An optimization model of renewable electricity price and construction of new wind power plants for Kermanshah, Iran

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Abstract

The purpose of this study is to provide a mathematical model for determination of optimal wind power price in the case of construction of new off-grid connected wind power plants is different areas. The proposed model is based upon 9 criteria including: construction cost, side costs (cost of replacement, maintenance, and repairs), pollution, electricity generation, profit, renewability level, green economy, rate of return on investment, and consumption. First, the inputs of the mathematical model were obtained by technical-economic feasibility evaluation of the study areas in the software Homer using the 10-year wind speed data (2006-2016). The optimal wind power prices were then determined in three different modes by solving the mathematical model with MATLAB. The modes considered in optimization were the construction of 1, 2, and 3 wind power plants in the study areas. Simulation of construction of wind power plants in each mode was conducted in the software Homer. The proposed mathematical model was found to have sufficient capability in determination of optimal wind power price

Keywords
Wind Energy; Mathematical Optimization Model; Pricing; Wind Power Plant; Kermanshah.

1. Introduction

Recent years has witnessed a steady increase in the share of renewable energies in the world's energy portfolio; an increase that has contributed not only to reduction of greenhouse gas emissions but also to diversification and security of energy supplies and growth of business and employment in renewable energy industry (Qolipour et al., 2017; Alavi et al., 2016). Despite the high potentials of a variety of renewable energies in Iran, inadequate pricing and access to relatively cheap oil and gas resources have impeded the progress of renewable energies in this country (Rezaei-Shouroki et al., 2017). In the past 15 years, guaranteed purchase of renewable electricity has been as common support measure in many countries. This practice is relatively new in Iran and investment in this sector under current situation is not cost-effective (Ghaith et al., 2017). It has been shown that pricing is one of the key factors of promotion and success of renewable energies. Renewable energy pricing is identical to fossil energy pricing except that it also takes account of environmental impacts of fossil fuel (Qiu et al., 2017).
Price is a numerical quantity representing the value of a commodity relative to others, so pricing of a product may serve as an incentive for both investors and consumers (Wang & li, 2015). In addition, there is a close association between price, consumption, and sectorial development. This association also applies to wind energy, so proper wind power pricing leads to a stable power generation sector and better motivation and organization of small and

large generators participating in renewable power generation efforts (Diaz et al., 2015). Nevertheless, renewable electricity purchase prices need to be higher than conventional electricity prices of the same market so that producers remain interested in further investment in renewable electricity generation (Martinez-Anido et al., 2016). In Iran's current electricity market however, per kilowatt price of wind electricity is being computed without any incentive to motivate private investment, so the pricing method actually impedes the development of this sector. There is an extensive literature on the electricity pricing in different parts of the world, and more specifically on pricing of wind power. Levitt et al. (2011) studied the pricing of electricity produced from coastal wind farms using the data gathered from 35 projects in Europe, China and the United States of America, and computed the breakeven price of this type of electricity. Simao et al. (2012) studied the pricing of wind power to ensure integration in a European competitive electricity market. Rubin and Babcock (2013) assessed the impact of wind power capacity developments and wind power pricing methods on the performance of unregulated electricity markets. Heydarian-Forushani and Golshan (2015) used a flexible pricing schedule and TOU (time of use) pricing scheme to introduce flexibility to wind power pricing. Oskouei and Yazdankhah (2015) presented a scenario-based stochastic optimal operation for iteration-based optimization of wind, solar, and pumped-storage electricity prices. Gao et al. (2016) performed a metric based analysis on the wind power prices to promote the use of wind energy by identifying the trends of change in wind power prices. Katz et al. (2016) analyzed the effect of residential electricity expenditures on the changes in electricity price by using a partial equilibrium model. Brenna et al. (2016) investigated different possible comparison methods for electricity production for Ethiopia. They used different variations for this study, also used HOMER software. It was concluded that the optimum result was by implementing a hybrid system model including Photovoltaic (PV)–Wind–Hydro–Battery. Amirnekooei et al. (2017) used the interior point algorithm for pricing of natural gas and electricity based on technical-economic constraints. Oseni and Pollitt (2017) conducted a business-model study on various aspects of energy prices based on 50-year records of residential power pricing. Gersema and Wozabal (2017) introduced an equilibrium pricing model for wind power features. Pircalabu et al. (2017) used the copula model to study the association of size of wind power generation with the costs that affect wind power pricing in Danish power market. Brenna et al. (2017) developed a model for evaluating solutions to reduce wind curtailment in South and North parts of Italy. Many researchers in Iran performed different studies which illustrate feasiblity of using renewables (Alavi et al., 2016a; Alavi et al., 2016b; Alavi et al., 2016c; Ezzabadi et al., 2015; Fereidooni et al., 2018; Goudarzi and Mostafaeipour, 2017; Minaeian et al., 2017; Mostafaeipour and Abessi, 2010; Mostafaeipour et al., 2016a; Mostafaeipour et al., 2016b; Mostafaeipour et al., 2014; Mostafaeipour et al., 2017; Mohammadi et al., 2016a; Mohammadi et al., 2016b; Qolipour et al., 2016; Qolipour et al., 2017; Ramezankhani et al, 2016; Sedaghat et al., 2017; Zarezade and Mostafaeipour, 2016).Therefore, this study aims to accommodate the need of Iran's wind power sector for a wind power pricing model that could update the price according to changes in area's wind power generation capacity and supply-applicant levels. This aim is achieved by development of a multimode mathematical model and analysis of different modes by simulation of wind power plants. In the end, capabilities of the introduced mathematical models in wind power pricing under different conditions is evaluated. The scope of this study is to address access to clean energy for three cities of Kermanshah province in Iran.

2. Geographic specifications

Kermanshah Province is one of the 31 provinces of Iran and is regarded as part of Iranian Kurdistan. The average temperature in the hottest months is above 22 °C (Wikipedia, 2017; IRIMO site of Iran, 2017). In present research 3 area including: Taze-Abad Salas, Gilan-Gharb and Sumar have choose. Figure 1 show map of Iran including Kermanshah province and the case studies
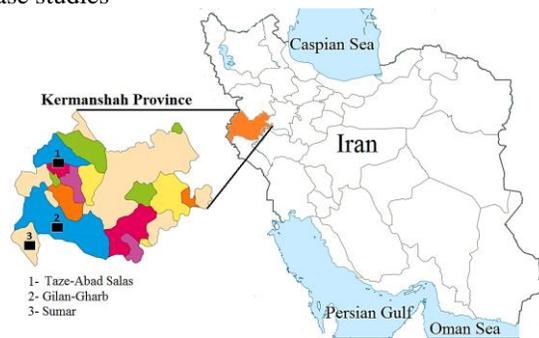

Figure 1. Map of Iran including Kermanshah province and the case studies.

3. Methodology

3.1. Model description

The mathematical model proposed in this paper is a modified version of the model proposed by Rabbani et al. (2015). The model proposed by Rabbani et al. (2015) is a mathematical model for simultaneous optimization of product price and launching of new product lines. The present study aims to modify the mathematical model of Rabbani et al. (2015) for simultaneous optimization of wind power price and construction of new wind power plants. It is assumed that there is a plan to construct several new wind power plants. Each wind power plant is characterized by K features, each with a level L_K. It is also assumed that all combinations of all levels of features are executable. Given the possibly wide range of customers with different power requirements and preferences, the region (which demand electricity) is assumed to be divided into M smaller areas with uniform preferences. M is a finite number. Given that the number of new electric power plants needed is not known, therefore, M is a number that can be one, two, three, or more. Also, the maximum M can be equal to the number of areas and at least one.

It is assumed that there are Q_i applicants in each area. Also, the region has N existing generators that provide power at price P_j \$ per Kilowatt.

Different points of the region have different utilities, which depends on different levels of different features of wind power plant. The objective is to determine, for each of the M plants, the level of features that must be selected to ensure maximum customer satisfaction as well as maximum benefit. This study is concentrated on M new wind power plants (M>1) to account for different preferences in regard to wind power in different areas of the region. On this basis, a multimode mathematical model is formulated to express the problem.

Out of 10 parameters used in the proposed model, 4 parameters including: the numbers of applicant in area i (Q_i), the probability of the electricity produced by wind power plant m being bought by area i (PR_{im}), the utility of the electricity produced by wind power plant m for area i (U_{im}), and the variable \$ per kilowatt production cost of wind power plant m (C_m^{var}) must be determined by the following equations, and others are assumed to be available (Rabbani et al., 2015).

$$Q_m = \sum_{i=1}^{I} Q_i PR_{im} \quad \forall m \in M \tag{1}$$

$$PR_{im} = \frac{U_{im} - P_m}{(U_{im} - P_m) + \sum_{n=1}^{N}(U_{in} - P_n)} \quad \forall m \in M; \forall i \in I \tag{2}$$

$$U_{im} = \sum_{k=1}^{K}\sum_{l=1}^{L_k} u_{ikl} x_{mkl} \quad \forall m \in M; \forall i \in I \tag{3}$$

$$C_m^{var} = \sum_{k=1}^{K}\sum_{l=1}^{L_k} c_{kl} x_{mkl} \quad \forall m \in M \tag{4}$$

Having defined the model indices, variables and parameters, the proposed model for optimization of wind power price and construction of new wind power plants is expressed as follows (Rabbani et al., 2015):

$$\text{Max} \quad Z = \sum_{m=1}^{M} Q_m (P_m - C_m^{var}) - C^{fix} \tag{5}$$

s.t:

$$\sum_{l=1}^{L_k} x_{mkl} = 1 \quad \forall m \in M; \forall k \in K \tag{6}$$

$$\sum_{m=1}^{M} y_{im} = 1 \quad \forall i \in I \tag{7}$$

$$x_{mkl}, y_m = \{0,1\} \quad \forall m \in M; \forall i \in I; \forall l \in L_k; \forall k \in K \tag{8}$$

$$P_m \geq 0 \quad \forall m \in M$$

$$\tag{9}$$

The objective function (5) expresses the profit to be gained by the wind power plants and is determined by subtracting the fixed and variable costs from the power sales revenue. Since the fixed cost (C^{fix}) has insignificant impact on the optimality of parameters, this function can be rewritten as (Rabbani et al., 2015):

$$\text{Max} \quad Z = \sum_{m=1}^{M} Q_m (P_m - C_m^{var}) \tag{10}$$

Constraint (6) states that only one level of each feature can be allocated to a wind power plant. Constraint (7) states that only one wind power plant can be allocated to an area of the region (each area will buy power from only one plant). Concerning the final objective function (Eq. 10), it should be noted that greater difference between utility (U_{im}) and variable cost (C_m^{var}) translates into higher plant profit (or better objective function value).

The final objective function (Eq. 10) will be solved in two Steps. In the first Step, the variables x_{mkl} and y_m will be determined, and in the second Step P_m will be optimized. In the following, the procedure of this two-Step solution for each mode is explained.

Step 1 of the solution: to optimize x_{mkl} and y_m, the problem will be defined as (Rabbani et al., 2015):

$$\text{Max}\quad Z = \sum_{i=1}^{I}\sum_{m=1}^{M} Q_i (\sum_{k=1}^{K}\sum_{l=1}^{L_k} (u_{ikl} - c_{ikl})x_{mkl}\, y_{im}) \tag{11}$$

$$\sum_{l=1}^{L_k} x_{mkl} = 1 \qquad\qquad \forall m \in M; \forall k \in K \tag{12}$$

$$\sum_{m=1}^{M} y_{im} = 1 \qquad\qquad \forall i \in I \tag{13}$$

$$x_{mkl}, y_m = \{0,1\} \qquad\quad \forall m \in M; \forall i \in I; \forall l \in L_k; \forall k \in K \tag{14}$$

Step 2 of the solution: Having the optimum x_{mkl} and y_m, the optimal \$ per kilowatt price of wind power plant m will be obtained from the following equation (Rabbani et al., 2015):

$$\text{Max}\quad Z_m = \sum_{m=1}^{M} Q_i \frac{U_{im} - P_m}{(U_{im} - P_m) + \sum_{n=1}^{N}(U_{in} - P_n)} \times y_{im}(P_m - C_m^{\text{var}}) \tag{15}$$

$$P_m \geq 0 \qquad\qquad \forall m \in M \tag{16}$$

After calculations of the first and second areas, there will be three different modes depending on the number of proposed wind power plants (m). The Steps of the solution that must be followed for each of these modes will be different. The first and second Steps of the solution procedure in each mode will be explained.

Mode 1: the number of new wind power plants to be constructed equals to the number of applicant areas ($m=1$).

Step 1: in order to solve the objective function in this mode, for each area, we select the level of the feature ($x_{kml} = 1$) that yields the greatest $u_{ikl} - c_{ikl}$, and this give the optimal value of x_{mkl}. Since each area is associated with only one new plant, y_m has no effect on the optimality of the solution.

Step 2: Since each plant is allocated to only one area, the problem can be summarized as (Rabbani et al., 2015):

$$\text{Max}\quad Z_m = \frac{U_{im} - P_m}{(U_{im} - P_m) + \sum_{n=1}^{N}(U_{in} - P_n)} \times (P_m - C_m^{\text{var}}) \tag{17}$$

$$P_m \geq 0 \qquad\qquad \forall m \in M \tag{18}$$

In the above problem, the optimum amount of P_m is obtained using MATLAB.

Mode 2: Only 1 wind power plant will be constructed in the areas ($m=1$). In this mode, the index m will be removed from equations and the solution process will be summarized as shown below.

Step 1: In this Step, the model is summarized as follows:

$$\text{Max}\quad Z = \sum_{i=1}^{I} Q_i (\sum_{k=1}^{K}\sum_{l=1}^{L_k} (u_{ikl} - c_{ikl})x_{mkl}) \tag{19}$$

$$\sum_{l=1}^{L_k} x_{kl} = 1 \qquad\qquad \forall k \in K \tag{20}$$

$$\sum_{m=1}^{M} y_{im} = 1 \qquad\qquad \forall i \in I \tag{21}$$

$$x_{kl} = \{0,1\} \qquad\qquad \forall l \in L_k; \forall k \in K \tag{22}$$

To solve the above model, we select the level of the feature ($x_{kml} = 1$) that yields the greatest $\sum_{i=1}^{I} Q_i(u_{ikl} - c_{kl})$, and this gives the optimal value of c_{kl}.

Step 2: Since only 1 wind power plant is allocated to all areas, the problem is summarized as (Rabbani et al., 2015):

Max (23)
$$Z = \sum_{i=1}^{I} Q_i \frac{U_i - P}{(U_i - P) + \sum_{n=1}^{N}(U_{in} - P_n)} \times (P - C^{var})$$

$$P \geq 0 \qquad (24)$$

Since the problem has a low number of applicant areas, the maximum value of this unconstrained objective function can be obtained by coding model in MATLAB.

Mode 3: In this mode, m new wind power plants will be constructed in the areas.

Step 1: In this Step, the model is linearized as follows (Rabbani et al., 2015):

Max (25)
$$Z = \sum_{i=1}^{I} \sum_{m=1}^{M} Q_i \cdot \sum_{k=1}^{K} \sum_{l=1}^{L_k} w_{ikml} \cdot (u_{ikl} - c_{ikl})$$

$$\sum_{l=1}^{L_k} x_{mkl} = 1 \qquad \forall k \in K ; \forall m \in M \qquad (26)$$

$$\sum_{m=1}^{M} y_{im} = 1 \qquad \forall i \in I \qquad (27)$$

$$x_{mkl} + y_m - 1 \leq w_{imkl} \qquad \forall m \in M ; \forall i \in I ; \forall l \in L_k ; \forall k \in K \qquad (28)$$

$$w_{imkl} \leq x_{mkl} \qquad \forall m \in M ; \forall i \in I ; \forall l \in L_k ; \forall k \in K \qquad (29)$$

$$w_{imkl} \leq y_{im} \qquad \forall m \in M ; \forall i \in I ; \forall l \in L_k ; \forall k \in K \qquad (30)$$

$$x_{mkl}, y_m, w_{imkl} = \{0,1\} \qquad \forall m \in M ; \forall i \in I ; \forall l \in L_k ; \forall k \in K \qquad (31)$$

Given the presence of binary variables and also the linearity of the model, this model can be solved with GAMS.

Step 2: this Step is the extended version of the procedure followed in Mode 2. More specifically, the y_{im} value obtained for each plant is used to determine the area to be allocated to that plant. Then, like in the second mode, the optimal per kilowatt price for each plant is obtained by solving the following equation using coding in MATLAB (Rabbani et al., 2015):

Max (32)
$$Z_m = \sum_{i=1}^{I} Q_i \frac{U_i - P}{(U_i - P) + \sum_{n=1}^{N}(U_{in} - P_n)} \times (P - C_m^{var})$$

Now, we present the sensitivity analysis of the proposed mathematical model.

3.2. Sensitivity Analysis

Assume P_m^{max} to be the offered \$ per kilowatt price of the electricity generated by wind power plant. Also, suppose there are several potential applicant areas that may be interested in buying wind power if there is a price drop. Let α be the rate of decline in the price of wind power for a unit increase in applicant, and D_m to be the increase in applicant for the electricity of power plant m after implementation of pricing strategy. In the case, intuitive diagram of sensitivity analysis of the model will be as shown in Figure 2.
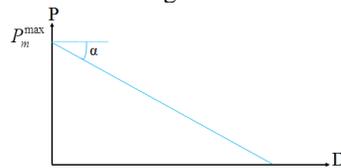

Figure 2. Graph of sensitivity analysis

In the next step of the sensitivity analysis process, the model of the second mode is turned into the following form (Rabbani et al., 2015):

For plant m:

(33)
$$MaxZ_m = \sum_{i=1}^{I} (Q_i \frac{U_i - (P_m^{max} - \alpha D_m)}{(U_i - (P_m^{max} - \alpha D_m)) + \sum_{n=1}^{N}(U_{in} - P_n)} + D_m) \times (P_m^{max} - \alpha D_m - C_m^{var})$$

$$D_m \geq 0 \qquad \forall m \in M \qquad\qquad (34)$$

Now, we provide a practical problem instance for these three modes and then analyze the results on a mode by mode basis.

4. Numerical Analysis

To develop a practical problem instance, first, the features associated with pricing of wind power in Iran were gathered from the website of Iran's Renewable Energy Organization (SUNA). These features are presented in Table 1. Out of 9 features listed in this table, 5 features (Marginal cost, Capital, Production, Consumption, and Sustainability) were obtained from the results of existing literature reviews and expert discussions made available on the SUNA website. The remaining 4 features were added by the authors to cover more aspects of the wind power pricing. In Table 1, each feature is expressed with three levels denoted by 1, 2 and 3, which are only for notation and have no numerical value.

Table1. Specifications title and the level of specifications for wind power pricing (SUNA site of Iran, 2017).

Specification title	Unit	Level of specification			Coding[1]		
Emission	Kg/yr.	Low		High	1	2	
Marginal cost	$/yr.	< 5000	Between 5000-10000	> 10000	1	2	3
Capital	$	< 50000	Between 50000-100000	> 100000	1	2	3
Production	KWh/yr.	< 30000	Between 30000-50000	> 50000	1	2	3
Income	$/yr.	< 15000	Between 15000-25000	> 25000	1	2	3
Sustainability	-	Has		Hasn't	1	2	
Green economic	-	Has		Hasn't	1	2	
PBP[2]	Year	< 5	Between 5 - 9	> 9	1	2	3
Consumption	KWh/yr.	< 31000	Between 31000-50000	> 50000	1	2	3

The studied case is three areas with applicant size of 6100, 3300, and 4200 households respectively in the Kermanshah province. The level of utility for the features used for pricing of the electricity generated by wind power plant in the study areas are listed in Table 2. The utility level of each feature is a level that is located in the standard range. The code numbers in Table 2 are taken from the last column of Table 1 which is listed as coding.

Table 2. Utility levels of 9 features used for pricing of the electricity generated by wind power plant in each area.

Area	Emission	Capital	Marginal cost	Production	Income	Sustainability	Green Economic	PBP[2]	Consumption
Taze-Abad	2	3	3	3	2	1	1	1	3
Sumar	2	3	3	3	2	1	1	2	2
Gilan-Gharb	2	3	3	3	2	1	1	2	2

Features of renewable electricity sources already active the market (rivals) are presented in Table 3. Similar to Table 2, these features were obtained from the results of existing literature reviews and expert discussions made available on the SUNA website. The figures (codes) given in each row represent the value and range of change in each feature. The code numbers in Table 3 are taken from the last column of Table 1 which is listed as coding.

Table 3. Features of renewable electricity sources already active the market (rivals) (SUNA site of Iran, 2017).

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[1] This coding done for facilities in context of the paper
[2] Pay Back Period

Energy name	type	Emission	Capital	Marginal cost	Production	Income	Sustainability	Green Economic	PBP	Price ($/kw)
Bioenergy	1	2	3	2	1	1	1	1	3	0.073
	2	2	3	3	1	1	1	1	3	0.095
	3	2	3	3	1	1	1	1	3	0.100
Solar farm	1	1	2	1	1	1	1	1	2	0.087
	2	1	3	1	2	2	1	1	2	0.108
	3	1	3	2	2	2	1	1	1	0.133
Geothermal	-	1	2	2	1	1	1	1	2	0.133
Industrial recycles	-	2	3	3	1	1	1	1	3	0.079
Small Hydropower	1	1	1	2	1	1	1	1	3	0.057
	2	1	2	2	1	1	1	1	2	0.041
Solar	1	1	1	1	1	1	1	1	3	0.190
	2	1	2	1	1	1	1	1	3	0.217

The studied province is divided into three separate applicant areas, so a minimum of 1 and a maximum of 3 new wind power plants can be constructed in the province. Therefore, as described in the solution procedure in Section 3, the problem was solved for every mode and the features of the electricity produced from wind power plants and the price of wind power were determined with the newly added wind power generation capacity taken into account.

The precedence of areas for construction of wind power plant may be unclear, so in this study, the order of the construction is set based on the wind potential of areas (the area with a higher potential is given precedence). While all three studied areas have considerable wind potential, their ranking in terms of wind potential is: Taze-Abad, Sumar and Gilan-Gharb. This ranking was obtained from 10-year wind speed data of the areas (Figure 3) and the priority of construction was set to match the said order.
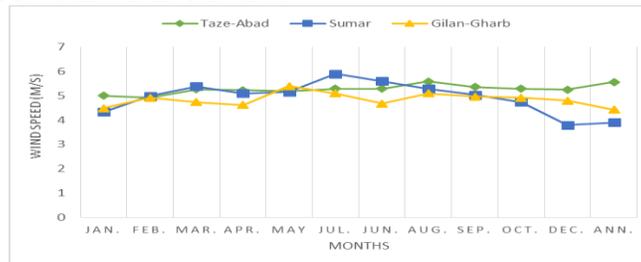

Figure 3. Wind speed in the studied areas (SUNA site of Iran, 2017)

Next, we solved the model in different modes and determined the optimal price of wind power in each mode.

Mode 1: construction of 1 new wind power plant

This mode is similar to the second solution procedure described in section 3. First, the technical-economic feasibility of building a wind power plant in Taze-Abad area was evaluated by Homer software. The outputs of this software were then used as the input of the proposed mathematical model to determine the optimal per kilowatt price of wind power. Table 4 shows the technical-economic values for electricity generation by this plant. After using MATLAB to solve the mathematical model in this mode, the optimal price of electricity to be produced by such wind power plant was calculated to 0.159 $ per kilowatt.

Table 4. Feature values used for pricing of power to be produced by a wind power plant in Taze-Abad area.

Specification title	Unit	Specification's Level
		Wind Power plant
		A

Emission	Kg/yr.	70,837
Marginal cost	$/yr.	51,133
Capital	$	3,750,000
Production	KWh/yr.	21,658,148
Income	$/yr.	4,331,630
Sustainability	-	✓
Green economic	-	✓
PBP	Year	4
Consumption	KWh/yr.	6,441,198

Mode 2: construction of 2 new wind power plants

Using the third solution procedure described in section 3, the technical-economic feasibility evaluation by Homer software was repeated for a wind power plant in Taze-Abad area and another plant in Sumar area. The outputs were again used as the input of the proposed mathematical model to determine the optimal per kilowatt price of wind power. The features of electricity generation by these two separate plants are given in Table 5. After coding the model in MATLAB, the mathematical model was solved by this software and the optimal price of electricity to be produced by these wind power plants was calculated to 0.151$ per kilowatt.

Table 5. Feature values used for pricing of power to be produced by two wind power plants in Taze-Abad and Sumar areas.

Specification title	Unit	Specification's Level	
		Wind Power plants	
		A	B
Emission	Kg/yr.	70,837	74,740
Marginal cost	$/yr.	51,133	51,360
Capital	$	3,750,000	3,750,000
Production	KWh/yr.	21,658,148	19,833,280
Income	$/yr.	4,331,630	3,966,656
Sustainability	-	✓	✓
Green economic	-	✓	✓
PBP	Year	4	5
Consumption	KWh/yr.	6,441,198	6,282,816

Mode 3: construction of 3 new wind power plants

For this mode, the model was solved using the first solution procedure described in section 3. For this purpose, Homer software was used for technical-economic feasibility analysis of construction of three wind power plants in Taze-Abad, Sumar, and Gilan-Gharb areas and the results were used in the proposed mathematical model to determine the optimal per kilowatt price of wind power. Table 6 shows the features of electricity generation by three isolated plants in the mentioned areas. The resulting model was again solved by MATLAB and the optimal price of electricity to be produced by these wind power plants was calculated to 0.140$ per kilowatt.

Table 6. Feature values used for pricing of power to be produced by three wind power plants in Taze-Abad, Sumar, and Gilan-Gharb areas.

Specification title	Unit	Specification's Level		
		Wind Power plants		
		A	B	C
Emission	Kg/yr.	70,837	74,740	79,450
Marginal cost	$/yr.	51,133	51,360	51,352
Capital	$	3,750,000	3,750,000	3,750,000
Production	KWh/yr.	21,658,148	19,833,280	18,988,448
Income	$/yr.	4,331,630	3,966,656	3,979,690
Sustainability	-	✓	✓	✓

Green economic	-	✓	✓	✓
PBP	Year	4	5	5
Consumption	KWh/yr.	6,441,198	6,282,816	6,201,662

Mode 4: construction of more than 3 new wind power plants
In this case study, this mode exceeded the applicant of areas, so construction analysis and power price optimization were not carried out. This mode can be used for simultaneous optimization of renewable electricity price and construction of new wind power plants in larger regions, which will be discussed in future study.

5. Conclusion

The aim of the present study was to facilitate the simultaneous optimization of renewable electricity price and construction of new isolated wind power plants in different areas of a region with the help of mathematical modeling. In the case study, three areas, Taze-Abad, Sumar and Gilan-Gharb (in the order of their wind energy potential) were selected as candidate for construction of isolated wind power plants in Kermanshah. This study attempted to optimize the price of electricity generated from wind power plants such that maximum profit from the sales of new and existing plant and also applicant satisfaction would be ensured. For this purpose, a mathematical model was introduced for determination of optimal wind power price according to the number and capacity of wind power plants based on 9 features including: construction cost, side cost (cost of replacement, maintenance and repairs), pollution, electricity generation, profit, renewability level, green economy, rate of return on investment, and consumption. The case study was conducted by considering the possibility of building one, two or three wind power plants in abovementioned areas of western Kermanshah. Plant construction simulation was conducted by the Homer software, and all three modes of the mathematical models were coded in MATLAB. First, the 10 years wind speed data (2006-2016) of these three areas was used for evaluation of technical-economic feasibility of wind power plants by simulation in Homer, and then software outputs were used for solution of mathematical model in MATLAB. The results showed that building only 1 wind power plant will result in an optimal power price of 0.159 $ per kilowatt, and simultaneous construction of two wind power plants will result in an optimal price of 0.151 $ per kilowatt. In the third mode, simultaneous construction of three wind power plants was found to result in an optimal price of 0.140 $ per kilowatt. In conclusion, the proposed mathematical model was found to have sufficient capability in optimization of wind power price.

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