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NATURAL GAS INVESTMENT REGION SELECTION BY MULTI-CRITERIA DECISION MAKING AND GIS : A CASE STUDY IN KOCAELI CITY, TURKEY

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ABSTRACT

Ensuring gas supply to customers is among the top customer satisfaction goals of natural gas distribution companies. Natural gas strategic investment projects are planned according to the annual budget determined by Energy Market Regulatory Authority (EPDK) in order to provide natural gas supply in line with customers' connection demands. The presence of many criteria in the planning process makes region selection very difficult. Choosing the right investment area is extremely important in terms of budget and material/equipment management. The aim of the study is to minimize the difficulties experienced in determining natural gas strategic investment project regions and to provide natural gas supply to customers in the fastest and most efficient way. In the study, natural gas investment regions in the Kocaeli Region were determined by multi-criteria decision support analysis (MCDA) and the most suitable regions were determined. These criteria are customers' natural gas connection requests, distance to natural gas distribution lines, settlements, forest areas, highways, active faults, proximity to regional regulators and protected (natural protection) areas. These criteria are divided into 6 score classes. Vector and raster maps of the determined criteria were obtained and classification and weighting processes were applied. The most suitable investment regions were determined according to their importance by using the weighted overlay method on the maps obtained.

Keywords: Multi-Criteria Decision Analysis, GIS, Natural Gas Investment, Weighted Overlay Method.

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INTRODUCTION

Today, natural gas, a clean, efficient and low-carbon fuel, is an important source of energy for many countries. The positive role of natural gas in achieving carbon neutrality around 2050 is also noteworthy. One reason for this is that the process of reducing carbon emissions is gradual (Carvalho et. al. 2022; Wang et al. 2022). In this process, the use of renewable and green energy sources will not increase rapidly. In fact, fossil energy sources such as oil and natural gas are still needed for the conversion of electricity. Similar to hydropower, their energy supply is less stable. Another reason is that natural gas has lower greenhouse gas emissions than coal and oil. At the same time, the development of energy technology over the last few decades has significantly changed the global energy structure. This has structural implications for natural gas demand. First, advances in technology have led to greater utilization of unconventional sources of natural gas, such as shale and tight gas, resulting in more gas being produced and supplied at a lower price (Salygin et al. 2019).

Investments are a vital tool for the implementation of development policies and firms' investment decisions are important for the realization of strategic development objectives. In addition, the decision maker often has to choose between some parameters. Choosing between several investment projects involves using different methods of analyzing investment projects and selecting the most acceptable one. It is necessary to clearly define the investment objectives, the criteria to measure the achievement of these objectives, and then select among the available investment projects the one that best meets the investment objective set. The classical approach to the evaluation of investment projects is to analyze and measure the results obtained after the investment becomes operational using static or dynamic evaluation methods. The classical approach has been criticized for ignoring risk and uncertainty (Zopounidis, 1999). Early work in quantitative finance considers the profit maximization of the business as the main criterion for decision-making, and in addition to the basic principles of microeconomic theory, there are a number of important and relevant criteria: the revenue maximization model (Baumol, 1959), the manager's utility model (Williamson, 1964), the satisfaction model (Simon, 1957) and behavioral models (Cyert and March, 1963). The question of whether investment decisions can be made based on a single criterion or whether these problems have a multi-criteria structure is important (Bhaskar and McNamee 1983, Xiao et al. 2017). In addition, this study raises the question of determining the importance of the criteria in the model for investment decisions and which criteria should be prioritized. In a similar study, Bhaskar (1979) points to three different critical reviews of the solution of investment decision-making problems where only one criterion is listed as relevant. Once the decision maker has selected certain indicators against which the evaluation of investment alternatives will be made, a decision needs to be made on which of several projects to execute. The problem here is the possibility that there are more investment alternatives that meet all the criteria, so it is necessary to rank the investment alternatives and make the appropriate decision. It requires multi-criteria decision-making, which relates to decision-making situations where there are a number of criteria, often conflicting with each other, in order for the decision maker to make an optimal decision. The reality and topicality of the decision-making domain has led to a rapid and continuous development of methods used to solve the most complex problems. In fact, in the majority of decision problems, the results obtained must be analyzed from different angles and evaluated according to various criteria. Nowadays, this type of analysis with fast results has become possible by using geographic information system (GIS), which is an effective engineering tool for systematically organizing the factors influencing the selection of a suitable investment location. Once these factors have been identified, depending on the size of the project, a GIS should be used to evaluate these factors simultaneously. Furthermore, GIS-based visualization technologies and cartographic capabilities are often sufficient to identify suitable sites (Chand and Gloven, 2009, Chen et al. 2010). There are a number of factors that influence the investment site selection process. With GIS technologies, it is possible to analyze and examine such dense spatial data sets and interpret the results effectively. At a regional level, geographic information (GIS) on existing infrastructure can be included for natural gas investment to find site-specific solutions and take into account local characteristics (Then et al. 2020).

There are indications that natural gas, one of the petroleum derivatives, was first used in China in the 10th century BC. Natural gas began to be widely used in England in the last quarter of the 18th century. Its use increased rapidly in the first quarter of the 20th century after natural gas began to be transported through pipes and was discovered in the energy sector. Natural gas is one of the most preferred energy sources because it is environmentally friendly. It is used in industry, residential, commercial and public services, transportation and other areas. It is also used in industrial areas by converting it into electrical energy. Among the energy products used in our country, the natural gas usage rate ranks second with 22.8%, according to the 2021 data of the Turkish Statistical Institute (Figure 1).

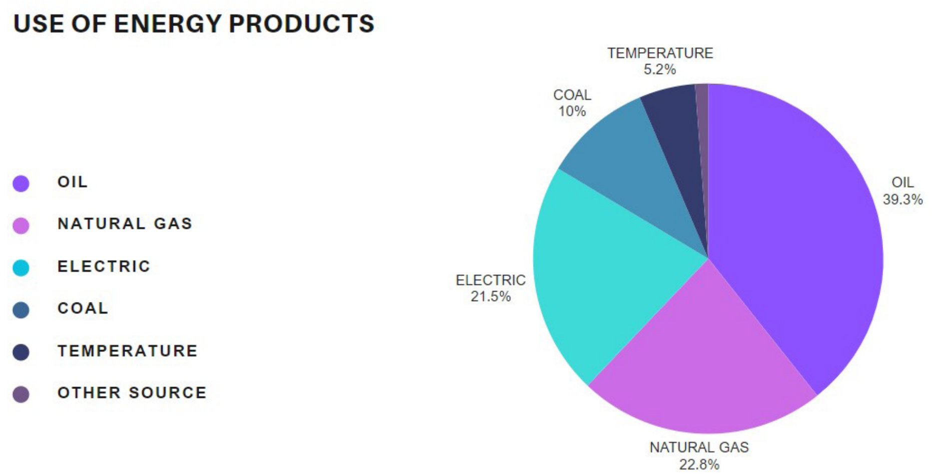


Figure 1. Use of Energy Products.

In general, investments are made in a specific exploration and development process. This is the main reason why the economic evaluation and investment management of conventional natural gas projects is worth further study. However, there are many uncertain and complex relationships involved in the economic evaluation process of conventional natural gas projects. In particular, these factors can be considered separately as technical and economic aspects. On the technological side, some parameters will affect the specific development technology project returns. In economic terms, the macroeconomic environment, structural energy demand, capital source, shareholder composition of companies, international market price fluctuations, fiscal and tax subsidies and other factors will affect project returns through different channels and mechanisms. Moreover, in these projects, technical and economic evaluation components are located in different sectors of the business. Index systems, objective functions and decision-making processes are not the same. It is difficult to economically evaluate such projects in a unified framework, and thus to make more systematic and scientific decisions (Yong et al. 2023).

Delivering natural gas to customers is a process that extends from city supply stations to customer service boxes. The main elements of the city network are: City supply stations, district supply stations, lines, valves and service boxes (Figure 2).

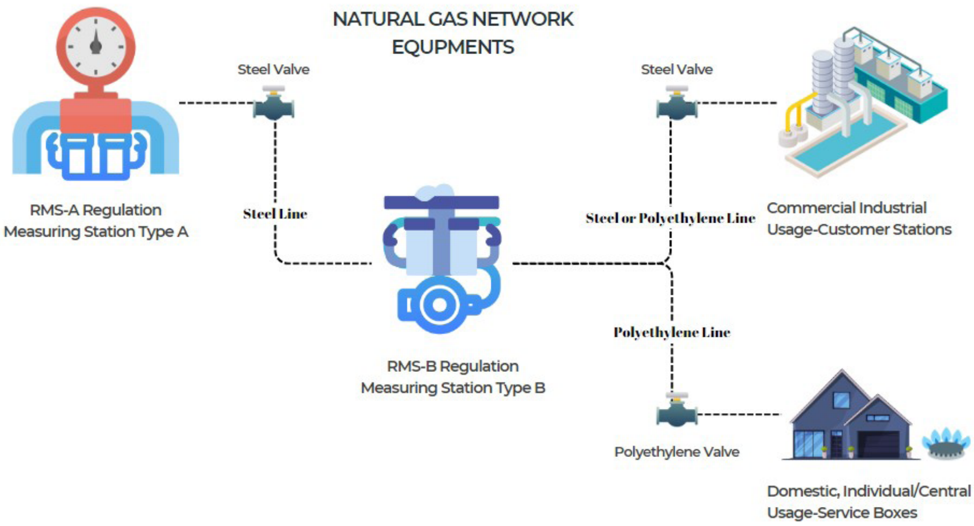


Figure 2. Natural Gas Network Equipment.

Natural gas, which is largely imported, is transported via high-pressure steel lines and stored in City Supply (RMS-A) Stations. The natural gas coming out of the city supply stations is reduced by medium pressure lines and transferred to the Regional stations. Natural gas from regional stations is transported to service boxes via distribution lines to provide gas supply to customers. Natural gas is typically transported to industrial customers via large-diameter, medium-pressure steel lines. It is also delivered to individual customers via low pressure polyethylene lines.

The most important step in planning activities for natural gas transmission pipeline projects is the selection of a feasible route. However, determining the optimum route on a topographic surface is a complex process. It is clear that many factors must be considered simultaneously in these projects. At each stage, the route will have economic, environmental, sociological and temporal impacts on the project. The aim is to minimize the negative impacts on nature and the environment as much as possible and to complete the project with the most efficient route at the least cost. Determining the best route depends on investigation and research, together with the analysis of a large number of complex data. Nowadays, a GIS can be used to evaluate these factors simultaneously, depending on the length of the project, in order to systematically organize the factors that influence routing.(Chand & Gloven, 2009; Wang et al. 2009; Balogun et al. 2015; El-Abbasy, et al. 2015).

Designing distribution lines in line with connection demands and ensuring gas supply to customers is possible by determining investment regions, which is the first step of the line manufacturing process. After the investment regions are determined, a capacity adequacy analysis of the existing network is made and its load carrying potential is examined. According to the analysis results, investment projects are prepared and simulated. The prepared projects are shared with the field teams and production is carried out. After the production is completed, gas supply is provided to the customers (Figure 3).

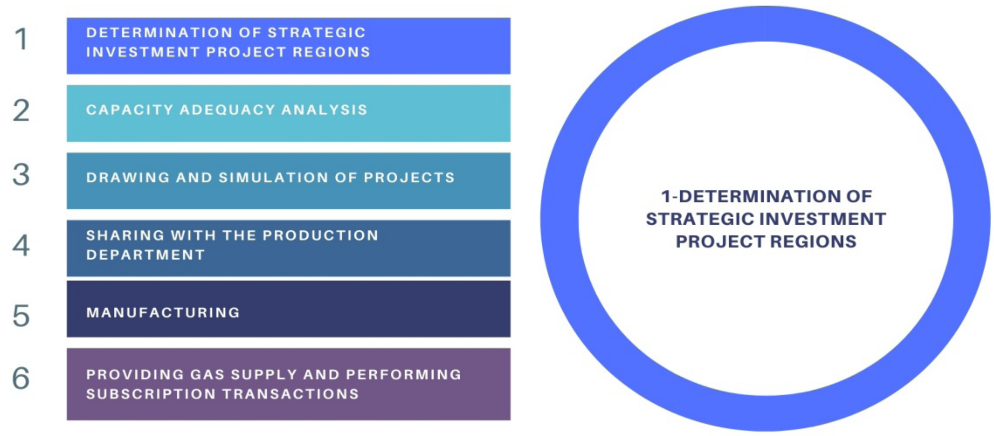


Figure 3. Line Manufacturing Process Flow Chart.

Determination of investment regions, which is the first step of the line manufacturing process, is very important in terms of efficient use of budget/cost, time and workforce, so it must be determined as soon as possible and with accurate modeling. Since many criteria are evaluated in determining strategic investment regions, determining suitable regions can take a long time. It takes time and makes the decision maker's prediction difficult. With this study, the most suitable investment regions will be determined by evaluating and weighting many criteria. In order to carry out activities such as operation, maintenance and repair of natural gas distribution lines in a safe manner, these lines must be constructed on public zoned roads. Ensuring gas supply to customers is among the most important customer satisfaction targets of natural gas distribution companies. Natural gas strategic investment projects are planned according to the annual budget determined by Energy Market Regulatory Authority (EPDK) in order to ensure natural gas supply in line with customers' connection requests. The presence of many criteria in the planning process makes it very difficult to select a region. Selecting the right investment region is extremely important in terms of budget and material/equipment management.

The aim of this study is to develop a framework that can minimize the difficulties in determining natural gas strategic investment project regions and provide natural gas supply to customers in the fastest and most efficient way. In the study, natural gas investment regions in Kocaeli Region were identified by using Multi-Criteria Decision Support Analysis (MCDA) and the most suitable regions were determined. MCDA is an analysis process that aims to model the decision-making process according to the criteria and maximize the benefit that the decision maker will obtain at the end of the process. In the first stage of the MCDA process, the difficulty in identifying natural gas strategic investment project regions was selected as the main problem and the criteria for this purpose were determined according to expert opinions and EPDK regulations. These criteria are; customers' demand for natural gas connection, distance to natural gas distribution lines, settlements, forest areas, highways, active faults, proximity to regional regulators and protected areas. These criteria are divided into 6 score classes between 0 and 5. Vector and raster maps matching the criteria were obtained and classification and weighting processes were applied. By using the weighted overlay method on the obtained maps, the most suitable investment regions were determined according to their importance. In this work, a study that can be taken as a basis by natural gas distribution companies regarding investment location selection has been carried out and this study has an original value since there are not enough studies on this subject in our country.

1. METHODOLOGY

Planning activities, by its nature require analysis of different data and approaches of together in one process. In order to solve a complex problem for certain purposes planers generally analyze and examine different types of input data with different kinds of approaches. Evaluation of these data and approaches with respect to the information regarding spatial positions are called "Suitable Site Selection Activities" (Olcan and Şeker, 2007).

MCDA is a set of methods that constitutes a sub-branch of Decision Science and incorporates different approaches. MCDA is based on the process of modeling the decision process according to criteria and analyzing it in a way that maximizes the benefit that the decision maker will obtain at the end of the process (Figure 4).

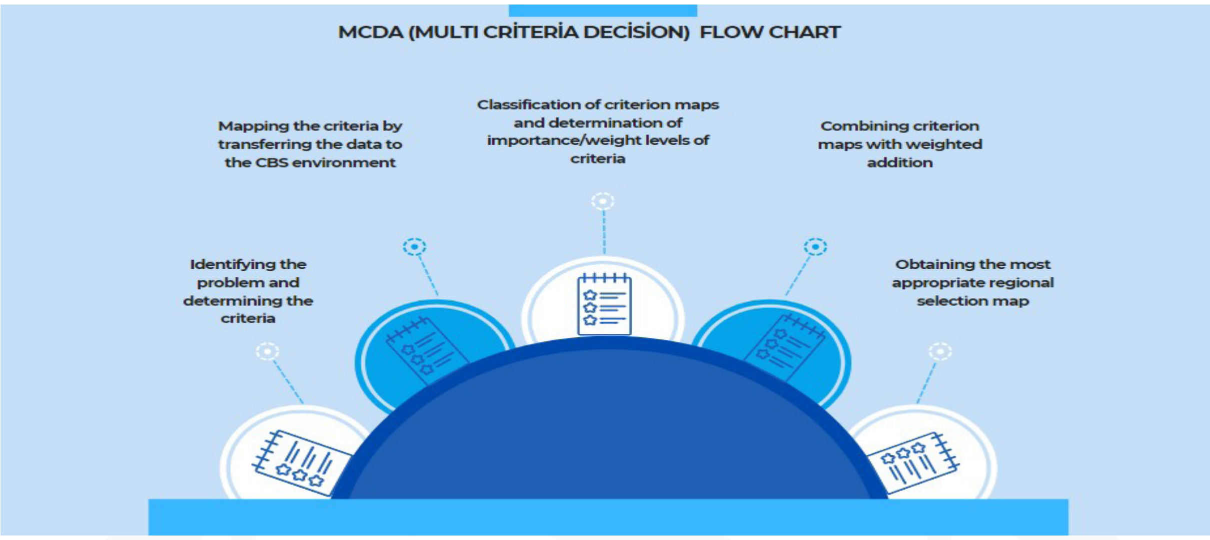


Figure 4. Multi Criteria Decision Flow Chart.

Since there are many criteria in selecting the most suitable location for Strategic Investment Project Regions, AHP (Analytical Hierarchy Process), one of the MCDA (Multi-Criteria Decision) methods, was used (Figure 5).

The AHP method was developed by Thomas L. Saaty in the 1970s and it is one of the MCDA approaches based on bilateral comparisons (Saaty, 1980). AHP is a method that has attracted the attention of many researchers due to the ease and practical use of the data needed to model and solve the decision problem. AHP is a decision support tool that can be used to solve complex multi-criteria decision problems. It is an approach that can incorporate concrete and quantitative criteria as well as abstract and qualitative criteria based on the judgment of experts. This method ensures that both objective and subjective factors are taken into account when selecting the best alternative. Most people today make decisions using judgments based on self-evaluation or using mathematical models with unprovable or inconclusive results. What is needed in this situation is a decision methodology that simplifies the complex problem, makes it easier to understand and reveals the relationship between the components of the problem.

The criteria used in determining investment regions, which is the first stage of the line manufacturing process, were selected in accordance with EPDK regulations and expert opinions. Data for each criterion were transferred to the GIS environment. Vector data of the determined criteria were converted to raster format with distance analysis using ArcGISPro. Criteria were prioritized and their weights were determined by the AHP method. Re-classification was performed on raster data. Re-classification criteria are combined with weighted overlap. As a result of the study, investment regions were determined according to the suitability level and the resulting map was discussed.

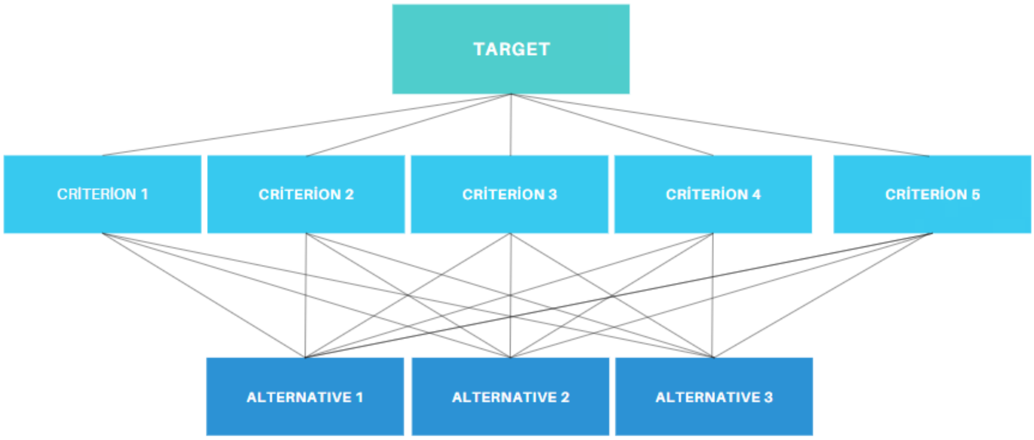


Figure 5. AHP hierarchical structure (adapted from Pala, 2013).

2. STUDY AREA AND DATA

Kocaeli Province was chosen as the study area (Figure 6). Kocaeli is one of the most important industrial centers of Turkey and the Marmara Region and forms an intercontinental transit network thanks to its D-100 and TEM railway connections connecting Europe and Asia. Kocaeli has a surface area of 3,505 km2 and the provincial center of Izmit has a population of 371,002 (2021 census). It's geographical location is between 40-41^{0}N and 29-31^{0}E. Kocaeli is located on the northwestern coast of Anatolia, on the Gulf of Izmit in the Sea of Marmara, about 100 km east of Istanbul. The rapid continuation of natural gas investments in the Kocaeli region is the main factor in choosing the region. Data was obtained from various public institutions and natural gas distribution companies (Figure 7, Figure 8). The study area data were collected and a database was prepared with ArcGIS software, which includes a geographic database with vector and raster dataset features. The geographical database used in the analyses consisted of the collected data. A single database was created for both raster and vector data. The symbolic structure of the database is shown in Figure 7-8.

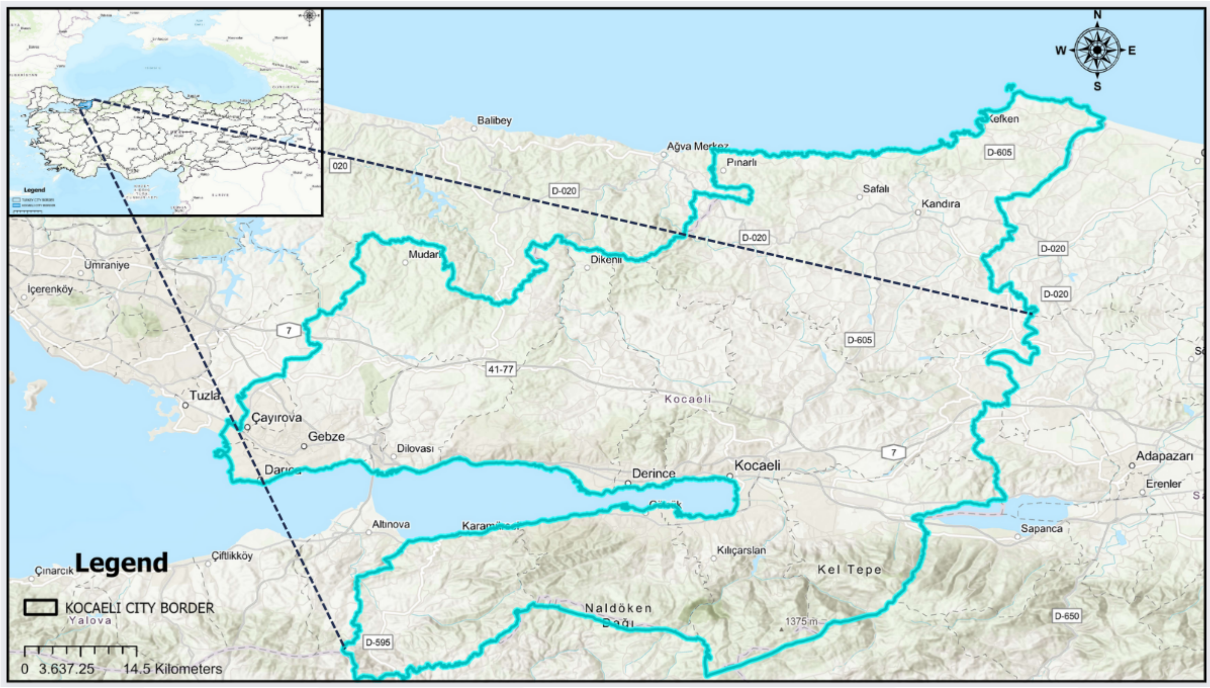


Figure 6. Study area.

Several criteria must be considered when selecting a natural gas investment site. In addition, many important environmental and economic parameters need to be taken into account to select a suitable site. These criteria can be presented in many ways. Investment land selection criteria may vary from one region to another depending on local conditions and circumstances. There are eight criteria to consider when selecting an investment site in Kocaeli region. These are public requests, proximity to the natural gas distribution line, proximity to RMS-B Stations, settlement area, forest, highway, active faults and protected areas (Figure 7).

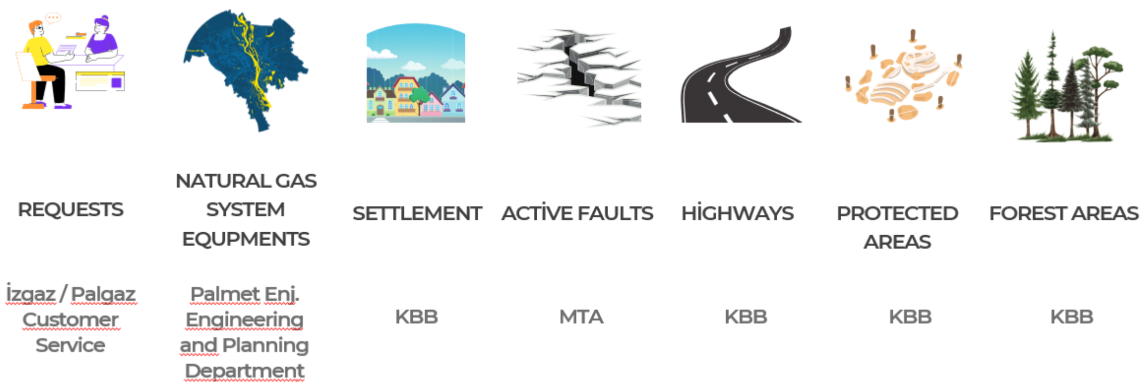
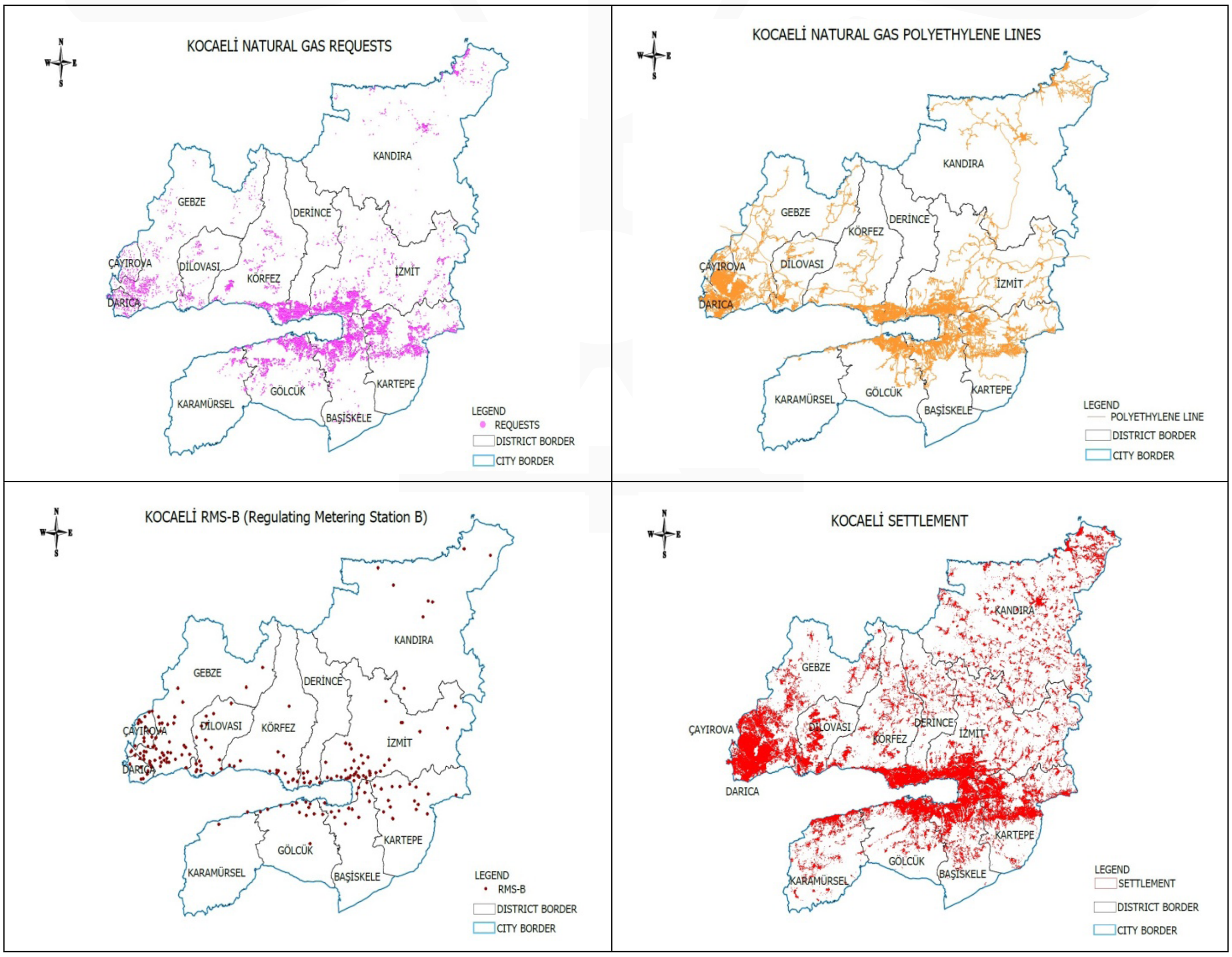


Figure 7. Criteria data and the institutions from which the data is obtained.

In the study, the criteria determined by taking into account expert opinions in accordance with EPDK regulation are as follows: Demands: In the selection of investment regions, regions with customer demands are given priority within the budget. Proximity to the natural gas distribution line: Providing gas supply to demands close to the distribution line is more convenient than in remote areas. Proximity to RMS-B Stations: For technical reasons such as capacity and pressure, it is preferred that investment areas be close to regional storage stations. Settlement: It is important to find a settlement in the region where the investment will be planned in terms of the determined budget/cost. Forest: Since forest areas require permission from public institutions, they are not primarily preferred when choosing an investment region. Highway: Passing natural gas lines through highways is not preferred due to high costs and institution permits. Active Faults: Active faults are not included in the EPDK regulation, but natural gas distribution companies avoid fault lines as much as possible in line with their own preferences due to disaster risk. Protected Areas: Natural gas line manufacturing cannot be carried out in protected areas without obtaining the opinion of the institution; therefore it is not preferred as an investment area. The layer maps containing data on these criteria are shown in Figure 8.



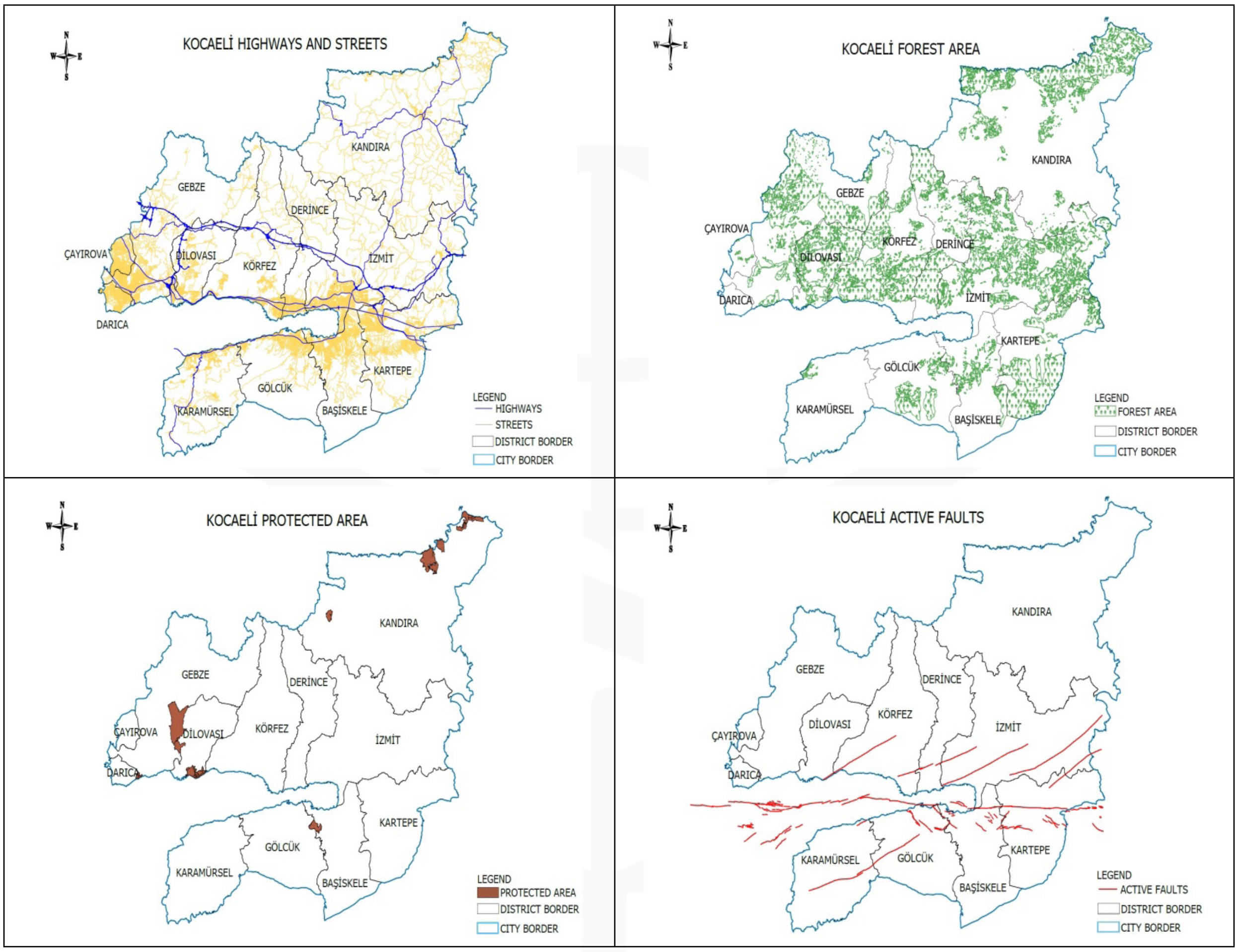


Figure 8. Data maps produced for the criteria.

3. METHOD

Solving geo-spatial decision problems often requires an intelligent and integrative use of information, domain-specific knowledge and an effective communication tool. While GIS and MCDA play important roles in solving spatial decision-making problems, each of these tools has its own limitations in dealing with such problems. For example, GIS is a great tool for addressing physical suitability analysis. However, it has limited abilities to incorporate decision makers' preferences and heuristics into the problem solving process. There is a wide range of related methodologies that attempt to solve 'real world' GIS-based planning and management problems. They offer a variety of techniques and applications that integrate the preferences of decision makers as well as incorporate knowledge from various disciplines.

AHP is one of the most popular methods for obtaining criterion weights in MCDA and has been used in GIS-based MCDA. It calculates the required weights associated with the criteria map layers with the help of a preference matrix in which all relevant criteria are compared against each other with preference factors. The weights can then be aggregated with the criteria maps in a similar way to weighted combination methods. GIS-based AHP is popular due to its capacity to integrate large amounts of heterogeneous data and the ease of obtaining weights for a large number of criteria; hence it has been applied to address a wide range of decision-making problems (El-Abbasy, Senouci, Zayed, & Mosleh, 2015; Nyström & Söderholm, 2010; Pala, 2013; Yaralıoğlu, 2004). AHP was basically carried out through 6 main steps in this study and the first 4 steps of the AHP method used in the study are outlined as in the following. The first step of AHP is the decomposition of the decision making problem into a hierarchical structure. The structural hierarchy for the decision problem consists of several levels. Several criteria, including demands, proximity to the natural gas distribution line, proximity to RMS-B Stations, settlement area, forest, highway, active faults, protected areas are established to form the hierarchy of the main objectives of selecting a suitable investment site. These criteria (e.g. environmental factors) are then divided into various sub-criteria such as geology, surface water, land use, etc. The second step is to create decision tables at each level of the hierarchical decomposition. The matrices capture a series of pairwise comparisons using relative data. The comparison can be done using a nine-point scale or real data if available (Saaty and Vargas, 2001). The nine-point scale includes: [9, 8, 7, ..., 1/7, 1/8, 1/9], where 9 means extreme preference, 7 means very strong preference, 5 means strong preference and 1 means no preference (Figure 10). This pairwise comparison simplified the decision-making process by providing an independent assessment of the contribution of each factor (Rezae and Karami, 2008).

The pairwise comparisons of the determined criteria are organized into a square matrix. The diagonal elements of the matrix are 1. The principal eigenvalue of the comparison matrix and its corresponding normalized right eigenvector give the relative importance of the criteria being compared. The elements of the normalized eigenvector are weighted according to the criteria or sub-criteria and ranked according to the alternatives (Bhushan and Rai, 2004). The consistency of the nth order matrix was then evaluated. If this consistency index failed to reach a threshold level, the responses to the comparisons were re-examined. The consistency index, CI, can be calculated as follows:

$$\text{CI(consistency indicator)} = (\lambda\max - \text{Number of criteria})/(\text{Number of criteria} - 1) \quad (1)$$

where CI is the consistency index (1), $\lambda\max$ is the largest or principal eigenvalue of the matrix and n is the order of the matrix. This CI can be compared to a random matrix, RI, such that the ratio CI/RI is the consistency ratio, CR. As a general rule, CR < 0.1 must be satisfied for the matrix to be consistent. Homogeneity of factors within each group, a small number of factors in the group and a better understanding of the decision problem improve the consistency index (Saaty, 1993). For this study, CR = 0.08 was obtained; therefore, this result indicates that a consistent matrix was created. In the third step, the rating of each alternative was multiplied by the weights of the sub-criteria and summed to determine the local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and summed to determine the global ratings (Bhushan and Rai, 2004). In this study, each criterion was given different scores from 1 (least favorable) to 6 (most favorable).

Step 1: The first step is to define the problem, alternatives and criteria are determined.

The number of criteria used (n) is 8 as shown in the Figure 9.

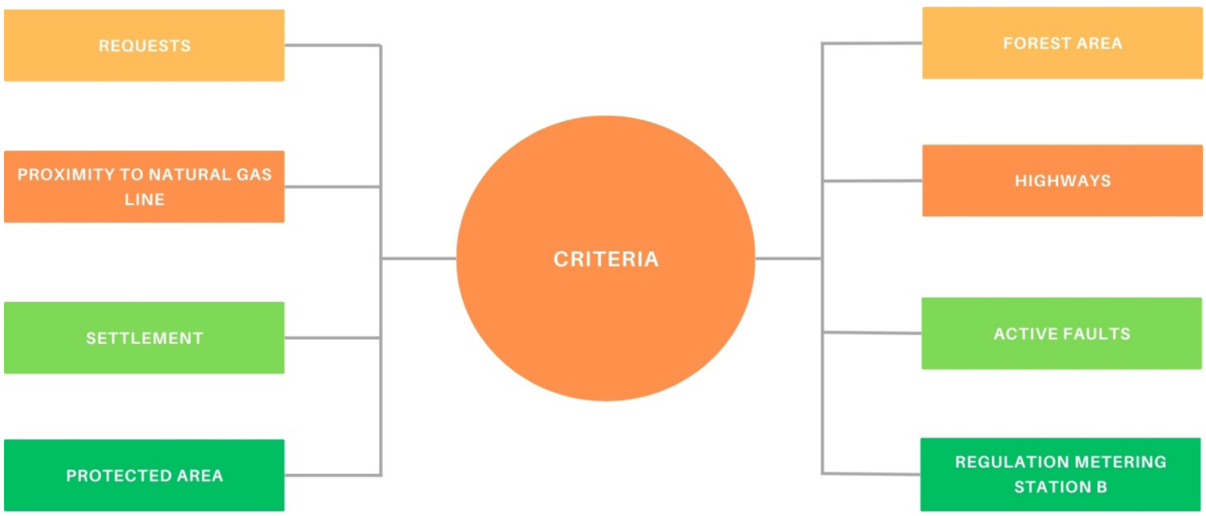


Figure 9. Criteria used in the study.

Step 2: Obtaining the Pairwise Comparison Matrix (A)

The pairwise comparison matrix is an nxn size square matrix. Pairwise comparisons were made based on expert opinions on the determined criteria. The Survey example used for pairwise comparison purposes is shown in Figure 11. AHP scoring scale was used when obtaining this matrix. The AHP scoring scale is divided into severity levels from 1 to 9. 1 means equal importance, while 9 means extremely important. As you move from 1 to 9, the level of importance increases (Figure10).

During creating the binary comparison matrix, the index corresponding to the criterion takes the value of 1 since it has the same importance level. Therefore, all the elements on the diagonal of the matrix take the value 1. When determining index values, for example, if the first criterion is 9 degrees more important than the second criterion, the a_{12} element becomes 9, while the a_{21} element takes the value 1/9. Conversely, if the second criterion is 9 degrees more important than the first criterion, a_{12} takes the value 1/9 and a_{21} takes the value 9. The pairwise comparison matrix is shown in Table 1.

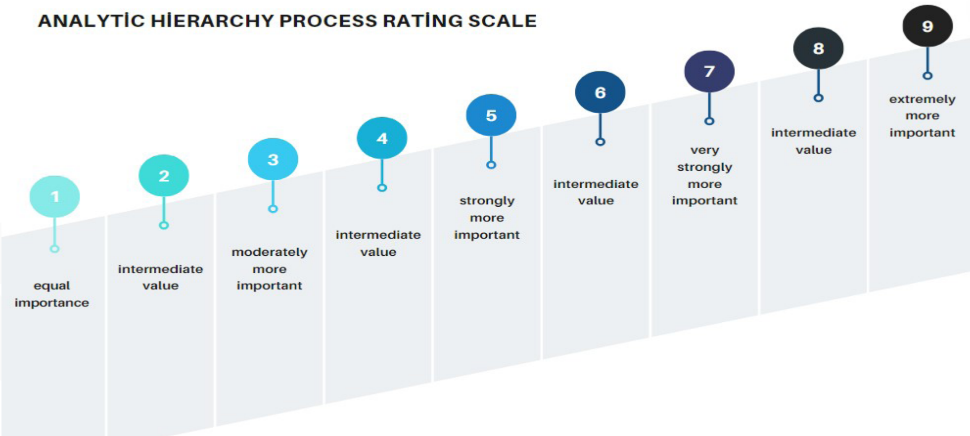
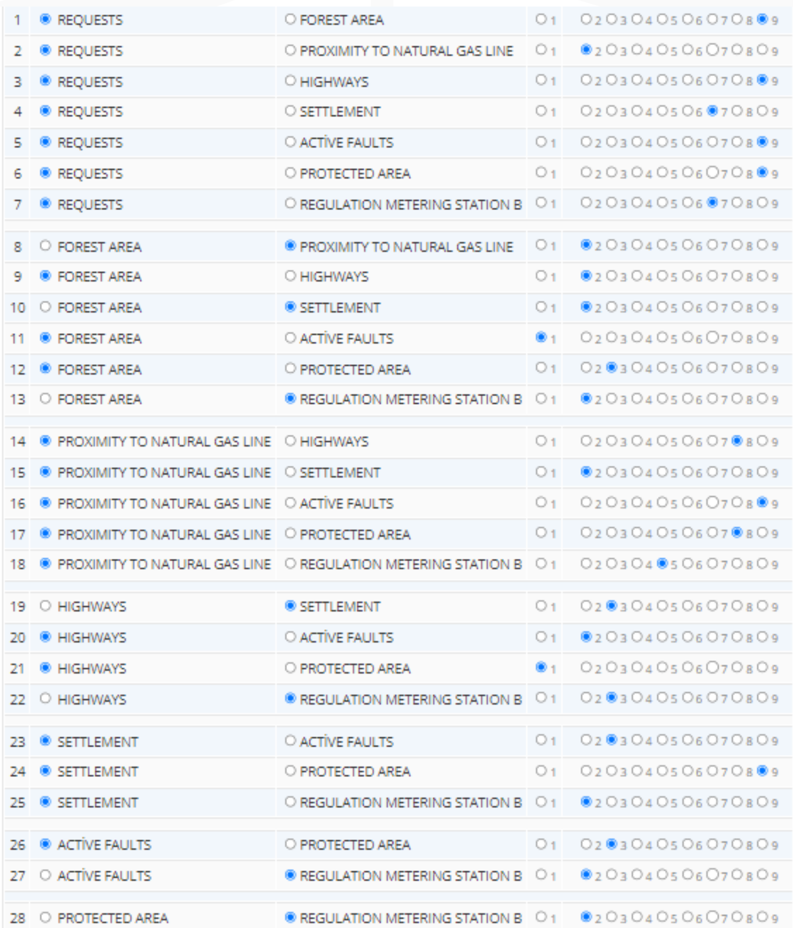


Figure 10. Analytic Hierarchy Process Rating Scale.

Pairwise comparisons were naturally performed with expert opinions on the determined criteria and the survey sheet used for pairwise comparison purposes is shown in Figure 11.



1	● REQUESTS	○ FOREST AREA	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
2	● REQUESTS	○ PROXIMITY TO NATURAL GAS LINE	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
3	● REQUESTS	○ HIGHWAYS	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
4	● REQUESTS	○ SETTLEMENT	○1 ○2 ○3 ○4 ○5 ○6 ●7 ○8 ○9
5	● REQUESTS	○ ACTİVE FAULTS	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
6	● REQUESTS	○ PROTECTED AREA	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
7	● REQUESTS	○ REGULATION METERING STATION B	○1 ○2 ○3 ○4 ○5 ○6 ●7 ○8 ○9
8	○ FOREST AREA	● PROXIMITY TO NATURAL GAS LINE	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
9	● FOREST AREA	○ HIGHWAYS	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
10	○ FOREST AREA	● SETTLEMENT	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
11	● FOREST AREA	○ ACTİVE FAULTS	●1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
12	● FOREST AREA	○ PROTECTED AREA	○1 ○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
13	○ FOREST AREA	● REGULATION METERING STATION B	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
14	● PROXIMITY TO NATURAL GAS LINE	○ HIGHWAYS	○1 ○2 ○3 ○4 ○5 ○6 ○7 ●8 ○9
15	● PROXIMITY TO NATURAL GAS LINE	○ SETTLEMENT	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
16	● PROXIMITY TO NATURAL GAS LINE	○ ACTİVE FAULTS	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
17	● PROXIMITY TO NATURAL GAS LINE	○ PROTECTED AREA	○1 ○2 ○3 ○4 ○5 ○6 ○7 ●8 ○9
18	● PROXIMITY TO NATURAL GAS LINE	○ REGULATION METERING STATION B	○1 ○2 ○3 ○4 ●5 ○6 ○7 ○8 ○9
19	○ HIGHWAYS	● SETTLEMENT	○1 ○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
20	● HIGHWAYS	○ ACTİVE FAULTS	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
21	● HIGHWAYS	○ PROTECTED AREA	●1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
22	○ HIGHWAYS	● REGULATION METERING STATION B	○1 ○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
23	● SETTLEMENT	○ ACTİVE FAULTS	○1 ○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
24	● SETTLEMENT	○ PROTECTED AREA	○1 ○2 ○3 ○4 ○5 ○6 ○7 ○8 ●9
25	● SETTLEMENT	○ REGULATION METERING STATION B	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
26	● ACTİVE FAULTS	○ PROTECTED AREA	○1 ○2 ●3 ○4 ○5 ○6 ○7 ○8 ○9
27	○ ACTİVE FAULTS	● REGULATION METERING STATION B	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9
28	○ PROTECTED AREA	● REGULATION METERING STATION B	○1 ●2 ○3 ○4 ○5 ○6 ○7 ○8 ○9

Figure 11. Survey sheet used in the study.

Table 1. Comparison Matrix (A).

Criteria	Request	Forest Area	Proximity To Natural Gas Line	Highways	Settlement	Active Faults	Protected Area	Regulations Metering Station B
Request	1.00	9.00	2.00	9.00	7.00	9.00	9.00	7.00
Forest Area	0.11	1.00	0.50	2.00	0.50	1.00	3.00	0.50
Proximity To Natural Gas Line	0.50	2.00	1.00	8.00	2.00	9.00	8.00	5.00
Highways	0.11	0.50	0.12	1.00	0.33	2.00	1.00	0.33
Settlement	0.14	2.00	0.50	3.00	1.00	3.00	9.00	2.00
Active Faults	0.11	1.00	0.11	0.50	0.33	1.00	3.00	0.50
Protected Area	0.11	0.33	0.12	1.00	0.11	0.33	1.00	0.50
Regulations Metering Station B	0.14	2.00	0.20	3.00	0.50	2.00	2.00	1.00
Column Totals	2.23	17.83	4.55	27.50	11.77	27.33	36.00	16.83

Step 3: Obtaining the Standardization Matrix (N) and W Column Vector (Weights)

In order to examine the percentage importance distributions of the criteria, each element in the pairwise comparison matrix (A) is normalized by dividing it by the total of its column. As a result of this process, Standardization Matrix (N) is obtained. (Table 2).

Table 2. Standardization Matrix(N).

Criteria	Request	Forest Area	Proximity To Natural Gas Line	Highways	Settlement	Active Faults	Protected Area	Regulations Metering Station B
Request	0.45	0.50	0.44	0.33	0.59	0.33	0.25	0.42
Forest Area	0.05	0.06	0.11	0.07	0.04	0.04	0.08	0.03
Proximity To Natural Gas Line	0.22	0.11	0.22	0.29	0.17	0.33	0.22	0.30
Highways	0.05	0.03	0.03	0.04	0.03	0.07	0.03	0.02
Settlement	0.06	0.11	0.11	0.11	0.08	0.11	0.25	0.12
Active Faults	0.05	0.06	0.02	0.02	0.03	0.04	0.08	0.03
Protected Area	0.05	0.02	0.03	0.04	0.01	0.01	0.03	0.03
Regulations Metering Station B	0.06	0.11	0.04	0.11	0.04	0.07	0.06	0.06

The weight vector (W) is found by dividing the sum of each row of the normalization matrix (N) by the number of criteria (n). After the AHP steps are completed, when the result is within a consistent value range, the Weight vector (W) obtained at this stage can be used as weight in the application (Table 3).

Table 3. Weights vector.

W Column Vector (Weights)	1	2	3	4	5	6	7	8
	0.414	0.060	0.233	0.036	0.120	0.041	0.026	0.070

Step 4: The consistency ratio (CR) is calculated

CR values were computed for understanding the degree of consistency in the pairwise comparison of the criteria. If the CR value is less than 0.10, pairwise comparisons are considered consistent. If greater than 0.10, comparisons are inconsistent and need to be reevaluated. D column vector were obtained by matrix multiplication of Decision Matrix (A) and Priority vector (W) as shown in Table 4.

Table 4. D Calculated Vector.

AxW=D column vector	1	2	3	4	5	6	7	8
	3.677	0.508	2.015	0.310	1.019	0.343	0.217	0.597

Each element of vector D is divided by each element corresponding to W, and the arithmetic mean of the resulting column is taken. The resulting value is the lambda coefficient (λ =8.53). From the eqauation (1) CI value is obtained as CI = (λ –Number of criteria (8))/(Number of criteria (8)–1) = 0.08

$$CR = CI / RI \quad (2)$$

where RI is Random Index. The RI value is 1.56, which is considered the standard correction value. Then CR value was calculated as 0.05. Since CR<0.10, it was concluded that the values in the W priority vector could naturally be used as weights. The determined weight percentages are shown in Figure 12.

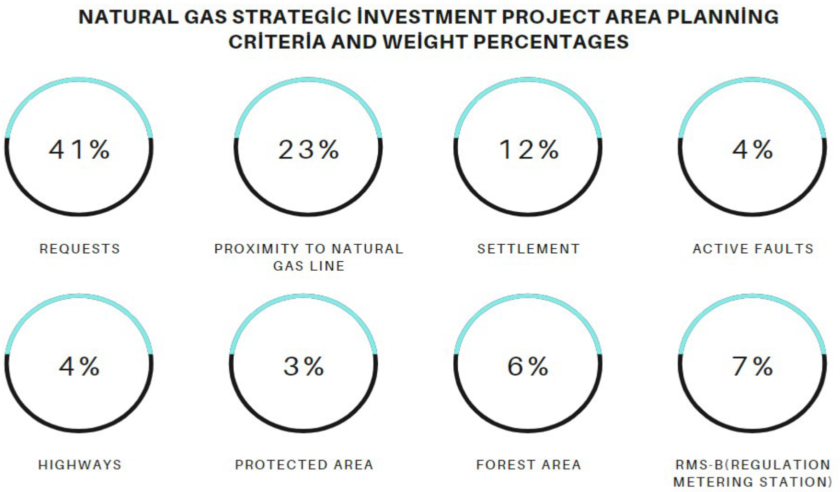


Figure 12. Weight percentages of criteria determined for the investment project area.

The analysis method, data type, priority levels and weight distributions of the criteria can be examined in Table 5.

Table 5. Priority order of the criteria.

Criteria	Data Structure	Data Type	Analysis Method	Priorty Order	AHP Weight(%)
Requests	Point	Vector	Multiple Ring Buffer (MRB)	1	41.4
Polyethylene Lines	Line	Vector	Multiple Ring Buffer (MRB)	2	23.3
Settlement/ Building	Polygon	Vector	Density	3	12.0
Active Faults	Line	Vector	Multiple Ring Buffer (MRB)	6	4.1
Highways	Line	Vector	Multiple Ring Buffer (MRB)	7	3.6
Regulation Metering Station B	Point	Vector	Multiple Ring Buffer (MRB)	4	7.0
Protected Area	Polygon	Vector	Vector to Raster	8	2.6
Forest Area	Polygon	Vector	Vector to Raster	5	6.0

The data layers required for each criterion were obtained using GIS analysis tools (Multiple Ring Buffer, Density, Vector to Raster) and the raster images thus created are shown in Figure 13. These layers were prepared for weighted overlay analysis to be used for the identification of suitable investment areas.

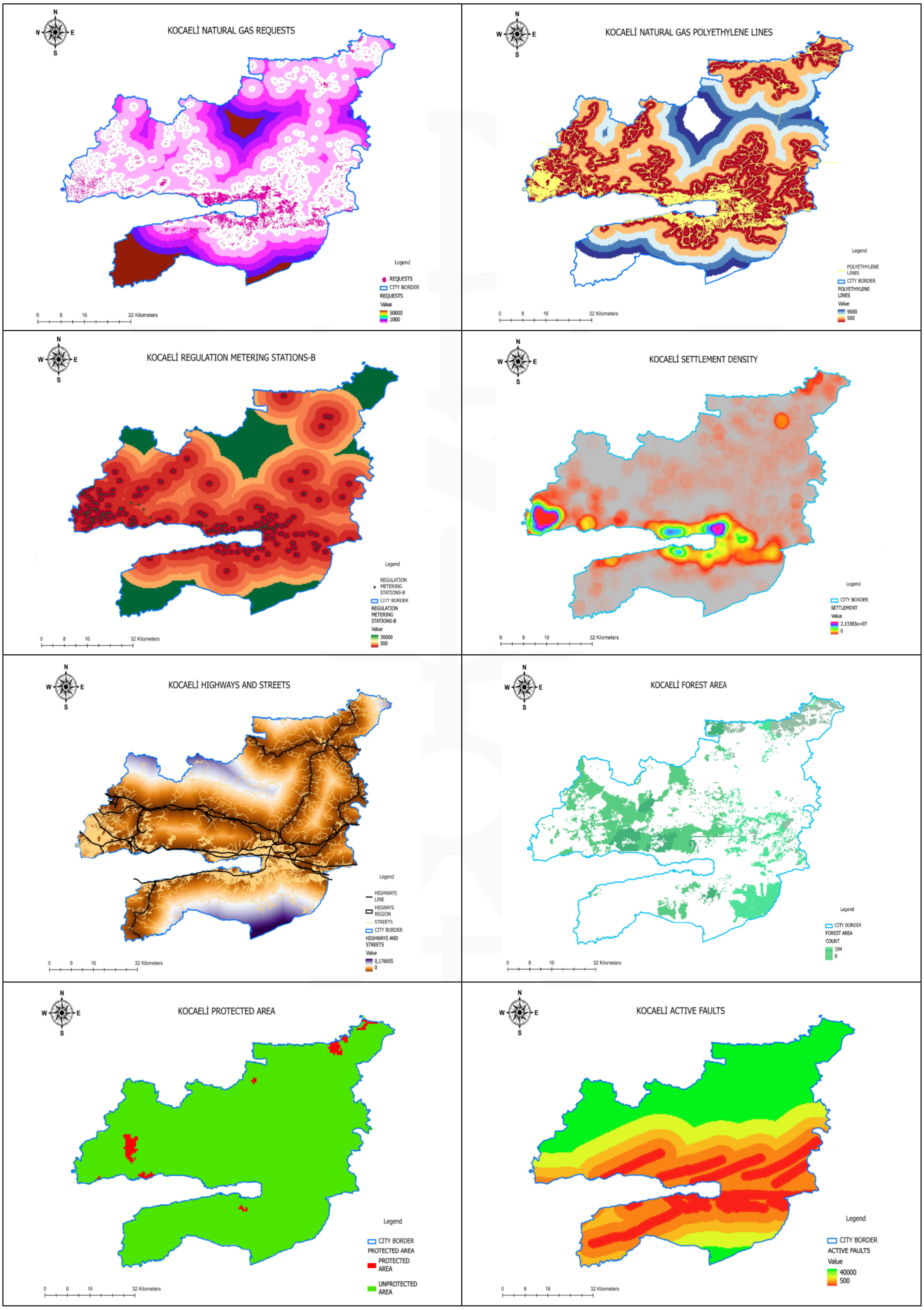
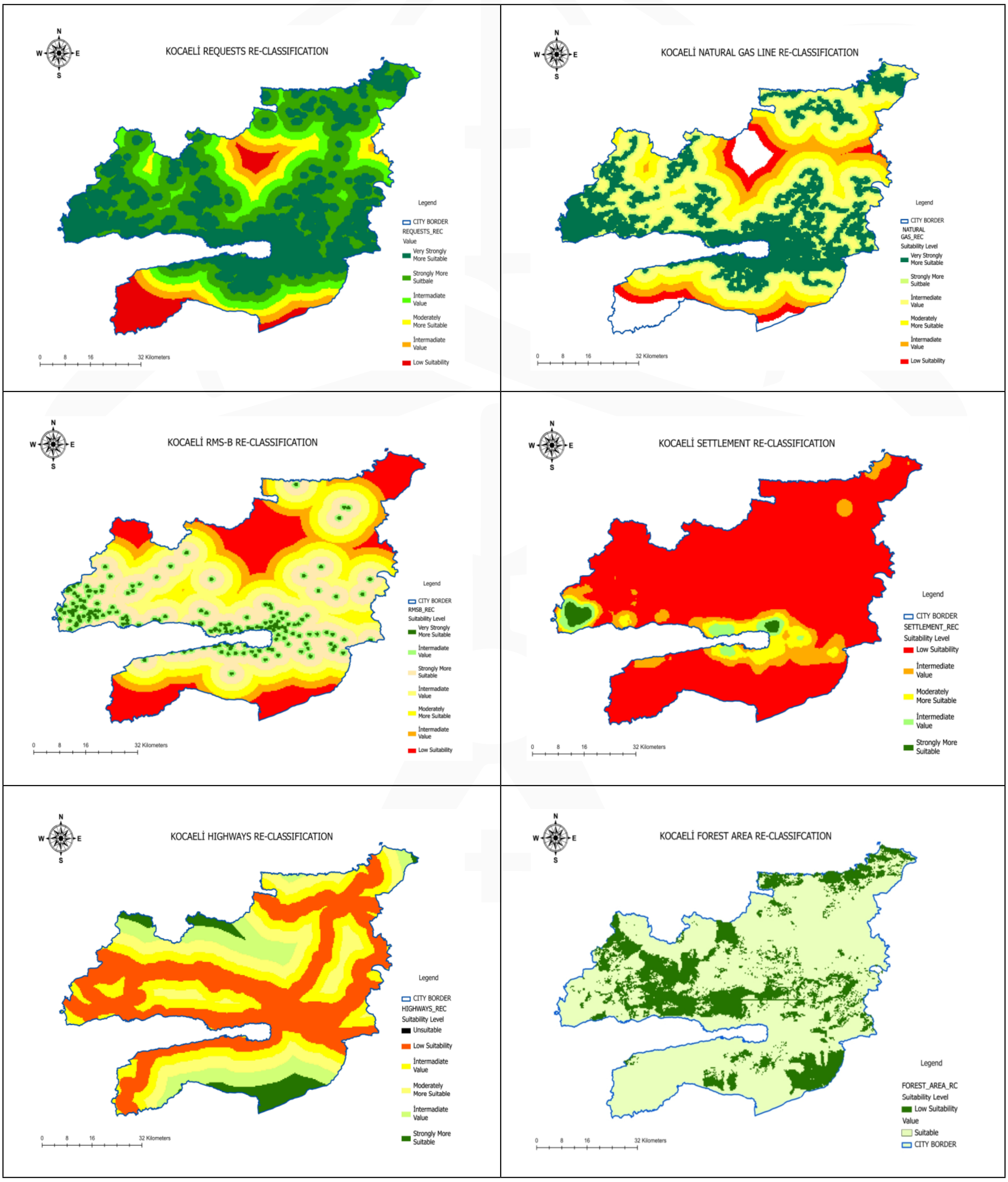


Figure 13. Raster Data created for the weighted overlay analysis.

During reclassifying, values from 1 to 9 on the AHP rating scale were used as shown in Figure 10. These values were entered into the application in accordance with the expert survey in Figure 11. The data in raster format was reclassified with the "reclassification tool" in the ArcGIS Pro application, and the separation of suitability classes is observed more clearly in Figure 14.



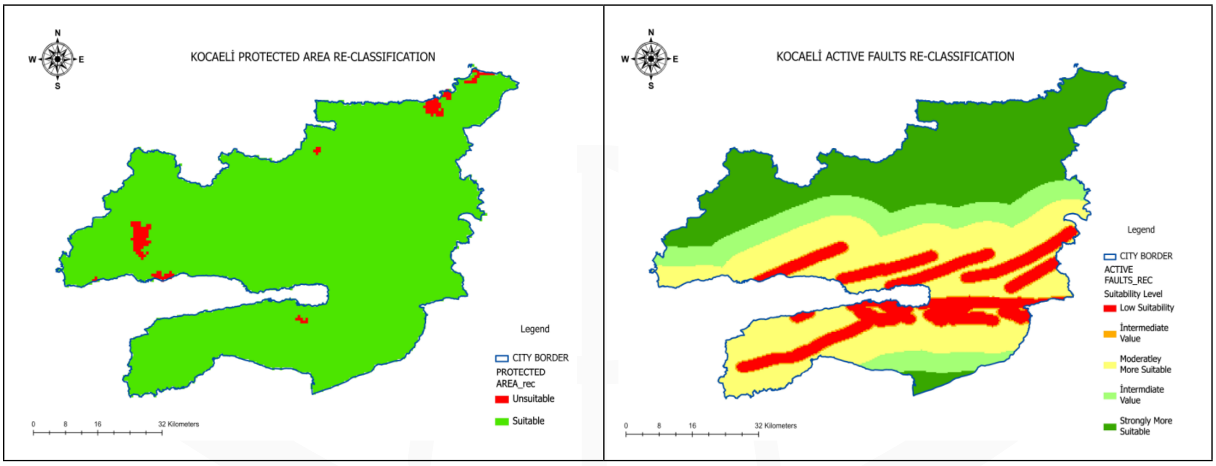


Figure 14. Reclassified Data required for the suitability analysis.

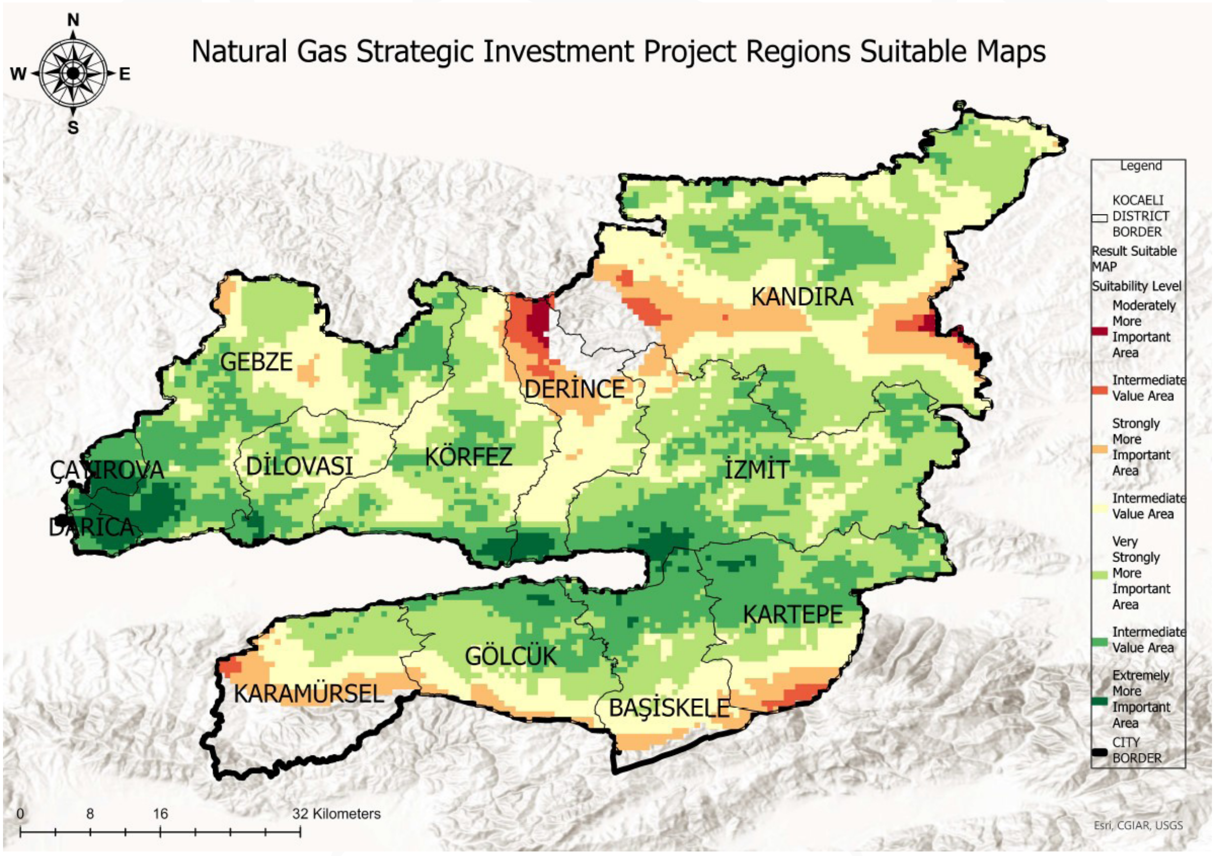


Figure 15. Strategic Investment Project Regions Suitability Map.

The result map was obtained by combining the reclassified criteria in the ArcGISPro application with the weighted overlap method (Figure 15). The weights used during weighted overlay are the W column vector obtained in the step 3 of the AHP method (Table 3). When the resulting suitability map is examined, it was determined that most of the Darıca district of Kocaeli Province and the southern parts of Çayırova, Gebze, Derince, Körfez and İzmit Districts were the most suitable areas for the project area. As a second alternative, the north-east of Gebze district and some inner regions, the northern parts of Gölcük, Başiskele, Kartepe and Karamürsel districts, and the inner regions of İzmit Kandıra and Körfez Districts can be preferred. It was understood that the least preferred areas were the northern parts of Derince district, the eastern and western extremes of Kandıra district, and the southern parts of Kartepe, Başiskele, Gölcük and Karamürsel districts. It has been determined that the unsuitable areas are the north of Derince district, the eastern end of Kandıra district, the southern parts of Karamürsel and Başiskele.

CONCLUSION

In this study, the issue of the most appropriate location selection of Strategic Investment Project regions in terms of time/cost management is addressed on the basis of Kocaeli region. Criteria were selected in line with expert opinions and EPDK Regulation and prioritized by pairwise comparisons. ArcGIS Pro was used to prepare the data for the analyses used and to determine the most suitable location with the weighted overlay method, and the result suitability map was produced using ArcGispro. The purpose of using AHP, one of the MCDA methods used in this study, is to weight a large number of criteria in a consistent and realistic way. The reason why the weighted overlap method is preferred is that it is one of the most appropriate methods for determining the most suitable region in decision-making studies involving a large number of criteria. Consistent, fast and reliable results were obtained as a result of the joint use of AHP and GIS in determining strategic investment project regions. In cases where the study area is much larger, it is thought to give more meaningful results. In line with the information received from the experts, these superficially estimated regions are detailed and investment projects are prepared by considering the capacity adequacy according to the zoning plans and cadastral situation. The map produced as a result of the study shows that Kocaeli Province has natural gas investment potential and that the methods used produce meaningful results.

As a result of the study, a study that can be taken as a basis by natural gas distribution companies regarding investment site selection has been carried out. One of the unique aspects of this study is that there has not been enough work on the selection of suitable investment site locations for natural gas investment projects in our country. It is thought that finalizing this important and complex process with the method used in this study will create a more reliable result. Thus, it is aimed to create an investment plan in which time, labor and economic losses are tried to be prevented.

This paper establishes an analytical framework for the technical assessment of conventional natural gas projects at the investment stage. Technical and economic uncertainties are objectively present in the investment activities of natural gas projects and the impact of both should be systematically considered. The evaluation of an enterprise's investment plan under different decision objectives will be structurally influenced by technical and economic factors. Businesses and relevant institutions are required to develop investment plans in the light of scientific, technical and economic evaluations. These plans can be differentiated and dynamically optimized. In connection with the research in this article, projects with better technical evaluations using the multi-criteria decision analysis method may have better economic returns. Businesses need to invest more in such investment projects and accelerate their development in the energy market. Apart from the technical features of the natural gas investment projects presented in this article, economic research perspectives should also be taken into consideration in terms of investment planning. That is, it should allow investment plans to be evaluated economically from the perspective of analyzing technical effects. The research framework proposed in this paper has good scalability. Based on the availability of data, the framework proposed in this paper can be further calibrated with more advanced statistical analysis and spatial data analysis techniques to further calibrate the relevant parameters including technical factors such as production and declining rate, dynamic demand, and international energy price fluctuations.

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