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Evaluation of installing photovoltaic plants using a hybrid approach for Khuzestan province, Iran

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ABSTRACT

Iran is one of the countries that enjoys remarkable solar energy potential; thus, the shift toward solar energy utilizations offers numerous environmental advantages. This research aims to perform a technical–economic feasibility study on the construction of Photovoltaic power plants in 14 areas of Khuzestan province using HOMER software and by using a hybrid approach composed of Data Envelopment Analysis (DEA), Balanced Scorecard (BSC) and Game Theory (GT) to rank the selected areas. The proposed hybrid approach outperforms the simple DEA by its ability to acquire more accurate results in order to distinguish the relationships between decision-making components and criteria. Technical–economic feasibility study is conducted by gathering the information related to the solar resources for each candidate site, selecting the required equipment and then simulating these plants in HOMER software. The outputs of the software included the type of equipment to be used in the construction of each plant, benefit, cost, total net capital expenditure, depreciation cost and the amount of electricity generated by each plant. After solving the hybrid model composed of DEA, BSC and Game theory by Lingo, candidate sites were ranked based on four criteria: the net cost of construction, earnings, the amount of power generated, and pollution produced per plant. According to the results, the sites of Abadan, Omidiyeh, and Aghajari gained the highest ranks, and the sites of Behbahan and Ahwaz gained the lowest rank. In addition, the validation results show that ranking gained by the proposed hybrid approach is almost same as the simple DEA method.

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1. Introduction

The ever growing world population, limited energy resources and the environmental impacts resulting from excessive consumption of fossil fuels, have attracted the people's attention to a more proper use of renewable sources of energy. Some countries have chosen to increase the use of renewable energies such as solar and wind powers; others use nuclear power plants, some still rely on fossil fuels but many governments use a combination of renewable and non-renewable energies to meet the needs of their communities. Solar energy is a potent renewable energy that is widely used by many countries as a supplement to other energy resources. Many other countries, including Iran, are still developing the infrastructure required to use renewables [1]. There have been numerous works related to renewable energy as a clean source substitutes for fossil fuels [2–8]. Iran with substantial renewable energy potential was one of the first countries that used renewable energy in ancient time [9]. Mohammadi et al. [10] evaluated the potential of hybrid solar-wind for three free economic and industrial zones of Iran using key solar parameters like monthly mean global, beam and diffuse solar radiation as well as clearness index. Rawat et al. [11] investigated that a solar photovoltaic system that comprises of photovoltaic panels, converter, inverter, and battery with suitable capacity and arrangement could provide the required electricity demand of the specific location.

Iran has a total area of 1,648,965 km^2 with the average of 300 sunny days per year and the total annual solar radiation of 2200 kW h. Iran's daily solar power generation potential is about 9 million megawatts which can be maximized to about 14.7 TW. It is predicted that by 2030 only 2% of Iran's solar capacity, i.e. 2.8 GW, in Shiraz, Taleqan, Yazd, Tehran, Semnan and Khorasan will be utilized, and it needs 2.8 billion dollars investment from 2010 to 2030 [12].

The phenomenon that generates electricity upon exposure to light and without using any moving mechanism is called photovoltaic, and the system that uses this phenomenon to generate electricity is called photovoltaic system. Photovoltaic systems are the most widely used and most common source of renewable energy generation in the world [13]. The increasing environmental pollution and decreasing fossil fuel resources have pushed the societies to reduce the exploitation of non-renewable resources and have encouraged the efforts to rely on renewable energy resources such as solar energy [14]. Many efforts have been made to achieve the optimal balance between energy consumption and generation. Solar house technology provides a suitable platform to achieve optimal solar energy generation, energy efficiency and consumption balance, which increases the potential benefits of using this type of energy. [15].

The amount of power produced by photovoltaic systems in New York is usually between 2 to 50 kW. For example, a photovoltaic system with the power generation capacity of 2 kW that is made for home use can annually produce 3600 kW h of electricity, which leads to a saving in energy consumption equal to 4.3 t of coal per year and in addition prevents the emission of 5000 pounds of pollutant gases each year [16]. Solar systems include concentrating solar collectors, photovoltaic systems, solar water heaters, solar air heaters, and etc. The use of solar cells in remote areas can return the investment within a few years. Considering the existing technologies and current status of global solar energy market, it appears that this energy can compete with conventional sources of energy in applications such as air conditioning, heating, water heating, cooking, drying, and desalination [17]. It can be argued that price and safety are the most important criteria commonly assessed in solar energy discussions. Given the availability of solar energy in the country, solar thermal power plants will be used rapidly in the future. Solar power is one of the cleanest sources of renewable energy sources and this fact has further encouraged its research and development in many countries [18].

Solar energy has many applications in residential buildings. Low cost and easy installation of solar energy systems can be effectively used as a clean energy [19]. 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 [20]. 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% of energy demand of buildings in Greece [21]. 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 [22].

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% [23]. Many studies have attempted to optimize various components in production–consumption cycle which link the solar power generation [24].

Sivakumar et al. [25] investigated deviations of solar panels under non-linear conditions, an algorithm of incremental conductance coefficient and maximum power point tracking to simulate this system in MATLAB and experimentally calculated the cost efficiency and measurements. The scope of researches on technical optimizations of solar systems have also reached the concept of storing electrical energy in batteries, which is undoubtedly the first available option to deal with high tariffs of electrical energy. A research on characteristics of batteries used in solar systems while considering 0, 4 and 6% increase in power tariffs by 2012, 2017 and 2021 showed that a significant amount of cost and a significant proportion of revenues of a solar system can be optimized by conducting technical studies on the batteries used in these systems [26].

There is an extensive amount of literature in relation to the technical–economic feasibility studies. 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 [27]. A study on validation and simulation of solar heat transfer in some areas of China showed that with the minimum temperature of 9.4 °C, each greenhouse can annually save up to 1290 US dollars in the consumption of biogas energy [28]. The results of a technical–economic study on solar capacity of Italy, which has incorporated the sunlight exposure and temperature of the study area, has shown that this country has a good potential in using the solar energy [29]. A feasibility study of solar energy generation in the Gulf of Mexico illustrates that the southern and northern regions have a daily solar energy generation capacity of 4 kW h and 6.7 kW h respectively [30]. 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.

The benefits of solar energy have caused that Iranian society to be interested in developing this kind of energy [31]. Shekari et al. [32] used a Data Envelopment Analysis (DEA) method to rank the photovoltaic plants in Iran.

The objective of this paper is to perform a technical–economic feasibility study on 14 candidate sites within Khuzestan province, located in south-west of Iran, to evaluate their suitability for the construction of photovoltaic plants. For this aim, a hybrid model composed of Data Envelopment Analysis (DEA), Balanced Scorecard (BSC) and Game Theory (GT) is developed to rank and prioritize these sites based on the amount of generated power, the