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Technical Potential Investigation and Economic Evaluation of PS-10 Solar Power Plant in Khuzestan Province of Iran

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ABSTRACT

Due to being located on the solar radiation belt, Iran has a great potential to use of this source of energy. Among different parts of Iran, given the direct radiation and climate conditions, Khuzestan has a higher potential to use solar energy. The lack of a significant increase in supply along with the growing demand for electricity makes the evaluation of various electricity generation projects inevitable. Hence, a solution must be found to respond to this growing need. In this study, the potential of oil-rich region of Iran will be investigated in solar power generation. After technical potential review based on meteorological and geographical information and data of this region, the technology of PS-10 solar power plant in Seville, Spain, is economically evaluated in Khuzestan Province. The results show that the cities of this province have a great potential to use solar energy using the technology of central receiver system power plants. The economic evaluation also demonstrates that the installation of thermal power plant in the current situation is affordable, despite interest rate and guaranteed purchase price and currency rate in two regions of Ize-Baghmalek and Lali.

Keywords: Solar energy, solar thermal power plant, economic evaluation, PS-10, Khuzestan

1.INTRODUCTION

Nowadays, electric energy is highly important in all fields; however, there have been always concerns on the electrical generation. Most of the power plants for electrical generation use fossil fuels that are associated with many problems. Moreover, given the annual world population growth of 1.1% in 2018, which will double the world population in 60 years, the increased consumption of the international community will clearly lead to reduced amount of fossil energy resources. Research shows that the average life of underground energy resources (oil, coal, and natural gas) won't be longer than 100 years; such a consumption growth shows the need for alternative resources (Ahmadpour, 2014) CO2 emissions around the world was due to the use of common fossil fuels. The estimates show that energy use and CO2 emissions will be increased by 56% and 46% from 2010 to 2040, respectively (Kahia et al., 2016). Following climate

change after CO2 emissions caused by fossil fuels, different countries are seeking plans to find alternatives for these fuels (Thellufsen and Lund, 2016). These problems lead to communities to use alternative power plants for electricity generation. The important point in these power plants is to use renewable and non-renewable resources in alternative power plants. Renewable energies have the potential to respond to total energy demand of the world. One of the major benefits of renewable energies is their sustainability. Despite volatile prices of fossil fuels with increased use of renewable energies and increased experience in this regard, the investment and production costs in this sector are constantly decreasing. Use of renewable energies leads to safety of energy supply and declined environmental pollutants (Herzog et al., 2001).

Renewable energies are created through a natural and continuous process, which are directly obtained from sunlight, wind, rain, ocean tides, and geothermal energy (Mohtasham, 2015). Facilities related to any type of renewable energy are built in various locations depending on the need; but it should be noted that, in economic and technical terms, the construction plan of power plants is not possible and affordable in every location.

One of the most important ways of electricity generation via renewable energies is to use solar thermal power plants. Solar thermal power plants require direct solar radiation for electricity generation, and because of this feature, their installation is limited to hot and desert areas. The higher the direct solar radiation, the lower the costs for these power plants would be (IRENA, 2012).

Due to being located on the solar radiation belt, Iran has a great potential in terms of this divine blessing; we have very effective sunlight in 90% of the Iran's soil. The amount of solar radiation in different parts of Iran is estimated to be between 1800 and 2200 kWh/m^2, which is higher than the global average (Tamjidtash, 2012). This favorable potential of solar energy has provided a suitable background to use solar equipment. Moreover, due to the abundance of oil and gas resources in Iran, relying on any other source of energy does not seem economically affordable; but these must be kept in mind that, at first, these resources are declining reservoirs and we reach the end of these resources over time; second, the use of fossil fuels emits the greenhouse gases, which results in global warming that is now one of the most important concerns of different societies. Hence, we should reduce the reliance on these resources and find a proper alternative. The use of solar thermal power plants for overcoming limitations such as exhaustible sources as well as environmental pollutions can help resolve the problems with fossil fuels. The necessity of using renewable and clean energies in Iran is also undeniable. Hence, in this research, the potential of Khuzestan, the oil-rich region of Iran, in solar power generation will be investigated. It seems that Khuzestan has a great potential for the installation of this technology due to the useful direct radiation and suitable climatic conditions. Hence, this study investigates the technical potential of solar energy and evaluates the technology related to a solar power plant in Khuzestan, similar to PS-10 solar power plant in Seville, Spain.

Note that due to the hot climate of Khuzestan province, at first it seems that solar thermal power plants are a good choice for investment in this province. On the other hand, since PS technology is the world's first commercial concentrating solar power tower, there is appropriate financial and operational data for its economic evaluation. Based on these points, this technology has been selected in this study.

The explicit question of this research is whether in the current situation, the construction of a solar thermal power plant in Khuzestan province with PS-10 technology is cost-effective or not. To answer this question, the study is divided into four sections. In the second section, the related literature and review of empirical background will be discussed. In the third section, the data and findings of the research are expressed and, finally, in the last section, a conclusion is provided.

2. PREVIOUS STUDIES AND THEORETICAL FOUNDATIONS

In this section, we will have a review of previous studies and theorical foundations. In this review, the emphasis is on the studies that have investigated the solar thermal power plants.

Purohit and Purohit (2010) focused on the technical and economic evaluation of solar thermal power plants using data from two PS10 and Andasul1 power plants and the simulation of these two power plants in different regions of India. The results of this study showed that the cost of power generation unit of these two types of power plants in Rajasthan and Gujarat was less than the electricity tariff of Ministry of Renewable Energy, indicating that these power plants were affordable in these two regions of India. Ummel (2010) studied the proper areas for

CSP as well as the installation costs of these power plants. As a general conclusion, the total available technical potential was 16-23 times as much as the total energy generated by fossil fuels (coal) in China and 3-4 times as much in India. The examination of costs for different locations demonstrated that the lowest cost of installing CSP equipment belonged to Tibetan Plateau region in China and, then, the Thar Desert in India; this was due to the cost of transporting equipment that was less in the desert and flat areas. Powell et al. (2012) investigated a linear parabolic power plant despite having an energy storage system that contained two tanks with a direct energy storage process. The focus of this review was on the presence or absence of an energy storage system. The results of this study showed that power plant was capable of generating power with a constant rate, despite having an energy storage system, and the rate of power generation did not vary at different times of the day; but, without an energy storage system, the rate of power generation was variable during the day and night.

Boukelia and Mecibah (2013) investigated the parabolic power plants and potential of installing these power plants in Algeria. The studies showed that Algeria had the basic requirements for installing a solar thermal power plant, including direct irradiation, suitable land, access to required water resources, and electricity grid. Gakkhar and Soni (2014) examined the effective parameters for better use of CSP technologies in India via the technical and economic evaluation of power generation by solar thermal power plants. Dale (2013) compared the cost of three types of photovoltaic power plants, solar thermal power plants, and wind power plants in meta-analysis method. The general conclusion of this study showed that wind had the lowest cost of capital, followed by CSP, and then the photovoltaic cells that had the highest cost of capital. The lowest cost of capital belonged to wind power plants, followed by CSPs, and then photovoltaic cells. Behar et al. (2013) in the study entitled "Review of Studies on the Central Receiver Power Plant" reviewed the studies on this power plant. Desai et al. (2014) investigated the construction of a 1MW solar thermal grid-connected power plant in Delhi, India. As a result, the power plant would generate about 1365 MWh of energy with the capacity coefficient of 15.6% and annual direct radiation of 1273 kWh/m^2. Trabolsi et al. (2016) investigated a linear parabolic power plant with 50 MW of power generation and 7.5 hours of energy storage in desert conditions despite having water constraints for cooling system applications in southern Tunisia.

Shabanian (2007) investigated the factors affecting the technical potential and calculated the net present value and internal efficiency rate of solar thermal energy in Iran. In this paper, the role of subsidies and interest rates in the affordability of the project under consideration was mentioned. The general conclusion of this study was that Iran had a high technical potential in the field of solar energy. In case of eliminating fossil-fuel subsidies as well as taxes on renewable energy sector and preferential interest rates for such plans, a sustainable development in the field of renewable energy could be promising. Esfandiari et al. (2011) investigated the climatic potential assessment of Khuzestan Province to find the areas with high potential for the construction of solar thermal power plants. The general conclusion of this study showed that total annual sunny hours, number of cloudy days, number of dusty days, altitude, relative humidity, and annual precipitation affected the proper location of solar thermal power plants. According to these cases, the cities of Behbahan, Ramhormoz, Baghmalek, and a small area of Shushtar were suggested as suitable sites for the construction of a solar thermal power plant. Tamjidtash (2012) focused on the technical and economic examination of thermal power plants for Iran. By investigating the technical and economic potential, it was concluded that the efficiency of linear parabolic and central receiver technology had higher efficiency than other technologies. Mahdavi Adeli, and Khaje Naeini (2014) analyzed the construction of 25 MW solar photovoltaic power plant and, then, investigated the effect of utilizing the incentives used in construction of such power plants in various countries. The results showeed that incentives of sharing tariffs had the greatest impact on improvement of the financial properties of the plan.

Nohegar et al. (2015) located the suitable sites in Hormozgan Province for construction of solar thermal power plants. According to this method, 18308428686 km² of area of Hormozgan Province was located at the very good category for construction of solar thermal power plant. Ahmadi et al. (2016) investigated the suitable sites for construction of solar thermal power plant in Ilam Province. The results of this study demonstrated that the regions that were identified in the area with a very good power had area of 1510812500 m^2, and the southern and western regions of Ilam Province were the best sites for construction of solar thermal power plants.

In this research, the goal is to investigate the technical potential of the Khuzestan region and, then, the economic evaluation of central receiver system solar power plant (CRS). The central receiver system power plant consists of a set of mirrors that are known as heliostat or receiver system of solar beams (glass or membrane); each separately concentrates the solar energy and transmits it to the central receiver tower. Energy is absorbed by a heat exchanger mounted on a tower, called a receiver. There, the water turns into steam and this steam drives the generator turbine installed at the bottom of the tower to generate electricity. In the prototypes, the water and steam were used as absorbing and transmission fluids of thermal energy; but in the more advanced designs, the fluids such as molten sodium and potassium salts are used. For permanent use of this type of power plant, when there is no solar radiation, such as cloudy hours or nights, the heat storage systems are used.

Perhaps the most obvious advantage of CSP is that it's renewable. Its supply will never be exhausted and be can used continually, so it's a sustainable energy source. It also reduces carbon footprint. Unlike fossil fuels, which emit carbon dioxide when burned, CSP uses the earth's natural resources, which is kinder to the environment. It can improve the quality of air and reduce the rate of climate change. Despite the many benefits of CSP, it does have its downsides. For one, it's largely dependent on location. Similar to solar PV and wind power, CSP plants require a large area of land to operate, which makes it uneconomical in populated areas. Concentrated solar power uses a lot of water to drive steam turbines and to cool thermochemical reactors. Although seawater may be seen as a possible solution, this could present solar radiation issues for the surrounding landscape. Similarly, CSP plants can attract animals with its light, and the heat can be fatal for some species. CSP plants are also expensive to run. Thermal energy storage materials that can withstand high temperatures are costly and difficult to source.

Planta Solar 10 (ps-10) power plant is the world's first commercial power plant that is a central receiver power plant, and was established in 2007 in Seville, Spain. In this study, the PS-10 power plant in Seville, Spain, was evaluated for Khuzestan.

Evaluation of technical potential of solar generation with solar thermal power plants needs the assessment and measurement of physical, geographical, and technical potential. The physical potential includes a usable solar radiation equal to the amount of direct radiation reaching the surface of the earth. Direct measurement of solar radiation energy is available at meteorological stations. Geographic potential includes available and usable area for installation of power plants. Calculating the extent of usable area for power plant installation given the characteristics and conditions of the area are determining factors of electricity generation. The technical potential shows the exploitable energy from a specific area and radiation considering the power plant capacity coefficient. Solar radiation of reliable data of long-term sunlight is available only for areas with metering stations. In areas with lack of sunlight data, the desired area is placed below a part of the area containing data. In general, the large-scale solar energy potential analysis is possible with acceptable approximation of the amount of solar radiation (Broesamle et al., 2001)

Technical potential of solar thermal energy refers to all facilities of utilizing solar radiation using available current technology with specific efficiency regardless of economic considerations and market proximity.

Total net amount of technical potential is the amount that deducts natural barriers to computations. For example, the area of mountains, forests, plains, agricultural fields, pastures, rivers, etc. is deducted from the total area that can be used for the installation of solar units; but, the economic potential of solar thermal energy is that part of technical potential that is affordable.

To calculate the technical potential, the annual solar radiation, average daily solar radiation, average annual solar radiation, efficiency, or capacity coefficient of solar thermal unit are used. The technical potential of solar thermal energy is calculated as follows (Izquierdo et al., 2010):

(1) $$S = CF \times f \times sqm$$

where S is the amount of solar radiation absorbed by the solar thermal unit and refers to technical potential of solar thermal energy. CF is the capacity coefficient of the solar thermal unit for the power plant, f is the solar daily radiation per kWh/m^2, and Sqm indicates the area usable for installation of solar thermal systems.

Capacity coefficient of the power plant, its actual output ratio over a period of time to its potential output, is in a state that continuously operates in the same period of time as its full nominal capacity. To calculate the capacity coefficient, the total energy generated by the power plant in a certain period of time must be divided by the amount of energy that should be generated based on full nominal capacity of the power plant.

According to Izquierdo et al. (2010), the capacity coefficient is calculated by the symbol CF as follows:

(2) $$CF = \frac{\lambda * SE}{\tau * C}$$

where C is nominal capacity of power plant and τ is the time that power plant operates during a year. If the power plant is operating at the maximum time, it is equivalent to 24 × 365 or 8760 hours per day. λ is also the constant coefficient as follows:

$$\lambda = 3/6 * 10^6 j/kwh$$

SE is the annual generation rate, calculated as follows:

(3) $$SE = E * \eta_t * \eta_c * \eta_m$$

The values related to collection efficiency η_c and maintenance efficiency η_m can be observed for the receiver power plant in Table (1). Since the power plant under study is the PS-10 central receiver system power plant, Seville, Spain, the data related to this plant are required.

Table (1): η_c, η_m, **for two linear parabolic and central receiver power plants**

	linear parabolic plant	central receiver power plant
η_c	5.27%	12%
η_m	96%	96%

η_t is calculated as a ratio of the force generated by the power plant to thermal energy collected at the solar field, using the following equation:

(4) $$\eta_t = \left(\eta_{opt} - \left(\frac{\tau}{\lambda} \times \frac{Fg \times U}{E} + \frac{\tau}{\lambda} \times \frac{Fg \times \epsilon \times \sigma}{E} (TA^4 - Tamb^4)\right)\right) \eta_{th} \times \eta par$$

where $Tamb$ is ambient temperature per K. η_{th} is thermodynamic cycle efficiency that is calculated in Equation (5).

(5) $$\eta_{th} = Z(1 - \frac{Tamb}{TA})$$

where Z=0.6, TA is the amount of heat absorbed by the power plant, which is equivalent to k838 for the central receiver power plant. ϵ that is the concept of emissivity (power transmission of a surface compared to the surface that is black) and is calculated as follows:

(6) $$\epsilon = 04795/0 + 00023331/0 \times TA$$

The following equation shows η_{par} for the central receiver power plant:

(7) $\eta_{par} = 90/1 - 1/1\,SM$

As shown in Equation (7), η_{par} is directly related to solar coefficient (SM). Solar coefficient (SM) represents the size of the solar farm and is a true criterion of the size of the solar farm. In each power plant, based on designs of that power plant, the field collectors and their storage (SM) are different (Boukelian and Mecibah, 2013). In this study, SM of power plant in Seville, Spain, was equal to 1.3. Thus, η_{par} is equal to 0.8867.

Optical efficiency η_{opt} is the ratio of light absorbed by the collectors to the total solar energy and U is the convection coefficient, which indicates the heat transfer rate between heat and fluid collectors. Fg is the geometric factor and c is the concentrating factor that indicates the concentration of solar radiation received by collectors; the greater this factor, the higher the transferable heat to fluid would be available. As a result, a higher amount of energy is generated. σ is Boltzmann's constant and all these values are known for the PS10 power plant. Hence, as noted in this section, the technical potential of the regions of Khuzestan Province can be studied.

3. STUDY DATA AND RESULTS

Although Khuzestan Province is one of the oil-rich provinces of the country, due to the intensity of solar radiation in most places, it could lead to considerable savings in fossil fuel consumption utilizing the solar energy. Not so complex technology, reduced air and environmental pollution, and most importantly reduced fossil fuel consumption for the future or exporting, processing, and converting into petrochemicals are the causes of using clean and renewable energies, particularly solar energy, in the country and particularly in Khuzestan Province. Therefore, in this study, the technical and economic evaluation of solar thermal power plant are focused. In this section, the cities of Khuzestan Province are transparently investigated in terms of technical and economic potential. In this study, according to Purohit, the installation of 11.02 MW PS10 power plant, Seville, Spain, which is a central receiver power plant, is investigated in Khuzestan Province.

Solar radiation data from meteorological organizations, for 15 sites in the province, were provided based on the average daily radiation intensity during the year. The average daily solar radiation for each year was expressed per kWh/m^2. In the following, the usable area for installation of solar power plants will be calculated. The desired area was calculated based on the deduction of natural constraints, including mountains, rangelands, forests, and agricultural lands, from the total area of the province, so that the areas where the solar units can be technically installed were obtained. The total area of the province, natural constraints, mountains, rangelands, forests, agricultural lands, and protected regions by Khuzestan cities in 2011 were obtained from Statistical Centre of Iran. The natural constraints, mountains, rangelands, forests, and agricultural lands were deducted from the total area of the province to calculate areas where the solar units can be installed technically. In Table (2), the total area of the city, total natural forest areas, green spaces, forest reserves, protected areas, and agricultural land are brought for each city. The annual sunshine hours (data related to 2010) was collected for each city and, via dividing the data by 365 days a year, the average daily sunshine was obtained per day.

E is the total horizontal radiation and $Tamb$ is the ambient temperature of the month. Data of different regions of Khuzestan Province are obtained from Global Solar Atlas and are shown in Table (4).

Table (3) shows some parameters used in solar power plants.

Using the information above and substituting aforementioned items in Equations (4), (5), and then (2), the capacity factor (CF) can be estimated for regions in the province. The calculated values related to ηt, SE, and CF, are reported in Table (4).

Table (2): Geographic information and solar radiation for regions of Khuzestan Province

City	Area of city*	Sum of unprofitable area for plant *	Annual sunshine hours (hour)	average daily sunshine (hour per day)
Abadan and Khorramshahr	4836	328.36	3166.1	8.67
Omidiyeh	2330	231.83	3092.4	8.47
Andimeshk and Shoosh	6746	2428.6	2697	7.38
Ahvaz	10969	3042.34	3089.3	8.46
Izeh and Baghmalek	6048	4128.87	3113.6	8.53
Mahshahr and Ramshir	3528	565.8	3090.2	8.46
Behbahan	2999	604. 11	3108.4	8.51
Dezful	4646	3254.79	2915.4	8.09
Dasht Azadegan	1972	1760.8	3119.3	8.54
Ramhormoz	6385	1319.047	3089.9	8.46
Shadegan	3598	480.95	2988.7	8.11
Shushtar	2433	1839.66	3045.7	8.34
Masjed Soleyman andika	4545	3617.84	2782.3	7.62
Lali	1400	205.97	2994.3	8.2
Hendijan	3780	301.95	3231.7	8.85
Gotvand	973	0	2981.1	8.16

*** All data related to area are in square kilometers (km^2)**

Table (3): Parameters used in solar power plants

	Unit	linear parabolic plant	central receiver power plant
ηopt	%	75	54
U	W/(m2K)	2	2
TA	K	653	838
Fg		c/π	1/C
C		80	800
σ	W/M2/K4	5.67×10^{-8}	5.67×10^{-8}
Z		0.6	0.6
ηpar	%	ηpar=90/1-1/1 SM	ηpar=90/1-1/1 SM

Table (4): Estimated values of capacity factor

City	total horizontal radiation(kw/m^2)per year	($Tamb$) ambient temperature, (taken as the monthly mean, °C)	ηt	SE	CF
Abadan and Khorramshahr	2027	798	0.01372	3.2037	0.1194
Omidiyeh	2016	792	0.015767	3.6618	0.1365
Andimeshk and Shoosh	1957	741	0.033242	7.4943	0.2794
Ahvaz	1995	789	0.016795	3.8599	0.1439
Izeh and Baghmalek	2045	648	0.065099	15.3362	0.5719
Mahshahr and Ramshir	1995	804	0.011655	2.6784	0.0998
Behbahan	2050	759	0.027075	6.3941	0.2384
Dezful	1956	750	0.030159	6.7956	0.2534
Dasht Azadegan	1973	786	0.017823	4.0510	0.1510
Ramhormoz	1997	774	0.021936	5.0463	0.1881
Shadegan	2012	801	0.012683	5.9396	0.1096
Shushtar	1956	786	0.017823	4.0161	0.1497
Masjed Soleyman andika	1982	741	0.033242	7.59	0.2830
Lali	2000	654	0.063043	14.5250	0.5416
Hendijan	2022	813	0.00857	1.9962	0.0744
Gotvand	1952	768	0.023991	5.3949	0.2011

As can be seen, the capacity factor is reported very high in most parts of the province and is below 10% only for Hendijan, Mahshahr, and Ramshir. Some sites, such as Izeh, Baghmalek, and Lali, have very high capacity factor.

In Table (5), using the data in Tables (1), (2), and (4), the technical potential is obtained. In this table, the usable area (sqm) for installation of a thermal power plant is obtained from deduction of areas used for natural forest areas, green spaces, protected areas, and agricultural land, from total area of the city. CF is the capacity factor of power plant in different regions that is calculated in Table (5). DNI is the average direct solar radiation during the day per hour and s is the technical potential.

The results in Table 6 show that the regions of Khuzestan Province have a good potential for installing solar thermal power plants. In other words, they have a high potential in absorbing solar radiation by the solar thermal unit. In the following, the economic evaluation of PS10 solar power plant with capacity of 11.02 MW was carried out in different regions of Khuzestan Province.

For economic analysis of solar thermal power plant, according to Purohit and Purohit (2010) in Khuzestan conditions, the PS-10 project that was founded based on central receiver technology in city of Seville, Spain, was considered as a reference for this study. This system was simulated in different regions of Khuzestan Province. Using the results, the necessary primary indicators can be obtained for identifying areas suitable for installation of solar thermal power plant in Khuzestan.

Data consisted of the costs related to PS-10 solar thermal power plant and the revenues of this power plant in climatic conditions of Khuzestan Province. First, the costs the included initial and operating costs were investigated. Solar thermal power plants are capital-consuming, but their fuel costs are zero. In this study, the primary costs included the installation and operating costs of PS10 power plant in Seville. According to Purohit and Purohit (2010), the cost was € 35 million, which was converted into IRR. The exchange rate of the Euro to IRR was considered IRR 49,000 in accordance with Central Bank Iran, which was multiplied by € 35 million, to obtain the initial investment cost of installing a PS10 power plant in Khuzestan. Assuming government support and foreign exchange payments at the exchange rate, the conversion process was accomplished. It was also assumed that the government cooperated with the investor for the land used by the power plant. The initial cost of installing the power plant was as follows.

$$C_0 = 35000000€ \times 49000$$

Hence, the initial cost of installing a solar thermal power plant was 1.71×10^{12} Rial.

Table (5): Technical potential calculation

City	Sqm(m^2)	DNI (hour per day)	CF	S: Technical potential**
Abadan and Khorramshahr	4507.64	8.67	0.1194	4669. 25
Omidiyeh	2098.17	8.47	0.1365	2426.827
Andimeshk and Shoosh	1743.39	7.38	0.2794	8902.842
Ahvaz	7926.66	8.46	0.1439	9652.953
Izeh and Baghmalek	811.13	8.53	0.5719	3957.077
Mahshahr and Ramshir	2962.2	8.46	0.0998	2503.18
Behbahan	2394.89	8.51	0.2384	4852.752
Dezful	1391.21	8.09	0.2534	2852.27
Dasht Azadegan	211.2	8.54	0.1510	272.48
Ramhormoz	5065.95	8.46	0.1881	8065.41
Shadegan	3117.04	8.11	0.1096	2773.97
Shushtar	593.34	8.34	0.1497	741.13
Masjed Soleyman andika	927.15	7.62	0.2830	1992.72
Lali	1194.03	8.2	0.5416	5303.52
Hendijan	3478.05	8.85	0.0744	2291.4
Gotvand	973	8.16	0.2011	1597.37

*** Data related to area are in km^2. **S=sqm×DNI×CF**

In the following, the maintenance and operating costs were discussed that might include the cost of installing and replacing broken mirrors and washing mirrors and similar items. According to Purohit and Purohit (2010), the cost is about two-hundredths of the total initial capital for the power plant that can be reduced over time for solar thermal power plants with the progress in technology. The variable cost for PS10 power plant, Seville, for the first year, which was 0.02 from total initial investment cost (C0), was obtained via multiplying two-hundredths by C0.

$$C_{o\&m} = 0/02 \times C_0 = 0/02 \times 1/71 \times 10^{12}$$

3.43×10^{10} is equivalent to maintenance and operating costs of power plant establishment for the first year. The present value of the cost was calculated for 25 years (project life) despite the interest rate that was 14% in accordance with Shabanian (2007).

The total cost (C) of installing this power plant was achieved from the total present value of operating and initial investment costs.

$$C = C_{o\&m} + C_0 = 95/1 \times 10^{12}$$

Since the major part of costs in a solar power plant is for the construction and as the electricity price varies every few years, the inflation in both cost and income sectors was not included. To investigate the revenues, the annual electricity generation should be calculated. According to Purohit, the annual electricity generation (AEG) was obtained from the following equation.

$$AEG = 24 \times 365 \times P \times CF$$

P is the nominal power plant generation that is equal to 11.02 and CF is the capacity factor of the power plant calculated in Table (5). To achieve the present value of revenues of the power plant, in accordance with Purohit and Purohit (2010), the following equation was used.

$$\text{Present value of revenues} = \sum_{i=1}^{25} \frac{AEG * 1000 * 5600}{(1+r)^i}$$

where AEG is the annual electricity generation of the power plant per kWh; so, it is multiplied by 1000, IRR 5,600 is for guaranteed purchase price per KW from solar power plants in accordance with SATBA (Renewable Energy and Energy Efficiency Organization) in 2016, r is interest rate, i is the year under study, and 25 is power plant lifetime per year.

Table (6) shows the net present value of a power plant with lifetime of 25 years by the regions of Khuzestan Province. According to the table, the regions of Ize-Baghmalek and Lali had the highest present value of revenue for installing power plants, respectively.

Table (6): Net present value for interest rate of 14%

City	Total cost	Total revenue	NPV
Abadan and Khorramshahr	$1.9507*10^{12}$	$4.44*10^{11}$	$-1.5071 *10^{12}$
Omidiyeh	$1.9507*10^{12}$	$5.07*10^{11}$	$-1.4435 *10^{12}$
Andimeshk and Shoosh	$1.9507*10^{12}$	$1.04*10^{12}$	$-9.1263 *10^{11}$
Ahvaz	$1.9507*10^{12}$	$5.35*10^{11}$	$-1.416 *10^{12}$
Izeh and Baghmalek	$1.9507*10^{12}$	$2.12*10^{12}$	$1.7414 *10^{11}$
Mahshahr and Ramshir	$1.9507*10^{12}$	$3.71*10^{11}$	$-1.5799 *10^{12}$
Behbahan	$1.9507*10^{12}$	$8.86*10^{11}$	$-1.649 *10^{12}$
Dezful	$1.9507*10^{12}$	$9.42*10^{11}$	$-1.0092 *10^{12}$
Dasht Azadegan	$1.9507*10^{12}$	$5.61*10^{11}$	$-1.3897 *10^{12}$
Ramhormoz	$1.9507*10^{12}$	$6.99*10^{11}$	$-1.2518*10^{12}$
Shadegan	$1.9507*10^{12}$	$4.07*10^{11}$	$-1.5435 *10^{12}$
Shushtar	$1.9507*10^{12}$	$5.56 *10^{11}$	$-1.3945*10^{12}$
Masjed Soleyman andika	$1.9507*10^{12}$	$1.05 *10^{11}$	$-8.9925*10^{12}$
Lali	$1.9507*10^{12}$	$2.01 *10^{12}$	61565144984
Hendijan	$1.9507*10^{12}$	$2.76 *10^{11}$	$-1.6743*10^{12}$
Gotvand	$1.9507*10^{12}$	$7.47 *10^{11}$	$-1.2035*10^{12}$

Despite the positive net present value, an investment in the plan is cost-effective; otherwise, unprofitable. Therefore, according to the information obtained from the table, the installation of power plant in all regions of Khuzestan Province had a negative present value and was unprofitable, except for regions of Lali and Izeh Baghmalek, and installation of solar power plants was only cost-effective in these two regions. Given that the exchange rate was considered IRR 49,000, it is clear that, at the exchange rate of more than three times in the current market and the present electricity purchase price, an investment is not profitable in any of the regions. However, at the same euro exchange rate, but at a different interest rate, the analysis is repeated. According to the multi-exchange rate system in Iran, the change in the discount rate can be considered as a sensitivity analysis. The banking interest rate for construction of solar thermal power plant is considered 6% in accordance with the National Development Fund in 2012. Thus, the economic evaluation of the solar thermal power plant was performed despite this interest rate.

Table (7) shows the present value of revenue for a power plant with lifetime of 25 years and at the interest rate of 6% by regions of Khuzestan Province. According to the table, the regions of Lali and, then, Izle Baghmalek had the highest present value of revenue for installation of power plants; but, the present value for different regions was increased. The results showed that, despite 6% interest rate, not only the regions of Lali and Izeh Baghmalek, but also the regions of Andimeshk and Shush, Masjed Soleyman, and Andika, had a positive present value; in case of government support, the installation of power plant in these regions is also cost-effective.

Table (7): Net present value despite interest rate of 6%

City	Total cost	Total revenue	NPV
Abadan and Khorramshahr	2.1534 *10^{12}	9.58 *10^{11}	-1.1957 *10^{12}
Omidiyeh	2.1534 *10^{12}	1.09 *10^{12}	-1.0586 *10^{12}
Andimeshk and Shoosh	2.1534 *10^{12}	2.24 *10^{12}	87677907788
Ahvaz	2.1534 *10^{12}	1.15 *10^{12}	-9.9921 *10^{11}
Izeh and Baghmalek	2.1534 *10^{12}	4.59 *10^{12}	2.4339 *10^{12}
Mahshahr and Ramshir	2.1534 *10^{12}	8.01 *10^{11}	-1.3529 *10^{12}
Behbahan	2.1534 *10^{12}	1.91 *10^{12}	-2.4119*10^{11}
Dezful	2.1534 *10^{12}	2.03 *10^{12}	-1.2188 *10^{11}
Dasht Azadegan	2.1534 *10^{12}	1.21 *10^{12}	-9.4226*10^{11}
Ramhormoz	2.1534 *10^{12}	1.51 *10^{12}	-6.4467*10^{11}
Shadegan	2.1534 *10^{12}	8.79 *10^{11}	-1.2743*10^{12}
Shushtar	2.1534 *10^{12}	1.2 *10^{12}	-9.5268*10^{11}
Masjed Soleyman andika	2.1534 *10^{12}	2.27 *10^{12}	1.1655*10^{11}
Lali	2.1534 *10^{12}	4.34 *10^{12}	2.1908*10^{12}
Hendijan	2.1534 *10^{12}	5.97 *10^{11}	-1.5567*10^{12}
Gotvand	2.1534 *10^{12}	1.61 *10^{12}	-5.4039*10^{11}

To complete the sensitivity analysis, this experiment was repeated at an interest rate of 18%. The results of these calculations (Which is not provided for brevity here) show that at this level of interest rates, the current net value of the project is positive only in Izeh Baghmalek and Lali. Of course, the present net value is less than the corresponding values in previous experiences. Given the existence of a guaranteed purchase price for electricity generated from solar power plants in Iran, the calculation of the head-to-head price can include another dimension of sensitivity analysis.

A head-to-head point is a point where the total costs and the total revenue are equal; from that point on, a profit can be made. Prior to reaching a head-to-head point, no profit or loss is achieved and only the costs made for the business are compensated for and the initial capital is returned. In short, all expenses are returned; but, the profit is still equal to zero. To find the head-to-head price, it must be found at what price the costs are equal to revenues. Table (8) shows the price at head-to-head point for different regions in Khuzestan Province.

Table (8): Price at head-to-head point

City	head-to-head price
Abadan and Khorramshahr	24624.5281
Omidiyeh	21539.6971
Andimeshk and Shoosh	10523.1519
Ahvaz	20432.0268
Izeh and Baghmalek	5141.0537
Mahshahr and Ramshir	29460.6078
Behbahan	12332.9222
Dezful	11602.8755
Dasht Azadegan	19471.3156
Ramhormoz	15630.8807
Shadegan	26826.3563
Shushtar	19640.4052
Masjed Soleyman andika	10389.2885
Lali	5428.6718
Hendijan	39518.3959
Gotvand	14620.4309

As can be seen in the above table, the price required to cover all costs in most regions was very different from the current guaranteed purchase price of electricity and the guaranteed purchase was much lower than the head-to-head price. This means that the current price of electricity did not cover the costs. Given the high price of the currency and very low guaranteed purchase price of electricity from power plants, the installation of this solar thermal power plant in most regions of Khuzestan Province is not affordable; it is cost-effective only in two regions.

4. CONCLUSION

According to the results of this study, the installation of power plant in all regions of Khuzestan Province had a negative net present value and was unprofitable, except for Lali and Izeh Baghmalek. Comparison of electricity price at head-to-head point with guaranteed purchase price of electricity also showed that investment at the guaranteed electricity purchase price was not only profitable, but also could not cover the costs.

According to Fourth Development Plan Act, the government is required to announce the guaranteed purchase prices of electricity to encourage other domestic entities for further power generation from power plants beyond the management and supervision of Ministry of Energy. In order to develop the use of renewable energy, the government has put the incentive laws and regulations for investment and arrival of private sector. Hence, the guaranteed purchase of renewable electricity was on the government's agenda. In recent years, tariffs for electricity purchases from solar power plants have not only increased, but also reduced from IRR 560 per kWh in 2016 to IRR 4,000 in 2017. All the items used in determining the purchase price of electricity depend on the oil price, which can be varied with basic changes in world oil price. Since the electricity generation and oil prices are directly associated with each other and given that the electricity subsidies are expected to be supplied from profit of oil sales, with a decline in the price of black gold in the world market, the justification for investment in the renewable energy sector is facing a problem. As the oil price decreases, the price of electricity generation with fossil fuels is lowered and the development of new energies is no longer considered; whenever oil price rises, this sector will grow again. Also, with a decrease in oil price, the oil generation from fossil fuels is more cost-effective than clean energies in Iran.

In spite of having oil and gas resources, Iran can take even bigger steps in the use of renewable energies. The increased energy price could give us a good opportunity. The electricity generation cost of solar thermal power plants and fossil fuel power plants should not be compared. Naturally, the initial investment in construction of solar thermal power plant is several times that of fossil fuel power plants; but, in a long run, the costs of fossil fuel power plants are much higher. The point we believe in that should be cared is the real price of fuel. At present, the electricity generation power plants have access to fuel with low and unreal prices and the electricity generation price is also lower. Rationalizing energy subsidies could be in favor of electricity generation via solar thermal power plant. Moreover, we believe that we must also think about the future generations. By converting oil into higher value-added derivatives, a higher revenue can be provided for the country. Furthermore, air pollution is one of problems of the country and the world that can be reduced with greater use of clean energies. If social and health costs are added to electricity generation costs via fossil fuel power plants, the cost of electricity generation will be higher than the current price, and better justifications will be provided for investment in solar thermal power plants.

Based on assignments of Article 4 of the Constitution given to Ministry of Energy, this ministry must provide the presence of the private sector in the electricity industry; the conditions must be met in a way, so that the generating and consuming sectors can interact with each other on electricity purchase or sales.

Finally, given that the economic evaluation in this research is only made for PS10 thermal power plant in Seville, it is suggested to investigate the installation of various solar power plants in Khuzestan Province in future studies. Since the research findings show that the head-to-head cost for solar thermal power plant is much higher than guaranteed purchase price of electricity by government, this finding can be interpreted in a way that the price can be used as a tool to attract private investors in this field. Therefore, first, the price liberalization policy is suggested to increase the investor's willingness to invest and, second, the monopoly policy is changed to a competition in electricity purchase. Another finding of the study showed that despite the declined interest rate, the present value of this investment plan was increased. Then, it is suggested to support the investor in this field with low interest rate facilities.

Regarding the limitations of the research, it should be noted that more accurate calculations in this study require more historical data about the average humidity, temperature and pressure, which is not available for some regions in this province. In addition, ignoring the positive external consequences of renewable energy investment schemes underestimates the benefits of such investments. On the other hand, technologies for the use of renewable energy sources are very diverse and rapidly growing, the lack of access to operational information of other types of use of solar energy has made it impossible for researchers to compare.

In conclusion, it seems necessary to mention that the most important variables influencing the decision to invest in renewable energy, including interest rates, exchange rates (due to the import of the main equipment) and guaranteed purchase prices in Iran are all determined by the government. This shows that the government in Iran has the ability to significantly affect the incentive to invest in renewable energy.

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Table (9): Nomenclature

symbol	description	symbol	description
S	technical potential of solar thermal energy	η_{opt}	ratio of light absorbed by the collectors to the total solar energy
CF	capacity coefficient of the solar thermal unit for the power plant	η_{th}	thermodynamic cycle efficiency
sqm	area usable for installation of solar thermal systems	η_{par}	parasitic efficiency
C	nominal capacity of power plant	TA	the amount of heat absorbed by the power plant
τ	the time that power plant operates during a year	Fg	geometric factor for thermal losses
λ	conversion factor	ϵ	emissivity (power transmission of a surface compared to the surface that is black)
SE	annual generation rate	σ	Boltzmann's constant
η_c	collection efficiency parameter	Tamb	ambient temperature
η_m	maintenance efficiency parameter	U	convection coefficient
η_t	ratio of the power generated by the power plant to thermal energy collected	SM	solar multiple
E	global horizontal irradiance	Z	convective losses coefficient

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