

Article

Investigation of the Optimal Model for the Development of Renewable Energy in Iran using a Robust Optimization Approach

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Abstract: Due to its geographical location, Iran has numerous capacities in renewable energy, and this issue has made the need to develop renewable energy on the authorities' agenda. This underscores the need to provide an optimal model for developing renewable energy. Therefore, in this study, the main purpose was to provide an optimal renewable energy model. In line with this goal, by choosing the cost function as the objective function and considering the potential constraints of renewable energy (resource constraints), the amount of electricity consumption in each of the 16 electricity regions (demand constraint) and the limitation of renewable energy production coefficient (Technical constraints), the optimal model of renewable energy use was designed and solved using a solid programming model in LINGO software. The optimal model results show 15.19% small hydropower, 24.30% wind energy, 5.52% biomass energy, 6.13% is geothermal energy, 4.79% is tidal energy, and 44.07% solar energy. The optimum portfolio of renewable energy is estimated in this paper using the robust optimization approach. The results showed which renewable technology has the greater potential to take more share of the energy portfolio. The results of this investigation help policymakers to choose the most suitable renewable technologies to support.

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1. Introduction

Energy plays an infrastructural role in societies' economic life, which means that economic development will be possible when sufficient and timely energy is available. A look back shows that there has always been great global competition for energy resources, as national security and the Robust Optimization Approach of government systems depend largely on access to these resources[1]. Fortunately, Iran is one of the world's richest countries in diverse energy resources and reserves. These resources are offered to the consumer in our country at much lower prices than in other countries and more easily. Undoubtedly, these energy sources will run out one day. Since modern man's normal life is not possible without using energy resources, it is necessary to invest in energy efficiency methods and new technologies for energy extraction[2].

Renewable energy is a new issue in our country and the world. Also, the stages of development and progress of different renewable energy technologies are different. Some, such as wind and photovoltaic energy, have evolved to a higher degree, and some, such as solar waves and thermal power plants, are in the lower stages of development, but all need research and development to improve performance [3]. Due to the novelty of renewable energy technology, research and innovation on these systems are far more important, so that the issue of research is an integral part of renewable systems and the only way to overcome obstacles to the development and promotion of renewable energy, creating areas for research development, technology transfer, and technology modernization[4,5].

Despite the importance of renewable energy in providing clean energy, there is still no study to provide a suitable model for using and expanding this energy type in Iran. Therefore, in this study, an attempt has been made to provide an optimal model for renewable energy use [6,7].

This study is organized into five sections; After the introduction, the status of renewable energy, its place and importance globally, and Iran is examined, the article's background and research method are stated. In section 3, the model is designed and solved, and in section 4, simulations are performed, and the analysis of the results is stated, and in the end, a summary and suggestions are presented.

1.1. Renewable energy

Fossil fuels provide more than 81% of the world's energy consumption and more than 95% of Iran's energy [8]. Iran is the second-largest OPEC member in oil production, with about 8.6 percent (12.3 billion tons) of the world's oil resources and 17 percent (26.6 trillion cubic meters) of the world's gas resources located in Iran. Iran's oil production in 2011 was about 1470 million barrels, with 4.1 million barrels per day. Gas production is 288.7 billion barrels per day, which in 1991 was about 78.8 thousand barrels per day [9]. These and other detailed statistics clearly show the rapid extraction of the country's fossil resources. On the other hand, industrialized and developed countries, which are the major consumers of energy globally, are always trying to increase the share of renewable energy in their energy basket [10].

From a political and strategic point of view, one of Iran's most important capabilities and strengths is its power in the world's fossil energy market, on which developed countries currently depend. On the other hand, global warming has reached a critical level, and other environmental issues have caused the use of fossil fuels to be subject to fundamental criticism. Hence, the global approach of the powers limits fossil energy use [10, 11].

The share of renewable energy in supplying the European continent's energy needs is about 24.5 percent. Simultaneously, a developing country like India ranks fifth in installed capacity of all renewable energy and fourth in installed wind farms' installed capacity [12]. Iran's share so far is 900 MW of production capacity and mainly solar PV and wind turbines, and if we consider medium and large hydropower plants as renewable resources, this capacity will reach 7700 MW [13].

According to the announcement of the New Energy Organization of Iran, "reduction of environmental pollution," "reduction of fossil reserves," "economic savings," "promotion of security of energy supply," "distributed generation and reduction of reliance on global energy transmission networks" "Employment and development in remote areas" and "Solving the problem of urban waste" can be cited as reasons for the need to use renewable energy [14].

1.2. Renewable energies in Iran

During 2018, 905 MW renewable energy capacity (small water, wind, solar, and biogas) was used to generate electricity in Iran, and small hydropower plants, wind, solar, and biogas were 105.93, 306.6, 405, and 10.53 MW, respectively. Regarding geothermal energy, two power plants are under construction in Ardabil province, operational by the end of 2022. In connection with the use of wave energy, a plan has not yet been developed concerning exploiting the existing potential in our country [15].

Solar energy: At present, according to the latest statistics published by the Ministry of Energy in 2019, a total of 720,000,000 kilowatt-hours of solar electricity has been produced in the country by 406 MW photovoltaic projects, Yazd Darbid and Semnan and Tabriz solar power plants [16].

Biomass energy: According to the latest information published by the Ministry of Energy, two biomass power plants in two regions of Shiraz and Mashhad, with a capacity of 10 and 0.6 MW in 2019, respectively, have been put into operation. The practical power of these two power plants is equal to 10000 and 600 kW, respectively [17].

Small hydropower: Currently, 0.64% of the total capacity of hydropower plants in operation belongs to small hydropower plants, and the share of specific production of these power plants, including 44,271 GWh per year, is 0.61% [18].

Wind energy: According to the latest information in the energy balance sheet of the Ministry of Energy in 2019, with a total of 431 wind turbines in the provinces of Gilan, Khorasan, East Azerbaijan, and Sistan and Baluchestan, wind energy capacity in the country is 340,550 kW, with a typical production of 2667 GWh [19].

Geothermal energy: Currently, the Ministry of Energy is implementing two projects: constructing the Meshkinshahr geothermal power plant and constructing an 80-500 MW package. These two projects' design capacity is about 187 MW in total, and their annual production is estimated at 1530 million kWh [20].

1.3. Literature Review

Regarding the use of renewable energy, no internal study has been conducted on optimizing this type of energy composition. However, in this field, various studies have been conducted around the world using linear programming and robust programming techniques, including the following:

In a study, have provided an optimal model for the development of renewable energy regions in the Eastern United States[21]. Other researchers, in their study, examined the potential of renewable energy and identified areas of Australia that have the potential to produce renewable energy, especially solar and wind energy. They proposed an optimal hybrid model for developing wind energy prospects in a region of Australia, taking into account production costs, energy costs, emission reduction costs[22]. An article studied the imbalance between energy supply and consumption; Finally, they studied the Greek energy system[23]. This study's ultimate goal was to provide an optimal model to meet Greece's energy needs concerning renewable energy sources and focus on the potential of energy production from municipal solid waste (MSW) in each region. In a study researchers examined the integration of CCS technology, emissions trading, and fuel price volatility for sustainable energy planning using a robust optimization approach[24]. In a study, a technique for planning power systems at the regional scale and carbon dioxide management" of the basis-based optimization method for planning energy systems and carbon dioxide trade in the framework of parametric-base combinations optimization has been used in conditions of uncertainty[25]. In a study researchers used the robust optimization technique for planning energy systems and the management of CO₂ emissions in China by combining two parametric programming techniques - baseline and robust optimization[26]. In a study using a robust optimization approach designed a model to respond to electricity demand assuming a correlation of price information[27]. In a study, have proposed a method to provide the energy supply curve of centralized solar power plants. They used a solid linear programming model to present the studied power plant's power supply curve and maximized the profit objective function in this study[28]. In a study designed a model for the Philippine energy sector using robust planning techniques concerning non-operational constraints[29]. Other researchers, in a study, examined the role of government policies in optimizing renewable energy development in the southern Appalachian Mountains. This research presents a comprehensive system for energy planning, and their main goal in this system is to supply electricity from renewable energy sources[30]. Other authors, in their study using integer programming technique, have provided an optimal model for electricity generation intending to reduce carbon dioxide. This study showed that to reduce carbon dioxide emissions by 50% from the current level, an optimal model of the combined gas cycle, natural gas combined cycle, nuclear energy,

and biomass energy from landfills has been selected[31]. A research studied designed a model for planning energy systems under uncertain conditions[32]. In a study, researchers designed a comprehensive system for renewable energy management. This study has used a two-stage planning model with base parameters to provide a model to support and support large-scale renewable energy management[33]. A research studied the dynamic programming technique, presented a model for managing Gasoline and greenhouse gas emissions and sustainable development of energy management in Tehran[34].

2. Methods and Materials

Mathematical programming is one of the optimization methods. Optimization, the art and science of allocating resources limited to the best possible situation, and linear programming is a subset of mathematical planning[35]. The answer that results from solving a linear programming problem is usually: a specific program or plan that includes the optimal values of selected activities [36].

2.1. Robust Optimization Approach

The robust Optimization Approach means that the model's output should not be too sensitive to the model's parameters and inputs [37]. In other words, "firmness" or "firmness" is an attribute that refers to the capacity to stabilize vague estimates or uncertain points to prevent the adverse effects of degradation of properties that are desired and should be maintained [38]. Uncertainties often justify decision-making issues due to inaccuracies, constant variability, and the inability to see future events. Many authors have researched solid arguments, and their results have led to a wide range of research [39]. The discussion of model robustness is one of the most important issues in "ethics in modeling" and, consequently, "ethics in operations research." If the models are solid, the risk of misuse or misuse will be much lower[40].

Historically, uncertain optimization began in the late 1950s and developed rapidly in both theory and algorithms. Many approaches have been used to optimize uncertain situations, including minimizing mathematical hope, minimizing deviations from ideals, and minimizing maximum costs caused by all of these approaches to face problems[41].

But the approach developed in recent years to deal with data uncertainty is robust optimization, which deals with optimization when the worst happens and may lead to a goal-minimization function. In this approach, we look for near-optimal answers that are likely to be justified[42]. In other words, by neglecting the optimality of the objective function a little, we guarantee the justification of the obtained result. Of course, regarding the uncertainty in the coefficients of the objective function, by slightly deviating from the value of the optimal objective function, we are looking for an answer that with a high probability of real answers is better than that answer [43].

In general, it is assumed that the input data is equivalent to the nominal values in mathematical programming. This attitude does not consider the effect of uncertainty on the quality and justification of the model[44]. Data that take values that are different from their nominal values may lead to several constraints being violated, and the optimal answer may not be optimized for a long time, or even its validity may be lost[45]. This argument raises the natural urge to design and provide solution methods that protect against data uncertainty, and these methods are called "robust solutions" [46].

The first step in this direction was presented by Ben-Tal [47], who proposed a linear programming model to generate an answer that is justified for all data belonging to a convex set. The above model provides highly conservative solutions (highly conservative) concerning the optimality of the nominal problem to ensure consistency, meaning that in this approach, a large amount of optimization is required to ensure the Robust Optimization Approach of the solution. The nominal issue goes away. Each input data can take any interval value [48-51]. After this, other important steps have been taken independently in

the development of the theory of robust optimization by study[52-55]. In general, robust models are divided into two general categories: robust planning models with base data and robust scenario models. Stable programming models with their base data are divided into three mathematical models: "Stable model of Schwester", "Stable model of Ben Tal and Nemirovsky" and "Bertsims and Sim model," which "Bertsims and Sim" model is considered in this study[56].

2.2. Bertsims and Sim model

In robust optimization topics, a robust model called a robust counterpart is presented for each nominal problem (problem containing uncertain parameters). In other words, solid answers to the main problem are provided by solving a solid counterpart model. The nominal complex integer programming problem (equation 1) is considered with n variables, the first k of integer variables[57-59].

$$\begin{aligned}
 & \text{Minimize } (c'x) \\
 & \text{subject } (Ax \leq b) \\
 & 1 \leq x \leq u \\
 & x_i \in Z, i = 1, \dots, k
 \end{aligned} \tag{1}$$

Without losing the whole problem, it is assumed that matrices A and c contain indeterminate data, and vector b contains definite numbers. Assuming that each coefficient ($j \in N, a_{ij}$) is modeled as an independent random variable with asymmetric and finite distribution ($j \in N, \hat{a}_{ij}$) that takes a value in the range $[a_{ij} - \hat{a}_{ij}, a_{ij} + \hat{a}_{ij}]$. Each $j \in N, c_{ij}$ takes a value in the interval $[c_j - d_j, c_j + d_j]$, so that d_j indicates a deviation from the nominal cost factor c_j [60]. Also, the only assumption for a_{ij} coefficient's distribution is its symmetry. Besides, if the number on the right fluctuates like the technical coefficients in symmetric bases, there is no disturbance in the discussion, and its solid modeling is similar to the technical coefficients[61]. To achieve the answer's stability, numbers ($\Gamma_i, i = 0, 1, \dots, m$) are defined that takes a value in the range $[0, |J_i|]$ so that it is equal to the number $|J_i|$ of uncertain data in the limit i . The parameter's role Γ_i in constraints is to adjust the degree of stability versus the answer's conservatism level. The parameter Γ_0 controls the level of stability for the objective function. If $\Gamma_0 = |J_i|$ so, the effect of changes in cost ratios is not fully taken into account, but all possible changes are taken into account, which is the most conservative case. The strong counterpart of Bertsimis and Sim for equation (1) is in the form of equation (2) [62-66]:

$$\begin{aligned}
\text{Min}(z) &= c'x + z_0\Gamma_0 + \sum_{j \in J} p_{0j} \\
\text{St} : \sum_j a_{ij}x_j + z_i\Gamma_i + \sum_{j \in J_i} p_{ij} &\leq b_i; \forall i \\
z_0 = p_{0j} &\geq d_j y_j; \forall i \in J_0 \\
z_i + p_{ij} &\geq \widehat{a}_{ij} y_i; \forall i \neq 0, j \in J_i \\
p_{ij} &\geq 0; \forall i, j \in J_i \\
y_{ij} &\geq 0; \forall j \\
Z_i &\geq 0; \forall j \\
-y_i &\leq x_j \leq y_i; \forall j \\
l_j &\leq x_j \leq u_j \\
x_i &\in Z, i = 1, \dots, k
\end{aligned} \tag{2}$$

If the number on the right, b_i be in the interval $[b_i - \widehat{b}_i, b_i + \widehat{b}_i]$, also takes a value, the solid counterpart of the Bertsmis and Sim for equation (1) will be in the form of equation (3)[67]:

2.3. Model design

2.3.1. General form of a nominal model of electricity generation from renewable energies

$$\begin{aligned}
\text{Min}(z) &= c'x + z_0\Gamma_0 + \sum_{j \in J_0} p_{0j} \\
\text{St} : \sum_j a_{ij}x_j + z_i\Gamma_i + \sum_{j \in J_i} p_{ij} &\leq b_i; \forall i \\
z_0 = p_{0j} &\geq d_j y_j; \forall i \in J_0 \\
z_i + p_{ij} &\geq \widehat{a}_{ij} y_i; \forall i \neq 0, j \in J_i \\
z_i + p_{i0} &\geq \widehat{b}_i; \forall i \\
p_{ij} &\geq 0; \forall i, j \in J_i \\
y_{ij} &\geq 0; \forall j \\
Z_i &\geq 0; \forall j \\
-y_i &\leq x_j \leq y_i; \forall j \\
l_j &\leq x_j \leq u_j \\
x_i &\in Z, i = 1, \dots, k
\end{aligned} \tag{3}$$

In this section, using linear programming technique and selecting the cost function as the objective function and considering the potential limitations of renewable energy (resource constraints)[68], the amount of electricity consumption in each of the 16 electricity regions (demand constraint) and reliability limit Production of energy from renewable

energies (technical constraints), we present the optimal pattern of use of renewable energies. It is worth noting that the use of renewable energy is possible on both large and micro scales[69]. On a micro-scale, renewable energy is used locally and sparsely. Since this model aims to provide only 10% of the country's electricity from renewable energy, this figure can be provided through micro-level exploitation, so The issue of energy exchange on a large scale and in a centralized manner has not been considered, and the issue of energy exchange has not been included in this model. As shown in Table 1, the variables X1 to X96 represent the electricity generated from each of the renewable energies in each regional electricity[70].

Table 1. Model decision variables

State	Tidal	Hydropower	Wind	Geothermal	Bioenergy	Solar
Sistan	X1	X17	X33	X49	X65	X81
Azerbaijan	X2	X18	X34	X50	X66	X82
Bakhtar	X3	X19	X35	X51	X67	X83
Fars	X4	X20	X36	X52	X68	X84
the West	X5	X21	X37	X53	X69	X85
Gilan	X6	X22	X38	X54	X70	X86
Hormozgan	X7	X23	X39	X55	X71	X87
Khorasan	X8	X24	X40	X56	X72	X88
Mazandaran	X9	X25	X41	X57	X73	X89
Semnan	X10	X26	X42	X58	X74	X90
Zanjan	X11	X27	X43	X59	X75	X91
Esfahan	X12	X28	X44	X60	X76	X92
Tehran	X13	X29	X45	X61	X77	X93
Khuzestan	X14	X30	X46	X62	X78	X94
Kerman	X15	X31	X47	X63	X79	X95
Yazd	X16	X32	X48	X64	X80	X96

In this model, to obtain the optimal pattern of renewable energy use from the cost of electricity generation function in line with the minimum cost of electricity generation from renewable energy, including; Solar energy, biomass energy, geothermal energy, wind energy, small hydropower energy, and tidal energy have been used (equation 4)[71].

$$\text{Min} \left(A \sum_{i=1}^{16} x_i + B \sum_{x=17}^{32} x_i + C \sum_{x=33}^{48} x_i + D \sum_{x=49}^{64} x_i + E \sum_{x=65}^{80} x_i + F \sum_{x=81}^{96} x_i \right) \quad (4)$$

In this model, the objective function's coefficients include the cost of generating electricity from solar energy, biomass, geothermal, wind, small hydropower, and tidal[72]. Because the equipment and technology for using renewable energy in our country are often imported, so the cost of generating electricity from renewable energy in the 16 regional electricity regions in the country is considered the same. Table 2 shows the average cost of generating a one-kilowatt hour of electricity from each renewable energy source[73].

Table 2. Cost of a unit of electricity generation from various types of renewable energy (\$/kWh)

Renewable energy	Cost(\$/kWh)
Solar Energy	0.059
Biomass energy	0.088
Geothermal energy	0.078
Wind energy	0.064
Hydropower	0.053
Tidal energy	0.064

Renewable energy potential constraints in the whole country: One of the most important constraints considered in this model has been the constraint of renewable energy potential. Based on the calculations, the potential of solar energy, biomass, geothermal, wind, small hydropower, and tidal can be considered according to the values according to [Table 3 \[74\]](#).

Table 3. Values to the right of the potential constraint.

renewable energy	renewable energy potential [TWh]	Variable
Solar Energy	193161	R1
Biomass energy	196.2	R2
Geothermal energy	24.7	R3
wind energy	265.9	R4
Hydropower	12.2	R5
Tidal energy	26.1	R6

$$\begin{aligned}
 \sum_{i=1}^{16} x_i &\leq R_1 \\
 \sum_{x=17}^{32} x_i &\leq R_2 \\
 \sum_{x=33}^{48} x_i &\leq R_3 \\
 \sum_{x=34}^{64} x_i &\leq R_4 \\
 \sum_{x=65}^{80} x_i &\leq R_5 \\
 \sum_{x=81}^{96} x_i &\leq R_6
 \end{aligned} \tag{5}$$

Renewable energy potential limit per regional electricity: The values to the right of the renewable energy potential limit in each regional electricity, which includes the values R_8 to R_{102} , are given in [Table 4](#) for the renewable energy potential each regional electricity[75].

$$x_i \leq R_{i+6}; i = 1, \dots, 96 \tag{6}$$

Table 4. Renewable energy potential in different regional distribution electricity (GWh)

	Tidal	Hydro	Wind	Geo-thermal	Bio	Solar
Sistan	6308.358	0	35798.616	1716.96	3903.732	22897917.56
Azarbayjan	0	850.15	8936.718	7082.46	29264.662	9452557.66
Bakhtar	0	299.782	532.238	0	17150.98	8335888.82
Fars	1521.9792	207.662	15873.256	3433.92	18230.058	19000955.4
West	0	1717.646	6593.048	0	14631.204	8079242.5
Gilan	1736.756	3347.974	29033.774	0	10310.09	711376.12
Hormoz	8382.038	0	14482.538	1716.96	2116.31	9088987.46
Khorasan	0	23.324	69931.722	1716.96	20545.406	25746275.8
Mazanda-ran	2617.384	2019.878	2858.66	1716.96	19663.896	2896295.92
Semnan	0	52.038	61458.544	0	1925.798	11765191.06
Zanjan	0	373.38	15143.548	0	5270.146	3490300.38
Esfhan	0	1180.312	0	3433.92	11676.896	15391203.8
Tehran	0	598.878	0	1716.96	13513.612	3644326
Khuzestan	5013.386	1442.952	0	0	16390.01	8562267.84
Kerman	0	0	0	0	6247.402	23934565.48
Yazd	0	0	0	1716.96	1437.464	16300428.2
Total	25579.0192	12113.976	260642.662	24252.06	192277.666	189297780

Maximum power consumption limit in each of the 16 electricity regions: the values to the right of the regional power consumption limit (R_{103} to R_{118}) as the maximum amount of electricity use in each of the 16 electricity regions based on the latest statistics and information in the energy balance in 2010 and with Considering the assumption of 10% of electricity generation from renewable energy is considered[76].

$$\begin{aligned}
 x_1 + x_{17} + x_{33} + x_{49} + x_{65} + x_{81} &\geq R_{103} \\
 x_2 + x_{18} + x_{34} + x_{50} + x_{66} + x_{82} &\geq R_{104} \\
 &\vdots \\
 x_{16} + x_{32} + x_{48} + x_{64} + x_{80} + x_{96} &\geq R_{118}
 \end{aligned} \tag{7}$$

Reliability limits in each type of renewable energy: Constraints related to reliability are presented to estimate the optimal pattern of reliable electricity supply from renewable energy[77, 78]. These coefficients are 0.1 per 10,000 hours for solar and geothermal energy, 0.5 per 10,000 hours for wind and tidal energy, 0.2 per 10,000 hours for biomass energy, and 0.67 per 10,000 hours for hydropower[79].

$$\begin{aligned}
10 \sum_{i=1}^{16} x_i &\leq R_1 \\
5 \sum_{x=17}^{32} x_i &\leq R_2 \\
10 \sum_{x=33}^{48} x_i &\leq R_3 \\
2 \sum_{x=34}^{64} x_i &\leq R_4 \\
1.5 \sum_{x=65}^{80} x_i &\leq R_5 \\
2 \sum_{x=81}^{96} x_i &\leq R_6
\end{aligned} \tag{8}$$

Implicit constraint: Finally, the constraint on the non-negative nature of the model decision variables, or in other words, the implicit constraint, is presented[80].

$$x_i \geq 0; i = 1, \dots, 96 \tag{9}$$

2.3.2. Stable counterpart of the renewable energy use model

In this study, the Bertsimis and Sims model has been used to stabilize and provide a stable counterpart model. In this model, uncertainty in the objective function coefficients (cost parameters) is considered[81-83].

$$\begin{aligned}
P_0 + Q_i &\geq eA y_i; i=1, \dots, 16 \\
P_0 + Q_i &\geq eB y_i; i=17, \dots, 32 \\
P_0 + Q_i &\geq eC y_i; i=33, \dots, 48 \\
P_0 + Q_i &\geq eD y_i; i=49, \dots, 64 \\
P_0 + Q_i &\geq eE y_i; i=65, \dots, 80 \\
P_0 + Q_i &\geq eF y_i; i=81, \dots, 96 \\
-y_i &\leq x_i \leq y_i; i=1, \dots, 16 \\
x_i, Q_i &\geq 0; i=1, \dots, 16
\end{aligned} \tag{10}$$

The conservatism level is related to cost parameters Γ_0 , and e is the percentage of deviation in the objective function coefficients (uncertain cost parameters). After consulting with experts, professors, and experts of the New Energy Organization of Iran, this number is considered a maximum of 20%. Also, P_0 , Q_i , and y_i are stable variables that have been added to the model. It should be noted that the limitations of 29 to 35 include the constraints that are added to the model while converting the original model to a stable counterpart[84].

3. Results and Discussion

The model was programmed in the collection space in Lingo Link software with Excel to increase computational efficiency. Model input data were called from Excel, and the model was solved. Due to the high number of indefinite parameters in the designed model (96 indefinite parameters in the model's objective function)[85], the number of protection levels was considered bases on consultation with professors. In total, 13 levels of protection were considered. For each case, the protection level of a model is solved. The number of parameters of different protection levels is the number given in Table 5 [86].

Table 5. Reliability levels of stability parameters of models

Different Levels	Parameters												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Level of cost parameter Reliability	0	8	16	24	32	40	48	56	64	72	80	88	96

To examine the number of constraints and variables of a stable counterpart problem, we assume that the number k of the nominal matrix A has uncertainty. If the main nominal problem has m constraint and n variables, it has $m + n + k$ constraint and $n + k + 1$ variable according to the Bertsim's model and Sim. Table 6 presents the model statistics, including the number of main constraints, number of constraint constraints, number of main variables, and number of constraint variables[87].

Table 6. Statistics of the variables

Parameter	Number
The main limitations	134
Stability constraints	196
Main variables	96
Stability variables	194

3.1. Model Simulation

Table (7) presents the answers obtained from solving the model at different levels of protection. In other words, first, the values of the objective function and the deviation from the optimal are presented, and then the optimal solutions of the variables are presented.

According to the information in Table 7, with increasing protection level, the amount of deviation from the optimum and also the objective function worsens, which is fully consistent with the mathematical logic of model stabilization, so that the more uncertainty the decision-maker considers for the model, the more conservative the answers will receive. This increase in conservatism in the cost objective function will mean higher costs[88].

It is clear that as the level of protection increases, the amount of deviation from the optimal gets worse. In other words, the value of the minimum objective function increases. The higher the level of protection, the more strictly the model chooses the values of the variables in the allowable range, and ultimately the worse the response of the objective function, so changing the level of conservatism can have a significant effect on the decision maker's income. The level of protection is so significant that the decision-maker makes a sensible decision by balancing the level of risk with the extent to which the goals have been achieved[89].

Table 7. The values of the objective function of the stable counterpart of the model in different states of the protection level

Deviation from the optimal	Optimal values of objective function [M\$]	Reliability level
0.00000	2675.4	0
0.10584	2979.2	8
0.15288	3106.6	16
0.18326	3292.8	24
0.19502	3214.4	32
0.19600	3224.2	40
0.19600	3224.2	48
0.19600	3224.2	56
0.19600	3224.2	64
0.19600	3224.2	72
0.19600	3224.2	80
0.19600	3224.2	88
0.19600	3224.2	96

In this study, according to [Table 8](#) and the model simulation results, which are summarized in [Table 9](#) and is a reduction in decision risk due to increasing levels of protection. Also, in consultation with professors, protection level 8 is considered to analyze the results.

Table 8. Results for the variable parameters

X1	0	X25	0	X49	335301	X73	856561
X2	0	X26	0	X50	210273	X74	533174
X3	0	X27	0	X51	54315	X75	381069
X4	0	X28	522297	X52	576338	X76	1204479
X5	0	X29	1088436	X53	0	X77	611137
X6	0	X30	0	X54	0	X78	1472499
X7	0	X31	637499	X55	228209	X79	0
X8	0	X32	0	X56	1509580	X80	-
X9	0	X33	0	X57	0	X81	0
X10	0	X34	0	X58	199089	X82	0
X11	0	X35	0	X59	244199	X83	0
X12	0	X36	0	X60	0	X84	715879
X13	0	X37	0	X61	0	X85	0
X14	0	X38	0	X62	0	X86	0
X15	181513	X39	0	X63	0	X87	715879
X16	0	X40	0	X64	0	X88	0
X17	0	X41	0	X65	0	X89	0
X18	0	X42	0	X66	867547	X90	0
X19	915240	X43	0	X67	305988	X91	0
X20	0	X44	250078	X68	211940	X92	0
X21	0	X45	1752001	X69	535517	X93	0
X22	0	X46	0	X70	404309	X94	877763
X23	0	X47	0	X71	0	X95	0
X24	0	X48	472621	X72	23878	X96	0

In classical linear programming models, the sensitivity analysis technique was used to test the results' validation. In the robust planning method, the simulation method is used to test the results' validation, a simple expression of simulation that produces repetitions of realities in nature. In some cases, iterations of a natural reality are difficult or impossible, so simulation is an efficient tool for engineers and designers to generate iterations of phenomena at a low cost.

3.2. Monte Carlo simulation

One suitable simulation method is the Monte Carlo method (MCS), which has many applications in various sciences. In the discussion of uncertainty analysis, the Monte Carlo simulation method is of particular importance and interest to researchers. Today, the Monte Carlo method is used in stochastic process analysis and certain systems. In simulation practice, modeling a system's behavior during the simulation period can predict the system's actual performance. In other words, in the simulation method, modeling the system's behavior artificially during the simulation, the system's performance can be evaluated. In this paper, to achieve the degree of violation of the objective function in each case, the values of the variables obtained from each model solution were considered constant. Uncertain parameters in the considered interval were randomly generated and simulated in a uniform distribution function 10,000 times. The simulation operation of the Burtsims and wire solid model will occur in reverse of the model solution so that in the simulation operation, the values of the variables obtained from the solution of the model are assumed to be constant. The values of uncertain parameters are randomly generated in a uniform distribution. The general method of this simulation is: the objective function and its value are considered, the number of deterioration states of the objective function is considered, and it is assigned the number one. Otherwise, the value is considered zero, so each time Simulation The number of deterioration states of the objective function is determined. In short, for the designed model, the simulation operation is performed once for the definite model and with a different number of protection levels in the stable model (96 times).

3.2.1. Simulation of the definite model with uncertain parameters

To show the necessity of solidifying the designed model, we simulated the definite model to see if the definite model is used and the uncertain parameters change in their oscillation range. What is the probability of the answer getting worse and thus the model and results being unjustified? There is a result. For this purpose, the definitive model was simulated 10,000 times. The results showed that in 50.18% of cases, the answer is likely to worsen. Thus, it is necessary to solidify the model to use solidity issues' mathematical logic and decrease decision risk (probability of model violation).

3.2.2. Simulation of a solid model with uncertain parameters

The robust model operates so that the level of decision risk decreases to increase the level of protection. In this section, to prove the correct stabilization and provide information about how the balance between the level of risk in different levels of protection, the stable model was simulated. [Table 9](#) shows 10,000 simulations of the robust model with uncertain parameters performed for each protection level.

Table 9. Results of 10000 times model robust simulation per protection level (percentage)

The answer is likely to get worse	Reliability level	The answer is likely to get wors	Reliability level
0.1485	13	49.4109	0
0.1188	14	36.5013	1
0.0396	15	25.344	2
0.0297	16	17.0676	3
0.0297	17	10.9098	4
0.0099	18	6.7716	5
0	19	4.9599	6
0	20	3.2175	7
0	21	1.8117	8
0	22	1.4751	9
0	23	0.9009	10
0	24	0.5643	11
--	--	0.2079	12

3.3. Discussion

According to the results of the optimal model of renewable energy use, which is designed according to the goal of the sixth Development Plan - assuming the production of 10% of grid electricity - the largest share is related to the production of energy from small hydropower with 15.19%. Then electricity generation from energy Wind, biomass, geothermal, tidal, and solar is 24.30, 5.52, 6.13, 4.79, and 44.07 percent.

The optimal values are equivalent to 56.04% of the total potential of small hydropower, 1.26% of the country's wind potential, 1.61% of the country's biomass potential, 10% of the country's geothermal potential, and 8.84% of the country's tidal potential.

This 10% of renewable electricity generation includes only 3.4% of the total potential of these energies in the country (excluding the potential of solar energy), which is equivalent to 10.5 million barrels of crude oil per year, which means saving 10.5 million barrels of crude and free oil—increasing this number to sell and earn more government. Also, considering the average of 678 grams of carbon dioxide production per kilowatt-hour of electricity, this amount of renewable energy production means a reduction of 12.48 million tons of CO₂ pollutants.

On the other hand, due to the very high potential that the country has in receiving solar energy, this model's results show only one percent share of solar energy use. This model result is due to the high cost of technology, equipment, and technology of using solar energy in our country, which has caused the cost of producing one megawatt of solar electricity compared to other energies. Therefore, it is necessary to develop the use of renewable energy and especially solar energy as a representative of this group of energies due to the very high potential in the country, paving the way for industry growth to localize photovoltaic equipment and solar power plants to reduce electricity generation costs from this energy source (see [Table 10](#)).

Table 10. Share of optimal amounts of renewable energy from 10% of electricity consumption in each region (percentage)

Regional electricity	Tidal	Hydro	Wind	Geothermal	Bioenergy	Solar
Sistan	0	0	99	0	0	0
Azerbaijan	0	79.6851	19.305	0	0	0
Bakhtar	0	23.7402	4.2075	0	71.0325	0
Fars	47.1141	13.9491	37.9269	0	0	0
the West	0	99	0	0	0	0
Gilan	0	99	0	0	0	0
Hormozgan	75.0618	0	23.9283	0	0	0
Khorasan	0	1.5345	97.4556	0	0	0
Mazandaran	0	99	0	0	0	0
Semnan	0	20.8593	78.1308	0	0	0
Zanjan	0	60.3306	38.6595	0	0	0
Esfahan	0	60.3108	0	12.5235	26.1558	0
Tehran	0	17.523	0	50.2425	31.2147	0
Khuzestan	36.9666	62.0235	0	0	0	0
Kerman	0	0	0	0	77.0517	21.9384
Yazd	0	0	0	98.2872	0.7029	0

Table 11. Share of optimal amounts of renewable energy from 10% of the country's electricity consumption (percent)

Energy	Share of portfolio
Tidal energy	4.79
Small hydropower	15.19
Wind energy	24.30
Geothermal energy	6.13
Biomass energy	5.52
Solar Energy	44.07

In the Sixth development plan, it is stipulated that by the end of 2025, 10% of the country's electricity production will be provided from renewable energies. For this purpose, the optimal model of using renewable energies has been designed according to this goal in this study(see [Table 11](#)).

Comparing the values of the optimal model of 10% renewable energy development with the status of electricity production from these energies in 2019 is shown in [Table 12](#).

Table 12. Comparison of the output values of the optimal model and the current situation (MW-installed capacity)

Energy	Current Amount	Optimal Amount
Solar	405.1	4407
Biomass	10.56	552
Geothermal	80	613
Wind	302.4	2430
Hydropower	106	1519
Tide	0	479
Share	1.2	10

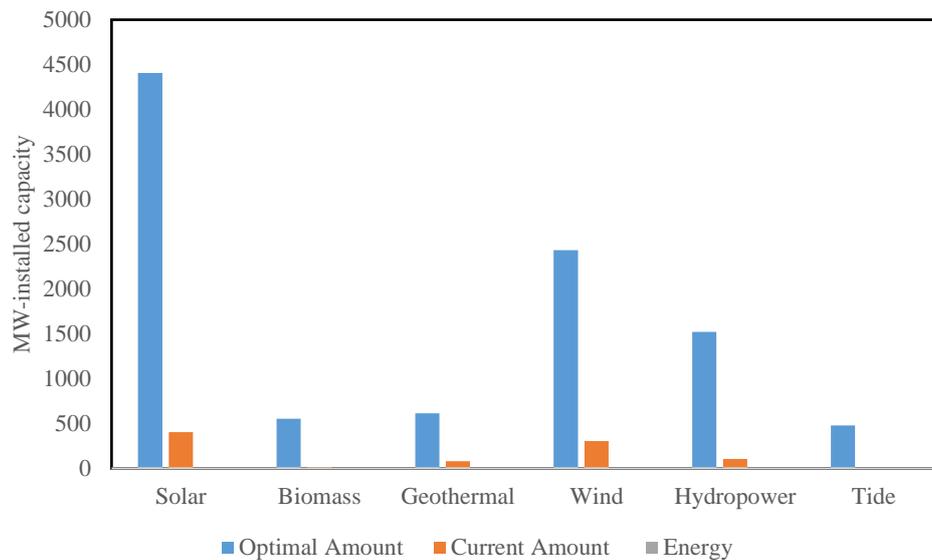


Figure 1. Current versus Optimal condition in the renewable energy installed capacity

The results of the optimal model (which is designed according to the Fourth Development Plan and shows a 10 percent share of renewable energy in the country's electricity production) show the production of 15.19 percent small hydropower, 24.30 percent wind energy, 5.52 percent biomass energy, 6.13% is geothermal energy, 4.79% is tidal energy and 44.07% solar energy. The optimal values are equivalent to 56.04% of the total small hydropower potential, 1.26% of the country's wind potential, and 1.61% of the country's biomass potential, 10 of the country's geothermal, and 8.84% of the country's tidal potential(see figure (1)).

Renewable energy is a new issue in Iran and the world, and at the same time, the stages of development and advancement of different renewable energy technologies are different [27,28]. If renewable energy in our country is not developed in parallel with other countries in the world, we will not have a place in the field of technical progress of this energy source, and as a result, it will cause technical and technological backwardness in this field, therefore [30]:

- The technical knowledge and technology of using renewable energy in the country should be developed as soon as possible, and the restrictions in this field should be removed, especially in the technology of using solar energy.
- The optimal combination for the medium-term development of 10% of renewable energy uses 15.19 percent small hydropower, 24.30 percent wind energy, 5.52 percent biomass energy, 6.13% is geothermal energy, 4.79% is tidal energy, and 44.07% solar energy.
- By replacing electricity generation from renewable energy, it is possible to save a significant amount of crude oil per year, which according to the current significant price of oil, this amount of oil can be exported, and a significant income can be earned from it.
- By developing the use of renewable energy sources, environmental pollution can be significantly reduced.

4. Conclusion

Given the growing need for energy in today's societies to meet different needs, scientists and researchers in many countries, including Iran, have fundamental approaches to achieving renewable energy on their agenda. Scientists believe that renewable and clean energy can become the first option for energy production due to the limited fossil

fuels and environmental pollution because this type of energy is clean, cheap, and especially renewable. Due to its geographical location, Iran has numerous capacities in producing new and renewable energy, and this issue has made the need to develop renewable energy on the authorities' agenda. In European countries, by 2020, it is planned that 30% of the installed capacity of countries will be for renewable resources, while in our country, due to the existence of large oil and gas resources, the country plans to use fossil energy to produce energy if which should gradually increase the share of renewable resources, as in most parts of the world. This issue emphasizes the need for an optimal model for the development of renewable energy use. Therefore, in this study, the main purpose is to provide an optimal renewable energy model, which provides the required electricity and reduces environmental pollution.

Supplementary Materials: All required data is presented in the paper.

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