Application of PROMETHEE-GAIA Method for Future Nuclear Energy System Selection

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1. Introduction

China is playing a growing role in the world economy, with its soaring energy demand and air pollution problems. In the race to replace its part of coal-fire power generation with low-carbon energy sources, Chinese government selected nuclear power as the most promising solution. Under the National 13th Five-Year Plan (2016-2020), China's nuclear power capacity will increase to 58 GWe in 2020 with an additional 30 GWe under construction [1]. The large expansion of nuclear power accompanied with the existing Once-Through (OT) fuel cycle, which inevitably bring the tough problem of rapid accumulation of radioactive nuclear wastes. However, China's current spent fuel reprocessing technologies are still far from maturation in the industrial scale.

The aim of this paper was to conduct a Multi-Criteria Decision Making (MCDM) case study analysis for a national-scale sustainability assessment of future nuclear energy systems and to further improve the weighting system for robustness enhancement in decision-making process.

2. Methodology

2.1 MCDM Framework of China's Nuclear Fuel Cycle (NFC)

In our past studies [2-3], we developed an MCDM framework to evaluate the nuclear sustainability in China based on dynamic modeling of NFC transition from the existing to advanced nuclear energy systems through 2100. Four nuclear energy system options for future NFC transition are selected: OT cycle, PWR(MOX) cycle, PWR(MOX)-FR(MOX) cycle, and PWR-FR(MOX)) cycle. Also to evaluate the sustainability of these NFC options, six major criteria (resource utilization, nuclear waste management, economic competitiveness, proliferation risk, environmental impact, and technological readiness) associated with total 12 detailed sub-criteria are defined, as shown in Fig. 1.

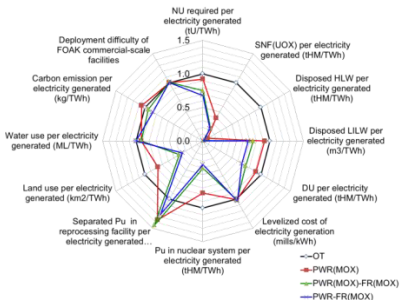

Fig. 1. Overall system performance comparison of the 12 sub-criteria in the Options 2-4 against OT.

2.2 PROMETHEE-GAIA

In some circumstances of MCDM applications, there are always many difficulties to select and determine the evaluation criteria, weight assignment, and decision-making methods due to challenging trade-offs and input data uncertainties. This paper applies an integrated Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) and Geometrical Analysis for Interactive Aid (GAIA) method to help the decision makers in selecting an optimal transitional path of future nuclear energy system from a sustainability perspective.

To stress on the uncertainties of weight assignment cause by the inherent weakness of any single Fuzzy Analytic Hierarchy Process (AHP) methodology, three different Fuzzy AHP approaches including

Interval Arithmetic (IA), Synthetic Extend Analysis (SEA), and Fuzzy Preference Programming (FPP) are selected in terms of different aggregation methods to derive fuzzy priorities and final weights for the overall criteria, and are tested to China's MCDM case study of NFC. All the original pair-wise comparison matrices for weighting the 12 sub-criteria were derived through a Matlab random sampling model [2]. Finally, by adopting the above three Fuzzy AHP approaches, the resultant weights for the 12 sub-criteria were simply aggregated to the final weights through the geometric mean, as shown in Fig. 2.

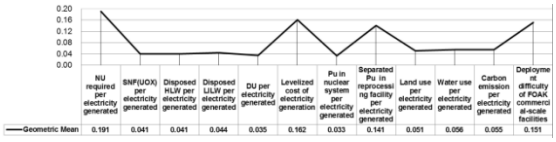

Fig. 2. Final weights for the 12 sub-criteria by using three Fuzzy AHP approaches.

3. Results and Discussions

The final weights for the 12 sub-criteria were applied in the MCDM analysis. The PROMETHEE rankings of four NFC options with the corresponding values of net flow score are displayed in Fig. 3.

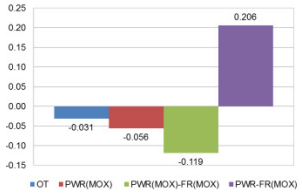

Fig. 3. The net flow scores of the four NFC options by using PROMETHEE.

PWR-FR(MOX) cycle got the top score among four candidate options, followed by OT cycle. PWR(MOX)-FR(MOX) cycle is the lowest-ranked option. Fig. 4 shows the GAIA plane for the case study in a standard 2D (U,V) view with a quite high information quality of 97.2%. In this plane, the 12 sub-criteria are represented by axes and the four options are shown as points. A long and thick decision axis in red indicates a strong decision power to compromise the confliction among the criteria and candidate options. Here, the decision axis clearly points towards PWR-FR(MOX) cycle, which indicates its best performance based on the given criteria weights. Additionally, the orientation of the decision axis indicates the proliferation risk criterion is in highest agreement with the PROMETHEE rankings compared to the other criteria.

Fig. 4. GAIA plan for China's MCDM case study.

4. Conclusions

From the above MCDM analysis results of four nuclear energy system options by applying PROMETHEE-GAIA method, the PWR-FR(MOX) cycle is proven to be a sustainable NFC transitional candidate. In the future, more integrated evaluation metrics and more reliable weighting system for assessing China's future NFC transitional path should be continuously developed.

REFERENCES

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