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Research article

Technical-Economic Evaluation of Solar Energy Potential for the City of Ahvaz

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Abstract

Renewable sources not only produce less pollution than fossil fuels, but also provide electricity generation capabilities. Solar energy is one of the most potent renewable sources, and performing careful analyses and estimations regarding its potential can lead to accurate determination of amount of power to be generated from this source. This paper is a technical-economic study on the solar energy potential of Ahvaz. The meteorological data and technical and economic analysis conducted with the help of Homer software are used to achieve research objective. The highest and lowest level of solar radiation in this city are 5.520 and 0.930 kWh per square meter, which can be received in July and December respectively. The economic analysis on the solar potential of Ahvaz showed that an initial investment of 25,902 $ will lead to an annual revenue of 5224.6 $, which result in a payback period of about 5 years. Overall, these results show that investments on Ahvaz solar energy sector are economically justified.

Keywords: Solar energy, technical-economic analysis, Homer software

Introduction

Global warming, which is caused by excessive energy demand and increasing rates of greenhouse gas emissions, have led to increasing tendency toward utilizing renewable energies [1]. The strategy of greater use of renewable energies could be a good way to reduce emissions and pursuing this policy could lead to improvement of environmental factors in a not too distant future [4]. Solar energy is one of the most potent renewable energies; but proper harnessing this energy requires performing careful analyses on the climatic conditions of the region. Accurate estimation of solar radiation play a particularly key role in planning, design, and development of solar plants [5-7]. Estimation of solar radiation is an important parameter of multi-criteria decision-making regarding the sites of solar power plants [8].

Fig 1 shows the cumulative capacity of renewable energies (in Gigawatts) for the years 2013 to 2020, based on baseline, enhanced low, and enhanced high. As this figure shows, the use of solar energy constitutes a significant portion of total use of renewable energies.

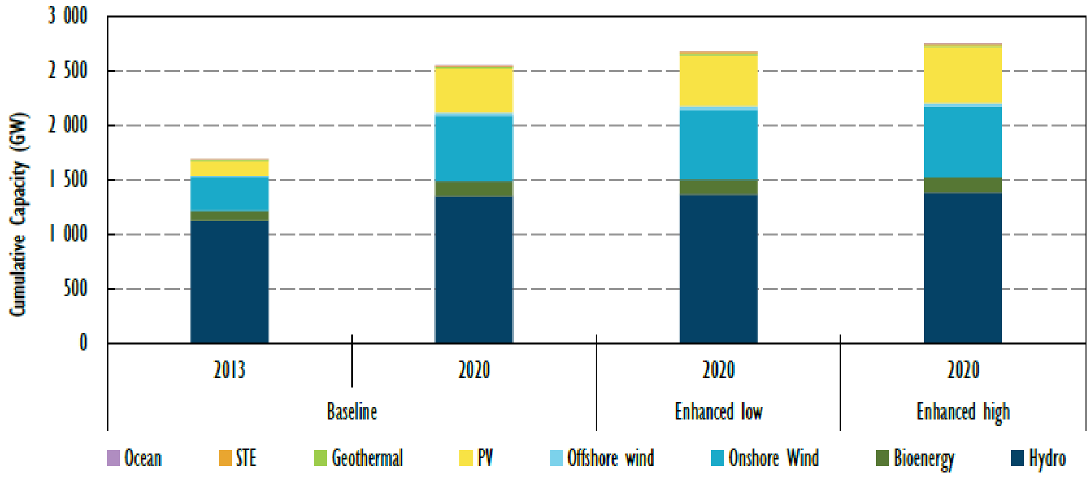

Fig 1. The cumulative capacity of renewable energies (in Gigawatts) for the years 2013 to 2020 [9]

Electricity generation capacity of renewable energies

Solar energy is one of the several renewable sources that can be used to generate electricity [10]. Electricity generation through renewable has become one of most popular energy-related topics and this is more true for solar energy since many countries throughout the world currently use (or plan to use) solar energy to produce electricity [11-13]. Fig 2 shows the amount of electricity produced (or to be produced) by renewable energies from 2005 to 2020. This fig shows a good measure of early investment in solar energy, which point to its importance.

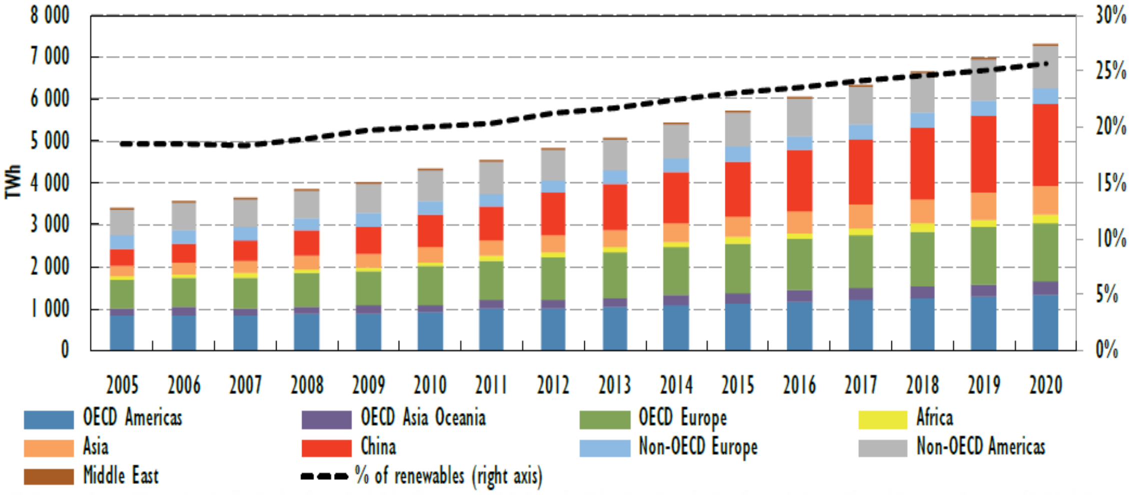

Fig 2. Global electricity generation by renewable energies [9]

Fig3 charts the growth of solar energy sector from 2004 to 2014. As this figure shows, power generation capacity has increased from 3.7 gigawatts in 2004 to 177 gigawatts in 2014.

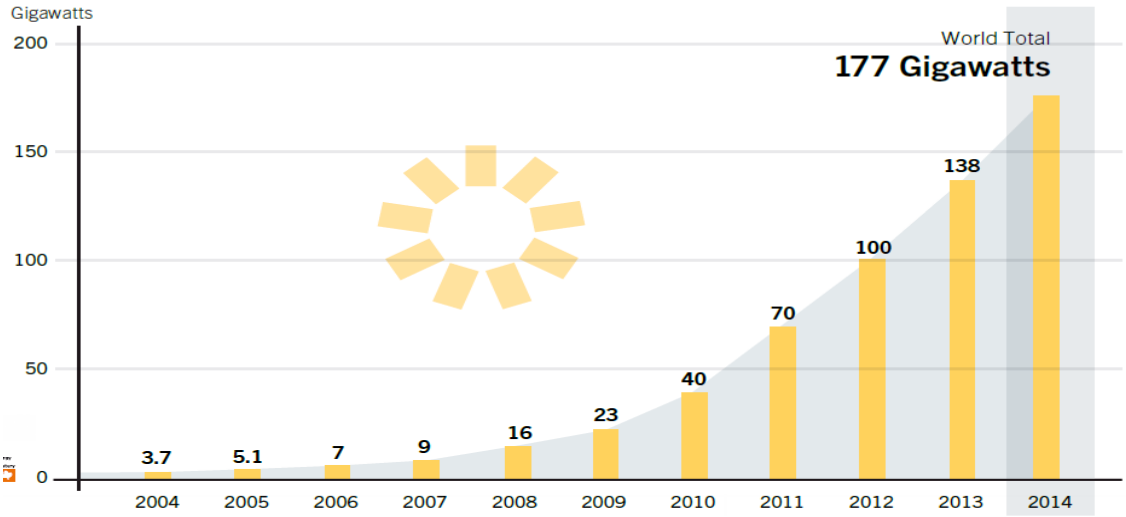

Fig 3. The growth of total worldwide photovoltaic solar energy capacity [14]

Solar energy in Iran

Iran is located on the Sun Belt which means it receives-and therefore has the capacity to utilize- a high level of sun radiation. Iran has an average annual sunshine duration of about 2800 hours and receives an average solar radiation of about 4.5-5.5 kWh per square meter per day, both indicating the high potential of solar energy in this country. Solar energy experts who have done extensive studies on the Iranian desert expanses believe that development of solar energy utilization systems in these regions will lead to provision of a significant portion of regional electricity needs, and the produced electricity may be abundant enough to be exported to other areas. Studies conducted by DLR Co. (Germany) on Iran have shown that more than 60,000 megawatts of solar thermal power plant can be installed over an area of more than 2000 kilometers [15,16].

Fig 4 shows Iran’s solar radiation atlas, where solar radiation potential is classified into a number of regions. As this figure shows, the provinces of Yazd, Fars, Kerman, which receive the highest amount of radiation are in the lower middle black frame.

Fig 4. The areas receiving high level of solar radiation within Iran [16]

Many researches and feasibility studies, which have estimated and analyzed the solar radiation for Iran's different areas, will provide the necessary groundwork for development of clean energy facilities, and especially solar power plant [17-19].

Geography of the study area

Ahvaz is the capital of Khuzestan province and one of Iran's metropolises. This city is located in the central region of Ahvaz County, on 31 degrees and 20 minutes north latitude and 48 degrees and 40 minutes east longitude, and on the floodplains of Khuzestan at 18 meters above sea level. According to the latest official statistics, 32 percent of population of Khuzestan province live within the boundaries of Ahvaz metropolis. 35 percent of this population live in suburbs, making Ahvaz Iran's second most suburbanized city after Mashhad. 51% of oil produced by National Iranian South Oil Company is currently produced in this city and it also houses some of largest Iranian companies. Ahwaz have an area of 31,800 hectares, which make it Iran's third largest city after Tehran and Mashhad. Karun, which is Iran's largest river in terms of discharge and originates from Bakhtiari Mountains, crosses the middle of Ahvaz, dividing this city into eastern and western parts. Cities around Ahwaz are: Masjed Soleiman, Dezful, Andimeshk, Shushtar and shush in the north, Rāmhormoz, Haftkel, Ize, Baghmalek in the east, Behbahan, Mahshahr, Shadegan and Khorramshahr in the south and Susangerd, Hoveize, and Bastan in the West [20, 21].

Fig 5 shows the position of Ahvaz on the map of Iran. Ahvaz is one of the Sothern cities in Iran.

Fig 5. Position of Ahvaz on the map of Iran [21]

Technical-economic analysis of wind and solar energy

Performing careful technical-economic evaluations on the potentials of renewable energies (such as solar and wind energy) is the most important step in the construction of such power plants. These evaluations can be conducted by using the following formulas to calculate the required parameters.
Annual cost can be calculated by the following equation [22]:

$$NPC=\frac{Ctot}{CRF\ (i,Tp)} \qquad (1)$$

Where NPC is the total annual cost in dollars, i is the real annual interest rate in percentage, T_p is the project time period and CRF is the capital recovery factor.
Capital recovery factor can be calculated by the following equation [23]:

$$CRF(I,n)=\frac{i(1+i)^n}{(1+i)^n-1} \qquad (2)$$

Where i the nominal interest rate and n is the number of years. In the Homer software, energy cost balance can be obtained from the following equation [23]:

$$COE=\frac{Ctot}{Etot} \qquad (3)$$

Where COE is the annual cost of energy, E_{tot} is the annual total electricity consumption in kWh per year.

Technical-economic analysis by the use of Homer software

We used the Homer software and the solar energy parameters such as daily solar radiation and sky clearness index to perform a technical-economic analysis on the study area. Table 1 shows the values of sky clearness index and daily solar radiation (in kWh per m² per day) of the study area. As this table shows, the highest level of solar radiation, which is 5.520 kWh per square meter, has been received in July and the lowest level, which is 0.930 kWh per square meter, has been received in December. Overall, the average annual radiation is 3.255. It can also be seen that maximum and minimum sky clearness index, which are 0.514 and 0.360, has been recorded in August and November respectively. Overall, annual average value of this factor is 0.472.

Table 1. Sky clearness index and daily solar radiation of the study area

Month	Clearness	Daily radiation ($kwh/m^2/d$)
January	0.431	1.180
February	0.465	1.950
March	0.461	2.960
April	0.453	4.020
May	0.495	5.320
June	0.467	5.400
July	0.496	5.520
August	0.514	4.910
September	0.482	3.490
October	0.450	2.180
December	0.363	1.110
November	0.401	0.930

Fig 6 shows the diagram of sky clearness index and daily solar radiation (in kWh per m² per day); as previously stated, July and December have the highest and lowest level of solar radiation respectively.

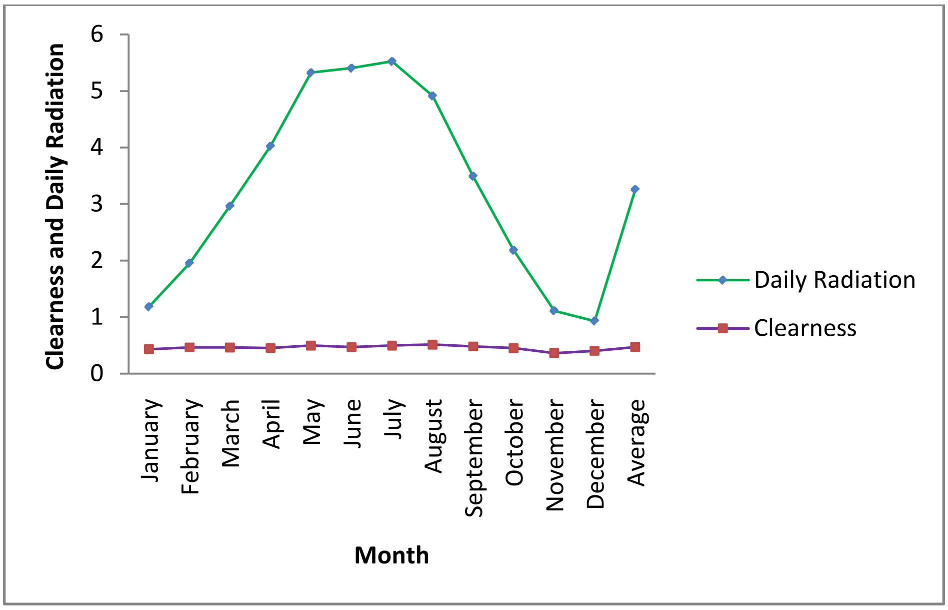

Fig 6. The diagram of sky clearness index and daily solar radiation of Ahvaz

Fig 7 shows the diagram of horizontal radiation pertaining to Ahvaz solar energy potential. In this diagram, clearness index (right) and daily radiation (left) are plotted with respect to different month of the year. Red line shows the relation between these axes and changes in these two parameters with respect to each other.

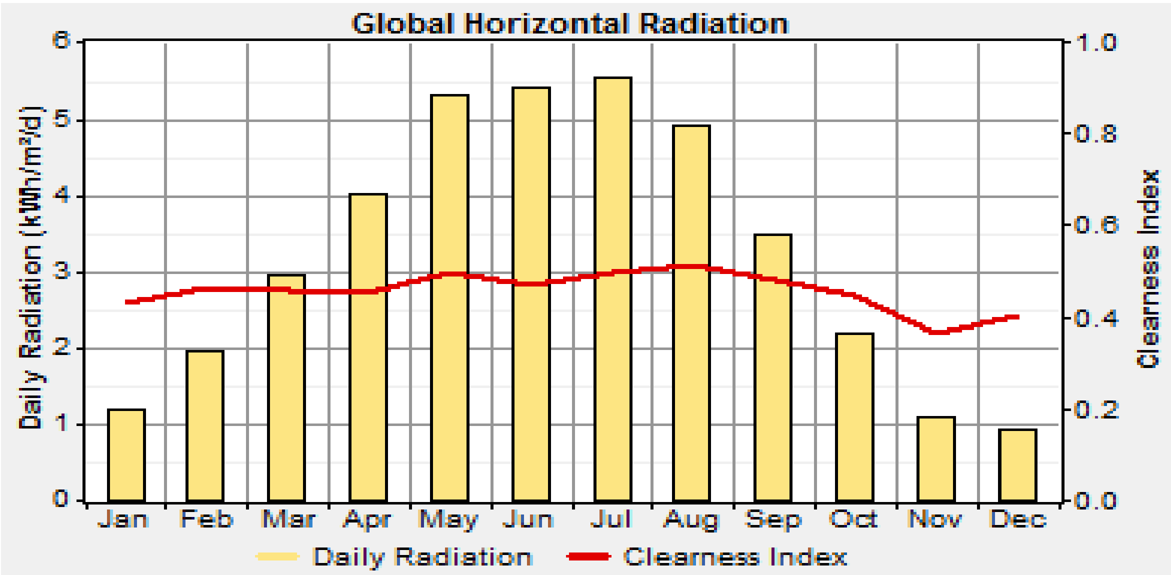

Fig 7. The diagram of horizontal radiation pertaining to Ahvaz solar energy potential

Homer software was used to obtain the economic-technical status of both sites and conduct a feasibility study on their solar energy potential. First, the equipment of solar power plant was determined and then data related to radiation angle, latitude and longitude of the area, the number of sunny days and temperatures were imported into the Homer software. Table 2 shows technical specifications and performance of each inverter and rectifier used for the simulation of power plants in the study area. The task of Inverter is to convert the power generated from the panels to usable electricity. Rectifier regulates the output voltage of inverter to enhance the efficiency of AC power generation.

Table 2. Technical specifications and performance of inverters and rectifiers

capacity (kw)		Mean output (kw)		Capacity Factor (%)		Hours of operation (hrs/yr)		Losses (kwh/yr)	
Inverter	Rectifier	Inverter	Rectifier	Inverter	Rectifier	Inverter	Rectifier	Inverter	Rectifier
7	7	1.1	0.0	2.2	0.0	2736	4138	1710	0

Table 3 describes the specifications of batteries used for the study area. As Table 3 shows, the selected battery is 12V - 6FM55D. Batteries must be the selected not only with respect to their storage potential but also with respect to amount of power losses incurred during the processes of charge and discharge. Proper consideration of latter factor improves the economic efficiency of the system and minimizes the losses in produced electrical energy.

Table3. Battery specification per each plant

Batteries	Type	Nominal capacity (kwh)	Lifetime throughput (kwh)	Energy in (kwh/yr)	Energy out (kwh/yr)	Losses (kwh/yr)	Bus voltage (v)
4	6FM55D	2.64	1024	4	3	1	12

Table 4 shows the specifications of power generation system. The specifications of the used photovoltaic system and its power output are presented in this table.

Table4. PV specification per each plant

Rated capacity (kw)	Mean output (kw)	Capacity Factor (%)	PV penetration (%)	Hours of operation (hr/yr)	Levelized cost ($/kwh)	Total production (kwh/yr)
10	3	29.8	84.2	4370	0.09333	26123

After determining the technical specifications of the system, these technical specifications should be considered in conjunction with economic factors to perform a feasibility assessment on each area. This requires the general information of each power plant including: the type of solar panel, number of batteries, the type of generator, net cost, capital needed for the construction, electrical energy to be generated and revenue of each system to be known. All these information are listed in Table 5. In addition to tables listing the specifications of equipment used in the simulation of power plant, diagrams extracted from Homer software contributed to gaining a better understanding about the relationship between various components.

Table 5 shows the specifications of each plant. Last column of this table show the total amount of electricity to be produced. In practice, the higher amount of electricity to be produced and higher average electrical efficiency mean better technical and environmental status of the plant.

Table5. Label specification per each plant

Number of starts (starts/yr)	Hours of operation (hr/yr)	Capacity Factor (%)	Mean electrical efficiency(kw)	Total production (kwh/yr)
474	7842	38.2	23.2	23418

Table 6 shows that Ahwaz will have a maximum payback period of 5 years; this result points to the necessity of further attention to this region's solar energy potential. The high solar energy potential of Ahvaz also points out the need for further scientific studies on all parts of Iran in order to fully map its solar energy generation potential. Factors and parameters obtained in this paper are presented in Table 6.

Table6. Total information of each plant

Total NPC($)	Capital cost($)	Levelized COE ($/kwh)	Operating cost($)	Electrical production (kwh/yr)	PV electrical production (kwh/yr)	Income ($/yr)	Return period (yr)
25902	24100	0.358	1766	26123	26123	5224.6	5^{th}

Conclusions

Estimation of solar radiation is a very important step in the design of different types of solar power generation systems and can have a significant impact on the overall manner and method of constructing these power plants; so obviously a more careful and accurate estimation of this parameter will ultimately lead to much better results. The importance of solar radiation estimation is not limited to electricity generation systems, since it is also among the important parameters of geological and ecological studies and among main factors of many hydrological and meteorological models. Iran has many solar radiation monitoring stations but they are still not enough to provide a solar radiation monitoring network adequate to this country's large area. In this paper, we conducted a technical-economic analysis on solar energy potential of Ahvaz by using meteorological data and technical-economic feasibility study performed with the help of Homer software. The diagram of horizontal radiation of Ahvaz showed that the highest level of solar radiation, which is 5.520 kWh per square meter, can be received in July and the lowest level, which is 0.930 kWh per square meter, can be received in December. The annual electricity to be generated by solar panels in Ahvaz was calculated to 26123 kWh per year. This analysis also showed that this project will need an initial investment of 25,902 $ and will have an annual revenue of 5224.6 $, which result in a payback period of about 5 years. This result points to the need for further attention to Ahvaz solar energy potential and indicates the necessity of further scientific studies on all parts of Iran in order to fully map its solar energy generation potential. Overall, these results show that investments on Ahvaz solar energy sector will be economically justified.

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