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Prioritizing Energy Sources to Generate Electricity (Application of Fuzzy Logic)

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ABSTRACT

Organizations, institutions, and different sectors of manufacturing, services and agriculture are constantly making decisions. Each of the aforementioned sectors, have strategies, tactics, and various functions that play a basic role in reaching the objectives. On the other hand, energy demand in developing countries is increasing day by day. The exact calculation of the cost per unit of electricity generated by power plants is not easy. Therefore, this study according to four sources of natural gas, nuclear energy, renewable energy and other fossil fuels other than natural gas that are used in a variety of electricity production plants is trying to clarify the ranking of generation electricity approach using “fuzzy preference relations” analysis. Accordingly, three models were used and the results showed that natural gas, with regard to the four criteria of low investment cost, low power, lack of pollution and the safety and reliability of electrical energy has priority over other alternatives. Full preferred model results also suggested that the energy of natural gas, renewable energies, nuclear and other fossil fuels should be considered in a priority for power generation. Sensitivity analysis results moreover demonstrated that the above models are not affected by the threshold values and the full stability of the models is observed.

Key words: Electric energy, energy planning, decision making, fuzzy ranking; JEL Classification: Q42, Q43, O21, L90, L99, D81.

INTRODUCTION

Energy has an infrastructural role at the industrial economy life of communities. That is, if enough energy is available at the right time, economic development would be possible.

On the other hand looking at the previous problems shows that a major competition has existed at the worldwide campaign to seize power. Because the national security and the stability of governing systems largely depend on access to these resources, Iran is among the world’s richest countries in terms of possessing resources and energy reservoirs. These resources are offered with cheaper prices and more easily than other countries. But this operation will not continue to infinity. Since the normal life of man is not possible without the use of energy resources. Coincided with the development of modern technologies for extracting energy, we should invest in efficient energy consumption methods (Khaksar Astaneh, 2012).In developing countries; energy demand is increasing day by day. The increasing demand for electrical energy is associated with a higher rate. The latter could be due to a variety of applications, high performance and ease of use. However, the accurate calculation of cost per unit of electricity by the power station is not an easy task. For power plants with natural gas or coal, one-third of the total executive cost is used for the initial investment, and the remaining two thirds for administrative costs.

While, for nuclear power plants, two-thirds of the cost will be allocated for the initial investment and the remaining one-third are the operating costs. If the issue is compared with inaccurate data and lack of previous experience in developing countries, the difficulties will be more evident (Zulal Gungor & Feyzan Arikan, 2000).

Primary energy supply in Iran was 1,601.2 million barrels of crude oil and the total final energy consumption in this year was 1192.8 million barrels of crude oil suggesting the excess energy. But that does not mean we should not try to consume and produce energy efficiently (Energy Balance, 2011). Considering that part of the country's production results from the oil sales, requirement of the optimization in energy sector will be more than ever apparent. Considering the consumption, an upward trend is observed and if careful planning is not done, in the near future the major problems of energy shortages will be outreached. Due to the increasing population and the population growth rate, the demand for electrical energy will increase rapidly. With respect to the issues listed, if these trends are maintained. It seems in the not too distant future, to generate electricity the imported resources should be used or to develop the production process the culture of consumption should be changed thoroughly.

According to the latest statistics available, electrical power generation of plants in 2011 was 240,063.2 GW/h. That had grown about 3.1 percent compared with the previous year. In the same year, total electricity sales of Power Ministry and major industries (including refineries power consumption, cock production units and blast furnace units) was approximately 191,455.8 GW/h that had a growth rate of 1.9 percent compared to the previous year (Energy Balance, 2011).On the other hand, according to the forecasts of Energy Efficiency Organization of Iran, energy consumption in 1404 is forecast at 390,459 GW/h hours (Khaksar Astaneh, 2012). According to figure cited equal with efficient consumption, power generation should also be promoted. According to different sources of electricity generation, this paper aims at improving the prioritization of resources to determine the electricity production. The second part of the paper, deals with a brief review of the theoretical and empirical literature in this area. The third section is an overview of the models used and applying them in Iran. The fourth section presents the results of the models to be investigated. The overall results and sensitivity analysis will be considered in Section 5 and the final section concludes the paper and presents the policy recommendations.

The main difficulties in energy planning are related to perfect awareness of supply and demand sides and coordination between them. As the country's energy resources are not infinite and will end some day and some problems will arise in the supply side. We have to formulate the appropriate strategies with careful planning, efficient use and supply. Decision making problems are categorized in four levels: deterministic, risky, uncertainty and fuzzy problems (Pentico, 2007). One of the basic assumptions in the optimization models of several studies is regarding the final amount of resources and the costs associated with it as certainly. While the values of these parameters are uncertain in the actual situations and rather than an exact value, they include a range of values (Khaksar Astaneh, 2012). In classical methods for the consideration of data uncertainty, the sensitivity analysis approaches and contingency planning are used. In the first approach, the impact of uncertainty on the data is ignored and subsequently for submitting the solutions obtained, sensitivity analysis method is used. But the sensitivity analysis is only a tool for evaluating the sufficiency of answer. Furthermore, performing sensitivity analysis simultaneously on parameters in models with a significant number of uncertain data is not practical (Azar et al, 2011).

Nugeyen et al (2014) applied a hybrid approach of the fuzzy ANP and COPRAS-G on the machine selection problem. The values that they use in making the machine selection are linguistic. Linguistic values are expressed as triangular fuzzy numbers. To determine the robustness of the rankings of alternatives they did the sensitivity analysis in the same way as Pang and Bai. There are 12 criteria in decision problems. They chose to switch the weight of 2 of the 12 criteria of a set. Therefore 66 different calculations must be implemented for the sensitivity analysis. In an effort to deal with subjectivity in criterion weights contributing to potential uncertainty, Feizizadeh et al (2014) suggested integrating the Monte Carlo Simulation with the conventional AHP.

Sengül et al (2015) have been ranked renewable energy supply systems using Multi-Criteria Decision Making (MCDM) technique. They used factors such as the cost of maintenance, installation capacity, productivity, payback period, the cost of investment, creating new job opportunities and the value of CO2 emissions as ranking criteria. Their research results showed that the hydropower station located at the highest priority and geothermal energy station and wind power station were the next priorities.

In this study, natural gas, nuclear energy, renewable energy and other fossil fuels other than natural gas are compared as the four main sources used in various types of power generation by applying "fuzzy preference relations" analysis. It can be said that the exact calculation of the cost of producing one unit of electricity is not easy and it should be noted that, even if the comparison is done with careful calculation of production costs. Due to fluctuations in the costs, comparisons may not be valid for a long time. So to deal with uncertainties in the data, and to judge the best alternative from among various alternatives, the fuzzy approach is used. Accordingly, the main task prior to power generation is creating strategies concepts, evaluation of alternatives and the selecting the best in terms of uncertainty. However, the other ranking methods such as the analytical hierarchy like what Lootsma et al did to compare and evaluate nuclear strategies, coal and natural gas to answer the demand for electricity by considering different scenarios of low, medium and high for economic growth have been implemented. Besides, Hamalainen and Seppalainen used the hierarchical process for complex decision-making about energy (Lootsma, &. Boonekamp, 1990, Hamalainen, & Seppalainen, 1986).

To achieve the economic and social goals of power producers four criteria are introduced that have a profound impact on decision-making measures: a) Low investment costs, b) Cheap or proper electricity price, c) Lack of pollution, and d) Safety and reliability.

These criteria are effective in generating electricity as the basic criteria that consider economic, social and political development simultaneously. So that if all four criteria are fulfilled satisfactorily, will have consequences for the country that are beneficial to people in the community, which is the overall objective of making decisions in the energy sector (Gungor & Arikan, 2000).

Selected criteria have a direct impact on energy policy. Some of these criteria may conflict with each other. On the other hand, some of these measures are difficult to be quantified. So for choosing the best alternative, we should apply an approach to overcome the aforementioned problems, and guide us in order to find the optimal decision. Phase analysis does not require quantified input but describes the performance of each criterion with some linguistic expressions such as strong, weak, very strong and will be expressed after a review on the empirical literature. Several experts did extensive research on energy demand such as Lee et al (2010) who applied the technique of fuzzy-contingency programming and began to design a model for planning systems under uncertainty. In their study, the presented model is designed for planning at the regional scale and taking into account ecological systems; as well as applicability in terms of the potential of various energies and environmental management policies.

In their study, Cai, et al., (2009) implemented to design a comprehensive system for the management of renewable energies. In this study, they have used a two-stage planning model with the interval parameters to provide a model for supporting the management of renewable energies in large-scale. The base of their method in this study was combining interval linear programming with a two-stage planning and planning based on fuzzy logic. These solutions can be used for deciding alternatives and helping to identify desired policies and apply according to various economic constraints and different levels.

In Iran, however, no study has been done in the field of energy planning and choosing the best alternative for the production of electric energy by fuzzy ranking approach. However, in the following, to mention a few studies on energy planning have been done using other methods, are mentioned. Sadeghi and Mirshojaeian (2006) attempted to make planning of energy supply in Iran by applying fuzzy linear programming. One of the major problems in energy planning and consequently energy models was considered uncertainty widespread in various economic, political and legal aspects of power programming. In fact, planners and policy makers utilize two strategies in order to deal with uncertainty: The first strategy is contingency planning strategy in which energy system designers define different scenarios and apply a clear probability for occurrence of each scenario. The second strategy is minimax-regret. Although these strategies are widely used, they are not flexible and not able to deal with uncertainty effectively as fuzzy techniques are. This study employs fuzzy programming techniques to optimize the Iranian power supply system.

Azadeh et al (2008) introduced a comprehensive model for assessing the performance and ranking of electricity distribution companies. In the proposed approach, Data Envelopment Analysis declared as a nonparametric model will be combined with Modified Ordinary Least Squares method declared as a parametric model, by Principal Component Analysis to obtain an accurate ranking of the Electricity distribution companies. They ranked 38 electricity distribution companies in Iran using the proposed approach.

Besides its application for Iran economy, the present paper can be helpful in an international perspective. It is obvious that resources, to meet the electricity demands in any country, is limited; therefore, each country must choose the optimum way to generate electricity; so that the country can achieve the development through optimized choices and prevent from loss of resources. This study can be a good model for decision-makers of the countries for planning to choose their primary sources for electricity generation. In a broader perspective, the method, employed in this study, can be applied for decision-making in other areas.

MATERIALS AND METHODS

In this paper, we try to rank the considered options using fuzzy approach introduced in 1965 by Professor Zadeh. Fuzzy Method is used in the face of vague and imprecise information and issues that make decision-making more difficult1. To choose the best options and prioritize them, in the midst of the uncertainty structure we are facing with some criteria selected as linguistic terms to express information in fuzzy language with the help of them. Accordingly, each criterion is related to a fuzzy set as a linguistic term.

Next, the options ahead are classified to binary sets and each set including two options are compared using each of mentioned criteria. To compare options, fuzzy preference relation and Hamming Distance Relationship are used. The result of this relationship includes one of the following three conditions:

Either Option A is prior to Option B or Option B is prior to Option A, or we will be indifferent towards the two Options. Similarly, for all options, a lot of fuzzy preference relations are obtained compared to other Options. These relationships are used for the fuzzy prioritization and combining them to prioritize options. In the meantime, three models are suggested for fuzzy prioritizations which include:

Pseudo-order preference model

This model regardless of any information about the weight and importance of each criterion discriminates among a set of options.

The semi-order preference model

The difference between this model and the previous model is that to identify a set of superior options we need to know the importance and weight of each criterion.

The complete-preorder preference model

This model determines the position of each of the options and does not deal with a set of options any more. In fact, it is a specific type of the previous model. This model does not use a threshold value. Thus, to set the full preference model, the degree of dominance is used. For further study on the subject and extraction of formulas and relationships, refer to Nasseri et al (2014). [2]

RESULTS

Pseudo-order preference model

As the relative importance of the criteria is unknown, Pseudo-order preference model is used for a set of dominant and non-dominant alternatives (Zimmermann, 1987) and the model output is shown in the ranking graph, Figure 2. Each node in ranking graph presents an alternative project while the arcs show the interrelationships between two alternatives. If alternative a outranks b, then an electrical arc is developed between a and b. The ranking graph represented in Figure 2 presents Pseudo-order preference model for the state $p_i = 0.85$ and $q_i = 0.25$.

The ranking graph shown in Figure 2 is obtained by relation (5) (and $p_i = 0.85$ and $q_i = 0.25$). Then, the dominant and non-dominant sets are derived as relation (9):

$$S_D=\{2\} \ ,S_{ND}=\{1,3,4\} \qquad ...(9)$$

It can be observed in the Figure (2) that alternative 1 is superior than, alternatives 2, 3 and 4. Hence, alternatives 1, 3 and 4 are not considered; so, only alternative 2 is considered as the recommended preferred alternative.

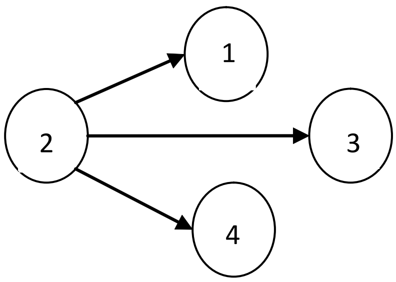

Fig. 1: Pseudo-order preference model graph

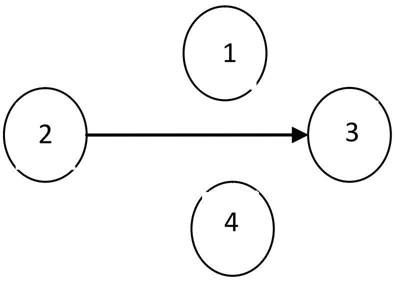

Fig. 2: Ranking Figure of the semi-order preference model when q_i=0.25

The semi-order preference model

Table (3) the relative importance of each criterion is estimated, and shown with linguistic terms. Normal weight is calculated and presented in Table (4)

Once indifference threshold is 0.25 (q_i = 0.25) and the ranking relations are obtained based on relation (5), the dominant and non-dominant sets are extracted as relation (10).

$$S_D=\{2\} \ ,S_{ND}=\{1,3,4\} \qquad ...(10)$$

That last relation is represented in Figure 3.

Alternative 2 is selected again by a semi-order preference model. Other alternatives are also incomparably based on this model.

The complete-preorder preference model

The complete-preorder preference model specifies the “best” project among 4 alternatives. Weighted priority matrix is obtained according to relation (3) and shown in Table (5). Degree of dominance of each alternative is calculated using relation (4) and presented in Table (6). Figure ranking obtained using Relation (5), is shown In Figure 4. Alternative2, production using natural gas, is selected as the best choice among four alternatives.

Discussion and sensitivity analysis

Organizations and departments are constantly making decisions, and each of them have separate strategies, tactics, and various functions which play a central role in achieving the objectives.

In this study, due to inaccurate information and the critical nature of decision making, fuzzy logic is used. Fuzzy logic due to inaccurate information of

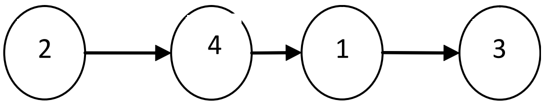

Fig. 3: The complete-preorder preference model

Table 1: Relative importance of the measures

Numerical scale	Linguistic terms
5	Very important
4	Relatively important
3	Important
2	Slightly important
1	Not important

Reference: Gungor & Arikan, 2000

Table 2: The relative importance of each criterion

Criterion	Numerical scale	Normalized weight
Investment cost	4	26.66
Cheap electricity	5	33.33
Inevitable pollution	3	0.20
Safety and reliability	3	0.20

Reference: Gungor & Arikan, 2000

Table 3: Weighted Priority Matrix

4	3	2	1	Alternatives
0.388	0.533	0.486	0.5	1
0.513	0.794	0.5	0.513	2
0.466	0.5	0.205	0.466	3
0.5	0.533	0.486	0.611	4

Table 4: Degrees of mastery of each alternative

Dominant degree	Alternatives
1.407	1
1.820	2
1.137	3
1.630	4

input variables described under linguistic expressions such as very important, medium important, or slightly important expressions, can be considered from a human perspective. According to the results of the three models discussed in the previous section, alternative 2; precisely, Production using natural gas, taking into account the general criteria listed in items one, three and four is in the priority.

When Pseudo-order preference and semi-order preference models are used to select among the alternatives, it is easy to see that natural gas is superior to all other alternatives. The difference is that in the latter model different weights are considered for each criterion.

When the complete-preorder preference model, will be used to select the best alternative, status and rank of all the alternatives will be obtained. Accordingly, natural gas is recommended as the best choice. Alternative 4 i.e. renewable energies, is considered as the next choice in second place. Alternative1, nuclear energy is considered in third place. Finally, alternative3, other fossil fuels, is considered in last place. It is worth noting, in order to analyze the sensitivity, by changing the values of p_i, and q_i representing the threshold of indifference and threshold of preference respectively. Power to discriminate between alternatives remain unchanged that suggests that on the basis of each method, according to the criteria mentioned above, reproduction using gas is in priority and the selection of projects is not dependent on selecting p_i, and q_i that indicates the explanatory power of the presented model.

CONCLUSIONS

Energy demand in developing countries is increasing. This increased demand for electricity has a much faster process. However, the accurate calculation of cost per unit of electricity by power plants due to inaccurate data and the lack of previous study in developing countries and also many variations in the variables is very difficult. The figures represent high estimates of electricity consumption in the coming decades and according to the same point par with optimized consumption, electricity generation should be promoted too. In this regard, given the primary energy sources used for electricity generation. This paper aims at prioritizing the improvement of power generation sources.

In determining priorities in the current paper the details of planning the production of electricity at base load, intermediate load and peak load that are of significant areas in power generation sector have been avoided. More importantly, this study has tried to manifest the use of fuzzy set priorities in planning studies of the electrical energy. In this study, three models were used, and the results of the models with regard to lower investment cost of natural gas standards, cheap power, lack of pollution, safety and reliability is preferred over other alternatives for generating electrical energy. The complete-preorder preference model results also suggest that the issue of energy, natural gas, renewable, nuclear and other fossil fuel energies should be considered in priority of power generation. The results of the sensitivity analysis also shows that all three models are not affected by the threshold values and own full stability of the models. Due to the low cost of natural gas and with regard to Iran's gas reserves as the world's second largest gas supplier and given the country's shared gas reserves with neighboring countries in addition to production for domestic consumption, to many neighboring countries electricity can be exported given the competitiveness feature and policy makers should pay enough attention to this issue. This process as well as considering Iran's regional security will provide a higher added value for Iran.

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