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ORIGINAL RESEARCH PAPER

The Location of Thermal Power Plants by Using an Integrated Models of AHP and TOPSIS

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ABSTRACT: Selecting optimal location of gas power plants is one of challenging issues in the environmental assessment of development projects. This article aimed to study the optimal location for the construction of a thermal power plant in Sirjan, Iran based in environmental criteria using an integrated method (AHP[1] and TOPSIS[2]). In this research, we studied the certain regional features. Delphi was used to identify the environment, power plant-related parameters affecting the location process. AHP was employed to prioritize and determine the weights of criteria and sub-criteria in Expert Choice. Then, TOPSIS and prioritized criteria by AHP were employed to form the decision matrix for 6 sites based on 13 macro indices and 36 sub-criteria. In this study, combined components were taken into account including power plant factors; environmental, physical, and biological factors, technical-economic factor, and background contamination. The results showed that Technical-Economic Factor with the weight of 0.4830 was prioritized first followed by Physical and Biological Index with weights of 0.272 and 0.157, respectively. Then, expert judgments were used in TOPSIS decision-making process in order to form the initial matrix. Once this stage was complete, the matrices were weighted using the weights of criteria. The distance of each option was estimated from the Positive Ideal Solution and Negative Ideal Solution. Accordingly, Closeness Coefficient was calculated. Eventually, the best site scenario was determined. Among the six proposed sites, Site II was found to be the best option in terms of environmental, economic, and technical factors.

Keywords: Environmental Decision-Making, Fuzzy Logic, Location, Gas Power Plant, Thermal Power Plants.

RUNNING TITLE: Thermal Power Plants by Using an Integrated Models

1 Analytic Hierarchy Process
2 Technique for Order of Preference by Similarity to Ideal Solution

INTRODUCTION

Natural resources of each land are the main components of its development. Along with HR and financial resources, they can create the basis for the economic and social development (Amelia, *et al.,* 2009). The exploitation of these resources is fruitful if they are in line with the sustainable development and have a suitable level of knowledge and awareness for using technology and resource management. Growing demand for electricity has made the construction of new power plants inevitable. The effect of power-plant location on production cost, energy transfer, environment, etc. makes the selection of optimal location difficult (Al- Najjar, and Alsyouf, 2003). Short-term construction and the possibility of constructing thermal power plants in most Iranian regions have made the construction of these power plants of particular importance. Due to the major share of gas power plants, the tendency to construct these power plants has increased. From the beginning, the optimal site of gas power plants is the conceptual study of these plans requiring special attention to various criteria and factors. Type, capacity, and location of the power plant are the

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most important factors used in the study phase because the construction is associated with frequent socioeconomic, political, and environmental consequences. As a result, it is essential to conduct comprehensive studies prior to the construction. Despite social and economic benefits of construction and exploitation in any region, it is necessary to investigate the environmental consequences by feasibility and location studies. As a result, the location would have minimum adverse environmental effect on the region's ecological and economic environment. Location is one of the most widely used spatial decisions which can be affected by many environmental factors. Optimal location process requires the investigation of an extensive set of factors and balance of multiple targets to determine a particular area for a particular use. In addition to meeting the technical needs, the process needs more accurate investigations on the thermal power-plant location. As a result, spatial phenomena affecting the construction and operation must be carefully analyzed and proper locations must be selected accordingly. Thermal power-plant location is important for two reasons: First, it is possible to construct a power plant from a technical point of view and it is justifiable from the economic view and secondly, it should have the least damage to the environment (Awasthi, *et al.,* 2010). Decision making is the process of selecting among options, hypotheses, locations, etc. The decision support system must consolidate its process. The world around us is full of multi-criteria issues. Multi-criteria decision making involves methods that help individuals decide on several different and sometimes contradictory criteria. In fact, multi-criteria decision-making through the decomposition of the problem into smaller components allows for scrutinized analysis. After investigating and decision-making on small parts, the components get together and show the final outcome of decision-makers' general tendencies (Charle and Pan, 2002). The number of comparison rises as the number of options and criteria increases (Chang, *et al.,* 2011). Due to social, economic and environmental effects, industrial projects have a significant impact on regional planning (Claver, *et al.,* 2007). Most location criteria depend on Iran's status qua, accessible resources, and other factors such as the type of industry (Christmann, Taylor, 2001). Over the years, hundreds of multi-criteria decision-making methods have been used that differ from each other in terms of the theoretical background, the type of question and the type of results (Chang, *et al.,* 2011). Decision-making stages in multi-criteria decision analysis involve the definition of decision-making problem, determination of criteria required for analysis, weighting, determination of relative importance, and combination of criteria (Diabat and Govindan, 2010).

AHP is a method that can only rank different options according to their weight, but cannot distinguish between acceptable and unacceptable alternatives (Eltayeb *et al*., 2011). The judgment of the decision on the characteristics of the options varies in shape and depth. TOPSIS is a multi-criteria decision-making method, of great importance due to the possibility of evaluating options based on qualitative and quantitative criteria as well as the ease and speed of its modeling solution. It was first developed by Gerrard and Kandlikar in 2007.

This article aimed to determine the optimal model for a new thermal power-plant location (Sirjan Gas Power Plant) from the environmental perspective and identify the factors affecting the environmental decision-making in order to provide managerial solutions. In this regard, an integrated algorithm (AHP+TOPSIS) is proposed.

Materials and Method

The optimal location for a power plant depends, to a large extent, on the full and correct recognition of the effective factors and how they are selected. First, technical, social, economic, and environmental factors related to the construction of the power plant were determined through the interviews with the experts and technical texts. Then, those with the possibility of providing data and model were selected. The area under study is located between latitudes of 54°30' and 56° 45' E and longitudes of 28°30' and 30° 15' N. It is 175 km south west of Kerman, Iran. After extracting the appropriate indicators for power-plant location and separating criteria and sub-criteria, a pairwise comparison questionnaire was developed to quantify and value the selected criteria for locating the 500 MW Sirjan Gas Power Plant. The questionnaire was forwarded to the experts. In line with the quantification of the extracted criteria, the professional comments of the experts were collected and then analyzed using AHP, consistent with the research method and type of variables. The data were analyzed in Excel 2007 and Expert Choice. Table 1 shows the scale of preferences between factors and indicators for a pairwise comparison

Preferences (Verbal Judgment)	Numerical Value
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Preference between Strong Intervals	2, 4, 6, 8

Table 1: Bipartite scale in Pairwise Comparison (Hervani, *et al.* 2005)

Incompatibility Rate is an important factor for pairwise matrices. Incompatibility Rate is a mechanism by which the validity of responses is evaluated by comparison matrix (Hori and Shimizu, 1999). Table 2 shows the randomness index according to the number of criteria (n).

N	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 2: Randomness Index (RI) for Criteria in Decision-Making Process (Jassbi, *et al.*, 2011)

According to Eq. (1) and (2), Inconsistency Rate (I.R.) is obtained by dividing the incompatibility index (I.I) into a randomness index (R.I).

$$\mathrm{I.I} = \frac{\lambda_{max} - n}{n-1}, n = 1,2,\ldots,m$$

$$\mathrm{I.I} = \frac{\lambda_{max} - n}{n-1}, n = 1,2,\ldots,m \quad (1)$$

$$\mathrm{I.R} = \frac{\mathrm{I.I}}{\mathrm{R.I}}, n = 1,2,\ldots,m$$

$$\mathrm{I.R} = \frac{\mathrm{I.I}}{\mathrm{R.I}}, n = 1,2,\ldots,m \quad (2)$$

If I.R≤0.1, the consistency of judgments is acceptable.

Then, TOPSIS was employed to rank the options (Kumar, *et al.*, 2010). Decision-making matrix elements were first quantified. Eq. (3) shows Step I in TOPSIS: Decision-making Matrix is normalized using Eq. (3) as follows:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x^2_{ij}}}$$

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$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x^2_{ij}}}, i = 1,2,\ldots,m \quad (3)$$

In Stage II, Positive Ideal Solution and Negative Ideal Solution are calculated using Eq. (4) and (5) for each criterion. Then, the Euclidean distance is calculated from each Positive Ideal Solution and Negative Ideal Solution using Eq. (6).

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(\vartheta_{ij} - \vartheta_j^+\right)^2}, i = 1,2,\ldots,m$$

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(\vartheta_{ij} - \vartheta_j^+\right)^2}, i = 1,2,\ldots,m$$

(4)

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(\vartheta_{ij} - \vartheta_j^-\right)^2}, i = 1,2,\ldots,m$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(\vartheta_{ij} - \vartheta_j^-\right)^2}, i = 1,2,\ldots,m$$

(5)

$$CL_i = \frac{D_i^-}{D_i^- + D_i^+}, i = 1,2,\ldots,m, 0 \le CL_i \le 1$$

$$CL_i = \frac{D_i^-}{D_i^- + D_i^+}, i = 1,2,\ldots,m, 0 \le CL_i \le 1$$

(6)

In this study, the criteria valued by the experts were analyzed and prioritized in Expert Choice. TOPSIS was used to determine six locations and select the top scenario.

Discussion

After collecting the experts' comments on indicators and weighting, the data were analyzed in Expert Choice. The results of input data analysis were quantified based in the elements, macro and micro indicators. In this article, environmental, power-plant, and regional factors were identified in the location of 500 MW Sirjan Gas Power Plant. Fig. 1 shows the pairwise comparison matrix after integrating the comments of 15 decision makers.

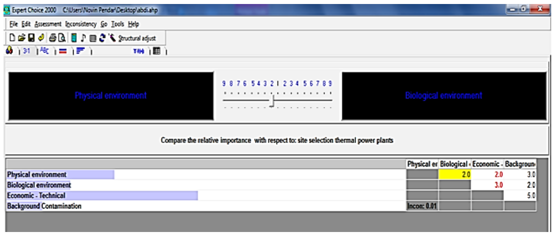

Fig. 1: Pairwise Comparison Matrix for Location of 500 MW Sirjan Gas Power Plant

The pairwise comparison matrix was calculated using the geometric mean. In this method, the geometric mean of each of the rows is calculated. Then, the columnar matrix is normalized by dividing the weights of each of elements by the existing elements. The new columnar matrix is the weight matrix in Sirjan Gas Power Plant location.

The extracted data are analyzed to process the weights of sub-criteria. Fig. (2) to (5) show the pairwise comparison matrix of sub-criteria for physical, biological, and economic-technical elements and background contamination .

$$\begin{bmatrix} a_{11} & \cdot & \cdot & a_{1n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & \cdot & \cdot & a_{nn} \end{bmatrix} \overset{1}{\rightarrow} \begin{bmatrix} \sqrt[n]{a_{11} \cdots a_{1n}} \\ \cdot \\ \cdot \\ \sqrt[n]{a_{11} \cdots a_{1n}} \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \cdot \\ \cdot \\ \pi_2 \end{bmatrix} \overset{2}{\rightarrow} \begin{bmatrix} \frac{\pi_1}{\sum_{i=1}^{n} \pi_i} \\ \cdot \\ \cdot \\ \frac{\pi_n}{\sum_{i=1}^{n} \pi_i} \end{bmatrix} = \begin{bmatrix} W_1 \\ \cdot \\ \cdot \\ W_n \end{bmatrix}$$

$$\begin{bmatrix} a_{11} & \cdot & \cdot & a_{1n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & \cdot & \cdot & a_{nn} \end{bmatrix} \overset{1}{\rightarrow} \begin{bmatrix} \sqrt[n]{a_{11} \cdots a_{1n}} \\ \cdot \\ \cdot \\ \sqrt[n]{a_{11} \cdots a_{1n}} \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \cdot \\ \cdot \\ \pi_2 \end{bmatrix} \overset{2}{\rightarrow} \begin{bmatrix} \frac{\pi_1}{\sum_{i=1}^{n} \pi_i} \\ \cdot \\ \cdot \\ \frac{\pi_n}{\sum_{i=1}^{n} \pi_i} \end{bmatrix} = \begin{bmatrix} W_1 \\ \cdot \\ \cdot \\ W_n \end{bmatrix}$$

(7)

The criteria, weighted by the experts, were loaded for the analysis. The weights of *Physical Element* criteria were estimated:

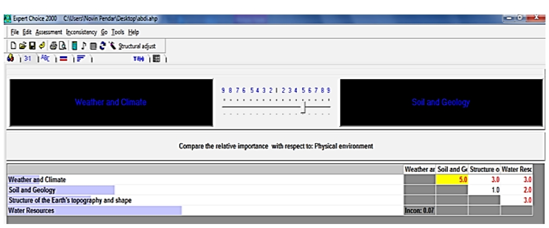

Fig. 2: Pairwise Comparison Matrix for Physical Dimension of 500 MW Sirjan Gas Power Plant Location

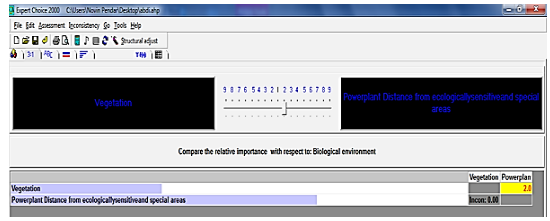

Fig. 3: Pairwise Comparison Matrix for Biological Dimension of 500 MW Sirjan Gas Power Plant Location

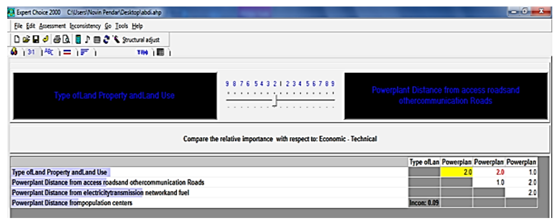

Fig. 4: Pairwise Comparison Matrix for Technical-Economic Dimension of 500 MW Sirjan Gas Power Plant Location

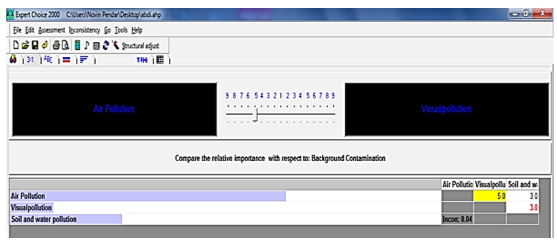

Fig. 5: Pairwise Comparison Matrix for Background Contamination of 500 MW Sirjan Gas Power Plant Location

After extracting and prioritizing the location criteria for Sirjan Gas Power Plant, appropriate spatial options were proposed using the basic maps, environmental conditions of the region, and quantified, classified criteria and indicators. Finally, the optimal location was proposed to construct the thermal power plant.

Construction of Sirjan Gas Power Plant/ Site I

The site is located at 29° 29' N latitude and 55°45' 30" E longitude in Najaf Abad, Central District, Sirjan, Iran.

Construction of Sirjan Gas Power Plant/

Site II

The site is located at 29° 31’ 21.3” N latitude and 55°43’ 51.1” E longitude in Najaf Abad, Central District, Sirjan, Iran.

Construction of Sirjan Gas Power Plant/ Site III

The site is located at 29° 30’ 56.4” N latitude and 55°43’ 51.3” E longitude in Najaf Abad, Central District, Sirjan, Iran.

Construction of Sirjan Gas Power Plant/ Site IV

The site is located at 29° 33’ N latitude and 55°43’ E longitude in Najaf Abad, Central District, Sirjan, Iran.

Construction of Sirjan Gas Power Plant/ Site V

The site is located at 29° 50’ N latitude and 55°28’ E longitude in Zeid Abad, Central District, Sirjan, Iran.

Construction of Sirjan Gas Power Plant/ Site VI

The site is located at 29° 45’ N latitude and 55°32’ E longitude in Zeid Abad, Central District, Sirjan, Iran.

To prioritize the proposals, the criteria rated in the previous section were used. Due to the many criteria and sub-criteria, screening was used to select the important factors in spatial scenario analysis. 13 macro indicators and 36 main sub-criteria were selected using the comments of the experts and the results of the graph in the previous section. The weights were scored on a 1 to 9 scale. Table 2 and 3 show the scaled decision-making matrix and 13 indicators.

To form the weighted scale matrix using obtained

Option	Weather and Climate	Soil and Geology	Topographic Structure and Landform	Water Resources	Vegetation	Power plant distance from sensitive and special ecological areas	Type of ownership and Land use	power plant's distance from access roads and other communication routes	Power plant distance from power transmission network and fuel supply source	Power station distance from the population centers	Air Pollution	Visual Pollution	Soil and Water Pollution
Site I	0.3458	0.4755	0.394771	0.0793	0.4672	0.38	0.40	0.5035	0.5144	0.49	0.2750	0.4950	0.507093
Site II	0.3458	0.4161	0.460566	0.7137	0.3634	0.38	0.40	0.6002	0.6002	0.49	0.2750	0.4950	0.507093
Site III	0.3458	0.3566	0.460566	0.3172	0.4153	0.38	0.40	0.4287	0.4287	0.49	0.4583	0.4950	0.422577
Site IV	0.4150	0.4161	0.394771	0.4758	0.4153	0.43	0.40	0.3429	0.3249	0.49	0.1833	0.4950	0.422577
Site V	0.4842	0.4161	0.328976	0.3172	0.4153	0.43	0.40	0.0857	0.0857	0.49	0.5500	0.0990	0.253546
Site VI	0.4842	0.3566	0.394771	0.2379	0.3634	0.43	0.40	0.2572	0.2572	0.49	0.5500	0.0990	0.253546

Table 3: Dimensionless Decision-Making Matrix for 13 Macro Indicators

in previous section using AHP, each element was multiplied by the corresponding dimensionless matrix entry. Table 4 shows the weighted matrix for 13 indicators.

Option	Weather and Climate	Soil and Geology	Topographic Structure and Landform	Water Resources	Vegetation	Power plant distance from sensitive and special ecological areas	Type of ownership and Land use	power plant's distance from access roads and other communication routes	Power plant distance from power transmission network and fuel supply source	Power station distance from the population centers	Air Pollution	Visual Pollution	Soil and Water Pollution
Site I	0.00	0.0344	0.0223	0.0095	0.0244	0.0401	0.0500	0.0595	0.0829	0.0395	0.0161	0.0055	0.0083
Site II	0.00	0.0301	0.0260	0.0856	0.019	0.0401	0.0500	0.0794	0.0968	0.0395	0.0161	0.0055	0.0083
Site III	0.00	0.0258	0.0260	0.0380	0.0217	0.0401	0.0500	0.0397	0.0691	0.0395	0.0269	0.0055	0.0069
Site IV	0.00	0.0301	0.0223	0.0570	0.0217	0.451	0.0500	0.0099	0.0553	0.0316	0.0107	0.0055	0.0069
Site V	0.01	0.0301	0.0186	0.0380	0.0217	0.451	0.0500	0.0397	0.0138	0.0237	0.0322	0.0011	0.0041
Site VI	0.01	0.0258	0.0223	0.0285	0.019	0.451	0.0500	0.0297	0.0415	0.0158	0.0322	0.0011	0.0041

Table 4: Dimensionless Decision-Making Matrix for 13 Macro Indicators

Conclusion

Depending on the indicator and its effectiveness on decision goals (optimal location), positive and negative responses for indicators with positive effects were considered the greatest and lowest values, respectively.

Positive Ideal (+): As the indicator increases, the utility rises for constructing the 500 MW Sirjan Gas Power Plant.

Negative Ideal (-):As the indicator decreases, the utility declines for constructing the 500 MW Sirjan Gas Power Plant.

Table 5 shows the relative distance of positive and negative ideals in prioritizing the spatial scenarios for the 500 MW Sirjan Gas Power Plant.

Location	Priority	+d	-d	CL
Location I	3	0.817742	0.111365	0.576605
Location II	1	0.01854	0.150406	0.890261
Location III	2	0.0689422	0.10042	0.59293
Location IV	4	0.0890992	0.093468	0.511965
Location V	6	0.0815566	0.047842	0.369724
Location VI	5	0.0711061	0.045101	0.388111

Table 5: Ranking Proposals using TOPSIS according to Macro Indicators

Important sub-criteria affecting the optimal location were quantified by the experts. According to the results by Expert Choice, Technical-Economic Factor was ranked first followed by Physical, Biological Factor, and Pollution in order. According to the results of criteria and sub-criteria for Physical, Biological, Technical-Economic factors, and Background Pollution, the most important criteria were quantified, identified, and then prioritized. Finally, the most important criteria were extracted by prioritization and quantitative and qualitative classification of sub-criteria by the experts in Expert Choice. Table 6 shows the coefficient of significance of each of the main components of the location of the 500 MW Sirjan Gas Power Plant.

No.	Element	Weight	Priority
1	Physical	0.272	2
2	Biological	0.157	3
3	Technical-Economic	0.483	1
4	Background Pollution	0.088	4

Table 6: Prioritizing Environmental, Power Plant, and Regional Elements for Location of 500 MW Sirjan Gas Power Plant

The results of TOPSIS showed that, at both micro and macro levels, Location II with greater CL compared to others was the most optimal location proposed by the Kerman Regional Electricity Company. Table 7 shows the ranking of the locations using TOPSIS.

Priority	Option
1	Site II
2	Site III
3	Site I
4	Site IV
5	Site VI
6	Site V
7	Site II

Table 7: Ranking Locations using FTOPSIS according to Macro Indicators

In other words, six proposals were made in Sirjan, Iran to select the best location according to the selected indicators and weights by AHP (13 Macro Indicators and 36 Sub-criteria) and integrating them with TOPSIS. The results showed that Location II had the greatest score at both macro and micro levels in FTOPSIS because it is optimal in terms of quantity and quality of groundwater resources, pptimal distance from the fault line, basins, surface and underground water resources, sensitive and special ecological areas, access roads and other communication paths, gas and electricity transmission lines, population centers, slope percentage, texture and depth of soil, vegetation, type of land use, and the site ownership, which is very important for the construction of thermal power plants. Location II is 6 km far from Sirjan, which is justifiable in terms of distance; however, it got lower scores on background pollution and inappropriate height from the sea level from the perspectives of the experts. Vegetation is more than that of II and III. It is poor in this regard, which makes it optimal for the industrial development. In terms of land use and ownership, it belongs to the government and it is an arid land; for these reasons, it received the greatest scores by the experts. It is also optimal in terms of access roads and gas and electricity transmission lines; as a result, it is the most optimal location for constructing the 500 MW Sirjan Gas Power Plant.

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