Computational Research Progress in Applied Science & Engineering

ISSN 2423-4591

CRPASE Vol. 02(01), 35-39, January 2016

A Framework for Assessment and Selection of Thermal Power Plant Location based on MADM Methods

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Keywords

Thermal power plant,
Location selection,
Fuzzy AHP,
TOPSIS.

Abstract

Selection of thermal power plant (TPP) location is a strategic decision with a remarkable influence on economic performance and sustainable development. Location selection decisions are multi-criteria decisions. To implement the first step of this study, the influential indexes in selecting TPP location were identified and extracted from reliable articles. To implement the second step, i.e., determining index weights, the significance of each index weight was determined through interviews with experts, paired comparisons and fuzzy AHP. Then, the weight of each index was calculated and introduced to the TOPSIS model for prioritizing the locations (in the form of options). The research is an applied research in terms of objective and is a descriptive study in terms of nature. In the first step, the required data is collected through the desk method from reliable national and international literature. The second step is to collect data from experts by using the field method. Data analysis is implemented through FAHP- TOPSIS. The results can be constructive for power ministries and constructors of TPPs including those who select TPPs locations.

1. Introduction

The vast majority of organizational problems have more than one solution with the final selected solution involving certain advantages as well as disadvantages. In cases where more than one criterion influence the solution, multi-criteria decision making (MCDM) approaches are implemented. Following the identification of the selection criteria, possible options are enlisted and appropriate solutions selected by MCDM in terms of qualitative and quantitative ranking criteria [1].

The purpose of this study is to present an AHP-Fuzzy TOPSIS framework for assessment and selection of the optimal location for a TPP with the least possible socioeconomic and environmental costs through increasing electricity generation efficiency, maximizing the total TPP value, decreasing production and energy transfer costs, maximizing TPP productivity, and minimizing negative environmental impacts. An AHP-Fuzzy TOPSIS framework is proposed for assessment and selection of an optimal location for constructing TPPs. This framework includes the most important factors affecting location and effective weights of the model. It has a realistic view due to its fuzzy structure and provided more realistic results. The methods used in this study are explained below. Then, the obtained framework, which is based on an AHP-Fuzzy TOPSIS framework, is explained and a case study reviewed. The final section concludes the study.

2. Materials and Methods

To achieve the final objective of this study, i.e., providing an AHP-Fuzzy TOPSIS framework for selecting the best location for constructing a TPP, three main stages were defined as follows

1- Identification of the main effective indexes

2- Adopting AHP for assigning a weight to each index

3- Adopting fuzzy- TOPSIS for prioritizing location options

2.1. Identification of Main Effective Indexes

First, a large amount of articles have been reviewed. amongst them, we have selected the most reliable literature for use in this study. Upon reviewing more than 40 papers, 31 assessment indexes for selecting TPP locations were derived. In the next step, the selected articles and criteria,

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Received: 01 November 2015; Accepted: 15 December 2015

measurement methods and research scope were studied more accurately and 15 indexes were selected for measuring, assessing, and prioritizing purposes. They are defined in the following.

Objective: Finding the best location for constructing a TPP

Primary indexes (Criteria): economic, Geographic, and environmental

Secondary indexes (Sub- Criteria): land cost, implementation cost, construction cost, power transmission cost, maintenance cost, labor cost, water sources accessibility, fuel accessibility, consumption area accessibility, labor accessibility, transportation network accessibility, distance from fault, impact on ground water, impact on agricultural lands, and impact on air pollution. Figure 1 shows the hierarchical graph of decisions [2-4].

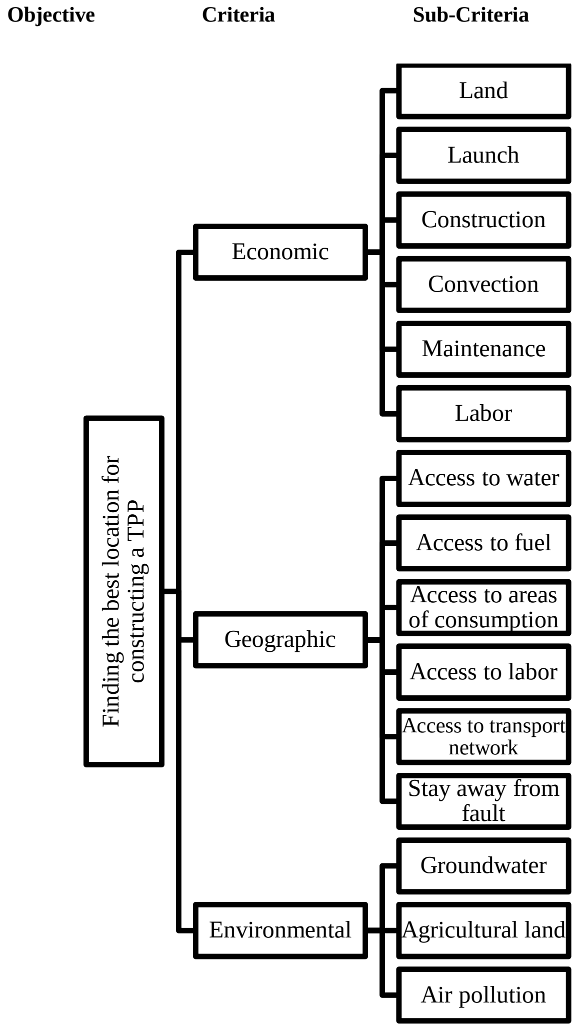

Figure 1. Hierarchical tree

2.2. Adopting AHP for Assigning a Weight to Each Index

In the next step, a questionnaire was designed for paired comparison of the main and secondary indexes, derived from selected papers. The validity of questionnaire: since hour-based intervals were used in paired comparison process, the questionnaire has an acceptable validity. In addition, the rate of inconsistency was measured by AHP and the consistency of the obtained matrix implies the acceptable

reliability of the questionnaire and the obtained data. When the questionnaire was designed and confirmed scientifically, experts were interviewed. To obtain the opinions of TPP and TPP location experts, they were interviewed in accordance with the designed questionnaire in order to apply their comments on the priority of the indexes in the form of paired comparisons. A total number of 19 experts, who were among the most experienced Iranian specialists in the fields of the selection of location, design, assessment and management of TPPs were interviewed.

To enhance speed and accuracy, only linguistic phrases were used during interviews for expressing priorities. In this way, linguistic phrases were transformed to paired comparison matrices with fuzzy numbers using Chang's extent analysis and Chang and Kahraman papers as per Table 1 and Figure 2 [5, 6].

Then, all matrices became consistent and provable after calculating and controlling the inconsistency rate of all 19 fuzzy field questionnaires and adjusting some inconsistent cases (inconsistency >0.1) using D.Cao adjustment initiative and Hadamrad product.

In this stage, the consistency of mean matrices was calculated and the obtained results showed an acceptable consistency. The tables of average fuzzy consistent matrix of criteria (Table 2) matrix of sub-criteria economic (Table 3), geographic (Table 4) and the environment (Table 5) are given as below.

Upon making sure that the matrices and mean matrices were consistent, we calculated the weight of each index. Table 6 lists the weights derived from the fuzzy AHP method for criteria. The weighted normalized to sub-criteria economic, geographical and environmental are given in Tables 7-9, respectively.

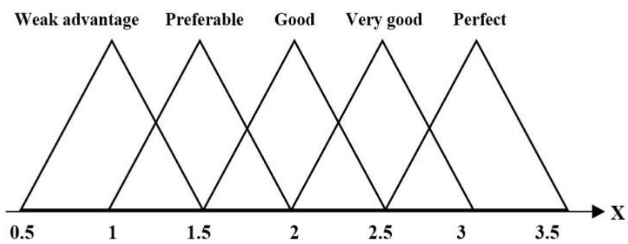

Figure 2. Membership functions of triangular fuzzy numbers corresponding to the linguistic scale

Table1. Membership function of linguistic scale [5, 6]

Linguistic Scales	Fuzzy Scales	Inverse Scale
Equal	(1,1,1)	(1,1,1)
Weak advantage	(1.2,1,3.2)	(2.3,1,2)
Preferable	(1,3.2,2)	(1.2,2.3,1)
Good	(3.2,2,5.2)	(2.5,1.2,2.3)
Very good	(2,5.2,3)	(1.3,2.5,1.2)
Perfect	(5.2,3,7.2)	(2.7,1.3,2.5)

Table 2. The fuzzy comparison matrix of criteria

Criteria	Economic	Geographic	Environmental
Economic	(1,1,1)	(0.79 ,1.039 ,1.449)	(1.232,1.666 ,2.116)
Geographic	(0.69,0.962 ,1.372)	(1,1,1)	(0.908 , 1.32,1.756)
Environmental	(0.447,0.6 ,0.811)	(0.569 , 0.757,1.101)	(1,1,1)

Table 3. The fuzzy comparison matrix of sub-criteria with respect to criteria economic

Economic (Cost of….)		Launch	Construction	Convection	Maintenance	Labor
Land	(1,1,1)	(0.523,0.678 ,0.942)	(0.386,0.473 ,0.609)	(0.47,0.588 ,0.758)	(0.496, 0.632,0.833)	(0.454,0.709,1.063)
Launch	(1.061,1.474 ,1.91)	(1,1,1)	(0.0406,0.502 ,0.64)	(0.524,0.67 ,0.941)	(0.545,0.706 ,0.984)	(0.535,0.82,1.4)
Construction	(1.641,2.115 ,2.59)	(1.526,1.992 ,2.461)	(1,1,1)	(1.223,1.692,2.167)	(1.174, 1.637,2.167)	(1.518,1.945,2.397)
Convection	(1.319,1.7,2.125)	(1.063,1.491,1.908)	(0.461,0.591,0.817)	(1,1,1)	(1.143,1.564,2.044)	(0.707,1.063,1.55)
Maintenance	(1.2,1.583,2.014)	(1.016,1.583,2.014)	(0.461,0.61,0.582)	(0.489,0.639,0.875)	(1,1,1)	(1.054,1.423,1.808)
Labor	(0.915,1.333,1.833)	(0.814,1.129,1.869)	(0.417,0.512,0.659)	(0.645,0.941,1.414)	(0.553,0.703,0.949)	(1,1,1)

Table 4. The fuzzy comparison matrix of sub-criteria with respect to criteria geographic

Geographic	Access to water	Access to fuel	Access to areas of consumption	Access to labor	network	Stay away from fault
Access to water	(1,1,1)	(0879,1.143,1.695)	(1.069,1.512,1.974)	(1.409,1.85,2.398)	(1.309,1.779,2.35)	(0.292,0.352,0.413)
Access to fuel	(0.59,0.875,1.137)	(1,1,1)	(1.357,1.857,2.357)	(1.487,1.92,2.405)	(1.107,1.525,1.974)	(0.287,0.234,0.415)
Access to areas of consumption	(0.506,0.661,0.935)	(0.424,0.538,0.737)	(1,1,1)	(1.143,1.67,2.155)	(1.152,1.524,2.024)	(0.286,0.333,0.4)
Access to labor	(0.417,0.54,0.71)	(0.416,0.519,0.686)	(0.464,0.599,0.875)	(1,1,1)	(0.528,0.78,1.03)	(0.286,0.333,0.4)
Access to transport network	(0.425,0.506,0.764)	(0.506,0.656,0.903)	(0.494,0.663,0.689)	(0971,1.469,1.893)	(1,1,1)	(0.286,0.333,0.4)
Stay away from fault	(2.421,2.931,3.421)	(2.41,2.895,3.485)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)	(1,1,1)

Table 5. The fuzzy comparison matrix of sub-criteria with respect to criteria environmental

Environmental (Impact on…)	Groundwater	Agricultural land	Air pollution
Groundwater	(1,1,1)	(0.957,1.369,1.799)	(0.883,1.273,1.7)
Agricultural land	(0.556,0.73,1.045)	(1,1,1)	(0.706,1.026,1.506)
Air pollution	(0.558,0.786,1.132)	(0.664,0.974,1.417)	(1,1,1)

Table 6. The weighted normalized to Criteria

Criteria	Normalized weight
Economic	0.429
Geographic	0.371
Environmental	0.2

Table 7. The weighted normalized to sub-criteria (Economic)

Sub-criteria	Normalized weight
Cost of land	0.165
Cost of Launch	0.161
Cost of Construction	0.17
Cost of Convection	0.168
Cost of Maintenance	0.175
Cost of labor	0.159

Table 8. The weighted normalized to sub-criteria (Geographic)

Sub-criteria	Normalized weight
Access to water	0.167
Access to fuel	0.16
Access to areas of consumption	0.166
Access to labor	0.161
Access to transport network	0.168
Stay away from fault	0.18

Table 9. The weighted normalized to sub-criteria (Environmental)

Sub-criteria	Normalized weight
Impact on Groundwater	0.41
Impact on Agricultural land	0.297
Impact on Air pollution	0.293

Table 10. The weights of alternative locations with respect to sub-criteria

Index	Symbol	(in final model)
Cost of land	X_1	0.071
Cost of Launch	X_2	0.068
Cost of Construction	X_3	0.073
Cost of Convection	X_4	0.072
Cost of Maintenance	X_5	0.076
Cost of labor	X_6	0.066
Access to water	X_7	0.0625
Access to fuel	X_8	0.057
Access to areas of consumption	X_9	0.0615
Access to labor	X_{10}	0.061
Access to transport network	X_{11}	0.063
Stay away from fault	X_{12}	0.068
Impact on Groundwater	X_{13}	0.08
Impact on Agricultural land	X_{14}	0.06
Impact on Air pollution	X_{15}	0.059

Finally, the respective weights of the primary and secondary indexes were combined to derive the overall weight of all the 15 indexes. Table 10 shows the results.

3. Case Study

In this step, alternatives were compared using TOPSIS technique. Then, four locations were ranked as per the proposed model using the weights derived from the AHP-Fuzzy technique. Finally, the alternatives were ranked in terms of their scale efficiency and technical efficiency, and the proposed model was confirmed. To this end, six persons who had either worked personally in the mentioned power plants or had comprehensive information about them due to their respective responsibility in Tavanir Co., were asked to estimate the status of the power plants in terms of utilizing each index. In the first stage, linguistic phrases were transformed to fit numbers using "bipolar distance scale". In the process of calculating the weights of indexes via the AHP-Fuzzy technique, their positive or negative aspects were not taken into account. Therefore, for combining fuzzy AHP and TOPSIS, first the options and indexes matrices were fuzzified via normalization and then normalized through vector normalization in order to take the positive or negative aspects of criteria into account.

Table 11. The relative proximity of each option

Plant Code	The close relative $CL^* = \frac{d^-}{d^+ + d^-}$
P1	0. 428
P2	0.561
P3	0.36
P4	0.693

According to the TOPSIS method, as shown by Table 11, CL ranges from zero to 1. The closer CL to unity, the closer the solution would be to the ideal solution and the more appropriate/logical the obtained solution would be. Therefore, considering Figure 3, the rank of power plants locations can be expressed as follows based on the weights derived from the fuzzy AHP method which is the product of expert opinions in this regard.

The results obtained from our proposed method are consistent with the efficiencies obtained for certain power plants, published in the latest energy balance sheet of The Ministry of Power. Table 12 shows the efficiency of the four studied power plants indicated in this energy balance sheet, which can be considered as proof for the accuracy and real representation of the proposed model.

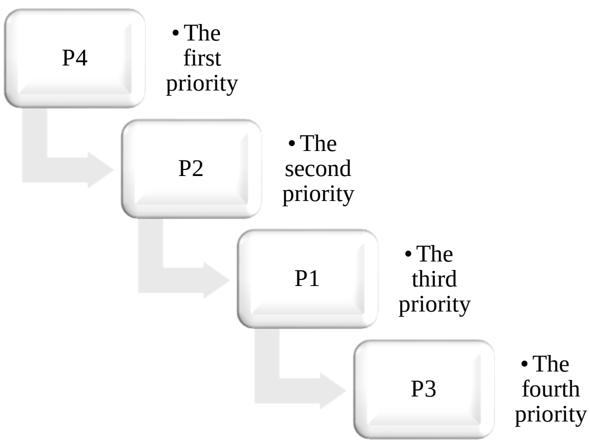

Figure 3. The rank of power plants locations based on the weights derived from the fuzzy AHP method

Table 12. The results obtained from our proposed method with the efficiencies obtained for certain power plants

Plant Code	Rank(in this model)	Efficiencies
P4	1	37.2
P2	2	36
P1	3	21.4
P3	4	20.4

4. Results and Discussion

Upon identifying the effective indexes for selecting a TPP location from reliable articles on the subject, we implemented the comments expressed by experts using the paired comparison method. Then, the weight of each index was obtained through the fuzzy AHP. The weights were introduced to the TOPSIS model in order to prioritize locations (as options). Table 13 shows the weights in a descending order.

Table 13. The weights of alternative locations with respect to sub-criteria

Index	Symbol	(in final model)
Impact on Groundwater	X_{13}	0.08
Cost of Maintenance	X_5	0.076
Cost of Construction	X_3	0.073
Cost of Convection	X_4	0.072
Cost of land	X_1	0.071
Stay away from fault	X_{12}	0.068
Cost of Launch	X_2	0.068
Cost of labor	X_6	0.066
Access to transport network	X_{11}	0.063
Access to water	X_7	0.0625
Access to areas of consumption	X_9	0.0615
Access to labor	X_{10}	0.061
Impact on Agricultural land	X_{14}	0.06
Impact on Air pollution	X_{15}	0.059
Access to fuel	X_8	0.057

According to Table 13, the status of ground water is very sensitive due to water shortage. As a result, the influence of TPPs on ground water is considered as the first priority in the selection of TPP location and the maximum weight is assigned to it. The conducted studies revealed that ground water (qanats and wells) had the maximum concentration in terms of most chemical parameters and, in some cases, this concentration exceeded the allowable limits. The reason may be traced to the high concentration of different industries within a limited area, excessive use of ground water and industrial sewages produced by the industries. Second rank belongs to procurement and maintenance costs and is of high importance due to the fact that they are continuous and current costs. Construction, power transmission and land costs rank the third followed by distance from fault. Here, the notable matter is that distance from fault has been considered as a priority. This means that experts believe that the existence of fault margin is a definite index and if it is not satisfied, no construction permit will be issued. This index is considered as a fuzzy index prioritized along other ones. In the next step, considering four locations as options, TOPSIS was used to prioritize the location in terms of weights derived from fuzzy AHP.

Table 14. The rank of power plants locations based on the weights derived from the fuzzy AHP method

Plant Code	Rank(in this model)
P4	1
P2	2
P1	3
P3	4

5. Conclusions

The results obtained for efficiencies of TPPs published in the last balance sheet of The Ministry of Power shows good conformity with our results. Table 14 shows the efficiency of the four studied TPPs indicated in the published balance sheet and this can be considered as a proof for the accuracy and real representation of the proposed model.

6. Suggestions

By the aid of this study, in the process of making decisions for selecting an option for constructing a TPP, one can select a correct option based on the scientific indexes approved by the experts of this field. In addition, even when no alternative has been considered, it is possible to study the quality of combining the indexes using GIS considering derived priorities and weights.

7. Limitations

Taking technical factors into account besides managerial macro-factors aimed at promoting technical efficiency: Adding technical indexes to available ones makes it possible to analyze the problem of selection TPP location more accurately and more applicably.

Social development factors, including influential factors of tourism, are factors affecting the selection of power plant location from cultural point of view and this has been neglected in this study.

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