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A Multi-Objective Mixed Integer Linear Programming Model for Energy Resource Allocation Problem: The Case of Turkey

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ABSTRACT

Energy is one of the most basic elements for raising social welfare, playing a fascinating role in economic and social progress of the countries and thus increasing the competitiveness of the countries in globalized world. Therefore, carrying out the sustainable energy policies which are based on social, economic and environmental factors and in this context, finding the local, sustainable, environmentally-friendly and economic resources and the optimal distribution of them have become a necessity in order to achieve the sustainable development thrusts. In this study, a multi-objective mixed integer linear programming (MOMILP) model which reflects the Turkey's realities and necessities and optimizes simultaneously the objectives of total cost minimization, CO_2 emission minimization, energy import minimization, fossil resource usage minimization, employment maximization and social acceptance maximization is proposed. This model is solved by Minimum Deviation Method (MDM) considering the most basic energy resources (solar, wind, coal, natural gas, hydroelectric, nuclear etc.) used for the electricity generation all over the world and a 11-years electricity generation plan is obtained on the basis of resources for Turkey.

Keywords: Energy resource allocation, energy planning, multi-objective programming, minimum deviation method

1. INTRODUCTION

The selection of the most appropriate energy policy has great importance in terms of the countries' sustainable development and environment. Therefore, finding local, sustainable, environmentally-friendly and economic resources and optimal distribution of them have become a necessity.

In this context, many scientific studies have been carried out concerning the energy resource allocation problem in the literature. The traditional energy resource allocation problem has been handled on the basis of limited resources under the single goal such as maximization or minimization until the middle of 90s. Diversity of considered resources has increased and the multi-objective optimization approaches have started to use optimal distribution of these energy resources in the scope of the problem in the last 20 years. Scientific studies which use the multi-objective programming (MOP) approaches in energy resource allocation problem literature are shown on Table 1 by descending years on the basis of optimized objectives, considered energy resources and methods.

In this study, a MOMILP model which optimizes simultaneously the objectives of total electricity generation cost minimization, CO_2 emission minimization, energy import minimization, fossil resource usage minimization, social acceptance maximization and employment maximization is proposed. This proposed model is solved for 18 types of power plants (Table 2) currently used and planned to be used in near future in Turkey by MDM and a resource based electricity generation plan is obtained for meeting the demand between 2013-2023 (Table 3).

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Table 1. Brief review of the literature [1-11].

Researchers	Objectives	Energy Resources	Methods
San Cristóbal	Minimization of CO_2 emissions, investment cost, operation and maintenance costs, distance between plants and maximization of generated power, labor and social acceptance	Wind, hydroelectric, solar and biomass	Goal programming
Arnette, Zobel	Minimization of cost and emissions	Coal, nuclear, hydroelectric, natural gas, fuel-oil, wind, biomass and solar	Multi-objective linear programming
Jinturkar, Deshmukh	Minimization of cost and emissions and maximization of social acceptance and use of local resource	Biomass, LPG, biogas, kerosene, dung cake and solar	Fuzzy mixed integer goal programming
Deshmukh, Deshmukh	Minimization of cost, emissions and use of petroleum products and maximization of employment generation, social acceptance, use of local resource, reliability and system efficiency	Biomass, LPG and solar	Goal programming
Jana, Chattopadhyay	Minimization of total cost of direct energy and use of non-local sources of energy and maximization of overall efficiency	Kerosene, grid electricity, biomass and solar	Multi-objective fuzzy linear programming
Antunes, Martins, Brito	Minimization of total expansion cost, environmental impact and environmental cost	Coal, petroleum products and natural gas	Multi-objective mixed integer linear programming
Borges, Antunes	Minimization of energy import and CO_2 emissions and maximization of self—production of electricity	Not specified	Multi-objective fuzzy linear programming
Agrawal, Singh	Minimization of life cycle cost, use of coal, petroleum and fuel wood products, carbon, sulphur and nitrogen emissions and maximization of usefully available energy, use of locally available resources, convenience and comfort of operations, degree of safety and continuity and predictability of performance	Coal, soft coke, kerosene, LPG, biomass, fuel wood, charcoal, solar, diesel and grid electricity	Fuzzy goal programming
Mavrotas et al.	Minimization of annual electricity generation cost and total amount of SO_2 emissions.	Lignite, petroleum and natural gas	Multi-objective mixed integer linear programming
Mezher et al.	Minimization of cost, use of petroleum products and natural gas, and emissions and maximization of system efficiency, use of locally available resources and employment generation	Diesel mechanical, natural gas, biogas, fuel wood, solar, diesel electricity, thermal electric power, wind and hydroelectric	Goal programming
Pokharel, Chandrashekara	Minimization of cost, energy input and pollution and maximization of efficiency, employment and use of local resources	Fuel wood, crop residues, animal manure, biogas, solar, hydroelectric, charcoal and kerosene	Multi-objective linear programming

Table 2. Types of power plants and basic data [12-16].

Type of Power Plant	Resource	Installed Capacity (MW)	[a]Max. Generation Capacity (GWh)	[b]Levelized Cost ($Cent/kWh)	Capital Expenditures (Million $)	CO_2 Emissions (g/kWh)	[c]CO_2 Reduction (tone/year)	Installation Time (year)	Number of Available Plants	Number of Employees	Resource Potential (GWh/year)
*T1-PV	Solar	30	48,8	14,15	74,37	32	28.792	1	0	16	380.000
*T2-CRS	Solar	15	26	28,42	69,86	11	15.340	2	0	26	
*[d]T3-PTC	Solar	50	128	29,31	378,70	13	75.520	2	0	54	
T4	Hard Coal	360	2.142	9,5	720	960	0	4	0	90	11
[e]T5	Hard Coal	360	1.525	8,57	0	1.140	0	0	16	360	
T6	Lignite	360	2.142	11	720	1.050	0	4	0	90	118
[e]T7	Lignite	360	1.507	7,45	0	1.055	0	0	24	360	
T8	Natural Gas	275	1.856	13,3	292,19	443	0	2	0	53	0
[e]T9	Natural Gas	275	1.773	11,96	0	480	0	0	79	65	
T10	Hydraulic	150	540	8,6	525	10	286.200	4	0	50	140.000
[e]T11	Hydraulic	150	500	1,04	0	10	265.000	0	130	50	
T12	Wind	30	110	5,9	66	10	64.900	1	0	12	144.000
[e]T13	Wind	30	83	5,9	0	10	48.970	0	69	12	
T14	Geothermal	15	114	9,2	60	38	60.420	2	0	32	4.500
[e]T15	Geothermal	15	111	9,2	0	38	58.830	0	8	32	
T16	Biomass	10	68	11,3	35,75	25	36.040	2	0	10	93.000
[e]T17	Biomass	10	43	11,3	0	25	22.790	0	13	10	
T18	Nuclear	1.200	8.880	12,6	8.824	66	0	5	0	125	0

[a]: These values are calculated by taking into account the annual working hours and capacity factors of the types of power plants in Turkey.
[b]: Operation, maintenance, rehabilitation and fuel costs are reflected to the levelized costs.
[c]: Maximum Generation Capacity x Emission Factor (0,59 tone/MWh for solar and wind, 0,53 tone/MWh for the other renewables).
[*]: PV: Photovoltaic; CRS: Central Receiver System; PTC: Parabolic Trough Collector
[d]: PTC has a storage facility about 9,5 hours.
[e]: Available power plants in operation in Turkey.

Table 3. Demand forecasts for 2013-2023 projection [17].

Year	Electricity Demand (GWh)	Increase (%)
2013	262.010	7,4
2014	281.850	7,6
2015	303.140	7,6
2016	325.920	7,5
2017	350.300	7,5
2018	376.350	7,4
2019	404.160	7,4
2020	433.900	7,4
2021	467.260	7,7
2022	501.791	7,4
2023	538.873	7,4

2. MATHEMATICAL MODEL

MOMILP model proposed in the scope of this study and which optimizes the objectives of total electricity generation cost minimization, CO_2 emission minimization, energy import minimization, fossil resource usage minimization, employment maximization and social acceptance maximization simultaneously includes 6 objectives and 17 groups constraints. The notations used in model are given below:

i: Type of power plant
j: Year
k: Energy resource
K: Set of energy resources; $K = \{1, 2, \ldots, k, \ldots, K_{max}\}$
I: Set of power plants; $I = \{1, 2, \ldots, i, \ldots, I_{max}\}$
I_m: Set of available power plants; $I_m = \{5, 7, 9, 11, 13, 15, 17\}$
I_y: Set of power plants with renewables; $I_y = \{1,2,3,10,11,12,13,14,15,16,17\}$
I_f: Set of power plants with fossil fuels; $I_f = \{4,5,6,7,8,9\}$
J: Set of years; $J = \{1, 2, \ldots, j, \ldots, J_{max}\}$
t_i: Max.generation capacity of i^{th} power plant
D_j: Demand amount in j^{th} year
x_{ij}: Supply amount of i^{th} power plant in j^{th} year
S_{ij}: Used numbers of i^{th} power plant in j^{th} year

S_{i0}: Available numbers of i^{th} power plant
h: The percentage of targeted generation = 0,3 [18]
ε_{kj}: Upper bound of potential amount of k^{th} energy resource in j^{th} year
u_k: Set of power plants which use the k^{th} energy resource; $u_k \in U$
c_i: Unit electricity generation cost of i^{th} power plant per kWh
c_{im}: Unit import cost = 0,07 \$ [12]
r_{ex}: Unit export revenue = 0,11 \$ [12]
μ_i: CO_2 emission amount of i^{th} power plant per kWh
δ_j: Imported energy amount in j^{th} year
ϑ_j: Exported energy amount in j^{th} year
F_i: Number of employees in i^{th} power plant
π_i: Social acceptance factor of i^{th} power plant
y_{ij}: 1, if i^{th} power plant is used in j^{th} year
0, otherwise
M: A big number
η_i: Installation time of i^{th} power plant
O_{ij}: The number of newly installed i^{th} power plant in j^{th} year
OM_i: Installation cost of i^{th} power plant
σ_i: Annual CO_2 reduction amount of i^{th} power plant
s: Revenue obtained from CO_2 reduction per tone = 5,73 \$ [16]
e: Inflation rate = 0,0806 [19]

2.1. Objective Functions

Minimization of the total electricity generation cost

$$MinZ_1 = \sum_{i\in I}\sum_{j\in J} x_{ij}\, c_i e^{j-1} + \sum_{i\in I}\sum_{j\in J} O_{ij} OM_i + \sum_{j\in J} \delta_j c_{im} - \sum_{j\in J} \vartheta_j r_{ex} - \sum_{i\in I}\sum_{j\in J} s S_{ij}\sigma_i \qquad (1)$$

Equation 1 includes the inflation effect generation cost (operation, maintenance, rehabilitation and fuel costs are reflected), installation costs of power plants being installed for using the available resource potential effectively and cost of electricity to be imported (Table 4). In addition to these costs, incomes to be gained from the electricity to be exported (Table 5) and from carbon markets for renewable energy resources are added to Equation 1.

Minimization of CO_2 emission

$$MinZ_2 = \sum_{i\in I}\sum_{j\in J} x_{ij}\mu_i \qquad (2)$$

Minimization of CO_2 emission which is an important criterion in terms of the sustainability of energy systems and mostly arisen from the conventional power plants is considered as another objective in this study.

Minimization of imported energy

$$MinZ_3 = \sum_{j\in J} \delta j \qquad (3)$$

Meeting the electricity demand by the countries' equities has great importance in terms of sustainable development. From this point of view, minimization of imported energy is incorporated into the scope of this study and formulated as above.

Minimization of the use of fossil resources

$$MinZ_4 = \sum_{i\in I_f}\sum_{j\in J} x_{ij} \qquad (4)$$

In Turkey, minimization of the use of power plants with fossil fuels in electricity generation is considered in the scope of this study and formulated in Equation 4 in terms of both import of the significant portion of fossil fuels which are costly and in the group of nonrenewable resources, and a strategical goal of [18] Republic of Turkey Ministry of Energy and Natural Resources (MENR).

Maximization of social acceptance

$$MaxZ_5 = \sum_{i\in I}\sum_{j\in J} x_{ij}\pi_i \quad (5)$$

Social acceptance which is the acceptability indicator of power plants by society and includes the parameters such as cost, green house gas emissions, area and water usage, employment opportunity, visual pollution, using domestic and renewable resources must be taken into account in the selection of a power plant. In this context, maximization of social acceptance is considered in the scope of this study and formulated in Equation 5.

Maximization of employment

Especially developing countries expect possibilities their infrastructure investments to provide opportunities in terms of employment. In addition to this, power plants are in the group of big infrastructure investments. In this context, by taking into account the importance of the employment opportunities of power plants, objective function of the maximization of employment is formulated as below.

$$MaxZ_6 = \sum_{i\in I}\sum_{j\in J} x_{ij}F_i \quad (6)$$

2.2. Constraints

Constraint of energy resource supply

$$x_{ij} - t_iS_{ij} \le 0 \quad \forall i \in I, \forall j \in I \quad (7)$$

Demand constraint

$$\sum_{i\in I} x_{ij} + \delta_j - \vartheta_j \ge D_j \quad \forall j \in I \quad (8)$$

Targeted generation constraints

$$\sum_{i\in I_y} x_{i11} \ge h \sum_{i\in I} x_{i11} \quad (9)$$

It is targeted to increase the share of renewable energy resources in electricity generation up to at least 30% (*h*=0,3) in 2023 [18].

$$\sum_{i=12}^{13}\sum_{j=1}^{3} x_{ij} = 36.670 \quad (10)$$

It is targeted to increase the amount of electricity to be generated in wind power plants up to at least 36.670 GWh until the end of 2015 [18].

$$\sum_{i=14}^{15}\sum_{j=1}^{3} x_{ij} = 2.280 \quad (11)$$

It is targeted to increase the amount of electricity to be generated in geothermal power plants up to at least 2.280 GWh until the end of 2015 [18].

Constraint of annual potential energy resource

$$\sum_{i\in u_k} x_{ij} \le \varepsilon_{kj} \quad \forall k \in K, \forall j \in I, \forall u_k \in U \quad (12)$$

Determination constraint of energy resource to be used

$$x_{ij} - M \le 0 \quad \forall i \in I, \forall j \in I \quad (13)$$

Constraint of installation time

$$\eta_i - j \leq M(1 - y_{ij}) \quad \forall i \in (I - I_m), \forall j \in I \tag{14}$$

Match-up constraint of power plant & generation

$$x_{ij} - t_i(S_{ij} - 0{,}9) \geq 0 \quad \forall i \in I, \forall j \in I \tag{15}$$

Power plant balance constraint

$$O_{ij} = S_{ij} - S_{ij-1} \quad \forall i \in (I - I_m), \forall j \in I \tag{16}$$

Available power plant constraint

$$S_{ij} \leq S_{i0} \quad \forall i \in I_m, \forall j \in I \tag{17}$$

Nuclear power plant constraints

$$S_{187} = 1 \tag{18}$$
$$S_{188} = 2 \tag{19}$$
$$S_{189} = 3 \tag{20}$$
$$S_{1810} = 4 \tag{21}$$
$$S_{1811} = 4 \tag{22}$$
$$S_{18j} = 0 \quad j < 7 \tag{23}$$

It is targeted to start the construction of the first nuclear power plant of Turkey in 2014, commission the first unit of 1.200 MW (=8.880 GWh electricity generation capacity) in 2019, commission the other three units of 1.200 MW within the following 3 years and use 4 units of totally 4.800 MW as from 2022 [18].

Other constraints

$$\begin{array}{ll} x_{ij} \geq 0 & \forall i \in I, \forall j \in I \\ S_{ij} \geq 0 \text{ and integer} & \forall i \in I, \forall j \in I \\ O_{ij} \geq 0 \text{ and integer} & \forall i \in I, \forall j \in I \\ y_{ij} \in \{0,1\} & \forall i \in I, \forall j \in I \end{array} \tag{24}$$

Table 4. Electricity import changes and forecasts by years in Turkey [12]

Years	Total Import	Increase %	Years	Total Import	Increase %	Years	Total Import	Increas e %
1990	175,5	-68,6	2003	1.158,0	-67,7	2015	7.245,6	7,6
1991	759,3	332,6	2004	463,5	-60,0	2016	7.789,0	7,5
1992	188,8	-75,1	2005	635,9	37,2	2017	8.373,2	7,5
1993	212,9	12,8	2006	573,2	-9,9	2018	8.992,8	7,4
1994	31,4	-85,3	2007	864,3	50,8	2019	9.658,3	7,4
1996	270,0	759,9	2008	789,4	-8,7	2020	10.373,0	7,4
1997	2.492,3	823,1	2009	812,0	2,9	2021	11.171,7	7,7
1998	3.298,5	32,3	2010	1.143,8	40,9	2022	11.997,3	7,4
1999	2.330,3	-29,4	2011	4.746,7	315,0	2023	12.883,9	7,4
2000	3.791,3	62,7	2012	5.827,0	22,8			
2001	4.579,4	20,8	2013	6.258,2	7,4			
2002	3.588,2	-21,6	2014	6.733,8	7,6			

Table 5. Electricity export changes and forecasts by years in Turkey [12]

Years	**Total Export**	**Increase %**	**Years**	**Total Export**	**Increase %**	**Years**	**Total Export**	**Increase %**
1990	906,8	-44,2	2002	435,1	35,0	2014	3.413,7	7,6
1991	506,31	-37,9	2003	587,6	94,7	2015	3.673,2	7,6
1992	314,2	87,4	2004	1.144,3	57,1	2016	3.948,6	7,5
1993	588,7	-3,2	2005	1.798,1	24,3	2017	4.244,8	7,5
1994	570,1	22,1	2006	2.235,7	-44,2	2018	4.558,9	7,4
1995	695,9	-50,7	2007	2.422,2	8,3	2019	4.896,3	7,4
1996	343,1	-21,0	2008	1.122,2	-53,7	2020	5.258,6	7,4
1997	271	10,0	2009	1.545,7	37,7	2021	5.663,5	7,7
1998	298,2	-4,3	2010	1.917,6	24,1	2022	6.082,0	7,4
1999	285,3	53,3	2011	3.833,3	99,9	2023	6.531,5	7,4
2000	437,3	-1,0	2012	2.954,0	-23,0			
2001	432,8	0,5	2013	3.172,6	7,4			

As can be seen in Table 4 and Table 5, there is no trend about imported and exported energy in Turkey. Therefore, while calculating the imported and exported energy values in 2013-2023 projection, increase percentages in Table 3 have been used.

3. SOLUTION OF THE PROPOSED MODEL

Goal programming is one of the most frequently used methods for solution of multi-objective optimization problems. The general aim of this method is minimizing the deviations from the targeted values of two or more precisely determinable objective functions [20]. In this context, because of the absence of the targeted values for 6 objective functions in proposed model, goal programming approach can not be used in this study.

MOP is another approach for solving the multi-objective optimization problems and MDM is one of the MOP solution techniques. MDM aims at finding the best compromising solution which minimizes the sum of the fractional deviations of individual objective. The fractional deviation of an objective refers to a ratio between the deviation of a value of that objective from its individual optimal solution and its maximum deviation. The maximum deviation of an objective is obtained from the difference between its individual optimal solution and its least desirable solution, which corresponds to the individual optimal solution of one of the other objectives [20].

In this context, MDM is used for the proposed MOMILP model which optimizes the objectives of total electricity generation cost minimization, CO_2 emission minimization, energy import minimization, fossil resource usage minimization, employment maximization and social acceptance maximization simultaneously. Basic implementation principles of MDM are given below.

3.1. Developing the Payoff Table

First, the optimal value of each objective function is determined subject to the original set of constraints. The values of other objective functions which correspond to the individual optimum are then calculated. When this procedure is completed for all objectives, payoff table can be obtained as shown in Figure 1. In payoff table, column j corresponds to the solution vector x^{j*}, which optimizes the j^{th} objective, $f_j(x)$. f_i^j is the corresponding value taken on by the objective $f_i(x)$ when $f_j(x)$ reaches its individual optimum value f_j^*. The individual optimum value of each objective function is on the diagonal elements of payoff table.

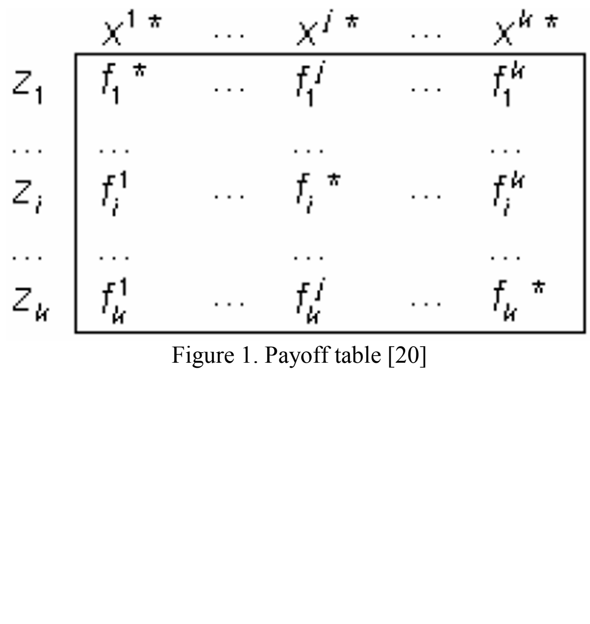

Figure 1. Payoff table [20]

Let x^* denote the ideal solution, which gives the k vector of the optimum value of each objective function. Thus,

$$F^*(x^*) = [f_1^*, f_2^*, \dots, f_k^*] \tag{25}$$

is the ideal objective vector. This vector can not be obtained unless all objective functions are not conflicting.

The best compromise solution is defined as the solution that will give the minimum of the sum of the fractional deviation of all objectives. The fractional deviation of each of the objectives is expressed as a fraction of its minimum deviation.

Let f_{j*} be the least desirable objective value of $f_j(x)$. The minimum deviation problem is formulated as follows [20]:

$$\text{Minimize:} \quad Z_0 = \sum_{j=1}^{k} \left[\frac{f_j^* - f_j(x)}{f_j^* - f_{j*}} \right] \tag{26}$$

Subject to: $x \in X$

3.2. Determining the Social Acceptance Factor

In order to calculate social acceptance factor (π_i) of each power plant type in "maximization of social acceptance" objective function given in Equation 5, among multi criteria decision making techniques, Analytical Hierarchical Process (AHP) has been used which aims at completing the decision making process in the most efficient way considering decision maker (DM)'s intuitional judgements and the consistency in comparison of the alternatives in decision making process by placing the related priorities into a scale (1-9 priority scale) for the given alternatives set [21].

The hierarchical structure prepared for the purpose of "Determining the Social Acceptance Factor" is presented in Figure 2.

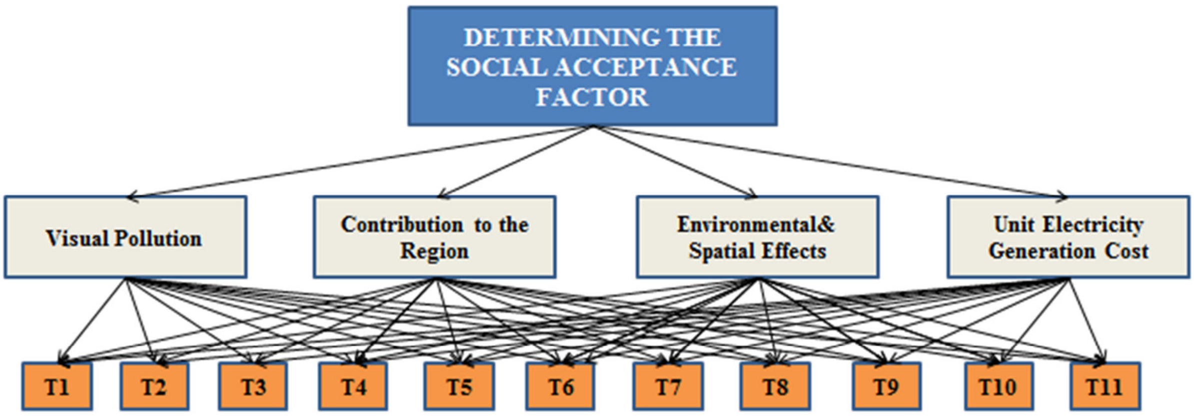

Figure 2. Hierarchical representation for determining the social acceptance factor

As can be seen in Figure 2, 4 criteria (*visual pollution*, *contribution to the region* with regards to employment, tourism income, prominence all over the country and in the world etc., *unit electricity generation cost* and *environmental and spatial effects* with regards to the utilization of land and water resources, air quality etc.) have been determined for 11 power plant alternatives (The number of power plant types assessed in the scope of the study is 18. However, some of these types - hard coal, lignite, natural gas, hydroelectric, wind, geothermal and biomass - include both the existing power plants and new power plants planned to be opened. These power plants were taken into account as a single power plant and alternative number was decreased to 11).

According to the criteria, pairwise comparison matrix and pairwise comparison between the criteria have been formed as a result of the interviews with people living in the areas where electricity generation power plants exist in various regions of Turkey and with the authorities of institutions which have a say in electricity generation field. The results obtained as a consequence of the evaluation according to AHP calculation procedure [21] are given in Table 6.

Table 6. Social acceptance factors of the power plants

Type of Power Plant	Social Acceptance Factor	Type of Power Plant	Social Acceptance Factor
T1	0,0959	T10	0,0639
T2	0,1137	T11	0,0639
T3	0,1053	T12	0,1340
T4	0,0479	T13	0,1340
T5	0,0479	T14	0,1312
T6	0,0492	T15	0,1312
T7	0,0492	T16	0,1270
T8	0,0537	T17	0,1270
T9	0,0537	T18	0,0782

As can be seen in Table 6, while the power plants using renewable energy resources have the highest priority value, acceptability of fossil fuelled power plants by the public is in the lowest level. This result is in compliance with societies' judgement of value in today's world about electricity generation power plants because renewable energy power plants cover smaller fields compared to fossil fuelled power plants, have superiorities in their outlook and especially they don't have negative effects on environment regarding greenhouse emissions. The priority order between the power plants which use renewable energy resources are as follows: wind power plants-geothermal power plants, biomass power plants-CRS power plants-PTC power plants and PV power plants. Among the main reasons for this order are generation capacity of the plants, employment opportunities, simplicity in the operation, maintenance and rehabilitation of the power plants and generation costs.

The fact that taking necessary measures in nuclear energy power plants prevents negative effects on environment and human has been accepted by the people making the evaluation and therefore social acceptance factor of this power plant type is in the middles of sequence.

The most remarkable result is that although social acceptance factor of wind, biomass, solar and geothermal power plants among renewable energy power plants is close to each other, social acceptance factor of hydroelectric power plants which is also a renewable energy power plant is quite low compared to the mentioned power plants. The main reasons for this are as follows: Hydroelectric power plants ruin natural structure of the region they are established in (they ruin riverside forest lands, destroy arable land by inundating and they change water flow route from the rivers in arable lands etc.), they oblige people to leave their settlements and they have technical difficulties in installation, high installation costs and long installation periods.

3.3. Determining the Weights of Objectives

Objectives which are considered in the scope of this study have different preferences. Because of this reason, proportioning method is used for determining the weight of 6 objectives in proposed model. In this method;

- DM usually determines a value from the continuous range of values such as 0-10 or 0-100 for each objective.
- More than one objective can take the same value.
- "0" value denotes that the objective is not important and the highest value denotes that the objective is very important for DM.

Final weight for l^{th} objective is computed by using the Equation 27 and Equation 28. Notations in these equations are given below [20]:

w_{lj} : computational weight value of given value by j^{th} DM for l^{th} objective

ρ_{lj} : given weight value by j^{th} DM for l^{th} objective,

n: the number of DMs

m: the number of objectives.

$$w_{lj} = \frac{\rho_{lj}}{\sum_{l=1}^{m} \rho_{lj}} \tag{27}$$

$$w_l = \frac{\sum_{j=1}^{n} w_{lj}}{\sum_{j=1}^{n} \sum_{l=1}^{m} w_{lj}} \tag{28}$$

6 objectives have been graded by mid-level managers and senior executives in MENR and objective weights are calculated according to the Equation 27 and Equation 28. The results are shown in Table 7.

Table 7. Objective weights

Objective	Grades											w_l
	DM 1	**DM 2**	**DM 3**	**DM 4**	**DM 5**	**DM 6**	**DM 7**	**DM 8**	**DM 9**	**DM 10**	**DM 11**	
Z_1	10	10	10	10	10	10	10	10	10	10	10	**0,36**
Z_2	5	4	4	6	4	5	5	7	4	6	5	**0,14**
Z_3	4	4	2	3	3	3	3	4	4	3	3	**0,05**
Z_4	6	6	6	6	6	6	7	8	7	6	6	**0,26**
Z_5	2	2	1	3	2	2	2	2	1	4	3	**0,15**
Z_6	3	3	3	4	2	2	3	3	5	4	2	**0,04**

The version of GAMS IDE 2.0.36.7 is used for solving the MOMILP model. First, each of the objective functions given in Equation 1-6 is solved subject to the original set of constraints (Equation 7-24) for determining the diagonal elements of payoff table. The values of other objective functions which correspond to the individual optimum are then calculated and payoff table is obtained as shown in Table 8.

Table 8. Payoff table

	x^{1*}	x^{2*}	x^{3*}	x^{4*}	x^{5*}	x^{6*}
Z_1	101.480.489.575,05	760.050.000.000,00	193.256.000.000,00	620.069.000.000,00	1.141.640.000.000,00	1.172.370.000.000,00
Z_2	1.515.354,43	177.878,46	1.737.912,59	230.044,37	980.127,63	247.236,50
Z_3	101.477,00	101.477,00	101.477,00	101.477,00	101.477,00	101.477,00
Z_4	2.492.224,80	186.751,00	3.038.051,00	186.751,00	1.032.730,90	314.959,20
Z_5	391.286,74	1.140.251,57	350.426,56	1.088.258,72	3.742.213,03	2.512.655,31
Z_6	299.579,36	421.911,78	255.449,79	375.204,70	497.533,33	585.649,37

According to the Equation 26, the minimum deviation equation which includes the 6 objectives is given below.

$$
\begin{aligned}
MinZ = {} & 0{,}36\left[\frac{101.480.489.575{,}05 - MinZ_1}{101.480.489.575{,}05 - 1.172.370\mathrm{x}10^6}\right] + 0{,}14\left[\frac{177.878{,}46 - MinZ_2}{177.878{,}46 - 1.737.912{,}59}\right] \\
& + 0{,}26\left[\frac{186.751 - MinZ_4}{186.751 - 3.038.051}\right] + 0{,}15\left[\frac{3.742.213{,}03 - MinZ_5}{3.742.213{,}03 - 350.426{,}56}\right] \\
& + 0{,}04\left[\frac{585.649{,}37 - MinZ_6}{585.649{,}37 - 255.449{,}79}\right]
\end{aligned} \quad (29)
$$

By solving the Equation 29 subject to the original set of constraints given in Equation 7-24, a 11-years resource based electricity generation plan for Turkey for meeting the demand between 2013-2023 is obtained. Results are given in Table 9.

Table 9. 11-years electricity generation plan for Turkey

Type of Power Plant	Resource	Generation by Years (GWh)										
		2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
T1-PV	Solar	-	19.178,4	172.947,2	172.947,2	177.583,2	177.583,2	177.583,2	197.444,8	282.942,4	282.942,4	282.942,4
T2-CRS	Solar	-	-	-	-	-	-	-	-	-	-	-
T3-PTC	Solar	-	-	-	-	-	-	-	-	-	-	-
T4	Hard Coal	-	-	-	-	-	-	-	-	-	-	-
T5	Hard Coal	10.516,0	10.832,6									
T6	Lignite	-	-	-	-	-	-	-	-	-	-	-
T7	Lignite	36.168,0	36.168,0									
T8	Natural Gas	-	-	-	-	-	-	-	-	-	-	-
T9	Natural Gas	140.067,0	140.067,0	-	-	-	-	-	-	-	-	-
T10	Hydraulic	-	-	-	-	-	-	-	-	-	-	-
T11	Hydraulic	65.000,0	65.000,0	65.000,0	500,0	500,0	500,0	65.000,0	64.973,2	65.000,0	65.000,0	65.000,0
T12	Wind	-	110,0	54.450,0	138.270,0	138.270,0	138.270,0	138.270,0	138.270,0	138.270,0	138.270,0	138.270,0
T13	Wind	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0	5.727,0
T14	Geothermal	-	-	114,0	3.612,0	3.612,0	3.612,0	3.648,0	4.389,0	4.343,4	4.343,4	4.343,4
T15	Geothermal	888,0	888,0	888,0	888,0	888,0	888,0	111,0	111,0	156,6	156,6	156,6
T16	Biomass	-	-	-	68,0	68,0	68,0	68,0	68,0	68,0	68,0	68,0
T17	Biomass	559,0	559,0	559,0	559,0	559,0	559,0	559,0	43,0	43,0	559,0	559,0
T18	Nuclear	-	-	-	-	-	-	8.880,0	17.760,0	26.640,0	35.520,0	35.520,0

4. CONCLUSIONS

In this study, a MOMILP model has been proposed which optimizes simultaneously minimization of total electricity generation cost, minimization of CO_2, minimization of energy import, minimization of use of fossil fuelled power plants, maximization of employment and social acceptance maximization. This model has been solved using MDM for determining electricity energy amount required in 18 power plant types in order to meet the demand between 2013-2023 in Turkey.

Examining the results in Table 9, it is seen obviously that renewable energy resources should be preferred dating from the year when it is possible to take the related power plants into operation in 11-years projection.

Among 3 power plant types using solar energy, only PV plants which can be established in a shorter period than the other two types, don't need solar radiation as in the other 2 types, more cost-efficient, have operation and maintenance simplicity and which can be constructed in slopes besides flat areas match up with investor trend in Turkey.

In planning period, 88,23% of generation is met from renewable energy resources and 2,94% of generation to be realized for 11-years is carried out in nuclear power plants.

In this 11-years plan, 46,5% of solar energy resource potential has been used. The main reason why the rest of the potential cannot be used is that initial installation costs and unit generation costs of these plants are higher compared to the other renewable power plants (except for hydroelectric). As in the reasons why solar energy potential cannot be used exactly, the model doesn't envisage the construction of a new hydroelectric power plant. Because, in addition to very high initial installation costs of hydroelectric power plants with long installation periods, social acceptance factor of these plants is lower than the other renewable energy power plants. In wind, geothermal and biomass power plants, it is suggested to use almost all resource potential.

The solution results of the model are in consistence with the strategically goals of the MENR [18] and Turkey's requirements as it produces results such as making generation in the first year when the construction of power plants using only renewable resources continue in the fossil fuelled power plants, abandoning natural gas the resource of which doesn't exist, using the wind energy in the most efficient way which is the most preferred resource by the investors in Turkey.

In parallel with the philosophy of uninterrupted, environment-friendly, economic and reliable generation which is accepted widely for electricity generation, it is understood that the objectives taken into account frequently in the studies in Table 1 are cost minimization, greenhouse gas emission minimization, fossil fuel usage minimization and social acceptance maximization. It is obvious that the objectives considered in this model proposed within the scope of this study are in compliance with the literature in this context.

Many studies in the literature deal with determining the most suitable resource combination in order to meet the electricity need in a specific region for specific purposes (cooking, lighting, heating etc.) (Table 1). However, the model proposed in this study is aimed at meeting all the electricity energy need, whatever the purpose is, and it has also been applied in all regions in Turkey, not in a specific region.

There isn't a time period in any of the studies in the literature except for one study (carried out by Mavrotas et al [9]). Because these studies have been prepared in order to determine the best resource combination, not to establish a generation and/or investment program. However, as a result of solving the model proposed in this study with actual data, the amount of electricity energy which Turkey needs to generate for 11 years has been obtained.

The objective of cost minimization which takes place in almost all studies in Table 1 is stated frequently and only as variable generation cost total. However, in the model proposed in this study, "total electricity generation cost minimization" objective function is quite comprehensive with regards to the fact that is consists variable generation cost, installation cost of the power plants to be established, import expenses and income to be obtained from carbon markets and energy export.

Also, there are differences between the proposed model and the studies in the literature for social acceptance factor which needs to be determined for the purpose of social acceptance maximization considered frequently in the studies in the literature. In these studies, either it is not mentioned how social acceptance factor is determined or this value is determined by assigning a value between the values 1-10. However, determining social acceptance factor is dealt as a multi criteria decision problem in this study and social acceptance factors calculated based on the power plant according to AHP methodology has been used in the proposed model.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

5. REFERENCES

1. San Cristóbal, J.R., 2012, "A Goal Programming Model for the Optimal Mix and Location of Renewable Energy Plants in the North of Spain", *Renewable and Sustainable Energy Reviews*, Vol. 16, pp. 4461-4464.

2. Arnette, A., Zobel, C.W., 2012, "An Optimization Model for Regional Renewable Energy Development", *Renewable and Sustainable Energy Reviews*, Vol. 16, pp. 4606-4615.

3. Jinturkar, A.M., Deshmukh, S.S., 2011, "A Fuzzy Mixed Integer Goal Programming Approach for Cooking and Heating Energy Planning in Rural", *Expert Systems with Applications*, Vol. 38, No. 9, pp. 11377-11381.

4. Deshmukh, S.S., Deshmukh, M.K., 2009, "A New Approach to Micro-Level Energy Planning—A Case of Northern Parts of Rajasthan, India", *Renewable and Sustainable Energy Reviews*, Vol. 13, pp. 634-642.

5. Jana, C., Chattopadhyay, N., 2004, "Block Level Energy Planning for Domestic Lighting - A Multi Objective Fuzzy Linear Programming Approach", *Energy*, Vol. 29, pp. 1819–1829.

6. Antunes, C.H., Martins, A.G., Brito, I.S., 2004, "A Multiple Objective Mixed Integer Linear Programming Model for Power Generation Expansion Planning", *Energy*, Vol. 29, pp. 613-627.

7. Borges, A.R., Antunes, C.H., 2003, "A Fuzzy Multiple Objective Decision Support Model for Energy-Economy Planning", *European Journal of Operational Research*, Vol. 145, pp. 304-316.

8. Agrawal, R.K., Singh, S.P., 2001, "Energy Allocations for Cooking in UP Households (India): A fuzzy Multi Objective Analysis", *Energy Conver Manage*, Vol. 42, pp. 2139–2154.

9. Mavrotas, G., Diakoulaki, D., Papayannakis, L., 1999, "An Energy Planning Approach based on Mixed 0-1 Multiple Objective Linear Programming", *International Transactions in Operational Research*, Vol. 6, pp. 231-244.

10. Mezher, T., Chedid, R., Zahabi, W., 1998, "Energy Resource Allocation Using Multi Objective Goal Programming: The Case of Lebanon", *Applied Energy*, Vol. 61, pp. 175-192.

11. Pokharel, S., Chandrashekara, M., 1998, "A Multi Objective Approach to Rural Energy Policy Analysis", *Energy*, Vol. 23, No. 4, pp. 325-336.

12. Republic of Turkey Ministry of Energy and Natural Resources, 2012, "Turkey's Electricity Statistics".

13. Energy Information Administration, 2011, "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011.

14. Lazard, 2009, "Levelized Cost of Energy Analysis".

15. Sovacool, B.K., 2008 "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey", *Energy Policy*, Vol. 36, pp. 2950-2962.

16. Estimation of Emission Reductions, http://www.cdmgoldstandard.org/project-certification/rules-and-toolkit, 2012.

17. Turkish Electricity Transmission Company (TEİAŞ), 2013, "Turkish Electrical Energy Generation Capacity Projections", pp. 24.

18. Republic of Turkey Ministry of Energy and Natural Resources, 2009, "Strategical Plan of Republic of Turkey Ministry of Energy and Natural Resources 2010 - 2014", pp. 25-30.

19. Republic of Turkey Prime Ministry, "2012-Mountly and Annual Inflation Rates, http://www.hazine.org.tr/tr/index.php/ekonomi/enflasyon, 2012.

20. Tabucanon, M.T., 1988, "Multiplecriteria Decision Making in Industry", Elseiver, Amsterdam-Oxford-New York-Tokyo.

21. Saaty, T.L., 1980, "The Analytic Hierarchy Process", McGraw-Hill, New York, A.B.D.