Investigation of using solar energy: a case study

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Abstract

This study analyzes the technical-economic feasibility study for construction of solar plants in 14 different locations of Khuzestan province in Iran. The HOMER software, Data Envelopment Analysis (DEA), Balanced Scorecard (BSC), and Game Theory (GT) were used for ranking the areas in the province. The outputs of the HOMER software includes the kind of equipment to be used for building of each plant, benefit, cost, total net capital expenditure, depreciation cost and the amount of electricity generated by each plant. Finally, nominated cities were ranked according to four criteria: the net cost of construction, earnings, the amount of generated power, and pollution created by the plants. It was concluded that the cities of Abadan, Omidiyeh, and Aghajari ranked the highest respectively, and the city of Behbahan and Ahwaz ranked the lowest. Also, the results of validation illustrated that ranking obtained by the hybrid approach is almost same as the simple DEA methodology.

Keywords
Solar energy; Data Envelopment Analysis (DEA), Balanced Scorecard (BSC); Game Theory (GT); HOMER software; Khuzestan.

1. Introduction

Solar energy is a kind of renewable which has numerous applications in residential and industrial buildings. Low cost and easy installation of solar energy systems can be effectively used as a clean energy [1]. A comparison between energy efficiency in terms of renewability and novelty of energy source for residential buildings in Europe has shown that the use of solar energy is the best option for providing energy for buildings [2]. Researches indicate that in some regions of the world, solar energy is now the most common type of energy used in the buildings, for example solar energy can supply about 50 percent of energy demand of buildings in Greece [3]. The use of solar energy for the greenhouses is another example of successful application of solar energy which leads to reduced fossil fuel costs, reduced greenhouse pollutions, and conversion of unconventional heating system of these greenhouses to a standard heating system [4].

Today, developed countries have adopted renewable portfolio standards which are emphasized on increasing the renewable energy generation, reducing the solar costs, and encouraging and promoting the solar industry. For example, in Michigan, solar output is 20% [5]. Many studies have attempted to optimize various components in production-consumption cycle which link the solar power generation [6].

There are extensive amounts of literatures related to the technical-economic feasibility studies in the world. A study on passive solar energy-saving potential in eight regions of Canada showed that 32-74% of the solar energy generated in residential buildings remain unused. However, public buildings have taken fewer measures (as compared to private buildings) to devise a plan to tackle this issue [7]. Given the availability of solar energy in Iran,

solar thermal power plants will be one of the main energy resources in the future. Solar power is one of the cleanest sources of renewable energy and this fact has encouraged the research and development in this field of energy generation. There have been many renewable energy works in the literature which shoes importance of this subject [8-24]. The benefits of solar energy have caused that Iranian society to be interested in developing this kind of energy [25]. The objective of this paper is to perform a technical-economic feasibility study on 14 candidate sites within Khuzestan province to evaluate their suitability for the construction of solar plants; This can be achieved using a hybrid model to rank and prioritize these sites based on the amount of generated power, the construction cost, net income and the amount of pollution at each site.

2. Geographic characteristics

Khuzestan Province is one of the 31 provinces of Iran that located on 31.3273°N 48.6940°E. It is in the southwest of the country, bordering Iraq's Basra Province and the Persian Gulf. Its capital is Ahvaz and it covers an area of 63,238 km^2. Other major cities include Behbahan, Abadan, Andimeshk, Khorramshahr, Bandar Imam, Dezful, Shushtar, Omidiyeh, Izeh, Baq-e-Malek, Mah Shahr, Susangerd, Ramhormuz, Shadegan, Susa, Masjed Soleiman, Minoo Island and Hoveizeh. The climate of Khuzestan is generally very hot and occasionally humid, particularly in the south, while winters are much more cold and dry. Summertime temperatures routinely exceed 44 degrees Celsius and in the winter it can drop below freezing, with occasional snowfall, all the way south to Ahvaz. Khuzestan is possibly one of the hottest places on earth with maximum temperature in summer soaring up to 55 degrees Celsius air temperature with temperatures coming close to 60 degrees Celsius at times. The world's highest unconfirmed temperature was a temperature flare up during a heat burst in June 1967, with a temperature of 87 °C in Abadan in the Khuzestan province. Reliable measurements in the city range from −5 to 53 °C (23 to 127 °F). Khuzestan has desert conditions and experiences many sandstorms [26]. Figure 3 illustrate areas of Khuzestan province and its location in Iran's map.

3. Methodology

3.1. HOMER software

The HOMER Software is an energy modeling software for hybrid renewable energy systems. The HOMER energy modeling software is a powerful tool for designing, simulating and analyzing hybrid power systems, which contain a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaic, batteries, fuel cells, hydropower, biomass, and other inputs. It is currently used all over the world by many researchers. For either grid-tied or off-grid environments, HOMER helps to determine how variable resources such as wind and solar can be optimally integrated into hybrid systems. Researchers use HOMER to run simulations of different energy systems, compare the results and get a realistic projection of their capital and operating expenses. HOMER determines the economic feasibility of a hybrid energy system, optimizes the system design and allows users to really understand how hybrid renewable systems work. As distributed generation and renewable power projects continue to be the fastest growing segment of the energy industry, HOMER can serve utilities, telecoms, systems integrators, and many other types of project to mitigate the financial risk of their hybrid power projects [27, 28].

3.2. Hybrid Approach of DEA, BSC and Game theory

DEA is a mathematical programming model to assess the efficiency of decision-making units (DMU) with multiple inputs and outputs. Measuring efficiency because of its importance in evaluating the efficiency of a company or an organization has always been considered by researchers [29]. The proposed approach to perform comparisons between samples with multiple inputs and outputs has combined three approaches: simple DEA and BSC and Nash bargaining game theory. Then nonlinear fractional model was simplified to simple linear model using change of variables. BSC is a conceptual framework for translating strategic objectives into a set of efficiency measures in four perspectives: financial, customer, internal processes, and development. Here, the use of a combination of several DEA models in which the output of a model will be the input of the other model allows the accurate comparison of several different populations by several different ways [25].

In this framework, the output of each model will be the previous model's input. Thus the output of the model of processes and equipment used in the plant is used as the input of the model of electrical energy production. Accordingly, output of electrical energy production model is the input of financial model and financial model output is the final output of our integrated model. But using the BSC model environmental issues are considered and pollution model is entered into the ranking and its impact factor is considered in the ranking of the studied areas. Although DEA is a powerful and common tool of ranking, it has failures like ignoring some vital information such as the environmental pollution caused by power plants and sensitivity to changes in the input-output [30].

Previous research suggests that combining DEA and BSC models can overcome these limitations. Then using Nash bargaining model, DMUs functions are measured simultaneously by the four models. In game theory, the goal of every player is to maximize the desirable results [31]. "Game theory" is a mathematical technique. This technique is used for the analysis of problems that encompass conflict situations. In the proposed model, the Nash bargaining game theory was used. The aim is to improve the total efficiency of the model. This bargaining problem can be defined as vectors b, S, N where N = {1,2, .., 14} is a set of 14 studied areas, S is a feasible subset of results space and b is the break-point and a subset of S. It has proven that to solve the game, there is a unique solution called "Nash" and is achieved by optimal solution where is i-th member of the vectors u, b, and u is the result vector [32]. If the values obtained from a player's withdrawal from the game are called break point and these points are the starting points of the game, we use a cross-efficiency to estimate these points. For this study, we will have three break points. These points will be considered for each model [28]. To calculate the break points the optimum weight of other units are used. Thus, cross efficiency of a given DMU is obtained by equations 1 to 3:

$$E_{qj} = \frac{\sum_{r=1}^{s} u_{rq} z_{rj}}{\sum_{i=1}^{m} v_{iq} x_{ij}} \qquad q, j = 1,\ldots, m \tag{1}$$

The total average of E_{qj} is cross efficiency of DMU_j:

$$\overline{E}_J = \frac{1}{n}\sum_{q=1}^{n} E_{qj} \tag{2}$$

Where, $\overline{E}_J$ is cross efficiency score of j-th unit. Cross efficiency method was used to set break points in this study.

$$\theta_{cross} = \inf_{q,j}(E_{q.j}) \tag{3}$$

According to equation (3), breakpoints for the first to the third models are shown with symbols θ^a, θ^b, θ^c respectively [34].

3.3. Non-fractional DEA-BSC-Game theory model

Suppose there are n units and every j-th unit has m entries in the first stage (equipment used in power plants) shown with $x_{ij}; i = 1,2,.., m$ that s_1 outputs of this stage is shown with $y_{rj}; r = 1,2,.., s_1$. s_1 is the input of the second stage (the electrical charge produced) that is the output of the first stage and second stage outputs that are shown with $y_{sj}; r = 1,2,.., s_2$ are the input of the third stage (the financial perspective). The output of financial funds is shown with $y_{pj}; r = 1,2,.., s_3$. Furthermore, all inputs and outputs necessary to perform calculations of models have been used for the six points as indices and funds of scorecard as the standard. Now, another constraint is defined and every four constraints 1 to 4 are shown as the constraints of Nash bargaining game showing that the efficiency of each unit in each of the funds must be greater than or equal to the values of the corresponding break points. Jahangoshaie Rezai et al [28, 31] proved that the feasible of this model is compact and convex. The hybrid model will be as equation 4:

$$\max \left(\frac{\sum_{r=1}^{s_1} u_r^a v_{r_0}^a}{\sum_{i=1}^{m_1} v_{i\times i_0}} - \theta^a\right) \cdot \left(\frac{\sum_{s=1}^{s_2} u_s^b v_{s_0}^b}{\sum_{r=1}^{s_1} u_r^a v_{r_0}^a} - \theta^b\right) \cdot \left(\frac{\sum_{p=1}^{s_3} u_p^c v_{p_0}^c}{\sum_{r=1}^{s_1} u_s^b v_{s_0}^b} - \theta^c\right) \tag{4}$$

s.t:

$$\frac{\sum_{r=1}^{s_1} u_r^a v_{r_0}^a}{\sum_{i=1}^{m_1} v_{i\times i_0}} \geq \theta^a, \qquad \frac{\sum_{s=1}^{s_2} u_s^b v_{s_0}^b}{\sum_{r=1}^{s_1} u_r^a v_{r_0}^a} \geq \theta^b, \qquad \frac{\sum_{p=1}^{s_3} u_p^c v_{p_0}^c}{\sum_{r=1}^{s_1} u_s^b v_{s_0}^b} \geq \theta^c$$

And also we have:

$$\frac{\sum_{s=1}^{s_2} u_s^b v_{s_j}^b}{\sum_{r=1}^{s_1} u_r^a v_{r_j}^a} \leq 1, \qquad j = 1,\ldots, n$$

$$\frac{\sum_{p=1}^{s_3} u_p^c v_{p_j}^c}{\sum_{r=1}^{s_1} u_s^b v_{s_j}^b} \leq 1, \qquad j = 1,\ldots, n$$

$$v_i, u_r^a, u_b^s, u_b^c \geq 0, \quad i = 1,\ldots, m; \quad r = 1,\ldots, s_1; \; s = 1,\ldots, s_2; \quad p = 1,\ldots, s_3$$

In the next stage, the relations are used and to get better output with fewer errors and easier implementation by software, by changing the variable using equations 5 to 16, the model is simplified [28].

$$t_1 = \frac{1}{\sum_{i=1}^{m} v_i x_{i0}} \tag{5}$$

$$t_2 = \frac{1}{t_1 \sum_{r=1}^{s_1} u_r^a y_{r0}^a} \tag{6}$$

$$t_3 = \frac{1}{t_1 t_2 \sum_{s=1}^{s_2} u_s^b y_{s0}^b} \tag{7}$$

$$t_1 v_i = \gamma_i \tag{8}$$

$$t_1 u_r^a = \mu_{1r}^a \tag{9}$$

$$t_1 t_2 u_r^a = \mu_{2r}^a \tag{10}$$

$$t_1 t_2 u_s^b = \mu_{1s}^b \tag{11}$$

$$t_1 t_2 t_3 u_s^b = \mu_{2s}^b \tag{12}$$

$$t_1 t_2 t_3 u_p^c = \mu_{1p}^d \tag{13}$$

Constraints 9 and 10 follow that:

$$\mu_{1r}^a t_2 = \mu_{2r}^a \tag{14}$$

Equations 11 and 12 follow that:

$$\mu_{1s}^b t_3 = \mu_{2s}^b \tag{15}$$

Using defined equations 8 to 15, simplified model will be as equation 16 [28]:

$$\max \left(\sum_{r=1}^{s_1} \mu_{1r}^{a} y_{r_0}^{a} - \theta^{a} \right) . \left(\sum_{s=1}^{s_2} \mu_{1s}^{b} y_{s_0}^{b} - \theta^{b} \right) . \left(\sum_{p=1}^{s_3} \mu_{1p}^{c} y_{p_0}^{c} - \theta^{c} \right) \tag{16}$$

s.t:

$$\sum_{r=1}^{s_1} \mu_{1r}^{a} y_{r_0}^{a} \geq \theta^{a}$$

$$\sum_{s=1}^{s_2} \mu_{1s}^{b} y_{s_0}^{b} \geq \theta^{b}$$

$$\sum_{p=1}^{s_3} \mu_{1p}^{c} y_{p_0}^{c} \geq \theta^{c}$$

$$\sum_{r=1}^{s_1} \mu_{1r}^{a} y_{rj}^{a} - \sum_{i=1}^{m} \gamma_i x_{ij} \leq 0 \qquad j = 1,\ldots, n$$

$$\sum_{s=1}^{s_2} \mu_{1s}^{b} y_{s_j}^{b} - t_2 \sum_{r=1}^{s_1} \mu_{1r}^{a} y_{rj}^{a} \leq 0 \qquad j = 1,\ldots, n$$

$$\sum_{p=1}^{s_3} \mu_{1p}^{c} y_{p_j}^{c} - t_3 \sum_{s=1}^{s_2} \mu_{1s}^{b} y_{s_j}^{b} \leq 0 \qquad j = 1,\ldots, n$$

$$\sum_{i=1}^{m} \gamma_i x_{i0} = 1$$

$$t_2 \sum_{r=1}^{s_1} \mu_{1r}^{a} y_{r0}^{a} = 1$$

$$t_3 \sum_{s=1}^{s_2} \mu_{1s}^{b} y_{s_0}^{b} = 1$$

$$v_i, u_r^{a}, u_b^{s}, u_b^{c} \geq 0 \;, \quad i = 1,\ldots, m; \quad r = 1,\ldots, s_1; \; s = 1,\ldots, s_2; \quad p = 1,\ldots, s_3$$

Research procedure is as follows:

1. The technical-economic feasibility study of each plant in HOMER software
2. Identifying and determining the components required for ranking
3. Extracting necessary data to rank power plants from HOMER software for each plant
4. Coding and solving model in Lingo software and entering values of ranking components
5. Obtaining efficiency values for two hybrid and simple DEA methods
6. Comparing the results and ranking

4. Analysis

4.1. Technical-economic analysis

For obtaining the inputs and outputs required to rank the 14 study areas, Homer was used to perform a technical-economic feasibility study on the intended solar stations. First, solar power plant equipment were determined and then the necessary information such as the angle of radiation, latitude and longitude, the number of sunny days and temperature of each site were entered into the Homer software. The candidate sites included Omidiyeh, Aghajari, Behbahan, Ahwaz, Shushtar, Masjed Soleiman, Izeh, Mahshahr Port, Boostan, Dezful, Rāmhormuz, Sefidabad in Dezful and Hendijan. The type of solar panels was also selected based on a technical feasibility analysis by the software. The HOMER software gets required inputs and give back the proper outputs including type of proposed system and economic evaluation [28]. The average electrical efficiency will also be incorporated in this ranking. This means that the amount of generated electricity and the average electrical efficiency in a plant will directly contribute to its technical and environmental standing [28].

To rank the studied areas, five factors were considered: the cost of construction, plant's revenue, electricity generated by the system, electricity generated by the panel, and the pollution generated by each plant. These five factors were selected for two reasons: first reason is the cost-effectiveness of solar energy, and second reason is the

security of solar energy in terms of cleanness and producing the least amount of pollution. These two features of renewable energies are the ones that make this energy superior to the similar types. Therefore, in this study we have attempted to incorporate these two important features in our evaluations.

4.2. Ranking the studied areas

After determining the inputs and outputs described in the previous section, the values of breakpoints for each step was obtained using cross efficiency approach. Then the efficiency score of each perspective of Balanced Scorecard method was obtained by putting information regarding each perspective in model 16, which were modeled as three consecutive goals in this model. Simple DEA model has a low accuracy and is inefficient in separating decision-making units, but the proposed hybrid DEA model has a better performance in this regard and reports a more accurate efficiency score. In other words, simple DEA model cannot properly recognize the relationships between factors, and this inability causes some factors or DMUs to be identified as efficient, while in the hybrid DEA model, these relationships are well recognized and the possibility of computational errors is taken into consideration.

The rank of each of the 14 areas was listed in Table 1 which clearly shows that there are minor differences between the ranking of simple DEA and that of hybrid DEA. The main reasons for this difference were mentioned in the previous sections.

Table 1: Ranking results of each of the 14 areas using by simple DEA and hybrid DEA.

	Ranking	
	Simple DEA	hybrid DEA
Omidiyeh	3	2
Ahwaz	11	13
Izeh	2	4
Abadan	1	1
Aghagari	8	3
Mahshahr Port	12	12
Boostan	10	9
Behbahan	14	14
Dezful	6	8
Ramhormuz	9	10
Sefidabad	4	6
shushtar	5	7
Masjed Soleiman	7	5
Hendijan	13	11

The important point in connection with the feasibility studies performed on these areas is that technical-economic feasibility studies were done only for one solar energy generation system, and was based on data obtained from meteorological stations of areas. As a result, the ranks of these 14 areas were based on data obtained for a relatively small geographic area so that calculations showed no significant difference between solar energy capacities of the 14 candidate sites. However, the proposed hybrid DEA method was able to properly rank these 14 areas despite this low level of difference.

5. Conclusions

Feasibility study for construction of solar power plants in 14 regions of Khuzestan province in Iran was investigated in this research work using a hybrid model to rank and prioritize the locations. Analysis was done using the Homer software and a hybrid method composed of DEA, BSC and Game theory to rank the options. The hybrid approach outperformed the simple DEA by obtaining more accurate efficiency scores and by making connections between decision-making units (DMUs). The highest ranks were obtained for Abadan, Izeh, Omidiyeh and Hendijan respectively. The hybrid approach composed of DEA, BSC and Game theory methods gave better results as compared to simple DEA approach. The construction cost of 14 solar systems in the 14 regions was calculated to $551,433 and the minimum annual benefit of these systems was calculated to $103,896.2. Also, the net income gaining from the construction of solar energy generation system was calculated to $1,870,131.6 over 25 years. The

results indicated that results of ranking by the proposed hybrid approach are different from those obtained from simple DEA approach.

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Biography

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