by coal, 12.2% by LNG, 8.2% by oil and 3% by hydro and others. Figure 1 is the comparison of electricity resources.

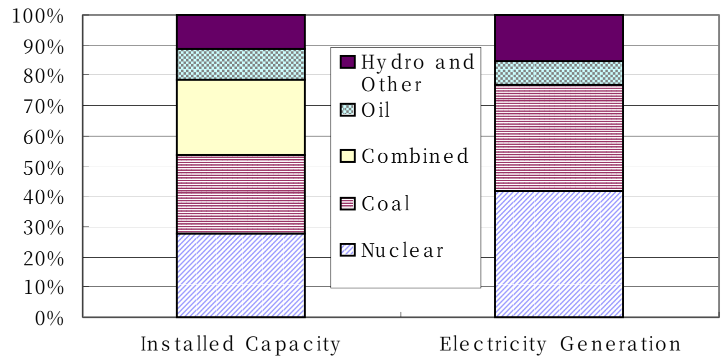

Figure 1. Installed Capacity and Electricity Generation

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].

2. Methodology

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. The details are omitted in this paper and further information is available in references from [3] to [7].

3. Construction of Environmental Data Set

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. Emission factors are available form Ministry of Environment (MOE) and Korea Electric Power Corporation (KEPCO). MOE 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. KEPCO has modified the emission factor of MOE with the sample measurement data. Besides MOE and KEPCO, International Atomic Energy Agency (IAEA) calculated the emission factors, however, they are not available in Korea because the assumption used is far from the Korean situation. Figure 2 shows the difference of emission amount calculated by MOE and KEPCO. Most of the air pollutants except particle show the similar amounts because particles are calculated by KEPCO under the conservative assumption. Emission factors listed in Table 1 means the suggestion of MOE [11]. "A" for emission factor of particle in Table 1 means the ash content of coal and "S" 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. Preliminary environmental data are showed briefly in Figure 3 where we can know that most hazardous pollutants are airborne materials.

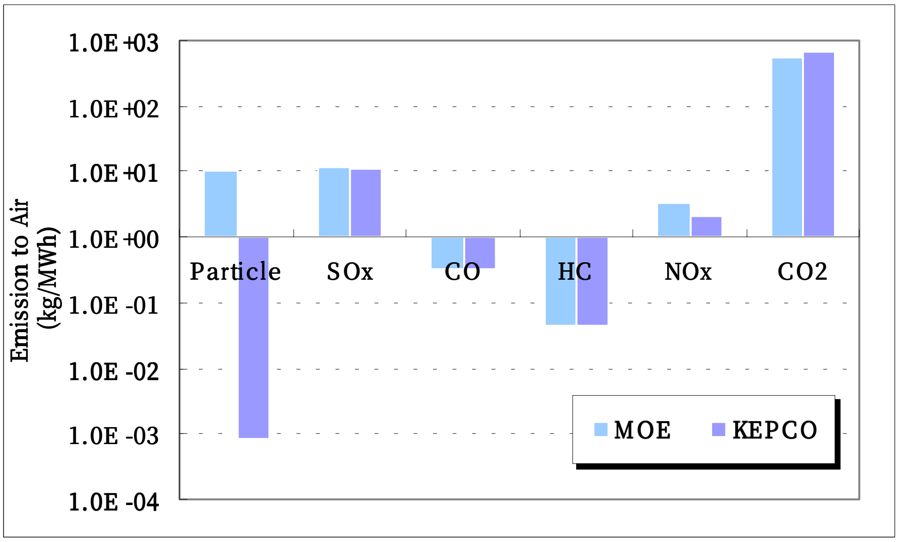

Figure 2. Comparison of Emission Amount by the Different Emission Factor

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

	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 2. Emission Amounts of Pollutants [kg/MWh]

	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

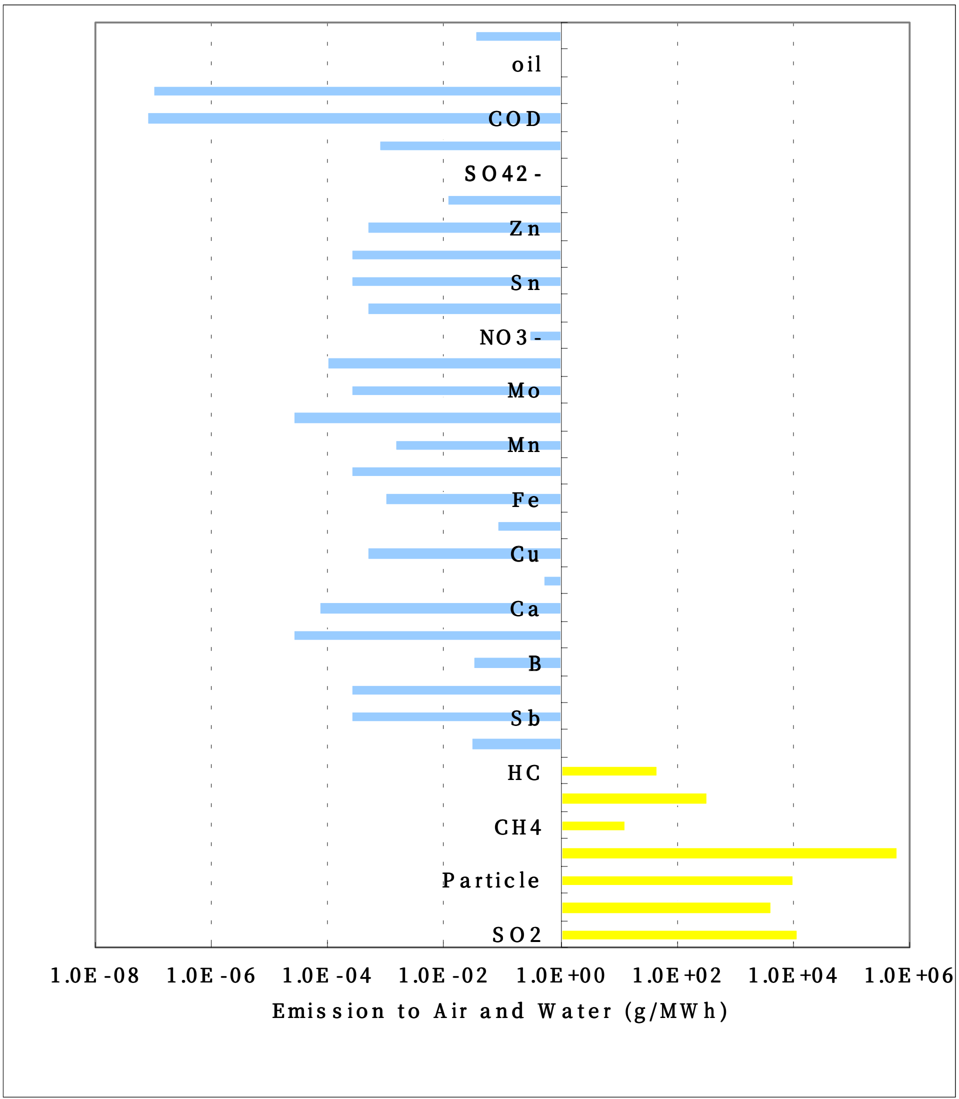

Figure 3. Emission to Air and Water from Coal-fired power Generation System

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.

Table 3. Normalization References and Relative Significance

	Abiotic Resource Depletion	**Global Warming**	**Ozone Depletion**	**Human Toxicity _Air**
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
	Human Toxicity _Water	**Eco Toxicity _Air**	**Acidification**	**Nutrification**
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

4. Results of Life Cycle 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 so that the comparison of radiological impacts caused by coal and nuclear fuel cycle is remained in further study.

Table 4 shows the environmental impact on the basis of weighting impact (WI) for the nuclear and the coal fuel cycle. Figure 4 means the overall comparison of coal and nuclear in terms of EI, NI, and WI. Two axes are log scales and bar and line graphs refer the coal and the nuclear respectively. Figure 5 shows the environmental impact of two resources as single value (this value is sometimes called as eco-indicator). As you know, electricity generation by nuclear turns out to cause less environmental impact than coal by one order of magnitude. 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].

Table 4. Environmental Impact of Coal and Nuclear

	Abiotic Resource Depletion	Global Warming	Human Toxicity _Air	Human Toxicity _Water
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
	Eco Toxicity _Air	**Acidification**	**Nutrification**	
WI_Coal	6.403E-02	3.046E+01	2.676E+00	
WI_Nuclear	4.803E-05	9.408E-06	3.433E-05	

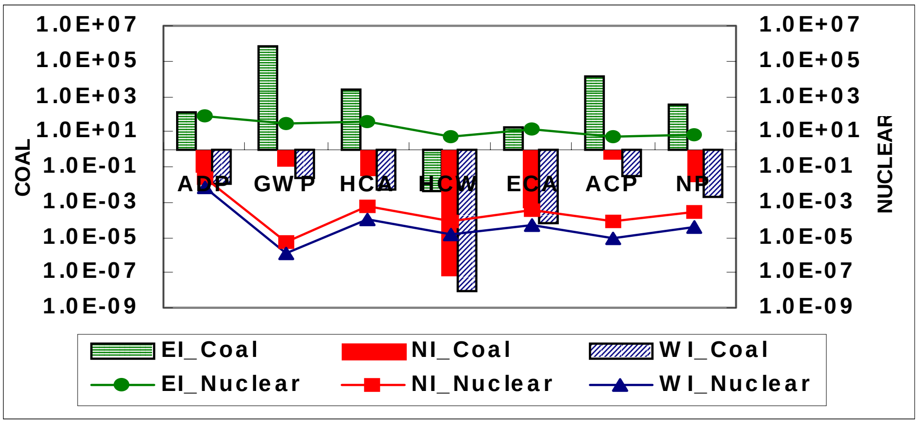

Figure 4. EI, NI, and WI of Nuclear and Coal

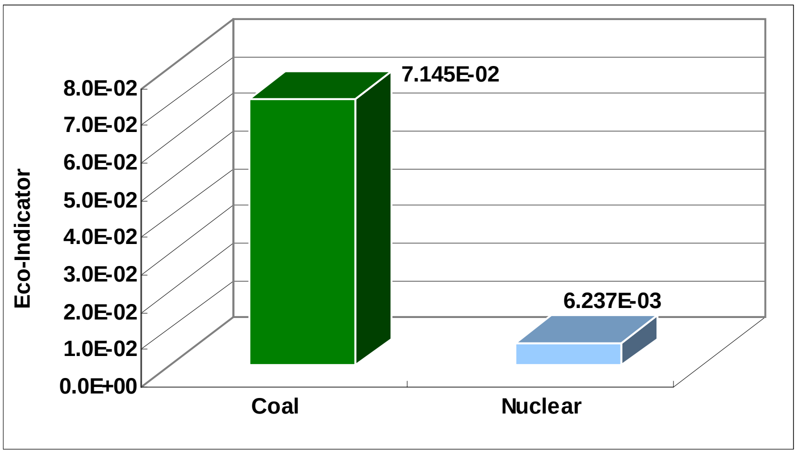

Figure 5. Total Environmental Impact as Single Value

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]. There is the merit in listing the dominant stage. Dominant stage means the life cycle step which causes the large environmental impact. For example, mining/milling stage of nuclear fuel cycle causes 93% of impact of total environmental impact. Once the environmentally dominant stage is known, total environmental impact can be greatly decreased by the reduction of hazardous materials utilization or by the replacement of less toxic substance in this stage. Therefore, listing of dominant stage gives the route of environmental improvement. 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.

5. 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. 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. 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 and the foreign references. 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 by one order of magnitude.

This study needs the progress such as radiological impact assessment of coal fuels cycle and Korean data supplement. Therefore this results are quite preliminary ones. However, the results will establish and provide the extensive infrastructure of database related with power generation stages and make it possible to compare the amounts and effect of chemicals used during the power plant operation. Finally this study will be much helpful to make a decision for the long term electricity planning and the energy mix optimization considering the environmental aspect in Korea.

References

[1] Korea Electricity Power Corporation (KEPCO). 2000. Status of electricity generation. Annual Report. KEPCO, Korea.
[2] International Standardization Organization (ISO). 1997. Environmental management - life cycle assessment - principles and framework. ISO 14040. ISO, Geneva.
[3] Lee, Y. and Lee, K. 2001, Application of Environmental Management Tool to Nuclear Energy Policy related with Environmental Issues. Proceedings of Korean Nuclear Society Spring Meeting 2001, Korea
[4] van den Berg, N., Dutilh, C., Huppes, G. 1995. Beginning LCA: a guide into environmental life cycle assessment. Center of Environmental Science. Leiden University, Netherlands.
[5] Heijungs, R., Guinee, J., Huppes, G., Lankreijer, R., Udo de Haes, H., Sleeswijk, A. 1992. Environmental life cycle assessment of products - guide and background. Center of Environmental Science. Leiden University, Netherlands, Appendix B.
[6] Wenzel, H., Hauschild, M., Alting, L. 1997. Environmental assessment of products. Chapman & Hall, the U.K.
[7] Lee, K. 1999. A weighting method for the Korean eco-indicator. International Journal of Life Cycle Assessment 4(3), 161-165.
[8] Dreicer, M., Tort, V., Manen, P. 1995a. Externality of energy. Vol. 5: nuclear, ExternE project report. European Commission, Luxembourg.
[9] Korea Electricity Power Corporation (KEPCO). 1998a. Nuclear power generation. Annual Report. KEPCO, Korea.
[10] Korea Electricity Power Corporation (KEPCO). 1998b. Radioactive waste management. Annual Report. KEPCO, Korea.
[11] Ministry of Environment (MOE). 1997. Emission of air pollutants. MOE, Korea
[12] Korea Energy and Economic Institute (KEEI). 1993. Study on the combination of coal and environmental policy. KEEI, Korea
[13] Fasella, P. 1995. Externality of energy. Vol. 3: coal and lignite. ExternE project report. European

Commission, Luxembourg.
[14] Korea Accreditation Board (KAB). 1999. Development of Korean eco-indicator. Document of public hearing on environmental management. KAB, Korea.
[15] British Nuclear Fuel Plc. (BNFL). 1999. Discharges and monitoring of the environment. Annual Report. BNFL, The U.K.
[16] Curran, M. 1996. Environmental life cycle assessment. McGraw-Hill, USA.