A Weighting Approach to Comprehensive Assessment of National Power Sectors

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ABSTRACT

In the present work, various national electricity generating systems associated with conventional as well as renewable energy resources are comparatively assessed in view of life-cycle multi-criteria (economic, environmental, health, and social) spaces.

The essential objectives of the study are (1) to comprehensively compare the options for an electricity supply, (2) to complementarily support nuclear power's role in a national energy sector, and (3) to contribute to sustainability-oriented research and development in the energy and power sectors.

1. INTRODUCTION

Here, various national power sources including conventional as well as renewable energy systems are comparatively assessed in view of multi-criteria decision-making (MCDM) spaces. The main objectives of this work are (1) to understand the priority of power sources and (2) to establish nuclear power's synergetic role in a national energy sector.

Previous MCDM approaches for energy mix policies are mostly based on risk factors or environmental factors. In the ExternE project, environmental aspects are quantified from the point of view of an externality of an energy development cycle. National energy mix policies of individual countries are still based on economic points such as power generation cost, fuel import cost, land availability, etc. In this paper a multiple aspects approach for making decisions on the selection energy generation technologies is considered. The framework of the decision making process for the energy mix alternatives in this study considered the environmental aspects, health aspects, risk aspects, social aspects, and economical aspects collectively. The AHP (analytical hierarchy process) is considered in this paper and it is demonstrated through an example work for an energy mix alternatives framework.

2. METHODOLOGY

An integrated assessment system for a comparison of power sources, such as a MCDM tool, is developed. The system is based on an analytic hierarchy process (AHP) method and a questionnaire method. The AHP modeling enables us to aggregate both subjective and objective information. The AHP method is applied as a multi-criteria decision-making (MCDM) methodology for aggregating both the subjective degrees of an importance for the criteria and the value estimates for the attributes.

The reason for the choice of the AHP method is that, even if the AHP assumes an independency among several criteria, an AHP-based quantification is both easy-to-compute and is readily extendable to a criteria-dependent framework in the near future.

Basically the procedure for a comprehensive assessment consists of (1) problem definition, (2) choice of the evaluation criteria, (3) weight estimate, (4) evaluation value estimate, (5) aggregation, and (6) interpretation. Finally, as regards to the aggregation phase, the foregoing evidence is integrated to obtain an overall priority score. With the calculated weight values and evaluation values, an aggregation is implemented by using a weighted arithmetic mean.

The aggregated score for each option is used for ranking the options or for managing the ranking of a target option of interest.

$$S_K = \sum_{i=1}^{11} W_i N_{ik}$$

, where S_K = Overall score of a power generation technology k (= nuclear, coal, oil, LNG, hydro, wind, PV), N_{ik} = normalized values of the sub-criteria for each I, which are obtained from a normalization of the absolute values (X_{ik}) of the sub-criteria for each power generation technology inside a main criteria. The normalization is obtained by either of the following equations:

$$N_i = \frac{x_i}{\sum_i x_i} \quad \text{or} \quad N_i = \frac{1/x_i}{\sum_i 1/x_i}$$

The weights W_i among the main criteria and among the sub-criteria are obtained by enquete by the pair-wise comparison method. After that, the weighting vector is computed by an eigenvector method.

3. APPLICATION TO POWER SECTORS

A hierarchy configuration for this study is shown in Figure 1. Electricity generation system options under consideration are the conventional systems such as nuclear and fossil-fuelled (coal-fired, heavy oil-fired, LNG) as well as the new and renewable energy systems (hydropower, wind power, photovoltaic (PV) power). In Korea in recent years, about 40% of it's electricity has been generated by nuclear, and about 40 % has been generated by coal, about 12% has been generated by LNG, about 6% has been generated by heavy oil, and less than 2% has been generated by hydro.

These seven options are evaluated in terms of several conflicting criteria: (1) economic aspects (power generation cost, land use), (2) environmental impacts (global warming, acidification, energy payback), (3) health effects (accident mortality, loss of life expectancy), (4) social view (environment quality, fuel/energy supply security, grade of terrorism protection, grade of sustainability). Here, as for the economic aspects, the generation costs correspond to market prices except for wind and PV in virtue of the mandatory fixed-price purchases. To quantify the environmental impacts, a life-cycle assessment (LCA) is performed for various energy generation systems. In addition, for the health effects, empirical fatality data is gathered from the various literatures published by various international organizations such as the IAEA, OECD/NEA, ICOLD, IIASA, IEA, WEC, etc.

3. RESULTS

The tendency of the preferences for the main criteria of the questionee: Environment (14%) π Economic (17%) π Health(33%) π Social (36%). For the 11 sub-criteria space, the highest weight is occupied by accident mortality (22%), terrorism protection(17%), land use(14%), and years of lost life (YOLL) (12%) and so on.

From an integrated viewpoint of the economical, the environmentally-friendly, the socially-acceptable, and the healthy aspects, nuclear power takes first place. Renewable energy sources (i.e., PV, wind, and hydro powers) are in second place. The last one is held by the fossil-fueled power sources (i.e., LNG, heavy oil, and coal). A sensitivity analysis is done and to the selection of different items of subcriteria and to different weighting factors. It shows that there are no changes in the order of preferences.

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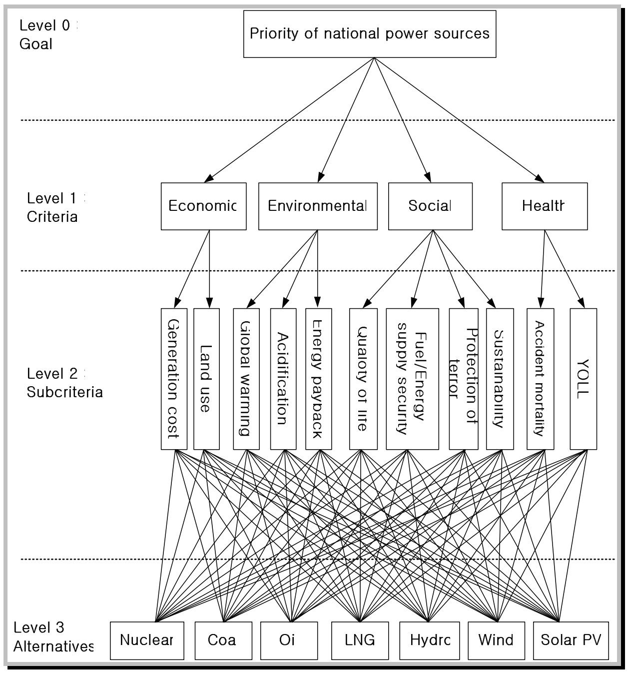

Figure 1. Hierarchical structure for power generation technologies.

Table 1. Absolute values X_{ik} and Normalized values N_{ik} of each subcriteria for various electricity generation technologies

Main and Sub-Criteria		Absolute value X_{ik}							Normalized values N_{ik}							Weighting Factors		
Main Criteria	Sub-Criteria *(i = 1 to 11)*	Nucl.	Coal	Oil	LNG	Hydro	Wind	PV	Nucl.	Coal	Oil	LNG	Hydro	Wind	PV	W_m	W_s	W_{ik}
Economical Aspects	Generation Cost [\kWh]	40.53	42.00	73.52	89.93	66.37	107.6	716.4	0.249	0.240	0.137	0.112	0.152	0.093	0.014	0.166	0.168	0.028
	Land use [km^2/TWh]	0.5	4	4	4	152	72	45	0.716	0.089	0.089	0.089	0.002	0.004	0.007		0.831	0.139
Environmental Aspects	Global warming [gCO_2-eq/kWh]	23.6	1094	778	524	15	9	13	0.140	0.003	0.004	0.006	0.221	0.368	0.255	0.140	0.203	0.029
	Acidification [g SO_2-eq/kWh]	0.115	3.5	8.013	0.778	157	144	99	0.834	0.027	0.011	0.123	0.001	0.001	0.001		0.363	0.051
	Energy payback [-]	16	7	7	5	205	80	9	0.048	0.021	0.021	0.015	0.623	0.243	0.027		0.433	0.061
Social Aspects	Quality of life [-]	0.122	0.125	0.139	0.157	0.131	0.151	0.172	0.122	0.125	0.139	0.157	0.131	0.151	0.172	0.357	0.231	0.083
	Security of Fuel Supply [-]	0.214	0.157	0.181	0.157	0.119	0.089	0.080	0.214	0.157	0.181	0.157	0.119	0.089	0.080		0.101	0.036
	Protection of terror [-]	0.131	0.122	0.151	0.151	0.145	0.139	0.157	0.131	0.122	0.151	0.151	0.145	0.139	0.157		0.480	0.175
	Sustainability [-]	0.145	0.101	0.119	0.166	0.172	0.139	0.154	0.145	0.101	0.119	0.166	0.172	0.139	0.154		0.178	0.064
Health Aspects	Accident mortality [death/GWh]	0.18	5.27	6.20	1.55	4.79	1.0E-5	1.0E-5	2.80E-05	9.50E-07	8.10E-07	3.20E-06	1.00E-06	0.499	0.499	0.335	0.652	0.218
	YOLL [yr/TWh]	10	61.25	139	28.75	6.25	12.5	56.25	0.240	0.039	0.017	0.083	0.384	0.192	0.042		0.348	0.117
Integrated Preference									0.23	0.07	0.07	0.09	0.15	0.21	0.18			