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A multi-objective decision-making model for renewable energy planning: The case of Turkey

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ABSTRACT

The rapid increase in the world population along with the rising trend of global economic growth triggers serious problems related to energy consumption. In this regard, a comprehensive analysis of the current and potential energy situation in the light of demographic trends, main economic indicators, technical conditions, social and environmental concerns has become a significant issue for developing well-planned global and regional energy strategies. In this study, a multi-objective decision-making model is constructed for renewable energy planning to determine the most appropriate resource diversity for Turkey by focusing on five renewable energy sources, namely solar, wind, geothermal, hydroelectric, and biomass. There are four objective functions presented in the proposed multi-objective model including maximization of the technical score of regions, maximization of the job creation, maximization of the environmental score, and minimization of the cost. As a solution methodology, a two-phase fuzzy goal programming approach is performed. The proposed model is solved using LINGO software as a comprehensive solver for model optimization. The appropriateness of the proposed method is analyzed by comparing it with other multi-objective methods. Results reveal that the majority of the energy demand should be met via solar and hydroelectric energies for the satisfaction of the indicated objectives.

1. Introduction

The ongoing growth in the world population and the global economic development of countries together with the effects of industrialization, urbanization, and technological developments, have caused a dramatic increase in the amount of resource consumption. In the meantime, the level of consumption, the most inevitable of which is the need for energy, maintains its rise in many ways despite the fact that the world's fossil resources are finite and rapidly depleting. Since the world already has limited reserves in terms of fossil fuel resources, and these resources are not evenly distributed between countries, it is not possible to meet the energy demand with the existing fossil resources in the short term. Moreover, the use of fossil fuels causes damage to the environment and living conditions, especially human health, animal life, and nature. This situation is also considered as another threat. Hence, it seems inevitable that the energy problem will be one of the major challenges humanity must deal with in the short term since energy is considered one of the most important subjects on the agenda of policymakers. In these circumstances, decision-makers have started to find out alternative sources to meet the energy needs. Energy sources in the renewable form are considered fundamental primary sources of alternative energy that require strategic planning in terms of sustainable development. Therefore, reducing the use of fossil resources and replacing them with renewable energy sources in a controlled manner are both critical for energy sustainability and vital for energy planning in the long term.

Energy planning, which is vital in technical, economic, sociopolitical, and environmental aspects, has recently become one of the most debated topics recently [1–3]. Thus, the planning process requires special attention to determine the suitable energy types and the most appropriate regions in an optimum way. In the meantime, meeting the energy demand is vital since it is projected by EIA [4] in the ‘World Energy Outlook 2019’ report that between 2018 and 2050, global energy consumption will increase by approximately half. For this reason, in order to meet the energy demand, decision-makers, who are interested in energy planning

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need to give necessary importance to the issue by being aware of the seriousness of the problem, particularly in regions that have limited availability in terms of natural resources or have restricted opportunities in terms of fossil fuel use. In other words, general energy planning by itself would not be sufficient in all cases. Thus energy planning from a regional perspective has an essential place in this process to be able to cope with the increased energy demand of each developing region. This process should cover mainly the analysis of the specific regions' needs and requirements in detail by considering the importance of technical conformity and financial analysis to minimize the total cost, the examination of social and employment issues, and the environmental effects of energy sources.

Although fossil fuels are still known as the energy source with the highest share of use in the energy field, it is observed that the share of renewable energy sources in the energy field is increasing day by day due to growing environmental concerns and global economic circumstances. Without a well-designed energy planning mechanism, the energy industry is closely linked to environmental factors that damage the ecosystem in case of the unbalanced use of fossil fuels. This situation adds further complexity to the problem, as these factors are very difficult to control or incorporate into investment planning [3]. Therefore, energy planning is considered one of the leading subjects of strategic future plans, which are of great importance to developing states worldwide. On the other hand, the country's energy status, whether it has adequate reserves to meet its energy needs from domestic resources or it has a high energy import dependency, is one of the most important factors in the economic growth that presents the level of production and development. In this regard, Turkey is considered among the countries having limited reserves in terms of fossil fuels and external energy dependence. However, it has a high potential for renewable energy sources across developing countries. In order to provide a solution to the energy supply problem, the state aims to increase the share of renewable energy in future energy plans.

The aim of this study is to analyze the current position and future potential of renewable energy sources in electricity generation and propose a multi-objective model for regional energy planning in Turkey. With the use of the developed model, it is aimed to contribute to the process of determining the most suitable renewable energy sources for the potential location, and the amount of energy production from these resources under multiple objectives. In order to decide on the most appropriate resource diversity, the main focus is given to five energy types from renewable energy sources, namely solar, wind, geothermal, hydroelectric, and biomass. The main reason for selecting these five energy types is that they are the most preferred types in electricity generation. Another purpose of the study is to reduce external energy imports and increase the use of domestic energy resources, particularly renewable energy alternatives, by developing a multi-objective decision-making model intended to utilize renewable energy potential efficiently. In this way, this study intends to raise awareness about the preference for renewable energy in energy consumption. Moreover, with the proposed methodology, the countries will be able to use their energy potential in the most efficient way not only by considering the cost but also by taking into account the social and environmental factors.

The literature is reviewed for analyzing the studies about renewable energy planning, and multi-objective decision-making methods (MODM) are found to be suitable for this complex process depending on their strength in handling conflicting objectives. Up to the knowledge of the authors, this is the first study utilizing two-phase fuzzy goal programming for renewable energy planning. Moreover, the case application part has reinforced this study's originality since it differs from other studies in terms of implementation by taking into account 21 electricity distribution regions of Turkey, five types of renewable energy sources, and reliable data obtained from various sources. Hence, in brief, the main contributions of this study can be listed as follows:

- Multiple objectives, including technical, economic, social, and environmental aspects are considered within renewable energy planning.
- A two-phase fuzzy goal programming approach is applied for the multi-objective decision-making problem concerning five main renewable energy sources, namely, solar, wind, geothermal, hydraulic, and biomass.
- A comparative analysis with alternative techniques including goal programming with absolute deviation, goal programming with percentage deviation, and lexicographic methods is provided.
- A real case in Turkey is performed for renewable energy planning under multiple objectives and energy sources.

The rest of this study is organized as follows: Section 2 introduces a literature review concerning the types of renewable energy sources and methods used in the renewable energy field. Section 3 explains the two-phase goal programming methodology and the proposed model in detail. Section 4 presents results and discussion by analyzing the implementation of the developed model in the case of Turkey and comparing it with other multi-objective methods. In Section 5, discussion and policy implications are given. Finally, the conclusions, limitations and recommendations for future studies are provided in Section 6.

2. Literature review

There are a wide variety of studies regarding renewable energy sources in the literature. However, this study mainly focuses on renewable energy planning from different perspectives. For a better analysis, the literature review part is examined under two main sections, including the types of renewable energy sources considered and methods used in the renewable energy field.

2.1. Types of renewable energy sources

It is observed from the literature that the scope of studies focusing energy sector varies depending on the depth of the subject and the type of approach. Especially, there are many studies in the literature analyzing the renewable energy field in terms of various resource types from different approaches such as separately, comparatively, or collectively. Researches in the renewable energy field mostly examine five main renewable energy sources, including solar, wind, geothermal, hydro, and biomass, under four main criteria covering technical, economic, social, and environmental aspects [5–7].

Although there are numerous studies in the literature that only focus on a specific renewable energy source in renewable energy planning, this paper aims to examine studies that deal with more than one renewable energy type together in a more comprehensive way. The planning process of determining the most suitable renewable energy resource among alternatives is critical for efficient energy generation. Solangi et al. [8] examine the prioritization of renewable energy sources for sustainable energy planning considering solar, hydro, biomass, wind, and geothermal energy types. Similarly, Wang et al. [9] discuss a renewable energy resources selection problem by evaluating solar, wind, and biomass renewable energy resources in electricity generation planning.

Furthermore, it is necessary to analyze the local and regional features of the countries in terms of renewable energy resources for developing a proper renewable energy generation plan. Al Hasibi [10] proposes a sustainable generation expansion planning model by optimizing renewable energy sources including solar, wind, geothermal, and biomass at the regional level. Moreover, Taghizadeh-Yazdi and Mohammadi-Balani [11] develop a mathematical model for renewable energy planning from a multi-regional and multi-source perspective by considering eight regions and five renewable energy types.

In general, renewable energy planning studies involve different evaluation methods under various criteria and perspectives on a national or regional scale. Governments are making efforts to focus on renewable energy in their future energy planning policies in order to provide a solution to the energy planning problem. As one of the developing countries, Turkey is known for its heavy dependence on energy imports, although it has a high potential in terms of renewable energy resources. Therefore, renewable energy planning became a crucial topic on the agenda of the country. However, a limited number of studies in the literature evaluate different alternatives of renewable energy resources for Turkey on a regional basis. In recent studies, Erdin and Ozkaya [12] propose a methodology to determine the most suitable renewable energy sources for electricity generation from five renewable energy alternatives, including hydropower, geothermal, biomass, wind, and solar concerning seven geographical regions of Turkey. Alkan and Albayrak [13] analyze the ranking of five main renewable energy sources according to twenty-six regions in Turkey. Also, Karaaslan and Gezen [14] evaluate five renewable energy sources to determine the most suitable alternatives by modeling them as a multi-objective optimization problem.

In brief, evaluating a group of renewable energy sources together and simultaneously in energy-related planning studies expands the scope of the subject and provides a more qualified result. Overall, fifty-one papers are reviewed and indicated in Appendix Table A1 to present a part of the literature that examines multiple renewable energy sources.

2.2. Methods used in the renewable energy field

In general, the field of renewable energy is reviewed and discussed by using many different approaches and techniques based on the purpose of the study. In other words, when the subject of renewable energy is examined in-depth, it is observed that the topic contains many different and complex elements that are dependent and independent from each other. Accordingly, one of the most important, complex, and difficult strategic decisions that investors have to make is determining optimal energy type, required installed capacity, and feasible plant location, which are the key factors for an energy plant to operate efficiently. Briefly, it can be clearly observed that usually decision problems consist of many conflicting criteria and requires simultaneous evaluation of alternatives. For this reason, the most common approach preferred by researchers to solve this kind of problem is the multi-criteria decision-making method (MCDM). In general, MCDM techniques are used in a wide variety of areas, particularly it is frequently used in the energy field. The most commonly used approaches in energy-related subjects are known as multiple attribute decision-making (MADM) and multiple objective decision-making (MODM) techniques, which are the two main categories of the MCDM methods [15].

Since the decision process contains several relevant and irrelevant factors which can also be time-varying, evaluation of the decision model for the problem must contain various criteria related to objectives. Farahani et al. [16] specify that decision-makers tend to pursue multiple objectives or examine several elements or parameters while evaluating real-world problems. Accordingly, energy planning decisions require considering several different factors related to the category of energy resource, cost of energy type, technical features of the energy resource in the region, employment opportunities provided by the energy type, and environmental impact of the energy source. Research on planning activities in the energy industry included in the literature essentially deals with four main aspects when evaluating the determination of criteria. The typical main criteria used in energy systems involve technical, economic, environmental, and social criteria. However, the most frequently used sub-criteria for technical criteria include energy efficiency, installed capacity, capacity factor, energy production, reliability, safety, technological maturity; for economic criteria, there are levelized cost of electricity, investment cost, operation and maintenance cost, fuel cost, payback period and service life; for environmental criteria, there exist greenhouse gas emission and land use. Finally, for social criteria, there are social acceptability, job creation, human health and social benefits [17–20]. Thereby, the decision-making process involves the assessment of multiple attributes and uncertain criteria due to the complexity of the decision problem.

The MCDM techniques have a wide range of applications performed in various fields such as facility location selection [21–23], warehouse location selection [24,25], climate change [26], energy sector [27–29] and ICT sector [30,31]. On the other hand, the renewable energy-related topics that are often studied by researchers in the literature using MCDM can be indicated as energy planning [32,33], energy policy-making [34], energy sources ranking [20,35], power plant location selection problems [36,37], energy project selection [38], and selection of appropriate renewable energy types among alternatives [39,40].

The MODM is known as one of the main categories of the MCDM methods, and it is considered an efficient approach that is widely used in the energy field. In MODM, a collection of objective functions is optimized concerning a group of constraints instead of predetermined alternatives [41]. In general, the amount of investment required for a renewable energy power plant installation is considerably high. Therefore decision-makers must ensure that specified criteria and objectives include a sufficient range of subjects based on accurate information for the investors before the installation process started. From this perspective, the optimal energy planning for the use of renewable energy sources also incorporates many other economic, technical, environmental, and social factors as reviewed in the literature.

The MODM models have been used in various areas, including renewable energy planning [2,5,42], electricity generation planning [43], energy resource allocation [44], evaluation of investments in renewable energy [45], flexibility in investment [46], investment optimization [47], regional optimization of renewable energy sources [48], spatial optimization of renewable energy sources [49], and planning of distributed energy sources [50]. There are many different MODM methods applied in the studies regarding various subjects of the renewable energy sector. Cui et al. [51] review multi-objective optimization methods in their research and briefly introduce problems and algorithms. Using the multi-objective optimization approach, Mousa et al. [52] investigate rooftop applications of specific solar energy systems, Wang et al. [53] conduct a study evaluating a combined cooling, heating, and power system driven by solar energy. Moreover, some studies in the literature related to MODM problems contain approaches consisting of more than one step or level in the proposed model to find the optimal solution. Ho et al. [54] develop a model concerning energy conservation and renewable energy for school campuses by employing multi-objective linear programming (MOLP) and a fuzzy two-stage algorithm. Prebeg et al. [55] propose a two-level approach for long-term energy planning focusing on renewable energy and the integration of electric vehicles. Studies referring to renewable energy sources with regard to multi-objective techniques essentially involve wind energy [56–58], solar energy [59], hydroelectric energy [60,61], geothermal energy [62], and biomass energy [63,64].

There are several different attributes involved in the decision-making process that have a vital role and huge impact on the result, thus determining the set of objectives for the investment decision based on renewable energy planning needs to be taken into account as a significant component. Renewable energy capacity growth planning is a complicated issue that covers the capacity increase of currently installed power plants, the capacity status of power plants under construction, and the capacity planning of new power plants to be established. Therefore, a goal programming model is a useful option for providing a reasonable solution to the problem of renewable energy planning since it is important to evaluate different objectives together and simultaneously based on the determined criteria. As Zografiodu et al. [65] and Aouni et al. [66] state, GP is a flexible mathematical formulation and capable of overcoming conflicting objectives. Hence, the GP methodology has been used in several areas in the literature including investment planning for renewable energy sources [67], renewable energy plant location selection [1,68], financial analysis of renewable energy production [65], renewable energy portfolio optimization [69], and resource allocation [70].

Moreover, there are numerous different techniques applied in various fields to achieve a realistic and reliable solution for the multi-objective goal programming problems in the literature. Namely, the two-phase fuzzy goal programming approach, which provides an effective solution mechanism for solving multi-objective goal programming problems, has been used by researchers in the mathematical model construction with membership functions. Liang [71] uses a two-phase fuzzy goal programming approach for solving the multi-objective project management decision problems in a fuzzy environment. Real-life decision-making problems generally have conflicting objectives in the problem structure. Therefore, Arıkan and Güngör [72] propose a two-phase mathematical approach for multiple objective decision problems with all fuzzy coefficients by considering fuzzy linear programming and fuzzy parametric programming. Moreover, Cavdur et al. [73] present a study using a two-phase binary-goal programming-based approach to solve a novel system design project-team formation problem that involves several restrictions, requirements, and the preferences of the potential team members. Furthermore, recent studies reveal that the number of studies, which combine different methods and modified versions of the two-phase concept as well as the classic two-phase procedure, show an increasing trend. In this regard, Kilic and Yalcin [74] propose a combined methodology consisting of the Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) and a modified two-phase fuzzy goal programming model for the green supplier selection problem.

As a result, in terms of the structure of the problem examined in this study, similar studies in the literature have been reviewed before determining the most suitable method to be used for the proposed model. Although the two-phase fuzzy goal programming method is rarely studied in the literature, it is observed that this approach provides a practical and satisfactory contribution to problem-solving, especially in multi-objective decision-making problems. In addition, another main motivation for selecting the two-phase fuzzy goal programming method is its suitability for the handled problem structure. In the considered case, the objectives' importance weights do not differ and it is desired to maximize the minimum of all the objectives. Moreover, to the best of the authors' knowledge, the two-phase fuzzy goal programming method has not been used in the literature for the regional renewable energy planning decision-making problem in Turkey. Since there are few studies in the literature on this topic, it is aimed to fill this gap and produce a work that will provide added value to the literature. Therefore, in this study, the two-phase fuzzy goal programming approach is used as an efficient and appropriate method to obtain the best solutions for the proposed mathematical model. Ultimately, it is thought that the analysis of the application results with this model will contribute to future academic studies in the field of energy planning as a reference resource.

3. Two-phase fuzzy goal programming and the proposed mathematical model

3.1. The two-phase fuzzy goal programming methodology

In this study, a two-phase fuzzy goal programming methodology is employed to determine the suitable renewable energy types among alternatives and the allocated amount of capacity for power plant installation that corresponds to specified renewable energy sources. There are four objectives involved in the proposed multi-objective model, unlike classic decision-making models with a single goal for planning problems. The first objective is maximizing the normalized technical score of regions based on energy type, whereas the second objective is minimizing the cost of energy types. The third objective is maximizing the number of jobs created regarding energy types, and the fourth one is maximizing the normalized environmental score concerning energy types. Since the decision-making model involves various objectives related to different areas and exhibits a complex structure, it is reasonable to use a problem-specific methodology. In this case, the two-phase approach is utilized as an appropriate solution method. The related information about the two-phase fuzzy goal programming methodology is presented elaborately in the following parts. However, the main steps of the proposed methodology are provided in Fig. 1.

3.1.1. The first phase (max-min approach)

There are various steps in the two-phase approach used in this study. Firstly, the objectives are determined. Afterward, the second step is to compute ideal and anti-ideal solutions for each objective function [75]. Accordingly, in the first place, it is necessary to find the best (z_{best}) and the worst (z_{worst}) values for each of the objective functions. By solving the related part of the proposed mathematical model separately for each objective, the best and worst values are obtained. Then, in the third step, those values are characterized by membership functions to measure the degree of achievement of the desired goal levels in the decision case [76]. According to the approach adapted from Tuzkaya et al. [77], the membership functions as illustrated in Fig. 2 are constructed for minimization and maximization based on Equations (1) and (2), respectively.

$$f_g(Z_g) = \begin{cases} 1, \ Z_g \le Z^g_{best} \\ \dfrac{Z^g_{worst} - Z_g}{Z^g_{worst} - Z^g_{best}}, \ Z^g_{best} \le Z_g \le Z^g_{worst} \\ 0, \ Z_g \ge Z^g_{worst} \end{cases} \tag{1}$$

$$f_g(Z_g) = \begin{cases} 1, \ Z_g \ge Z^g_{best} \\ \dfrac{Z_g - Z^g_{worst}}{Z^g_{best} - Z^g_{worst}}, \ Z^g_{worst} \le Z_g \le Z^g_{best} \\ 0, \ Z_g \le Z^g_{worst} \end{cases} \tag{2}$$

In the first phase, as the fourth step of the methodology, the max-min operator is used to improve the satisfaction degree of the objective function having the minimum degree of satisfaction. From the membership functions, it is understood that bigger $f_g(z_g)$ values reflect the higher objectives' satisfaction for maximization, whereas smaller $f_g(z_g)$ values provide the higher satisfaction for minimization [72]. Hence, introducing a new variable λ (the general satisfaction degree), also called threshold satisfaction degree, is tried to be maximized. In step five, for each objective function, the value of the first phase satisfaction degree (FPSD) is obtained and it is to be more than or equal to λ value as seen in Equations (3) and (4) [72,74,77].

$$Maximize \ \lambda \tag{3}$$

$s.t.$

$$\lambda \le FPSD_g \quad \forall g \tag{4}$$

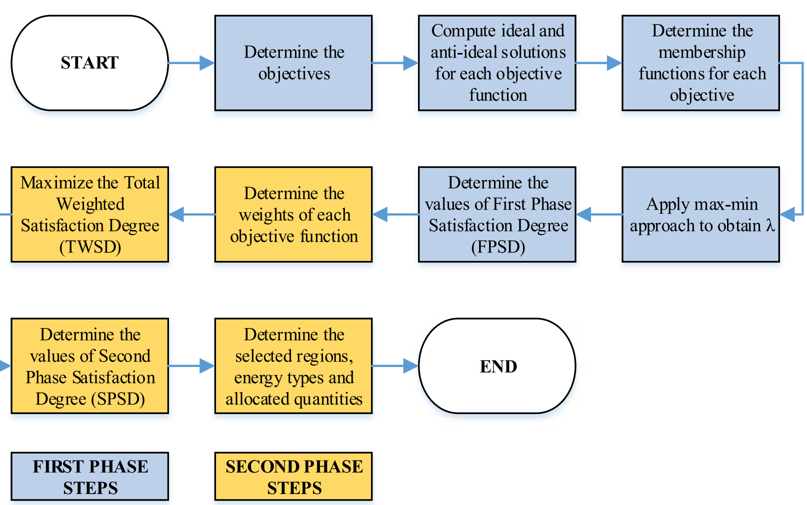

Fig. 1. The main steps of the proposed methodology.

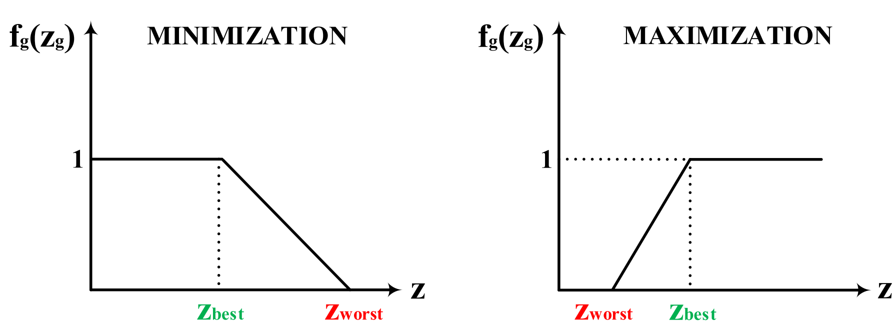

Fig. 2. Membership functions for minimization and maximization objectives.

3.1.2. The second phase (weighted sum approach)

In particular cases regarding multiple objective problems, using the max-min operator as in the first phase of the method is considered inefficient. However, the second phase of the two-phase method forces the solution yielded to be at least better than the solution obtained in the first phase, and the efficient solution obtained guarantees to achieve better utilization [78]. The main goal of the second phase is to maximize the composite satisfaction degree to at least as good as the degrees obtained by phase one [79]. In other words, in the second phase, the development of optimal solutions obtained in the first phase is investigated. Thus, the main aim of the second phase is to improve the values of the FPSDs.

The second phase involves the weighted sum approach and uses optimal solutions gathered in the first phase. In more detail, within this phase, the FPSD values of each objective are specified as lower bound, and the goal is to maximize the total weighted satisfaction degree (TWSD) by calculating the Second Phase Satisfaction Degree (SPSD) values of each objective as shown in Equations (5)–(9) [74].

$$Max\ TWSD = \sum_{g=1}^{K} w_g * SPSD_g \tag{5}$$

s.t.

$$FPSD_g \leq SPSD_g \quad \forall g \tag{6}$$

$$0 \leq SPSD_g \leq 1 \quad \forall g \tag{7}$$

$$\sum_{g=1}^{K} w_g = 1 \tag{8}$$

$$0 \leq w_g \leq 1 \quad \forall g \tag{9}$$

In brief, the general framework of the two-phase fuzzy multi-objective goal programming method for the second phase includes determining the weight of each objective function as the sixth step, TWSD maximization as the seventh step, obtaining the values of the SPSD as the eighth step, and revealing the selected regions, energy types and allocated quantities as the final step. However, the weight determination part is skipped since the importance weights of objectives are assumed equal in the proposed methodology. On the other hand, the explanations of abbreviations and symbols are provided in Table 1 for easy tracking. Moreover, the explanations for other abbreviations in the study are given in Appendix Table C1.

Table 1
Abbreviations and symbols used in the two-phase fuzzy goal programming method.

Abbreviation/Symbol	Definition
Z_g	Value of goal “g”
Z^g_{best}	Best value of goal “g”
Z^g_{worst}	Worst value of goal “g”
$f_g(Z_g)$	Membership function for goal “g”
w_g	Importance weight of goal “g”
$FPSD_g$	First phase satisfaction degree of goal “g”
$SPSD_g$	Second phase satisfaction degree of goal “g”
$TWSD$	Total weighted satisfaction degree

3.2. The proposed model

In this part, the developed mathematical model is presented in detail, by describing the study's objectives and providing an extensive evaluation of the determined constraints.

3.2.1. Indices

i : Region $(1\ldots m)$

j : Energy Type $(1\ldots n)$

3.2.2. Sets

I : The set of regions.
J : The set of renewable energy types.
A: The set of regions existing in the southeast of Turkey and having high unemployment rates (Regions 1 and 2).
B: The set of regions having high population density (Regions 7, 11, 12, 14, 15 and 17).

3.2.3. Parameters

NTS_{ij} : Normalized technical score of region “i” concerning energy type “j”
$Cost_j$: Cost of energy type “j” per MWh.
JC_j : Number of jobs created for energy type “j” per MWh.
$MinJCR$: Mininum job creation rate for the highly unemployed southeastern regions of Turkey.
NES_j : Normalized environmental score of energy type “j”
$MinNES$: Mininum NES value for the highly populated regions of Turkey.
D : Total renewable energy production demand.
$mincap_{ij}$: Minimum required energy that must be produced in region “i” concerning energy type “j” in case it is selected.
$maxcap_{ij}$: Maximum energy capacity that can be produced in region “i” concerning energy type “j”
M : A big number.

3.2.4. Decision variables

x_{ij} : The energy that will be produced in region “i” concerning energy type “j”
y_{ij} : Region “i” concerning energy type “j” is selected or not (0/1 binary variable).
yy_i : Binary variable becoming “0” in case region “i” is selected.

3.2.5. Objective functions

$$Max\ Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * NTS_{ij}) \tag{10}$$

$$Min\ Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * Cost_j) \tag{11}$$

$$Max\ Z_3 = \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * JC_j) \tag{12}$$

$$Max\ Z_4 = \sum_{i=1}^{m}\sum_{j=1}^{n}(x_{ij} * NES_j) \tag{13}$$

3.2.6. Constraints

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} = D \tag{14}$$

$$M * y_{ij} \geq x_{ij} \quad \forall_i,\ \forall_j \tag{15}$$

$$x_{ij} \leq maxcap_{ij} \quad \forall_i,\ \forall_j \tag{16}$$

$$x_{ij} \geq mincap_{ij} * y_{ij}\ \forall_i,\ \forall_j \tag{17}$$

$$\sum_{i\in A}\sum_{j}(x_{ij} * JC_j) \geq MinJCR * \sum_{i}\sum_{j}(x_{ij} * JC_j) \tag{18}$$

$$MinNES * \sum_{j} x_{ij} - \sum_{j}(x_{ij} * NES_j) \leq M * yy_i \quad \forall_{i \in B} \tag{19}$$

$$\sum_{j} x_{ij} \leq M * (1 - yy_i)\ \forall_{i \in B} \tag{20}$$

$$x_{ij} \geq 0, y_{ij} \in \{0, 1\}\ \forall_i,\ \forall_j \tag{21}$$

The model developed in this study indicated different regions and several energy types for energy planning. In the proposed model, two indices were defined as "i" and "j" in line with planned work where "i" denotes electricity distribution regions and "j" denotes the types of renewable energy sources. This study focused on five renewable energy types, including solar, wind, geothermal, hydroelectric and biomass. Moreover, energy regions of Turkey used in the study are identified by TEDAŞ as 21 electricity distribution zones, namely, Dicle, Vangölü, Aras, Çoruh, Fırat, Çamlıbel, Toroslar, Meram, Başkent, Akdeniz, Gediz, Uludağ, Trakya, Anatolian Side, Sakarya, Osmangazi, Bosphorus, Kayseri, Menderes, Göksu and Yeşilırmak. Hence, the regions used within the model range from 1 to 21, while the types of renewable energy sources range from 1 to 5 accordingly.

The parameters identified in the model contain "NTS_{ij}" which represents the normalized technical score of the regions concerning different energy alternatives, where the cost of renewable energy types per megawatt-hour (MWh) is indicated as "$Cost_j$". Another parameter, JC_j is used to demonstrate the number of jobs created for each energy type per installed capacity in megawatt (MW), while the normalized environmental scores of renewable energy sources are represented as "NES_j". The total electricity production demand from renewable energy sources is described as "D". Moreover, the parameter symbolized as "$mincap_{ij}$" expresses the minimum required energy that must be produced in regions corresponding to renewable energy types in case it is selected. On the other hand, "$maxcap_{ij}$" is another parameter in the model which represents the maximum energy capacity that can be produced in regions concerning the types of renewable energy sources. To include a parameter that corresponds to a big number, the symbol "M" is used.

One of the aims of this study is to determine what kind of energy plant should be installed and what amount of electricity should be generated from the renewable energy plants on a regional basis. For this reason, the decision variable "x_{ij}" specified represents the amount of energy that will be produced in regions concerning the types of renewable energy sources. The other decision variable "y_{ij}" is identified to show if the regions are selected or not for the electricity generation concerning renewable energy types.

The proposed multi-objective decision-making model was built in order to provide a consistent solution for a regional renewable energy planning problem. Equations (10)–(13) correspond to the objective functions of the proposed multi-objective decision-making model. The objective function (10) is incorporated into the model to maximize the normalized technical score of regions concerning renewable energy types. In order to minimize the Levelized cost of electricity of energy types depending on the power capacity of the renewable energy plant, the objective function (11) is integrated into the model. The objective function (12) is included in the model to maximize the total number of employment for specified renewable energy sources per installed power capacity. Furthermore, the maximization of the normalized environmental impact score of the renewable energy sources, which is considered one of the most important elements of the model, is used in the model as listed in the objective function (13). Constraint (14) is a demand constraint and ensures that the total electricity generated from renewable energy sources under any scenario is equal to the sum of the amount of the total energy demand of the regions. In this way, the proposed model aims to satisfy the regions' total demand from the sum of the electricity generated through renewable energy sources. Constraint (15) is intended to be used as a selection control mechanism constraint in the model in order to guarantee that the selection of the regions if electricity production activity from renewable energy sources exists in the region. Constraints (16) and (17) are capacity constraints of the proposed multi-objective model. The constraint (16) ensures that the sum of the electricity produced in regions that correspond to renewable energy types would not exceed the maximum energy capacity of each region concerning the types of renewable energy sources. On the other hand, constraint (17) ensures that the sum of the electricity produced in the regions corresponding to renewable energy types would be greater than or equal to the minimum required energy in the regions of the renewable energy types selected. The unemployment rate is considered in constraint (18) and ensures that highly unemployed southeastern regions have at least a portion (MinJCR) of all the created jobs. Constraints (19) and (20) ensure that each of the highly populated regions defined in set B will have a NES value bigger than a threshold value (MinNES) in case they are selected. Finally, constraint (21) is included in the model in order to ensure that the energy produced in regions concerning energy types must be positive and that the "y_{ij}" are binary numbers corresponding to 0 or 1 values.

4. Application results and comparative analysis

4.1. Application of the two-phase fuzzy goal programming method

In this study, a multi-objective decision-making problem is considered for 21 regions, as seen in Fig. 3, and five renewable energy types. There are various parameters used in the model. They are briefly explained and provided.

In the beginning, the normalized technical score of each region for selected renewable energy types is found as shown in Table 2. The provided data is obtained from different resources for each renewable energy type on a regional basis to create a technical score table. For solar energy, the regional data that contain specific photovoltaic power output (PVOUT) are gathered from the Global Solar Atlas (GSA) and arranged in a determined regional format [81]. PVOUT value is calculated based on several criteria including the amount of solar radiation falling on the tilted surface of the PV modules, which depends on the local climatic conditions as well as the mounting of the modules, inclination angle, air temperature, instantaneous sun position, terrain features, and losses due to environmental factors [82]. In brief, the technical score for solar energy is calculated by applying the linear normalization procedure to the gathered data.

Moreover, the data related to wind resources are gathered from the Global Wind Atlas (GWA) and arranged in a determined regional format [83]. From the GWA website, mean wind speed and mean power density values at a height of 50 m are obtained for each city in Turkey. First of all, the regional values for 21 sites are calculated by taking an average of cities with grouping by region. Mean power density (W/m^2) and mean wind speed (m/s) at a height of 50 m above ground are taken into consideration as equally important criteria. Therefore, before using the data in the model equal weights are assigned and the linear normalization operation is applied. In the second step, the linear normalization process is applied by assigning equal weights to the data of the selected criteria. In this way, a normalized technical score of the wind energy resource on a regional basis is obtained.

Regarding geothermal energy, this study is focused on the number of wells drilled in the relevant provinces as an important criterion for the model parameter. Since the government in line with the state policy concentrates on search activities for

Table 2
Normalized technical scores for each region.

REGIONS	ENERGY TYPE (Normalized Technical Score)				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	0.991	0.580	0.096	0.541	0.706
2-VANGÖLÜ	0.969	0.739	0.022	0.715	0.201
3-ARAS	0.921	0.762	0.056	0.597	0.159
4-ÇORUH	0.756	0.773	0.014	1.000	0.341
5-FIRAT	0.962	0.771	0.022	0.629	0.273
6-ÇAMLIBEL	0.909	0.812	0.174	0.590	0.592
7-TOROSLAR	0.985	0.809	0.051	0.589	0.890
8-MERAM	0.983	0.754	0.346	0.469	0.771
9-BAŞKENT	0.852	0.557	0.188	0.697	0.569
10-AKDENİZ	0.986	0.735	0.003	0.606	0.720
11-GEDİZ	0.953	0.934	1.000	0.601	0.601
12-ULUDAĞ	0.854	0.940	0.374	0.646	0.595
13-TRAKYA	0.837	0.919	0.008	0.611	1.000
14-ANATOLIAN S.	0.402	0.392	0.014	0.405	0.588
15-SAKARYA	0.800	0.574	0.110	0.800	0.718
16-OSMANGAZİ	0.916	0.711	0.767	0.564	0.614
17-BOSPHORUS	0.402	0.392	0.014	0.405	0.928
18-KAYSERİ	0.979	1.000	0.017	0.542	0.536
19-MENDERES	0.982	0.740	1.000	0.662	0.497
20-GÖKSU	1.000	0.899	0.017	0.612	0.676
21-YEŞİLIRMAK	0.810	0.641	0.087	0.740	0.621

Fig. 3. The 21 electricity distribution regions in Turkey [80].

geothermal resources in the regions where the potential is high, this study evaluates the technical feasibility of regions in terms of the number of wells drilled according to the Mineral Research and Exploration corporation of Turkey (MTA). The data are gathered from the report prepared by Akkuş and Alan [84] for the Union of Chambers of Turkish Engineers and Architects. The average values based on the provinces are distributed according to the electricity distribution regions. Moreover, the technical score of the geothermal energy resources by region is obtained after the application of the linear normalization procedure.

For hydroelectric power, the annual average number of rainy days and the monthly average total amount of rainfall values are evaluated as equally important criteria. The related regional data associated with these two criteria are gathered from the Turkish State Meteorological Service [85]. Before calculating the technical score of the hydropower resources, the data belonging to each province are arranged on a regional basis according to the electricity distribution regions by taking an average. Afterward in this study, equal weights are assigned to the data of the selected factors, and the linear normalization procedure is performed in order to calculate the normalized technical score of the hydroelectric energy resources.

The data related to biomass energy are obtained from the Biomass Energy Potential Atlas (BEPA) provided by the General Directorate of Energy Affairs [86]. For each province, the amount of plant and animal waste, the amount of municipal waste, and the amount of forest waste (tonnes/year) are obtained from the BEPA. Then, the tonnes of oil equivalent (toe/year) of these wastes are calculated for each province. Here, the total amount of waste for each province and the total energy equivalent of the wastes belonging to that province are proportioned, and the tonnes of oil equivalent per waste of the province are calculated. Later, these data are arranged on the basis of electricity distribution regions, and after linear normalization operation, the regional evaluation score for biomass energy is created.

The following parameters are determined for each renewable energy type and provided in Table 3.

- The cost values for each renewable energy type ($/MWh)
- The job creation numbers for each renewable energy type (People/MWh)
- The normalized environmental scores (NES) for each renewable energy type (NES/MWh)

While determining the data for the cost parameters, the Levelized cost of electricity (LCOE) is found as an important metric for the renewable energy industry. The value of LCOE is calculated as a result of a complicated process by considering investment expenditures (I_t), operations and maintenance expenditures (M_t), fuel expenditures (F_t), electricity generation in a given year (E_t), discount rate (r) and the economic life of the system (n). The formula used by IRENA for calculating this parameter is given in Equation (22) [87].

Table 3
The cost, job creation and NES values for each energy type.

ENERGY TYPE	COST ($/MWh)	JC (People/MWh)	NES (NES/MWh)
SOLAR	85	0.003056	0.236
WIND	65	0.000542	0.583
GEOTHERMAL	60	0.000580	0.654
HYDROELECTRIC	55	0.000330	0.365
BIOMASS	80	0.000848	0.030

$$LCOE = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{22}$$

The value of jobs created per renewable energy type is determined according to the reports published by IRENA regarding renewable energy capacity and employment statistics [88–90]. Finally, while determining the NES, it is found important to consider the Life Cycle Assessment (LCA) of greenhouse gas emissions in the study since this process evaluates the environmental impacts of GHG emissions as a whole. The related data regarding the life cycle of GHG emissions per electricity production (gCO_2eq/MWh) are obtained from Intergovernmental Panel on Climate Change (IPCC) reports [91,92].

The unemployment rate in Turkey changes with respect to the regions. In general, the unemployment rate is higher in Southeastern Turkey. Hence, this situation is considered in the model. Regions 1 and 2 approximately constitute 10% of the whole population but the unemployment rate average in these regions is more than 25% which is higher than Turkey's average of 13% in 2020 [93]. Hence, considering this case, it is planned to allocate at least 15% of all the jobs to be created in Southeastern Turkey. Besides this, another important topic considered within the model is the environmental scores of the highly populated regions. It is considered that more attention should be given to such regions. Hence, the regions (7,11,12,14,15,17) having a population density more than the average are determined and in case they are selected, their individual mean NES value is planned to be ensured more than the mean of five renewable energy sources' NES values ((0.236 + 0.583+0.654 + 0.365+0.03)/5 = 0.3736).

In 2018, the total electricity consumption in Turkey was 302,772.30 GWh [94]. In the same year, the share of renewable energy sources in electricity production was about 33%. As a result of the calculations, the demand for electricity production from renewable energy sources is determined as 100,000,000 MWh. This value is used for the demand parameter of the developed mathematical model. Moreover, the values of minimum and maximum capacity values for five renewable resources concerning 21 regions are provided in Appendix Table B1-B2 [86,95–100].

There are four objective functions presented in the proposed multi-objective model as Z_1, Z_2, Z_3, and Z_4 to represent the technical score of regions by renewable energy types, the unit cost of renewable energy technologies, job creation by renewable energy types, and the environmental score of renewable energy resources, respectively. As an initial step, the linear membership functions were used for preparing the objection functions included in the proposed model to find the positive and negative ideal solutions. Hence, the ranges of objective functions were determined by calculating the lower and upper bounds. The membership functions for the objective functions were established by maximizing the normalized technical score, job creation, and normalized environmental score, whereas minimizing the cost-related objective function as shown in the following Equations (23)–(26).

$$f_1(Z_1) = \begin{cases} 1, \; Z_1 \geq 99641640 \\ \frac{Z_1 - 34613510}{65028130}, \; 34613510 \leq Z_1 \leq 99641640 \\ 0, \; Z_1 \leq 34613510 \end{cases} \tag{23}$$

$$f_2(Z_2) = \begin{cases} 1, \; Z_2 \le 5500000000 \\ \dfrac{8500000000 - Z_2}{3000000000}, \; 5500000000 \le Z_2 \le 8500000000 \\ 0, \; Z_2 \ge 8500000000 \end{cases} \quad (24)$$

$$f_3(Z_3) = \begin{cases} 1, \; Z_3 \ge 305570.6 \\ \dfrac{Z_3 - 33048,88}{272521,72}, \; 33048.88 \le Z_3 \le 305570.6 \\ 0, \; Z_3 \le 33048.88 \end{cases} \quad (25)$$

$$f_4(Z_4) = \begin{cases} 1, \; Z_4 \ge 58597630 \\ \dfrac{Z_1 - 3008018}{55589612}, \; 3008018 \le Z_4 \le 58597630 \\ 0, \; Z_4 \le 3008018 \end{cases} \quad (26)$$

The mathematical model is solved for each objective function to obtain the best and the worst solutions. Hence, the ranges indicating the best and worst values of each objective function are given in Table 4.

The next step of the two-phase fuzzy goal programming method is described in the following Equations (27)–(32).

$$\textit{Maximize } \lambda \quad (27)$$

s.t.

$$\lambda \le \frac{(Z_1 - 34613510)}{(99641640 - 34613510)} \quad (28)$$

$$\lambda \le \frac{(8500000000 - Z_2)}{(8500000000 - 5500000000)} \quad (29)$$

$$\lambda \le \frac{(Z_3 - 33048.88)}{(305570.6 - 33048.88)} \quad (30)$$

$$\lambda \le \frac{(Z_4 - 3008018)}{(58597630 - 3008018)} \quad (31)$$

$$\lambda \in [0,1] \quad (32)$$

After solving the mathematical model via the solver program, the general first phase satisfaction degree (λ) was obtained as 0.4991. Moreover, the first phase satisfaction degrees $FPSD_1$, $FPSD_2$, $FPSD_3$, and $FPSD_4$ were obtained as 0.6386, 0.4991, 0.4991, and 0.4991, respectively. According to the applied method, the value of λ must be less than or equal to the membership function values of the goals. In this case, its value was found equal to the value of the third objective function.

Table 4
The worst and the best values of each objective function.

	Z_g^{worst}	Z_g^{best}
Z_1	34613510	99641640
Z_2	8500000000	5500000000
Z_3	33048.88	305570.6
Z_4	3008018	58597630

In the second phase solution procedure, the weighted sum approach was used in this study. It was assumed that all objectives have equal importance weights as 0.25. Accordingly, the mathematical model was revised in accordance with the second phase as shown in Equations (33)–(38). Also, Phase II aims to improve the TWSD as well as the values of the SPSD of the objective functions. In this phase, the FPSD values obtained in the first phase were used as lower limits. The objective function and constraints of the proposed model for the second phase are presented as follows.

$$\text{Maximize } TWSD = \sum_{g=1}^{K} w_g * SPSD_g \quad (33)$$

s.t.

$$SPSD_g \ge FPSD_g \quad \forall g \quad (34)$$

$$SPSD_1 = \left(\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * NTS_{ij}) - z_1^{worst} \right) \Big/ \left(z_1^{best} - z_1^{worst} \right) \quad (35)$$

$$SPSD_2 = \left(z_2^{worst} - \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * Cost_j) \right) \Big/ \left(z_2^{worst} - z_2^{best} \right) \quad (36)$$

$$SPSD_3 = \left(\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * JC_j) - z_3^{worst} \right) \Big/ \left(z_3^{best} - z_3^{worst} \right) \quad (37)$$

$$SPSD_4 = \left(\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} * NES_j) - z_4^{worst} \right) \Big/ \left(z_4^{best} - z_4^{worst} \right) \quad (38)$$

The general satisfaction degree of the first phase was not conserved in the second phase. As a result of the values obtained after solving the model for the second phase, a considerable improvement was provided in the satisfaction degrees. The weighted satisfaction degree of the second phase (TWSD) was obtained as 0.60. The second phase satisfaction degrees SPSD1, SPSD2, SPSD3, and SPSD4 of the goals were calculated as 0.9031, 0.4991, 0.4991, 0.4991, respectively. From here, it can be concluded that the satisfaction degree of the first objective was improved significantly and the satisfaction degree of the fourth objective was improved slightly in the second phase, whereas the satisfaction degrees of the second and the third objectives were conserved.

In the literature, there are many studies related to the scoring of the model parameters. For instance, Deveci and Güler [5] used defuzzified scores for renewable energy resources, and more specifically Chalvatzis et al. [101] used evaluation scores to develop a multi-objective optimization model to maximize the technical, environmental, and social utility of the electricity generation mix. Studies reveal that the technical aspect has been an important part of the renewable energy field's problems, especially in mathematical model development.

According to results obtained in the first phase, the model was suggested to select eight locations including Çoruh, Toroslar, Meram, Uludağ, Anatolian Side, Sakarya, Bosphorus, and Yeşilırmak for geothermal energy production, seven locations covering Dicle, Vangölü, Toroslar, Meram, Akdeniz, Uludağ, and Anatolian Side for solar energy production, and fourteen locations involving Dicle, Vangölü, Aras, Fırat, Çamlıbel, Meram, Başkent, Akdeniz, Trakya, Sakarya, Osmangazi, Kayseri, Menderes, and Göksu for hydroelectric energy production in order to meet the required energy demand.

On the other hand, the results obtained in the second phase provided a better solution for the decision-making problem. As seen in Table 5, the number of regions offered by the proposed model for hydroelectric energy production was decreased to six as a result of Phase II, namely Vangölü, Çoruh, Başkent, Sakarya, Menderes, and Yeşilırmak. It was observed that the Dicle region has the highest amount of energy production from hydroelectric resources in the first phase. However, Çoruh and Yeşilırmak regions have the highest amount of electricity production by far in the second phase. Similarly, the total number of regions suggested for solar power production decreased to three including Dicle, Akdeniz, and Göksu. These regions have the highest technical scores among others in terms of solar energy. Therefore, it can be concluded that improvements provided in the second phase of the method help to obtain more consistent results. In particular, a major difference observed in the results arose from the Göksu region. Regarding renewable energy planning in this region, it was not recommended to produce solar energy in the first phase, but based on the results revealed in the second phase, producing solar energy was presented as a more feasible option. Likewise, the number of regions selected in the second phase for geothermal energy production decreased to three regions that are Gediz, Menderes, and Sakarya. In the first phase, the Uludağ region has the highest energy production amount for geothermal energy, whereas in the second phase Menderes region ranked in the first place to produce electricity from geothermal resources. Since the effect of the technical score on the selection of the regions increases in the second phase and the Menderes region has the highest technical score in terms of geothermal energy, it is more reasonable to choose this region for geothermal energy production. Moreover, the Sakarya region was included in both phases for geothermal energy production.

In brief, it has been observed that in both phases, half of the total energy demand can be met by solar energy, while 48% of the total is from hydroelectric energy, and 2% of the total is from geothermal energy. From a regional perspective, Dicle, Akdeniz, Meram, Aras, and Uludağ regions were listed as the top five regions in terms of contribution to the total energy production in the first phase, producing 39%, 22%, 21%, 8%, and 3% of the total energy supply, respectively. In the second phase, this ranking has changed almost completely, except Dicle and Akdeniz regions. The top five regions with a large share in meeting energy demand were ranked as Çoruh, Dicle, Göksu, Yeşilırmak, and Akdeniz having a total share of 24%, 23%, 21%, 17%, and 6%, respectively. Moreover, the obtained results also reveal that the southeastern regions (Dicle and Vangölü) have approximately 41% portion of all the jobs created and the selected highly populated regions have average NES values bigger than or equal to the threshold value (Gediz = 0.6543; Sakarya = 0.3736).

In summary, this study has proposed a model for the multi-objective decision-making problem that assesses the amount of energy to be produced from renewable energy sources on a regional basis. In the context of the stated objectives and defined constraints, the results obtained from the proposed model have been evaluated in detail. Accordingly, it is observed that each region and renewable energy type selected by the model for energy production has been determined based on the feasibility of that location concerning relevant renewable energy resources.

Table 5
The selected regions and resource types for Phase I and II.

PHASE-I			
X(i,j)	REGION	RESOURCE TYPE	AMOUNT (MWh)
X(1,1)	DİCLE	SOLAR	4367795.00
X(1,4)	DİCLE	HYDROELECTRIC	34524090.00
X(2,1)	VANGÖLÜ	SOLAR	19872.94
X(2,4)	VANGÖLÜ	HYDROELECTRIC	1641636.00
X(3,4)	ARAS	HYDROELECTRIC	7944229.00
X(4,3)	ÇORUH	GEOTHERMAL	179914.70
X(5,4)	FIRAT	HYDROELECTRIC	2722.61
X(6,4)	ÇAMLIBEL	HYDROELECTRIC	5905.12
X(7,1)	TOROSLAR	SOLAR	45248.97
X(7,3)	TOROSLAR	GEOTHERMAL	22203.10
X(8,1)	MERAM	SOLAR	21541470.00
X(8,3)	MERAM	GEOTHERMAL	22203.10
X(8,4)	MERAM	HYDROELECTRIC	6460.68
X(9,4)	BAŞKENT	HYDROELECTRIC	4856.54
X(10,1)	AKDENİZ	SOLAR	22136710.00
X(10,4)	AKDENİZ	HYDROELECTRIC	6291.43
X(12,1)	ULUDAĞ	SOLAR	1575496.00
X(12,3)	ULUDAĞ	GEOTHERMAL	1739425.00
X(13,4)	TRAKYA	HYDROELECTRIC	71562.53
X(14,1)	ANATOLIAN	SOLAR	4473.91
X(14,3)	ANATOLIAN	GEOTHERMAL	23003.40
X(15,3)	SAKARYA	GEOTHERMAL	22203.10
X(15,4)	SAKARYA	HYDROELECTRIC	846.22
X(16,4)	OSMANGAZİ	HYDROELECTRIC	2201431.00
X(17,3)	BOSPHORUS	GEOTHERMAL	23003.40
X(18,4)	KAYSERİ	HYDROELECTRIC	1492006.00
X(19,4)	MENDERES	HYDROELECTRIC	11276.75
X(20,4)	GÖKSU	HYDROELECTRIC	3826.37
X(21,3)	YEŞİLIRMAK	GEOTHERMAL	359829.90
PHASE-II			
X(i,j)	**REGION**	**RESOURCE TYPE**	**AMOUNT (MWh)**
X(1,1)	DİCLE	SOLAR	22622710.00
X(2,4)	VANGÖLÜ	HYDROELECTRIC	1641636.00
X(4,4)	ÇORUH	HYDROELECTRIC	24108760.00
X(9,4)	BAŞKENT	HYDROELECTRIC	3199365.00
X(10,1)	AKDENİZ	SOLAR	5975356.00
X(11,3)	GEDİZ	GEOTHERMAL	370867.90
X(15,3)	SAKARYA	GEOTHERMAL	49808.09
X(15,4)	SAKARYA	HYDROELECTRIC	1544788.00
X(19,3)	MENDERES	GEOTHERMAL	1979063.00
X(19,4)	MENDERES	HYDROELECTRIC	731607.60
X(20,1)	GÖKSU	SOLAR	21091970.00
X(21,4)	YEŞİLIRMAK	HYDROELECTRIC	16684060.00

4.2. Comparison of the two-phase fuzzy goal programming method with other multi-objective methods

In addition to the two-phase fuzzy goal programming method proposed in this study, three additional methods including goal programming with absolute deviation, goal programming with percentage deviation, and lexicographic methods are also utilized. Since there is no superiority between the objectives with respect to importance weights in the case, the methods conforming to this situation [102] are selected for the comparison.

The main goal of the proposed method is to maximize the minimum of all the satisfaction degrees. For this aim, considering the comparative results indicated in Table 6, the minimum of satisfaction degrees is clearly stated for each method. Hence, it is observed that the two-phase fuzzy goal programming method has the maximum of the minimum satisfaction degrees. This result shows that the least satisfaction degree of any objective will be 49.91% in case the two-phase fuzzy goal programming method is utilized. Finally, this result is the best among the considered multi-objective methods.

Since there is no superiority between the objectives, it is not required to perform a sensitivtity analysis based on the objective importances. Hence, in the actual case, they are all evaluated as equal and given the same importance weights. However, a partial sensitivity analysis is performed based on the importance weights of the objectives that are used in the second phase of the proposed method and it is observed that there is no difference between the objective satisfaction degrees obtained for various importance weights.

5. Discussion and policy implications

The amount of global energy consumption is increasing in parallel with the growing human population in the world. Considering the fact that many countries are heavily dependent on fossil fuels in energy production to meet increasing national energy demand, it becomes very important to maintain the continuous balance of energy supply and demand in an efficient way. However, the world already has limited reserves in terms of fossil fuels, and these resources are not evenly distributed between countries. Therefore, it is not possible to meet the growing energy demand only with these resources. The need for a definite plan of action in energy policies has become inevitable. Additionally, the increasing level of environmental concerns, legal regulations, economic problems, and their possible consequences lead to a shift from fossil fuels to renewable resources in power generation. In this context, governments carry out short, medium, and long-term strategic plans for sustainable energy planning in order to meet their increasing energy needs and use existing renewable energy resources with maximum efficiency.

Although decision-makers and academics have made significant efforts and intensive studies on energy planning, it is difficult to find an ideal method for governments, institutions, and private companies to determine the appropriate energy source, select the suitable region, and utilize the potential resources efficiently. Thus, there should be a problem-specific set of proper objectives and a comprehensive evaluation of the determined criteria for developing a mathematical model as a useful method intended for renewable energy planning. In this way, this study aims to raise awareness of the preference for renewable energy in energy consumption and, so that countries will use their energy potential in the most efficient way and will benefit from many aspects,

Table 6
Comparative results of the multi-objective methods utilized.

METHODS	OBJECTIVE SATISFACTION DEGREES				
1-LEXICOGRAPHIC Importance Ranking Combinations	Objective 1 satisfaction degree	Objective 2 satisfaction degree	Objective 3 satisfaction degree	Objective 4 satisfaction degree	Minimum of satisfaction degrees
o1,o2,o3,o4	100%	32.20%	57.78%	42.71%	32.20%
o1,o2,o4,o3	100%	32.20%	57.78%	42.71%	32.20%
o1,o3,o2,o4	100%	32.20%	57.78%	42.71%	32.20%
o1,o3,o4,o2	100%	32.20%	57.78%	42.71%	32.20%
o1,o4,o2,o3	100%	32.20%	57.78%	42.71%	32.20%
o1,o4,o3,o2	100%	32.20%	57.78%	42.71%	32.20%
o2,o1,o3,o4	58.25%	100%	0%	60.17%	0%
o2,o1,o4,o3	58.25%	100%	0%	60.17%	0%
o2,o3,o1,o4	58.25%	100%	0%	60.17%	0%
o2,o3,o4,o1	58.25%	100%	0%	60.17%	0%
o2,o4,o1,o3	58.25%	100%	0%	60.17%	0%
o2,o4,o3,o1	58.25%	100%	0%	60.17%	0%
o3,o1,o2,o4	98.84%	0%	100%	37.02%	0%
o3,o1,o4,o2	98.84%	0%	100%	37.02%	0%
o3,o2,o1,o4	98.84%	0%	100%	37.02%	0%
o3,o2,o4,o1	98.84%	0%	100%	37.02%	0%
o3,o4,o1,o2	98.84%	0%	100%	37.02%	0%
o3,o4,o2,o1	98.84%	0%	100%	37.02%	0%
o4,o1,o2,o3	79.16%	67.74%	10.21%	100%	10.21%
o4,o1,o3,o2	79.16%	67.74%	10.21%	100%	10.21%
o4,o2,o1,o3	79.16%	67.74%	10.21%	100%	10.21%
o4,o2,o3,o1	79.16%	67.74%	10.21%	100%	10.21%
o4,o3,o1,o2	79.16%	67.74%	10.21%	100%	10.21%
o4,o3,o2,o1	79.16%	67.74%	10.21%	100%	10.21%
2-GOAL PROGRAMMING (Absolute deviation)	58.70%	99.99%	0%	60.19%	0%
3-GOAL PROGRAMMING (Percentage deviation)	91.09%	65.90%	10.61%	98.13%	10.61%
4-TWO PHASE FUZZY METHOD	90.31%	49.91%	49.91%	49.91%	49.91%

especially in economic and environmental areas. Thus, in this study, a multi-objective decision-making model was developed by considering technical, economic, social, and environmental aspects of renewable energy resources on a regional basis in order to contribute to the decision-makers, managers, and policymakers in the energy planning process.

As in the case of this study, the optimal planning of renewable energy sources requires technical, economic, social, and environmental analysis of energy alternatives on a local scale comparatively. One of the key points in making the most appropriate decision in a planning process is providing the optimum utilization of the available opportunities in the current conditions. Since there is no better or worse solution methodology, the basis of any improvement effort is the accurate analysis of the problem. Therefore, it is critical to analyze the decision problem in detail for the specific circumstances. Policymakers interested in renewable energy planning also need to give necessary importance to the regional analysis. For this reason, the technical analysis of renewable energy types from a regional perspective has been integrated into the model by providing a technical scoring mechanism. In this way, the study aims to improve the current position to be able to cope with the increased energy demand of each developing region and utilize the future potential of renewable energy sources in electricity generation efficiently. This process covers mainly the analysis of the needs and requirements of the specific regions in detail by considering the importance of technical conformity, financial analysis in a way that minimizes the total cost, the examination of social and employment issues, and environmental effects of energy sources. Moreover, government units, global organizations, institutions, agencies, and associations can benefit from the detailed analysis and outputs of the processes as a reference in their studies on many different subjects.

6. Conclusion

Real-world problems in planning activities require consideration of multiple conflicting objectives simultaneously. In recent years, renewable energy planning has become a very important issue, which poses itself as a multi-objective problem due to its impact on economic, social, and environmental concerns. As the number of options increases, it becomes more difficult for decision-makers to determine specific renewable energy technology among alternatives [103]. Therefore, the proposed model for the prioritization of renewable energy sources based on twenty-one electricity distribution zones in Turkey has been developed in a multi-objective structure.

The advantage of the proposed multi-objective model is that it can be further modified by integrating particular considerations such as national renewable energy targets and local incentive support schemes. In this way, the model enables the evaluation of several objectives simultaneously and better accommodates various parameters together in order to contribute to the process of determining the most suitable renewable energy technologies in future energy planning. Thus, this study presents a framework that provides a useful roadmap for decision-makers in the development and implementation of sustainable energy plans by analyzing renewable energy resources from a regional perspective to utilize energy potential efficiently. In addition, another contribution made through this study is the use of efficient solution methods comparatively in multi-objective analysis, which allows decision-makers to decide on the most appropriate evaluation method in the planning process. Hence, the two-phase fuzzy goal programming method is utilized for the evaluation procedures in comparison with three other multi-objective methods including lexicographic optimization, goal programming with absolute deviation, and goal programming with percentage deviation.

The developed model for renewable energy planning in Turkey is solved by using LINGO optimization modeling software. The results of the study suggest that the two-phase fuzzy goal programming is the most appropriate approach among the considered methods. According to the results obtained by solving the model, renewable energy sources including solar, hydroelectric, and geothermal energy have a significant role in energy production. It is provided that solar energy will be accounted for almost half of the total renewable energy production, followed by hydroelectric, and geothermal energy. From a regional perspective, the results obtained in the second phase of the two-phase method reveal that regions selected for solar energy production, namely, Göksu, Dicle, and Akdeniz have the highest technical scores in terms of solar energy, respectively. Similarly, the regions selected for geothermal energy production, such as Gediz and Menderes, are ranked first and second regions having the highest technical scores in terms of geothermal energy, respectively.

This study focuses on energy planning by considering only renewable energy resources to contribute to the sustainable development goals of countries. Therefore, different types of existing conventional energy sources, which include coal, oil, and gas, are not considered in the proposed model. Instead, the subject is examined from a generic approach with comprehensive evaluation criteria. Using both fossil fuels and renewable energy resources as an integrated model for the development of energy plans can provide more consistent solutions to determine national energy policies, prioritize available energy sources, and achieve country-specific energy targets. This paper presents a case study that deals with a country-specific renewable energy planning problem, which evaluates Turkey's current energy status, cost of energy production, job creation, and environmental impact in terms of renewable energy resources. Moreover, the accessibility of specific local data for renewable energy resources plays an important role in the energy planning process and the precision of the results obtained from the implementation of the proposed multi-objective model. In other words, the accuracy of parameters directly influences the results of the study as part of the model application. The case study was performed by using proper regional values in terms of technical parameters for each renewable energy type, whereas accessible national values are used for the economic, social, and environmental parameters. The reason for being unable to access valid and reliable regional parameter values is due to the lack of availability of research studies regarding economic, social, and environmental criteria at a regional level in the country. In brief, the evaluation of the multi-objective decision-making problem is a complex process containing certain limitations thus determination of the objectives, criteria, and model parameters after a detailed analysis is crucial for the development of the proposed framework.

For future study, the proposed framework can be improved by adding more attributes and assigning different weights to the determined objectives in the model to obtain comparisons of the goals under various conditions and reveal the major differences in the model coefficients. Furthermore, the scope of this study can be extended by evaluating more than five renewable energy alternatives and various regions in detail to provide more comprehensive perspectives into the field. In other words, the mathematical model can be customized based on specific locations. Moreover, the proposed model can be modified by adding more objectives or parameters including fuzzy values regarding different aspects to cover more subjects simultaneously in a single model. Even, the proposed model can be improved by integrating traditional fossil fuels into the evaluation process to provide a more accurate energy planning approach. The methodology used in this study for the model application can be enriched by using a combination of various multi-criteria decision-making techniques including a fuzzy approach. In addition, the global and national energy needs, total annual demand, and strategic targets can be examined by creating different scenarios related to renewable energy planning in the short and long terms. Afterward, crucial information and valuable insights for decision-makers, investors, policymakers, and academicians can be provided by solving the model under different scenarios.

CRediT authorship contribution statement

Muhammed Bilal Horasan: Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Validation. **Huseyin Selcuk Kilic:** Conceptualization, Methodology, Software, Formal analysis, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Literature Review Summary Table

Table A1
Literature review summary table

STUDY	RENEWABLE ENERGY SOURCE					SOLUTION METHODS									
	Solar	Wind	Geothermal	Hydroelectric	Biomass	AHP	Fuzzy AHP	ANP	TOPSIS	Fuzzy TOPSIS	VIKOR	WASPAS	COPRAS	ELECTRE	OTHERS
Büyüközkan & Güleryüz [103]	x	x	x	x	x			x	x						13
Kumar & Samuel [104]	x	x	x		x	x					x				
Özcan et al. [7]	x	x	x	x	x			x	x						
Haddad et al. [105]	x	x	x	x	x	x									
Çolak & Kaya [106]	x	x	x	x	x		x			x					
Ervural et al. [2]	x	x	x	x	x	x	x			x					19
Büyüközkan et al. [107]	x	x		x	x	x							x		
Ligus & Peternek [108]	x	x			x		x			x					
Karaca & Ulutaş [6]	x	x	x	x	x							x			4
Baysal & Çetin [67]	x	x	x	x	X		x								20
Wu et al. [109]	x	x		x	x	x				x					9,29
Chatterjee & Kar [110]	x	x	x	x	x				x		x		x		
Lee & Chang [35]	x	x	x	x	x				x		x			x	4,7
Luz et al. [111]	x	x		x	x										2
Yazdani et al. [112]	x	x		x	x			x				x	x		13
Erdin & Ozkaya [12]	x	x	x	x	x									x	
Solangi et al. [8]	x	x	x	x	x	x				x					16
Luz & Moura [113]	x	x		x	x										26
Dinçer & Yüksel [45]	x	x	x	x	x					x					30
Yu et al. [114]	x	x		x	x										31
Yurdakul & İç [115]	x	x	x	x	x		x			x					
Aksoy [42]	x	x	x		x	x									2
Aikhuele et al. [116]	x	x	x	x	x										8,33,34
Boran [117]	x	x	x	x	x	x									35
Rani et al. [118]	x	x	x	x	x					x					
Jahangiri et al. [119]	x	x								x					
Wang et al. [9]	x	x			x		x								
Yazdani et al. [120]	x	x	x		x						x	x	x		4,15,36
Sitorus & Brito-Parada [121]	x	x													4,38
Ahmadi et al. [122]		x		x				x			x				12,17
Deveci & Güler [5]	x	x	x	x	x		x								21,22
Alkan & Albayrak [13]	x	x	x	x	x										5,18,25
Alizadeh et al. [123]	x	x	x	x	x			x			x				3
Hori et al. [124]	x	x	x	x	x										6
Yilan et al. [125]	x	x	x	x											7,10

(continued on next page)

Table A1 (*continued*)

STUDY	RENEWABLE ENERGY SOURCE					SOLUTION METHODS									
	Solar	Wind	Geothermal	Hydroelectric	Biomass	AHP	Fuzzy AHP	ANP	TOPSIS	Fuzzy TOPSIS	VIKOR	WASPAS	COPRAS	ELECTRE	OTHERS
Taghizadeh-Yazdi & Mohammadi-Balani [11]	x	x	x	x	x										41
Ahmed et al. [126]	x	x	x		x	x			x						28
Bakhtavar et al. [127]	x		x		x				x						37
Li et al. [128]	x	x	x	x	x	x		x	x		x			x	1,7
Louis et al. [129]	x	x	x		x										2
Niu et al. [130]	x	x	x	x	x										27,29
Al Hasibi [10]	x	x	x		x										2
Ulewicz et al. [131]	x	x	x	x	x		x		x						32
Krishankumar et al. [132]	x	x		x	x						x	x	x		8,11,40
Ezbakhe & Pérez-Foguet [133]	x	x	x	x	x									x	
Pavlovi et al. [134]	x	x		x	x		x								
Shatnawi et al. [135]	x	x		x	x	x									
Wang et al. [136]	x	x			x	x						x			
Karaaslan & Gezen [14]	x	x	x	x	x										23,24
Abdul et al. [137]	x	x		x	x	x					x				
Assadi et al. [138]	x	x	x	x	x										16,39

Notes: 1- PROMETHEE, 2-EPSILON CONSTRAINT, 3-BOCR, 4-ENTROPY, 5-MULTIMOORA, 6-GENETIC ALGORITHM, 7-WSM, 8-IFTOPSIS, 9- Fuzzy SAW, 10-MAUT, 11-TODIM, 12-GIS, 13-DEMATEL, 14-MOORA, 15-MABAC, 16-DELPHI, 17-Fuzzy VIKOR, 18-Fuzzy COPRAS, 19-GP, 20-Fuzzy GP, 21-ARIMA, 22-CMOPSO, 23-MAXMIN, 24-IC, 25-Fuzzy ENTROPY, 26-HIERARCHICAL, 27-IVHFE, 28-MCA, 29-TFN, 30-Fuzzy DEMATEL, 31-IP, 32-AJC, 33-DIFWGE, 34-IFE, 35-IFVIKOR, 36-EDAS, 37-GPC, 38-IC-FSE, 39-SECA, 40-QROFS, 41-MO-NLP.

Appendix B. Model Parameter Values

Table B1
The minimum capacity values of renewable energy sources for the regions (MWh)

REGIONS	RENEWABLE ENERGY SOURCE				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	17975.52	2803.20	22203.10	43907.57	18697.34
2-VANGÖLÜ	19872.94	2803.20	22203.10	11405.52	9902.30
3-ARAS	9786.67	2803.20	22203.10	6780.77	8409.60
4-ÇORUH	4473.91	2803.20	22203.10	1821.20	29706.91
5-FIRAT	15978.24	35040.00	22203.10	2722.61	9916.32
6-ÇAMLIBEL	17975.52	35040.00	22203.10	5905.12	9916.32
7-TOROSLAR	4473.91	31536.00	22203.10	3587.22	6993.98
8-MERAM	4473.91	24528.00	22203.10	6460.68	5606.40
9-BAŞKENT	4473.91	2803.20	22203.10	4856.54	7029.02
10-AKDENİZ	4473.91	210240.00	22203.10	6291.43	3504.00
11-GEDİZ	4473.91	10512.00	80592.00	846.22	16118.40
12-ULUDAĞ	4473.91	2803.20	60444.00	6990.48	14955.07
13-TRAKYA	4473.91	10512.00	22203.10	846.22	8409.60
14-ANATOLIAN S.	4473.91	2803.20	22203.10	846.22	24528.00
15-SAKARYA	4473.91	35040.00	22203.10	846.22	2312.64
16-OSMANGAZİ	4473.91	95308.80	22203.10	1802.81	10519.01
17-BOSPHORUS	4473.91	10512.00	22203.10	846.22	256541.86
18-KAYSERİ	4473.91	42048.00	22203.10	1140.55	10519.01
19-MENDERES	9986.40	39244.80	30681.37	11276.75	4450.08
20-GÖKSU	4473.91	87600.00	22203.10	3826.37	8409.60
21-YEŞİLIRMAK	4473.91	31536.00	22203.10	7479.81	9916.32

Table B2
The maximum capacity values of renewable energy sources for the regions (MWh)

REGIONS	RENEWABLE ENERGY SOURCE				
	SOLAR	WIND	GEOTHERMAL	HYDRO	BIOMASS
1-DİCLE	22622713.82	1709482.43	359829.89	34524092.81	33069717.56
2-VANGÖLÜ	20757848.68	148569.60	935557.42	1641636.38	10899886.56
3-ARAS	18232993.42	607390.36	899574.48	8414053.02	17224512.10
4-ÇORUH	13223782.89	294563.75	179914.69	24108756.90	5214451.90
5-FIRAT	20235345.39	3655688.08	107948.81	15491479.59	4978960.53
6-ÇAMLIBEL	18767220.39	8373018.07	935557.42	4579501.72	13322083.57
7-TOROSLAR	21768217.11	12920589.76	251880.57	20767459.77	31555844.43
8-MERAM	21541470.39	4437167.67	1007523.29	4543433.98	44777003.13
9-BAŞKENT	17665460.53	1588131.90	1043506.23	3199365.00	21396073.62
10-AKDENİZ	22136713.82	3880592.32	35982.94	6410002.29	14196765.83
11-GEDİZ	21189226.97	25107820.37	2734705.86	411482.28	22270755.87
12-ULUDAĞ	18728851.97	45739599.70	2482824.78	1316027.73	24726594.51
13-TRAKYA	17131233.55	16355592.43	23988.46	71562.53	13927632.83
14-ANATOLIAN S.	19050720.39	3056377.95	23003.40	4999.69	5180810.28
15-SAKARYA	15587970.39	835802.09	647693.40	1544788.43	10597111.93
16-OSMANGAZİ	19371523.03	2132474.79	1691199.63	2201431.38	20857807.62
17-BOSPHORUS	19050720.39	3056377.95	23003.40	4999.69	5180810.28
18-KAYSERİ	20289967.11	2759007.49	359829.38	1492005.73	7300232.67
19-MENDERES	21043213.82	11609929.10	1979063.13	3700061.70	20252258.36
20-GÖKSU	21091973.68	4784414.06	35982.94	8888796.34	7535724.04
21-YEŞİLIRMAK	15512832.24	15139410.12	359829.89	16684063.04	22136189.37

Appendix C. Definitions of Abbreviations and LINGO Codes

Table C1
Explanations of abbreviations used in the the study

Abbreviation	Definition
EIA	Energy Information Agency
MCDM	Multi Criteria Decision Making
MODM	Multi Objective Decision Making
MOLP	Multi Objective Linear Programming
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje (Multi-criteria optimization and compromise solution)
WASPAS	Weighted Aggregated Sum Product Assessment
COPRAS	Complex Proportional Assessment
ELECTRE	ELimination Et Choix Traduisant la REalité (Elimination and Choice Expressing the Reality)
PVOUT	Photovoltaic Power Output
GSA	Gloabal Solar Atlas
GWA	Global Wind Atlas
MTA	Mineral Research and Exploration corporation of Turkey
MGM	Turkish State Meteorological Service
BEPA	Biomass Energy Potential Atlas
MENR	General Directorate of Energy Affairs
LCOE	Levelized Cost of Electricity
IRENA	International Renewable Energy Agency
LCA	Life Cycle Assessment
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
TEDAŞ	Turkish Electricity Distribution Corporation
TUIK	Turkish Statistical Institute
EMRA	Energy Market Regulatory Board
UCTEA	Union of Chambers of Turkish Engineers and Architects
LINGO	Modeling Language and Optimizer
GP	Goal Programming
ICT	Information and Communication Technology
NTS	Normalized Technical Score
NES	Normalized Environmental Score
JC	Job Creation

First phase LINGO Codes

FIRST PHASE LINGO CODES

```
SETS:
Region/1..21/:yy,RNES,REQ,RJC;
Energytype/1..5/:Cost,JC,NES;
Region_Energytype(Region, Energytype):NTS,mincap,maxcap,x,y;
Objectives/1..4/:FPSD,OF;
ENDSETS
DATA:
Cost=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','cost');
JC=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','social');
NES=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','environment');
NTS=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','technical');
mincap=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','mincap');
maxcap=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','maxcap');
Demand=100000000;
M=10000000000;
ENDDATA
MAX=LAMDA;
OF(1)=(@SUM(Region_Energytype:x*NTS));
LAMDA <= (OF(1)-34613510) / (99641640-34613510);
FPSD(1)=(OF(1)-34613510) / (99641640-34613510);
OF(2)=(@SUM(Region_Energytype:x*Cost));
LAMDA <= (8500000000-OF(2)) / (8500000000 - 5500000000);
FPSD(2)=(8500000000-OF(2)) / (8500000000 - 5500000000);
OF(3)=(@SUM(Region_Energytype:x*JC));
LAMDA <= (OF(3)-33048.88) / (305570.6 - 33048.88);
FPSD(3)=(OF(3)-33048.88) / (305570.6 - 33048.88);
OF(4)=(@SUM(Region_Energytype:x*NES));
LAMDA <=(OF(4)-3008018) / (58597630 - 3008018);
FPSD(4)=(OF(4)-3008018) / (58597630 - 3008018);
@sum(Region_Energytype:x)=Demand;
@for(Region_Energytype:y*M>=x);
@for(Region_Energytype:x <= maxcap);
@for(Region_Energytype:x >= mincap*y);
@for(Region_Energytype:@BIN(y));
@for(Region:@BIN(yy));
@sum(Energytype(j):x(1,j)*JC+x(2,j)*JC)>= 0.15*@SUM(Region_Energytype:x*JC);
@for(Region(i)| i #EQ# 7 #OR# i #EQ# 11 #OR# i #EQ# 12 #OR# i #EQ# 14 #OR# i #EQ# 15 #OR# i #EQ#
17:0.3736*(@sum(Energytype(j):x(i,j)))-(@sum(Energytype(j):x(i,j)*NES))<=M*yy);
@for(Region(i)| i #EQ# 7 #OR# i #EQ# 11 #OR# i #EQ# 12 #OR# i #EQ# 14 #OR# i #EQ# 15 #OR# i #EQ#
17:@sum(Energytype(j):x(i,j))<=M*(1-yy));
@for(Region(i):RNES=@sum(Energytype(j):x(i,j)*NES));
@for(Region(i):REQ=@sum(Energytype(j):x(i,j)));
@for(Region(i):RJC=@sum(Energytype(j):x(i,j)*JC));
```

Second phase LINGO Codes

SECOND PHASE LINGO CODES

```
SETS:
Region/1..21/:yy,RNES,REQ,RJC;
Energytype/1..5/:Cost,JC,NES;
Region_Energytype(Region, Energytype):NTS,mincap,maxcap,x,y;
Objectives/1..4/:FPSD,SPSD,OF,wo;
ENDSETS
DATA:
Cost=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','cost');
JC=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','social');
NES=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','environment');
NTS=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','technical');
mincap=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','mincap');
maxcap=@OLE
('C:\DOSYALAR_GİRİŞ_17_Temmuz\LAPTOP\YL_Tez_Danışmanlığı\Muhammed_Bilal_Horasan\TEZ\Sub
mission\Revision\PARAMETERS_NEW.xlsx','maxcap');
Demand=100000000;
M=10000000000;
wo=0.25,0.25,0.25,0.25;
FPSD=0.6386,0.4991,0.4991,0.4991;
ENDDATA
MAX=@SUM(Objectives:wo*SPSD);
OF(1)=(@SUM(Region_Energytype:x*NTS));
OF(2)=(@SUM(Region_Energytype:x*Cost));
OF(3)=(@SUM(Region_Energytype:x*JC));
OF(4)=(@SUM(Region_Energytype:x*NES));
SPSD(1)=(OF(1)-34613510) / (99641640-34613510) ;
SPSD(2)=(8500000000-OF(2)) / (8500000000 - 5500000000) ;
SPSD(3)=(OF(3)-33048.88) / (305570.6 - 33048.88) ;
SPSD(4)=(OF(4)-3008018) / (58597630 - 3008018) ;
@for(Objectives:SPSD>=FPSD);
@sum(Region_Energytype:x)=Demand;
@for(Region_Energytype:y*M>=x);
@for(Region_Energytype:x <= maxcap);
@for(Region_Energytype:x >= mincap*y);
@for(Region_Energytype:@BIN(y));
@for(Region:@BIN(yy));
@sum(Energytype(j):x(1,j)*JC+x(2,j)*JC)>= 0.15*@SUM(Region_Energytype:x*JC) ;
@for(Region(i)| i #EQ# 7 #OR# i #EQ# 11 #OR# i #EQ# 12 #OR# i #EQ# 14 #OR# i #EQ# 15 #OR# i #EQ#
17:0.3736*(@sum(Energytype(j):x(i,j)))-(@sum(Energytype(j):x(i,j)*NES))<=M*yy);
@for(Region(i)| i #EQ# 7 #OR# i #EQ# 11 #OR# i #EQ# 12 #OR# i #EQ# 14 #OR# i #EQ# 15 #OR# i #EQ#
17:@sum(Energytype(j):x(i,j))<=M*(1-yy));
@for(Region(i):RNES=@sum(Energytype(j):x(i,j)*NES));
@for(Region(i):REQ=@sum(Energytype(j):x(i,j)));
@for(Region(i):RJC=@sum(Energytype(j):x(i,j)*JC));
```

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