Comparative Life Cycle Sustainability Assessment of Enriched Uranium Supply Scenarios

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1. Introduction

Contribution to energy sustainability is becoming more important. Electricity demand rose by 4% nearly twice as more as overall energy demand in 2018. Electrification will continue due to the convenience and cleanliness during electricity use. This is why environmental sustainability is as important as power supply reliability.

The results of the sustainability assessment for nuclear power generation vary widely among researchers. This study compares the enriched uranium supply scenarios to the environmental sustainability in terms of climate change, air pollution, water use, exergy and land use(CAWEL). This is because there are many debates about the environmental burden from uranium enrichment phase in the whole life cycle of nuclear power generation. In particular, most nuclear power plants have the same opinions on climate change and air pollution reduction capabilities, but the evaluation of different environmental categories differs depending on the location.

For comparison, the evaluation focused on the technology applying to the uranium enrichment process. The reason for choosing this process is that there are many negative views on the environmental impact of the enrichment process in the life cycle of nuclear power generation, and it is easy to obtain reliable on-site data due to long-term use experience.

The life cycle analysis (LCA) is applied for evaluation. This is an effort to rule out international co-operation that avoids emissions burdens that impart pollution to other countries for cleanliness of one country.

This study used the CAWEL model, jointly developed by the Korea Atomic Energy Research Institute and VINATOM of Vietnam. If this model collects on-site data for the entire nuclear power generation process, it is also possible to evaluate environmental sustainability of Korea's own OPR and APR. The results of this evaluation can be used to improve the design of nuclear power plants, obtain environmental certifications both in Korea and in abroad, and to prove the eco-friendliness of Korean nuclear power plants to overseas nuclear power technology partners. The use of LCA results for their own power plants from Vattenfall in Sweden as an environmental responsibility and strategic tool gives us meaningful implications.

2. Methods and Results

2.1 Candidate technologies

In the case of greenhouse gas and air pollutant emissions, there is no disagreement in the analysis that there are no direct emissions from nuclear power plants. However, many opposition claims denied the cleanliness of the nuclear power plant by citing examples of foreign environmental impact assessment. For example, in the case of climate change, the survey of Sovacool (2008) cited 288gCO_2 eq/kWh, which is an example of the combination of maximum emissions at every phase of the life cycle, supporting the claim that there is no significant difference from LNG combined cycle power generation.

This study compares the environmental sustainability of the uranium enrichment phase in the life cycle of nuclear power generation from an LCA perspective. The uranium enrichment technology selected for comparison is a gas diffusion process, the most traditional technology, and a centrifuge process, which currently has an absolute market share (see Tables 1).

Table 1: Market share by supply source (%)

Process	2000	2010	2015	Projected 2020
Diffusion	50	25	0	0
Centrifuge	40	65	100	93
Laser	0	0	0	3
HEU ex weapon	10	10	0	4

Source) WNA, Uranium Enrichment (Updated January 2020)

Energy requirements on life cycle basis have been surveyed in this study to trace the energy flow through each enrichment technology (see Tables 2).

Table 2: energy requirements for uranium enrichment process (per SWU)

	unit	Diffusion	Centrifuge
Energy during construction	kWh_{th}	152	243
Energy in operation	kWh_{th}	22	19
Electricity	kWh_e	2,400	100
Total	kWh_e	2,458	187

Source) edited by author from Lenzen(2008)

2.2 impacts categories

For environmental sustainability assessment, the environmental impact category was selected as follows, considering Korea and global sustainability.

- Climate change(C): Reducing greenhouse gas emissions is an important global task for responding to climate change. Globally, about 78% of GHG emissions from human activity are from the production and consumption of energy. Among them, the share of power reaches 40%. In Korea, this share in 2017 was 87% and 40%, respectively. The supply of low-carbon electricity should be an important concern. Greenhouse gas emissions generally use gCO_2 eq as the evaluation unit.
- Air pollution(A): Air pollution is the fifth leading risk factor for mortality worldwide. For this reason, WHO or IEA has published a professional report that informs the risk of air pollution. Yale University, which publishes an EPI report annually in collaboration with Columbia University, has published two separate reports on air pollution risks in Korea. Air pollution is generally expressed in terms of TSP.
- Water footprint(W): In developed countries, the use of water resources in the electricity sector is the second largest after agriculture. In the analysis of water withdrawal and consumption of thermoelectric power plants, nuclear power plants use the most water resources. In the United States, France, and Switzerland, nuclear power plants had stopped operating due to deteriorating water resources. Some energy-environmental research in Korea raised the problem of excessive use of water resources in Korean nuclear power plants. Water use or water footprint is evaluated as water consumption (m^3).
- Exergy efficiency(E): Thermal flow performance of thermoelectric power plants has been evaluated based on thermal efficiency. However, exergy efficiency is a more useful measure for evaluating the impacts of primary energy resource depletion for non-renewable power plants or of power plant operation on the surrounding environment. Exergy uses the heat flow between the power plant and the environment as an independent variable.
- Land use(L): Non-renewable power plants have to gradually extract fuel from remote areas due to the depletion of necessary primary energies, and as the use of renewable energy with low energy density increases, land use along the entire power generation process has regarded as an important problem. The category of land use of a power plant is evaluated by dividing it into transformed- and occupied-land use (m^2) required throughout the entire power generation process.

2.3 Assessment model CAWEL

The CAWEL model used in this study calculates five evaluation categories based on four databases. Both input/output data and calculation database are managed based on MS-Excel (see Fig. 1).

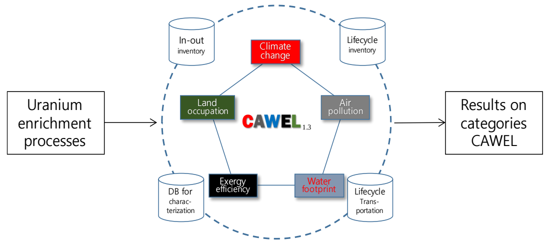

Fig. 1. Schematic information flows of CAWEL

Initial user interface of CAWEL is composed as user inputs specific data for selected uranium enrichment processes at the top line, and the remaining data are received through an prepared file. The results from CAWEL are provided in same format (see Fig. 2).

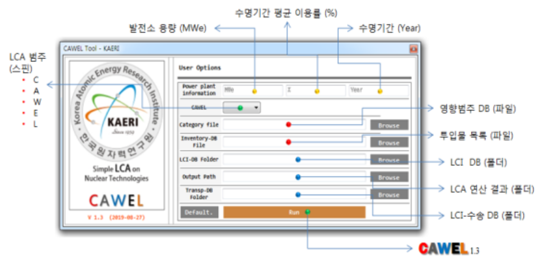

Fig. 2. User interface window of CAWEL ver3.1

The system boundaries of the study include the construction of facilities, enrichment activities, and transport of enriched uranium to Korea for the candidate uranium enrichment technologies. CAWEL's evaluation followed official global evaluation standards. C and A are based on the amount of output material emitted within the system boundary. The weights for each substance to be converted into the equivalent of the reference substance were based on AR5 of IPCC and NEEDS of Framework programmes of EU, respectively. W and L were based on the amount of input resources in each process. W evaluated the water withdrawal and consumption separately, and L was divided into transformation and occupation to evaluate the use of the site. Lastly, E was difficult to evaluate exergy efficiency in accordance with the definition due to the lack of heat flow information, and was replaced by energy efficiency evaluation instead.

2.4 Database preparation

The data required for the LCA are material and energy data from the construction, maintenance and disposal processes of the comparing uranium enrichment technology and on-site information on transportation. This data has gate to gate properties. And a cradle to grave concept database corresponding to these data should be prepared.

In addition, a characterization database is required that contains information on the list of substances contributing each impact category and information that can be used to equalize these substances as representative substances.

This study utilized second data and corresponding open DB sources reflecting the average of major countries to do uranium enrichment.

The transport data of enriched uranium has suggested a possible situation. Uranium enriched thru diffusion process in Russia transports by diesel train from St. Petersburg to Busan and uranium enriched by centrifuge process in France moves by air from Marseilles to Busan. Of course, if the situation of ship and truck transportation occurs, it can be evaluated easily.

2.5 Results

In the construction phase of the uranium enrichment facility (yellow bar), the diffusion process had an environmental impacts of over 700% in all categories compared to the centrifuge process. According to the LCA results for the enrich phase (pine green bar), category A had almost the same (103%) impacts, but in categories C and E, it was evaluated to have a very serious environmental impacts around 2000% (see Fig. 3). As a result, centrifuge process has much better sustainability characteristics in terms of CAWEL than diffusion process.

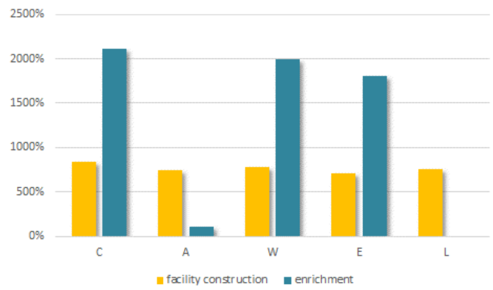

Fig. 3. Fraction of environmental impacts for each category in facility construction and operation process in the enrichment phase (bar height indicates the ratio of environmental impacts of diffusion to centrifuge process)

Concentrated uranium produced in Russia and France must be transported to a Korean nuclear fuel fabrication plant. As a result of performing CAWEL on resources and energy in the transportation process, air transportation has the largest burden in category C. In comparison, diesel train transport in category L emphasized more land use than air transportation (see Fig. 4).

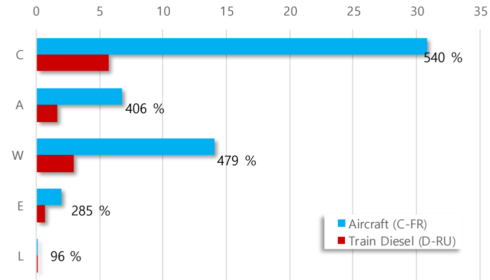

Fig. 4. Magnitude of environmental impacts for each category associated by selected transportation means (numbers at the end of the bar represent the ratio of the impacts of air transport to train transport)

3. Conclusions

Nuclear fuels with 4.2% concentration, which gives the same utility to users, were found to have different environmental-SD depending on the technology applied in the upstream phase. For global environmental categories such as Category C or A, the environmental impacts of the entire life cycle behind the function of the goods or services consumed should be considered. The contractor should also consider the responsibility of applying environmental sustainable technologies in the supply chain. The ability to think about the entire environmental impacts of a product is, of course, an analytical ability and a responsibility to be handled by a world-class company.

The CAWEL model used in this study needs to be expanded in all phases of nuclear power generation in Korea. This study still lacks DB and automatic processing capability to perform LCA perfectly. If the DB evaluation level of domestic evaluation and the improvement efforts of the model are complemented, evaluation and utilization equivalent to that of developed countries will be possible. This is why the participation of nuclear power plant owners is urgent.

When the de-Nuclearize policy came into force several years ago, the rise and fall of the nuclear industry ultimately affected public trust rather than the usefulness of nuclear power. Lessons learned that the acceptance of the public depends not on the inherent mass-supply ability or engineering safety, but on the analysis and communication capabilities of supporting issues such as environmental sustainability. This competency is well established in Japanese and Swedish power generation companies. It is time for Korea's nuclear industry, which has focused on the construction and operation technology development of nuclear power plants, to expand its scope of analysis capabilities in order to cooperate with the world.

We hope this experience will be a small starting point to the global sustainability contribution analysis of Korea's nuclear industry, and to be known as an analysis case to the world.

Acknowledgement

This analysis was evaluated using the algorithm designed by KAERI in Korea and the DB investigated by VINATOM in Vietnam in open-DB. We would like to appreciate KAERI and VINATOM's researchers who participated in the development of this model under a three-year technical cooperation agreement between KAERI and VINATOM.

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