

Multi Objective Approach for The Selection of Wind Farms' Location

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Abstract

The rise of population volume not only affects the current non-renewable energy sources but also renewable sources. Wind is one of the cleanest source of renewable energy. The design decision encompasses complex and conflicting parameters so that an analytical solution methodology for the problem consideration is necessary. In this study, considering the complex character of wind farm location selection problem, a two-phase fuzzy goal programming approach is applied. The aim of the model is to determine the appropriate locations of wind farms by considering the maximization of technical, social and economic objectives. The process of proper location determination consists of three main stages. The first stage is the determination of potential 30 districts from the Marmara Region and data collection. The second stage is the establishment and application of a single objective form of the model (social, technical and economic objective) separately. The third stage is the implementation of a multi-objective form with two-phase fuzzy goal programming approach. The proposed model is applied to the Marmara Region of Turkey. The most suitable alternatives have been selected out of 30 candidate districts. The inclusion of fuzzy logic within multi-objective approach provides proper evaluation of objectives' satisfaction values. The results of the applied models identify Bozüyük, Taraklı, and Malkara districts as suitable locations for wind farms, based on the fulfillment of objective functions related to technical, social, and economic factors. The findings point out that on average 25% of total electricity demand can be met by installing the determined wind farms in selected locations.

Keywords: Wind Farm, Two-Phase Fuzzy Goal Programming Approach, Multi-Objective Decision Making

I. INTRODUCTION

Energy is one of the fundamental needs of humanity. In today's technology, energy provides sustainable development to countries. Recently, the country's energy needs are provided by non-renewable energy sources such as natural gas, coal, and oil. These resources are limited, and their distribution varies for each country. The increase in the supply of these sources causes their prices to rise. At the same time, carbon dioxide gas produced from these sources creates environmental pollution. Environmental and economic reasons direct humanity to create energy policy with renewable energy sources.

Wind power is one of the most important renewable energy sources. According to 2024 electricity data in Turkey, wind energy ranks fourth in the distribution of electricity generation by resources [1]. Since wind is continuously produced on the planet, wind energy is an endless, sustainable energy source. The use of wind energy sources ensures that the gases emitted to the environment are reduced. In addition, it ensures energy independence as it reduces the loyalty to non-renewable energy sources. In addition to advantages of renewable energy sources, the location decision includes more than one parameter and criterion which may be conflicting in some cases. Considering the advantages of renewable energy sources and the complexity of the problem, the studies in the literature show a growing trend especially with the fast changing of the technology. It is worthwhile to pursue further research about one of these renewable energy sources which is wind energy. The area where multiple wind turbines are located is called the wind farm. The selection of wind farm locations is a complex problem that needs thorough consideration. The literature about location selection for the wind farm problem has been considered from diverse dimensions, the most general form is the off-site and on-site wind farm location selection. Although

these two problems seem similar, distinct criteria apply for location selection. In this study, on-site wind farm location selection problem is considered.

There is a plenty of literature about wind farm location selection problem. The great portion of the studies focus on the criteria selection and application of multiple criteria decision making (MCDM) methods. The criteria can be grouped under two categories, i.e. quantitative and qualitative [2]. Wind speed, slope, elevation, and distance from the electrical network, existence of radar areas, proximity to transportation areas, air density, distance to fault lines, land cost are examples for quantitative criteria. Legislation, bird habitats, cultural heritage, effect of wind turbines, noise are examples for qualitative criteria [2-5].

After the examination of criteria, the majority of literature applies MCDM methodologies such as Analytic Hierarchy Process (AHP), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE) [6-8]. The fuzzy theory is also the mostly integrated methodology to the MCDM techniques, such as Fuzzy AHP, Fuzzy DEMATEL, Fuzzy ELECTRE [9-11]. For better evaluation of the locations, Geographic Information System (GIS) which includes spatial data, graphs and charts for evaluation has also been utilized in MCDM studies [11-13].

The mathematical modelling approaches and optimization techniques are also effective and efficient for decision making problems and these are applied for location selection problems which are relatively lower than the MCDM methodologies [5,14-15]. In this study, a two-phase fuzzy goal programming approach is applied for optimal determination of locations of wind farms in Marmara Region of Turkey. The economic, social and technical objectives are considered and their maximum and minimum values are found via single optimization models. Afterwards, these values are utilized in the two-phase fuzzy goal programming approach and the results are obtained. The main contribution of this study to the current body of the literature is the application of fuzzy mathematical modelling for wind farm location determination in the Marmara Region by the inclusion of social, economic and technical factors. The output of the model identifies the optimal districts and their respective electricity generation capacities by maximizing the overall satisfaction level, which reflects all objectives.

In section 2, literature about the location selection problem for the renewable sources with an emphasis to wind energy has been discussed. In section 3, methodology has been detailed while in section 4, the results of the models have been explained and discussion about the solution has been given, and

finally section 5 gives a brief summary and findings of the study.

II. LITERATURE REVIEW

In this part of the study, the literature about wind farm location decision problems is analysed in terms of methodology adapted and important criteria.

The related problem is both handled as multiple criteria decision making and mathematical modelling approaches. In the following paragraphs, the multi-criteria decision methodologies and the top criteria considered are discussed.

The MCDM studies generally provide an application based evaluation of wind farm location selection such as Turkey, Persian Gulf, Iran Italy, Greece, Germany, Poland [3,10,16-20].

Most of the studies applied MCDM methods such as ELECTRE and its variants, SMAA-TRI, DEMATEL, ELECTRE, ANN, ANP, PROMETHEE, MABAC, OCRA, VIKOR. Applied methodologies have been also integrated with fuzzy theory for better evaluation of alternatives and also GIS (Geographic Information System) has been integrated to the MCDM problems for renewable energy location selection problems [3,16-18,21]. In Atici et al. [16] the feasible location selection problem for the western part of Turkey has been analyzed. ELECTRE III, ELECTRE TRI, and SMAA-TRI techniques integrated with GIS has been applied and results represent similar findings of all methodologies. In a similar study developed by Fetanat and Khorasaninejad [10], Fuzzy ANP, DEMATEL and fuzzy ELECTRE for offshore wind farm location selection have been utilized. GIS integrated fuzzy MCDM offshore wind farm location problem has been analysed for Western Macedonia in Greece.

The optimization and machine learning techniques have also been applied to the wind farm location selection problem such as Petrov and Wessling [22], Montusiewicz et al. [23], Pambudi and Nananukul [24]. Both machine learning and optimization algorithms have been found as effective methodologies. There are also studies for finding feasible locations in case of multiple renewable energy sources such as wind and solar [25-26]. The similar MCDM techniques have been applied by considering joint criteria which are suitable with all energy sources. For MCDM, machine learning and optimization techniques, the most applied technique has been found as AHP which is under MCDM. Regarding the criteria, the general finding is that they are grouped under technical, technological, social, and environmental categories, which are amenable to the dimensions of sustainability.

For technical criteria land slope, landscape, distance to electricity grids, wind speed, elevation, slope, distance to natural environment, population density, road utility,

air density criteria have been considered [4,18,22, 26-30]. The integration of GIS and other mapping tools affect the criteria considered. For studies integrating GIS to the developed methodology, landscape architecture, electricity grid, elevation, slope and utility maps have been considered [9,18,26-27]. These criteria considerations are generally quantitative in nature and they are considered as quantitative criteria. The technological criteria are generally considered in offshore wind power installation and maintenance problems which are the technology utilized for the wind turbines, type of connection, transmission system [31-33].

The selected social criteria are mostly qualitative in nature and include environmental compliance, legislative criteria [2,19]. Figure 1 represents the criteria considered for the analysed literature.

As seen in Figure 1, wind speed (for the candidate region) is the criterion that is mostly analyzed, followed by distance to the roads, slope of the land, distance to the settlement areas and height of the region, which implies distance from the sea level. The other named criteria include distance to transmission lines, depth, proximity to facilities, culture, current land usage, roughness of terrain, land type, flickering lights, noise of wind installations, tourist attractiveness, distance to substations and etc. In addition, factors such as airports, environmental protection areas, and historical sites in the region have been the potential cost criteria for wind farms in the region.

For evaluating the effect of criteria, MCDM methods generally applied sensitivity analysis and validity of the methodologies have been evaluated by comparison with the other methods in the literature.

After thorough analysis, it is concluded that MADM methods, which are one of the two main parts of MCDM—the other being MODM—are most commonly used in the literature to determine the location of wind farms for the problem concerning the accuracy performance measures.

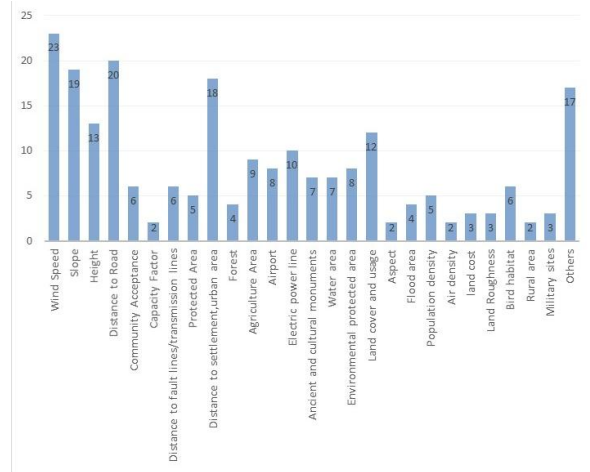


Figure 1. Criteria for wind energy location selection problem in the literature

In this study, wind speed, elevation (height), capacity factor, land cost and social acceptance of wind turbines by citizens are selected for representing economical, social, and technical objectives. These criteria selection process consist of detailed literature review and expert views. As mentioned in previous parts, optimization techniques are relatively scarce in the literature, despite being highly effective in location allocation. In addition, fuzzification is applied in the evaluation of qualitative criteria to incorporate vagueness into the assessment.

III. METHODOLOGY

The applied methodology process flow is represented in Figure 2. The methodology starts with the data collection. The collected data includes country reports for quantitative criteria [1,34] as well as surveys for qualitative criteria. After data collection, data cleaning and normalization (linear normalization) are performed. After data collection and normalization, the model is solved with single objective functions. The single objective linear programming model objective functions have been reported and they are used as constraints within the developed fuzzy goal programming model. The last step is the evaluation of the solutions obtained from the model.

3.1. Data Collection

The models developed in this study are designed to determine the best possible wind farm locations in the Marmara region; therefore, data related to the Marmara region has been obtained. In this study, districts were considered for the location of wind farms. Therefore, considering all 11 provinces, 30 districts with high wind speeds were selected in each province which are obtained from Wind Energy Potential Atlas (WEPA), [34]. Wind speed is categorized based on colours and represented with the relevant colours on the map. Taking into consideration the location of the selected districts, the maps are read, and the average wind speed is obtained.

After carefully analysing the wind speeds, 30 candidate districts have been finally selected for model application as seen in Figure 3. In addition to the wind speed criteria, the capacity factor, which represents the ratio of actual to maximum possible output, is also important for the wind farm location selection problem. These data were obtained for all districts from WEPA documents [35]. The elevation value of the candidate districts is obtained from the municipal websites. To obtain the social acceptance criterion score, interview has been performed in the candidate district citizens by asking "Would you accept a power plant with wind turbines in your district?" and the average score has been obtained. The average land cost data is obtained from one of the most popular retail website for land, houses and etc. [36]. For each district, sample terrains were selected, and average meter square prices are calculated. So, average meter square land cost data was obtained.

The next criterion is the capacity (MW) for the installed wind power plant which is also obtained from WEPA reports. The data for this criterion is obtained for each province in terms of MW per square kilometre. The candidate locations for the wind power plant has also been represented in WEPA reports however these reports ignore the settlement areas. To deal with this issue, digital maps provided in web sites have been utilized. After eliminating settlement areas, the results obtained from WEPA indicate the candidate locations for wind power plant installation. The obtained data for the for each province is in percentages for the available lands. In order to find the approximate surface area of each district where wind power plants can be installed, the surface areas of the districts were multiplied by the available area percentages. Thus, suitable surface areas in the districts were obtained. To calculate the power plant capacity, the upper bound for the power plant per kilometre square for each province has been multiplied by the area of the district which is suitable for power plant installation. The power capacity of the wind power plant, which can be installed per square kilometres for each province, has already been obtained. The power capacity of the wind power plant, which can be installed in the districts, was obtained by multiplying the power capacity per square kilometres of the province where each district is located, by multiplying the area of the district suitable for making power plants. For calculating electricity production of each candidate district, the formula in Equation (1) has been used [37].

For the lower bound of electricity production, the wind plant which has the lowest capacity installed so far has been obtained [38]. The power of this lowest capacity wind plant is 0.5 MW which has a capacity factor of 35% which corresponds to 1533 MWh per year after applying Equation (1).

For the demand criterion, 25% of the current wind energy is assumed to be satisfied from Marmara region which corresponds to 1,866,975.841 MWh.

For the objective functions, technical, economic and social acceptance scores have been decided. For technical score formulation, wind speed, capacity factor and elevation criteria are used. A linear weighted average approach has been applied for the formulation and the weight factors have been considered as 0.4, 0.32 and 0.28 for wind speed, capacity factor and elevation, respectively considering the study of Özşahin and Kaymaz [35]. For social acceptance, a 1-5 Likert scale has been used and the average score for each candidate province is obtained. In the same way, the economic score value is calculated by taking the average of land prices per square meter. The scores of each criterion for all candidate regions are given in Appendix Table A-I – Table A-VII.

3.2. Mathematical Model for Wind Power Plant Installation

In this part of the study, both models including single and multiple objective functions are provided. In the next subsection 3.2.1, the single objective function linear programming model is presented.

Electricity Production of Each District =

Plant power that can be installed in the districts x Capacity factor of the district x

(1)

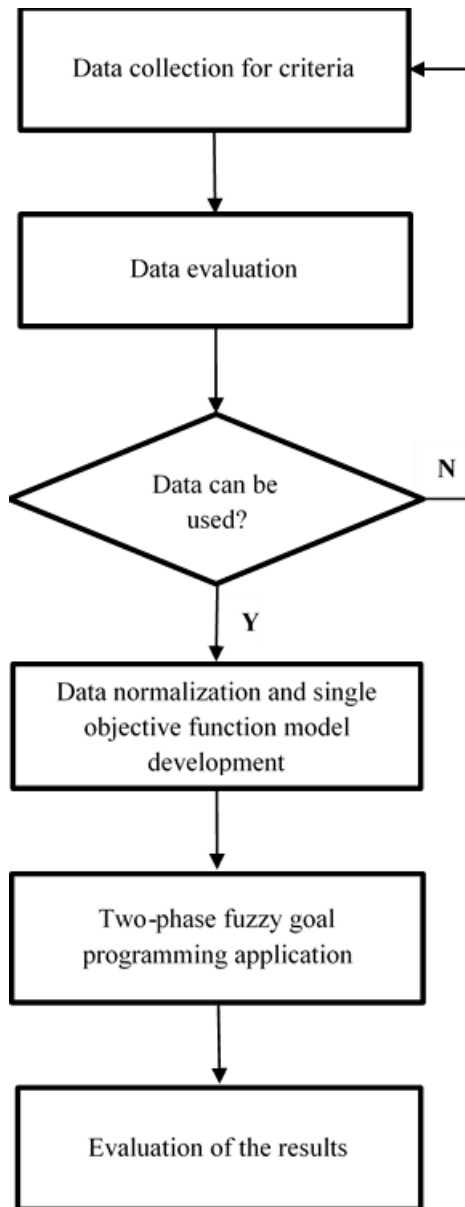


Figure 2. Flow of the methodology

3.2.1. Single Objective Function Model

In the single objective function model, linear normalization (Tchebycheff distribution) is applied since the scales of the criteria are not unique. For linear normalization, different calculations exist for benefit and cost attributes, See Equation (2) and Equation (3). In linear standardization, there are two types of calculation:

$$r_{ij}(\infty) = x_{ij} / \max\{x_{kj} | k=1, 2, \dots, m\}$$

(BENEFIT ATTRIBUTE) (2)

$$r_{ij}(\infty) = \min\{x_{kj} | k=1, 2, \dots, m\} / x_{ij}$$

(COST ATTRIBUTE) (3)

Where;

r_{ij} : Normalized value of x_{ij}

x_{ij} : Actual value of x_{ij}

It is clear that " $0 \leq r_{ij} \leq 1$ ", and the attribute is more favourable as r_{ij} approaches 1. Thus, technical score and social acceptance score normalizations are calculated by the formula Equation (2). Cost attributes are transformed to benefit attributes with the Equation (3). Since minimum expenditure will be preferred in the projects, the land costs are normalized by using the formula Equation(3).

Using the data obtained in the study, the decision-making model consisting of decision variables, constraints and goal function is developed. Accordingly, the proposed decision-making model is as follows:

Indices

i: District (1,...,n)

c: Objective function (1,...,C)

Parameters

TS_i : Technical score of district "i"

SS_i : Social score of district "i"

ES_i : Economical score of district "i"

D : Total energy demand

$mincap$: Minimum required energy that must be produced if power plant in district i is installed.

$maxcap_i$: Maximum energy capacity that can be produced in district "i"

M : A big number

Decision variables

x_i : The energy that will be produced in district "i"

$y_i = \begin{cases} 1, & \text{District "i" is selected} \\ 0, & \text{Otherwise} \end{cases}$

Mathematical Model

$$\text{Max } Z_1 = \sum_{i=1}^n (x_i * TS_i) \tag{4}$$

$$\text{Max } Z_2 = \sum_{i=1}^n (x_i * SS_i) \tag{5}$$

$$\text{Max } Z_3 = \sum_{i=1}^n (x_i * ES_i) \tag{6}$$

s. t.

$$\sum_{i=1}^n x_i = D \tag{7}$$

$$M * y_i \geq x_i \quad \forall_i \quad (8)$$

$$x_i \leq \text{maxcap}_i \quad \forall_i \quad (9)$$

$$x_i \geq \text{mincap}_i * y_i \quad \forall_i \quad (10)$$

$$x_i \geq 0, y_i \in \{0, 1\} \quad \forall_i \quad (11)$$

Equation (4), Equation (5) and Equation (6) aim to maximize technical suitability, social score and economic score, respectively. Equation (7) guarantees that amount of electricity generated equals to the demand. Equation (8) guarantees that power plant in district “i” is opened if electricity is generated in district “i”. Equation (9) and Equation (10) guarantee the capacity of power plant “i” doesn’t exceed the maximum capacity and generates minimum required electricity respectively. Equation (11) is the sign restriction of decision variables. The models have been solved for all 3 objective functions separately and the best Z_{best} , the worst Z_{worst} values are obtained and then the two-phase fuzzy goal programming approach is applied to determine the solution set.

3.2.2. Two phase fuzzy goal programming approach

After obtaining the best and worst values of the objective functions, the values are used to establish the membership functions i.e. $f_c(Z_c)$. The membership function for maximization is given in Equation (12) [39].

$$f_c(Z_c) = \begin{cases} 1 & Z_c \geq Z_{best}^c \\ \frac{Z_c - Z_{worst}^c}{Z_{best}^c - Z_{worst}^c} & Z_{worst}^c \leq Z_c \leq Z_{best}^c \\ 0 & Z_c \leq Z_{worst}^c \end{cases} \quad (12)$$

After calculating the membership function values, Phase I named max-min approach is applied:

Phase I. Max-Min Approach: This approach is used to increase the satisfaction level of the objective function which has a minimum satisfaction level. General satisfaction level (GSL1) is aimed to be maximized for each objective function. ($f_c(Z_c)$) in which values are required to be more than or equal to GSL1.

$$\text{Max } GSL1 \quad (13)$$

s.t.

$$GSL1 \leq OFSL_c^1 \quad \forall_c \quad (14)$$

$$OFSL_c^1 = f_c(Z_c) \quad \forall_c \quad (15)$$

(7)- (11)

Equation (13) aims to maximize the General Satisfaction Level 1 (GSL1). While Equation (14)

ensures that GSL1 is lower than or equal to membership function values of all objective functions and finally Equation (15) provides the value of each objective function. After solving Phase I, the objective function satisfaction level $OFSL_c^1$ are obtained and Phase II is applied.

Phase II. Weighted Sum Approach: All objective function satisfaction levels ($OFSL_c^1$) are added as constraints to the base model then model is solved. Objective function satisfaction degree ($OFSL_c^2$) for each objective function considering the relative importance weights, w_c are considered. The phase II is applied to improve the weighted objective function satisfaction level which is called as General Satisfaction Level 2 (GSL2).

$$\text{Max } GSL2 = \sum_{c=1}^C w_c * OFSL_c^2 \quad (16)$$

s.t.

$$OFSL_c^1 \leq OFSL_c^2 \quad \forall_c \quad (17)$$

$$OFSL_c^2 = f_c(Z_c) \quad \forall_c \quad (18)$$

$$\sum_{c=1}^C w_c = 1 \quad (19)$$

(7)- (11)

$$0 \leq w_c \leq 1 \quad \forall_c \quad (20)$$

Equation (16) aims to maximize the weighted sum of objective function satisfaction levels. Equation (17) ensures that each objective function satisfaction level is greater than or equal to objective function satisfaction levels obtained in Phase I. Equation (18) provides the value of each objective function Equation (19) ensures the total weights of objective functions equal to 1. Equation (20) assigns the allowable range for importance weights’ coefficients.

IV. RESULTS AND DISCUSSION

The first mathematical model developed finds the objective function values and these objective function values become input for the fuzzy goal programming model in which the satisfaction values of the objectives are added. To solve the fuzzy model, two-phase approach in which the first phase obtains the general satisfaction levels while the second phase aims to improve the results obtained in the first phase. In this section, the results of the models are discussed and finally general implications are provided.

4.1. Results of Single Objective Form of the Model

The single objective function linear programming model is solved to obtain the best and the worst values of objective functions for economic, social and technical objectives. Table 1 represents the results of the economic objective function. Malkara and Tarakli districts are obtained based on maximization of

economic criteria while Arnavutköy is obtained for the minimization of economic criteria value. The technical and social objective values are also calculated for Malkara, Taraklı and Arnavutköy and are presented in Table 2 and Table 3, respectively.

Table 1. Results of the economic score maximization and minimization model

ECONOMIC SCORE MAXIMIZATION AND MINIMIZATION			
MAXIMUM	MALKARA	TARAKLI	OBJECTIVE VALUE
X(Energy Production)	1058.034 GWh	809 GWh	1835.429
Technical Score	0.357	0.6	861.514
Social Score	0.86		1395.27456
MINIMUM	ARNAVUT KOY		OBJECTIVE VALUE
X(Energy Production)	1866.976 GWh		79.72247
Technical Score	0.229		427.734
Social Score	0.8086		1509.637

For the social acceptance objective function, Keşan district maximizes the social acceptance while Saray minimizes the social acceptance function. The technical and economic score values are also represented. For the technical objective Bozüyük maximizes the objective while Gemlik minimizes the objective. For Bozüyük and Gemlik economic and social objective values are also represented.

Table 2. Results of the social acceptance score maximization and minimization model

SOCIAL ACCEPTANCE SCORE MAXIMIZATION AND MINIMIZATION		
MAXIMUM	KESAN	OBJECTIVE VALUE
X(Energy Production)	1866.976 GWh	1866.976
Economic Score	0.386	718.590
Technical Score	0.158	295.235
MINIMUM	SARAY	OBJECTIVE VALUE
X(Energy Production)	1866.976 GWh	858.809
Economic Score	0.321	600.099
Technical Score	0.225	420.334

Table 3. Results of the technical score maximization and minimization model

TECHNICAL SCORE MAXIMIZATION AND MINIMIZATION		
MAXIMUM	BOZUYUK	OBJECTIVE VALUE
X(Energy Production)	1866.976 GWh	1866.976
Economic Score	0.562	1048.779
Social Score	0.98	1829.636
MINIMUM	GEMLIK	OBJECTIVE VALUE
X(Energy Production)	1866.976 GWh	39.256
Economic Score	0.321	600.099
Social Score	0.813	1518.474

After Z_{worst} and Z_{best} objective function values are obtained, the two-phase fuzzy goal programming model is applied.

4.2. Results of Two-Phase Fuzzy Goal Programming Approach

After obtaining the best and the worst objective function values, membership functions have been calculated then Phase I solution is obtained. The GSL1 values have been added as constraints to the Phase II to improve the values found in Phase I as indicated in Table 4.

Table 4. The best and the worst values for objective functions and phase I results

Objective Function Type	Maximization		Membership functions		
	Z_{best}	Z_{worst}	$f_1(z_1)$	$f_2(z_2)$	$f_3(z_3)$
(Single Objective-Technical) Z_1	1866.976	39.257	1	-	-
(Single Objective-Social) Z_2	1866.976	858.808	-	1	-
(Single Objective-Economic) Z_3	1835.429	79.722	-	-	1
General satisfaction level (GSL1) for the multi-objective solution (Phase 1)			0.756		

To improve the solution found in Phase I, Phase II is applied with equal weights for each objective function value. After applying phase II, the objective function values have remained unchanged so that the solution has not been improved concerning the satisfaction levels as seen in Table 5. It is 0.756 for all objectives. As observed in the studies by Tuzkaya et al. [39] and Kilic and Yalcin [41], this outcome does not seem unexpected. The unchanged outcome can be attributed to various factors, such as the closeness of objective function satisfaction levels obtained in the first phase, the limited number of alternative locations available, and the parameter values used in the model.

Table 5. Two-phase fuzzy goal programming approach phase II results

District	Electricity Production (GWh)	Technical Score	Social Score	Econ. Score
Bozüyük	1019.489	1.000	0.980	0.562
Taraklı	411.059	0.598	0.600	1.000
Malkara	436.428	0.357	0.860	0.970
Satisfaction levels $OFSL_c^2$		0.756	0.756	0.756

As represented in Table 5, Bozüyük, Taraklı and Malkara are the best options for the wind farm power plant installation. The selected districts are represented in colors in Figure 3.

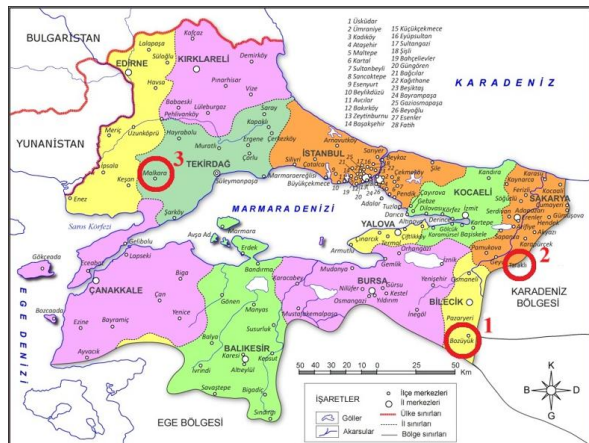


Figure 3. Candidate and selected districts after the application of two-phase fuzzy goal programming [40].

The electricity generation amounts are also found as 1019, 411 and 436 GWh electricity for Bozüyük, Taraklı and Malkara, respectively which correspond to 25% of Turkey's electricity demand from wind energy.

4.3. Discussion

Finding suitable land for installing wind power plant is a complex decision-making problem that includes both qualitative and quantitative criteria. Determining the appropriate criteria and their values are vital in the evaluation of the potential districts' feasibility. The criteria for wind power plant have been decided after careful consideration of the literature while the values of them have been obtained either from technical reports, web sites or surveys. To better determine the satisfaction values of the objectives, membership function within fuzzy logic is utilized within the mathematical model proposed. The developed models aim to maximize the economic and social sustainability dimensions. In addition to economic and social scores, technical score including elevation, wind speed has been aimed to be maximized. The results of the model provide 3 candidate districts which are located close to the borders of the Marmara Region. The results represent that the most influential factor is wind speed for the technical score. Among these three districts (Bozüyük, Taraklı and Malkara), Bozüyük has the highest technical score among all candidates, while Taraklı has the highest economic score, and Malkara ranks second in terms of economic performance. Considering these results, technical and economic scores are the most important factors for wind farm location selection. In determining the values of these factors, the decision makers should give more attention to these factors.

The limitations of the study are as follows;

- The number of districts considered,
- The precision of the available data,
- The factors which are not considered in the current study,

- Although the model can easily be adopted to the large-scale instances, the optimal results may not be found due to the size of the model.

For future research directions, Geographic Information System (GIS) and multi-objective approaches can be applied in an integrated manner, also the sensitivity analysis of the criteria can be performed to understand the most important ones. Lastly, for large-scale instances a heuristic algorithm can be applied to find good solutions to the problem.

V. CONCLUSIONS

When the scarcity of non-renewable energy sources is considered, the shift through renewable sources of energy is a must rather than a preference. Wind energy is one of most frequently utilized energy type for electricity generation. Wind energy is a system that contributes to energy by positioning and utilizing wind turbines efficiently. Wind energy does not pollute the water and there is no greenhouse gas emission. Wind energy plays a key role in protecting the world. Therefore, location allocation for wind farms is an important research topic for improving efficiency on energy production. As in all decision-making problems, the important criteria should be properly selected and applied thoroughly to the decision-making process. After criteria determination, an analytical solution methodology should also be developed in an efficient and effective way. Considering the importance of both criteria selection and model application, this study aims to define criteria for wind farm power plant location selection and developing a model for finding locations for wind farm power plant installation. For criteria selection, both literature and expert opinions have been utilized as details are discussed throughout the study. After determining the criteria, a multi-objective model is developed for the selection of wind farms' locations. Technical, social, economic objectives are considered in the model. Data are collected and normalized based on objectives. Two-phase fuzzy goal programming methodology is applied as the solution methodology. Also, linear normalization method is applied for the normalization of the data in the study. Developed models have been applied to the Marmara Region in Turkey.

Results of study provide a prediction for the companies working on wind energy. It is also an important resource for investors. This study provides insights for also companies and academicians who are interested in this hot topic. The contribution of this study is both determining qualitative and quantitative criteria and application of two-phase fuzzy goal programming approach in a real case and finally determine the best location and capacity allocation of candidate wind farm locations.

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