Multi-criteria Generation-Expansion Planning with Carbon dioxide emissions and Nuclear Safety considerations

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1. Introduction

A multiple criteria decision making (MCDM) method is developed to aid decision makers in Generation Expansion planning and management. Traditionally, the prime objective of an electric utility's generation-expansion planning has been to determine the minimum cost supply plans that meet expected demands over a planning horizon (typically 10 to 30 years).

Today, however, the nature of decision environments has changed substantially. Increased policy attention is given to solve the multiple tradeoff function including environmental and social factors as well as economic one related to nuclear power expansion. In order to deal with this MCDM problem, the Analytic Hierarchy Process (AHP) Model is applied.

2. Methods and Results

Korea launched an ambitious new long term plan to expand nuclear power, and by 2030, the nuclear share is expected to reach 59% of total electricity in terms of generation. An Optimal generation mix will minimize the costs to achieve this goal and has been calculated by dynamic programming methodology. This can be implemented with the already available dynamic-programming-based capacity-expansion planning tool, called Wien Automatic System Planning Package (WASP).

Trade off between costs and other policy attributes such as environmental degradation and nuclear safety has been examined. Cost-minimizing WASP-type models are now much less useful. Emerging carbon dioxide issues further aggravate it's usefulness due to difficulty in reflecting these factors a priority. We do not do this from scratch, but by using as much of the existing model as possible. This approach allows the practitioners' accumulated know-how and experiences to be utilized, which creates a set of theoretical questions.

This paper addresses these questions and presents a modified version(this sentence is not complete) to the multi attribute WASP model. It discusses a case study on Korea's generation-expansion planning under multiple-objective environments in order to glean helpful implications.

2.1 The Model

In previous paper[1], the given three decision attributes cost, CO2 emissions and nuclear hazards our model framework is involved in basically a typical vector-minimization model. Major decision variables are annual capacity additions by plant types while meeting reliability and other conventional technical constraints.

The generic formulation is

$$\min_{u_1,\cdots,u_T} (f_1(x_1,\cdots,x_T), f_2(x_1,\cdots,x_T), f_3(x_1,\cdots,x_T))$$

$$\text{s.t.} \quad P_t^L \le \sum_{i\in I} x_t^i \le P_t^U \qquad \text{for } t = 1,2,\cdots,T$$

$$LOLP_t(x_t) \le C_t \qquad \text{for } t = 1,2,\cdots,T$$

$$x_t = x_{t-1} + u_t \qquad \text{for } t = 1,2,\cdots,T$$

$$u_t \ge 0 \qquad \text{for } t = 1,2,\cdots,T$$

where

I	is the index set of plant types in the generation system in year t
x_t	is the cumulative capacity vector by plant types in year t with x_o being the initial capacity vector
u_t	is the capacity addition vector for year t
P_t^L and P_t^U	are the lower and upper bounds of installed capacity in year t
$LOLP_t(x_t)$	is the loss of load probability (days/year) given the system loads and the plant-forced outage rates in year t
C_t	is the reliability constraint of LOLP in year t
f_k	is the kth objective such as cost (f_1), environmental degradation (f_2), and risk of nuclear hazards (f_3).

The bounds or physical constraints on the CO2 emission quantities can be included in the formation. However, in this study these bounds are implicitly treated by discarding any policy that violates them. With these three objectives in the above model, we have the following structural formulation for each objective function.

1) Economic Objective: the minimal annual discounted investment and operating costs
2) Environmental Objective: the aggregate carbon dioxide emissions from fossil-fuel plants
3) Nuclear safety Objective: the minimization of nuclear hazards from nuclear power approximated by the additional capacity,

2.2. Preference Order dynamic programming Approach

Minimizing nuclear hazards quantitatively seems to be unattainable. In order to solve multiple objective problem, Zeleny introduced the concept of a compromise solution and distance measure.[2,3] He employed distance as a proxy measure of closeness, resemblance and similarity for human preference. A method to quantify the preference levels for various sub-policies was presented. In this paper we adopt this preference-order dynamic programming approach.

Since most nuclear power plants are run as base-load units, the installed capacity of nuclear power plants is used as a proxy for the representation of nuclear safety. If a more refined hazard measure becomes available, it can be accommodated as well.

The ranking scheme utilizes the concept of ideal and anti-ideal points. An ideal point indicates a vector whose component possesses the most preferable attribute value and an anti-ideal point implies a vector whose component possesses the least preferable attribute value. In our generation-expansion planning problem, these points for each year are determined. This procedure can be implemented within the existing algorithm of cost-minimizing WASP. Among costs-associated sub policies reaching up to a given year, the smallest is used as the cost component of the ideal point and the largest as that of the anti-ideal point.

With respect to the components corresponding to CO2 emissions and nuclear hazards, we can once again utilize the existing WASP model. By running the WASP model without allowing any additional nuclear power plants across the planning horizon, we can

obtain the C02 emissions component of the anti-ideal point. Symmetrically, by running the model without additional fossil-fuel plants, we can obtain the nuclear-hazards component of the anti ideal point.

These ideal and anti-ideal points could be difficult to estimate accurately but they can be used to reflect various realistic policy considerations. If a sub policy has attributes which fall outside of the range of the ideal and the anti-ideal points, it is discarded from the consideration.

2.3 Case Study

In order to illustrate the implications of introducing carbon dioxide emissions and nuclear safety to the conventional objective of cost minimization, we apply this version to Korea's generation expansion planning up to the year 2040.

In the pervious paper[1] we tried to run our multi attribute WASP model for a set of different weights . Our desire was to see the implications of different weights upon trade-off among costs, carbon dioxide emissions, and nuclear safety. Various weights were applied and the best compromise expansion plan was decided when decision maker prefers equal weights for three attributes. This warns of the dangers of one-sided environmental concerns i.e. either global warming or nuclear hazards. In other words, if we are to be concerned with the environmental issues of generation-expansion planning, we should at least take the comprehensive approach. We have also tried the weight-on-cost term of less than 1/3 to explore further the potential reduction of CO2 emissions and nuclear hazards.

Another noticeable phenomenon is that the system configuration is rather insensitive to the relative magnitudes of weights between the cost factor and the non cost factor. Rather, as it is observed the system configuration is quite sensitive to the relative weights between carbon dioxide emissions and nuclear hazards. As it can be seen in the case study, the plant-type mix is quite sensitive to the relative magnitudes of weights between carbon dioxide emissions and nuclear hazards. This justifies the simultaneous consideration of these two objectives.

We conducted a field survey to know about how much these weighting factors are really being influenced by stakeholders or interest groups. A Questionnaire was made by AHP Model where AHP aggregates found various aspects of the decision making problems into a single objective function as an optimal approach based on pair wise comparisons of decision criteria. Target audiences are composed of a management group and ordinary workers from electric utility and relevant companies, research institutes, SMEs, NGOs etc. Sample plan was determined and its size was around 500. All respondents were 215.

According to our survey, three attribute weights were 48%, 20%, 32% respectively. People in general were more concerned about nuclear safety than Global warming. In order to approach to minimum cost level we should make efforts to reduce nuclear safety attribute. Through this survey we found that SMEs and NGOs give higher importance of global warming than nuclear safety. This means that the more a population size is expanded, the closer will be two attributes.

Concerning the pair wise comparison between economic objective and environmental objective, Korea's long term electricity plan will be expected to compromising solution. However, if there is no policy measure to reduce CO2 emissions greatly, electric utility's burden to safety will be increased. Sensitivity analysis also shows that the reduction scenario of CO2 emissions should accompany improvement of nuclear safety possibly increase of public acceptance.

In this regard, we need some options. One option is to introduce energy tax to mitigate global warming. Another option is to start more harmonized and coordinated action plans between relevant Government agencies.

In summary, the high sensitivity of relative-weight values between global-warming effects and nuclear hazards should be noted. It seems desirable to acheive equal weights of two attributes in the contemporary society. This may be premature but the results from equal weight seem quite compatible with the current concerns of Korea's planners or decision makers who seek a cost-effective, yet environmentally sound capacity expansion plan.

Finally, we study Mitten's monotonicity principle problem. We test ex post facto and find whether or not Mitten's monotonicity holds for all states of given stages. Previously we counted the number of states violating monotonicity. It turned out that the violating states constitute from 3% to 7% of the total depending on the case. We want to proceed in this matter so that preference-order dynamic programming is acceptable for practical planning purposes.

3. Conclusions and Policy implications

We presented the model formulation and the recursive algorithm based on Mitten's preference-order dynamic programming and the case study of Korea's generation-expansion planning and the resulting implications. Rather than trying to develop a theoretical investigation on this, we attempted to devise a scheme that allows us to upgrade the existing dynamic-programming planning tool along with advanced MCDM AHP Model.

In conclusion, we are able to minimize not only CO2 emissions but nuclear hazards without the rising cost through the compromising solution. We believe that our multi-attribute WASP model will serve in the face of increasing concerns about global warming and nuclear hazards, the same role that the original WASP model has played in the last few decades of Korea's generation expansion planning.

In addition to that, we need more policy measures to reduce CO2 emissions eventually in order not to give negative effects for nuclear power expansion plan. We have to make a continuous efforts to enhance knowledge and awareness of general audience rather than local residents.

Even though we have not presented it in the case study, the suggested model is capable of incorporating the carbon dioxide emissions-reduction profile. This is done by desired sub policies to those satisfying the emissions-reduction scenarios together with nuclear hazards reduction measures ultimately economical achievements. Using this model, we are in the process of carrying out detailed implication analyses of possible greenhouse gas-reduction.

REFERENCES

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