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Valuation of Solar Power Generating Potential in Iran Desert Areas

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ABSTRACT Deserts with all their superficial harshness and in spite of having a limited number of agricultural products have hidden production potentials that if correctly recognized and exploited can pave the way towards de-desertification. Solar energy is one of the free and clean energy sources. In order to evaluate solar energy power generation potential in deserts, data related to radiation intensity in each hour of the day was collected from main Iran desert areas, for the Iranian month of Khordad (May–June) and the production power was calculated. After calculating the rate of each kilo watt hour of consumed electric power, the total monthly amount of power produced by solar cells was calculated. Finally, a comparison was made between consumed electric power prices before and after implementation of the Targeted Subsidies plan in Iran. In conclusion, the total production power of one solar cell during the month of Khordad was 98677.03 Kwh/$m^2$and the produced power prices before and after Targeted Subsidies Plan implementation, were 16236318.2 and 23306124.73 Rials respectively. Therefore, by determining new energy potentials, in particular solar energy and maximum utilization of the same, energy crises throughout the world and problems relating to using non-renewable energies can be minimized.

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There are two main types of solar energy technologies: Photovoltaic (PV) cells generate solar power by converting incident sun energy into electricity. PV systems can be integrated into buildings, used in large power plants or installed on rooftops. Solar thermal is the conversion of solar radiation into heat which can be used in space and water heating, generating electricity in turbines and in large scale power generation (Shinwari, 2004; Geoscience Australia and BREE, 2014). About assessment of the energy generation potential of photovoltaic systems (Ayompe and Duffy, 2014) have been a research in Cameroon by using monthly average daily global horizontal solar irradiation from long-term satellite-derived data available in Solar GIS software. Concentrating solar power (CSP) can provide low-carbon energy resources in regions with strong sunshine. CSP systems concentrate solar energy to heat a receiver which is first transformed into mechanical energy and then into electricity (International Energy Agency, 2010).

Renewable energies such as solar energy are an alternative for world energy supply that is presently facing various problems including limitation of fossil fuel resources, climate change and the use of radioactive materials. Deserts have the potential to be madeto sustainable powerhouses throughout the world (Knies, 2006). A climate crisis in the near future is unavoidable unless developing countries limit carbon emissions by facilitating the use of affordable low-carbon technologies for investors (Ummel and Wheeler, 2008). Most world regions have significant potential for concentrating solar power (CSP). Africa, Australia and the Middle East have the largest potential area (Trieb and Schillings, 2009).The solar energy resource is more than 200 times larger than all other renewable sources combined (Perez *et al*., 2011). The costs of solar energy technologies have reduced considerably in the past three decades that has resulted in expansion of the solar energy market (Timilsina *et al*., 2011).

Iran is situated between latitudes 25 to 40 degrees north in an area where solar energy is at a high level compared to other countries. The annual solar radiation level in Iran is estimated to be between 1800 to 2200 kilowatt hours per square meter that is higher than the world average. It has been reported that there are annually 280 sunny days in Iran on an average which is very significant (Ministry of Power, 2003).

Presently, solar energy is used by different systems which include: I) Utilization of thermal energy of the sun for household, industrial and power plant consumption and II) Direct conversion of sun rays into electricity through equipment called photovoltaics. In

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this research, direct conversion of solar radiation into electricity has been studied. In Figure 1 annual average of solar radiation in different areas of the world including Iran has been demonstrated.

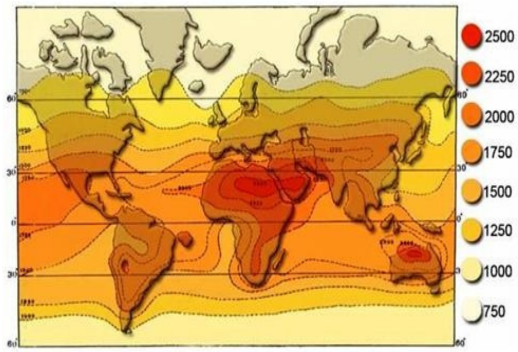

Fig. 1: annual average of solar radiation in different areas of the world including Iran (Source: Iran's Academy of Solar Industries)

Solar energy is one the greatest energy sources in the world. This energy is clean, cheap and never-ending and is available in almost all areas of the world. Limitations of fossil sources of energy and the outcomes of global environmental and climate changes have created appropriate opportunities for competitiveness of solar energy with fossil energies, in particular in countries with high potentials of radiation (Ministry of Power, 2003). According to scientific estimates, this flaming ball is around 6000 million years old and in each second 4.2 million tons of the sun mass is transferred into energy. Asthe sun weight is around 333 times that of the earth, this illuminating globe can be considered as a great source of energy for 5 billion more years. The temperature of the center of the sun is around 10 to 14 million degrees centigrade that is dispersed in space with a temperature of around 5600 degrees in the form of electromagnetic waves (KoshAkhlaq et al., 2005). The earth is located at a distance of 150 million kilometers from the sun and its receiving share of solar energy is only about ($1/ 2*10^9$) of the total radiated energy. In spite of this, the amount of solar energy radiated onto the earth is around 10,000 times the total amount of annual consumed energies on the earth which shows the importance of paying attention to this source in provision of man's daily needs (Ka'binejadian, 1997). Although the technologies of using solar energy have yet to reach maturity, attaining perfection in this regard is close such that nowadays photovoltaic systems have the ability to compete in suitable conditions (Lesourd, 2001). In similar research with this study, in Nigeria (Ohijeagbon *et al.,* 2014) have focused on estimating daily global solar radiation for any location in Nigeria to use in the design of the performance of solar applications.

Solar energy systems are new technologies used for provision of heat, warm water, electricity and even cooling of households in commercial and industrial centers. Many countries have turned to renewable energies in order to overcome negative impacts on the environment and other problems relating to fossil fuels and for control of the increasing energy demand (Khan and Latif, 2010). The residential areas in the European Union and also Greece require large quantities of energy that do not have negative effects on the environment. In particular, in Greece over 25% of provided renewable energy has been attracted in the residential section (Ministry of Development of Greece, 2006) where the most amount of energy is used for cooling and heating of households (European Renewable Energy Council, 2004). Based on the statistical energy polling conducted in 2010 throughout the world the accumulated solar energy capacity in 2009 was 22921.9 which shows a growth of 46.9 compared to 2008 (Othman *et al*., 2010). Production costs show that renewable energy, because of allotment of subsidies to fossil energies in Iran, is not economically justifiable. Electricity production cost in Iran is 1.3, 5.4 and 19.4 US cents per kilowatt hour in thermal, wind and solar power plants, respectively (Razdan, 2006). In Iran, around 612250 kilowatt hour of electricity was produced between the years 2005 – 2007 and around 3788 thermal solar bath water heaters were installed in rural areas. A geothermal power plant with a capacity of 55 megawatts is under construction in two phases in MeshkinShahr.

Furthermore, a combined cycle solar power plant started operation in Yazd in 2009 for power generation. This power plant is the first combined cycle power plant in the world that utilizes solar energy and natural gas. Yazd Combined Cycle Solar Power Plant has the capacity of production of 467 megawatt hour of energy. In this power plant, solar energy is used for completion of the water evaporation process using centralized solar power techniques. Yazd Solar Power Plant was the eighth largest solar power plant in the world in 2010. In spite of the ongoing efforts for development of renewable energies, the subsidy for fossil energies is a major obstacle for the development of these energies (She'rbafian, 2007). The average annual solar radiation in the studied area is 5.2 – 5.4 kilo watt hour per square meters and is the highest amount of received solar radiation in the country (Figure 2). Considering the shortage of rain and humidity and on the other hand extreme air dryness in the area, the conditions for practical utilization of solar energy are met.

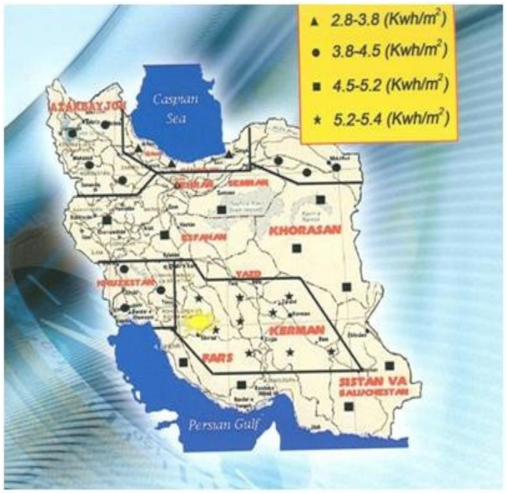

Fig. 2: Average annual solar radiation in Iran, (Source: Iran's Academy of Solar Industries)

MATERIALS AND METHODS

Iran has some proper desert area for producing solar power electricity. One of the main important and potent areas for this object is Abarkuh that has long time suny day. Abarkuh town with an area of 5641 square kilometers falls between 52°, 50' to 54°, 1' longitude east and 30°, 30' to 31°, 35' latitude north with an altitude of 1550 meters is situated in the western part of Yazd Province. Climatologically, Abarkuh town possesses a hot and dry desertic condition. Day and night temperature variation is very high. Maximum atmospheric precipitation occurs between the months of Bahman to Ordibehesht (January to April) and the average amount of precipitation varies slightly in different areas. This amount in Abarkuh city is less than 100 mil and in the center of Mehrabad district is 74.8 mil. The evaporation in the region is very high and reaches up to 3500 mil per annum. Abarkuh is situated in a desertic area and due to its unfavorable climatic and soil condition there are few towns and villages inhabited in the area. Topographically, the Abarkuh Plain falls within the Central Iranian Plateau and is surrounded by the Zagros Mountains to the south and west. The Kavir of Abarkuh with an elevation of 1450 m is the lowest basin of the area.

Although wind energy is presently the leading energy among the renewable energies, utilization of solar cells in various places and capacities is increasing because solar energy is more accessible and unlike wind generators, prediction of the production changes in 24 hours is easier (Rastegar *et al*., 2011). The output power of solar cells mainly depends on three factors: solar radiation intensity, temperature and cell output. Therefore, contrary to ordinary power plants, the production power of solar cells is not definite and depends on environmental conditions. In the present research, the production power of solar cells and the equivalent price in Rials during the Iranian month of Khordad (May – June) has been studied. In line with this, the radiation intensity data in each hour of a day was collected for the month of Khordad. Considering that in the month of Khordad the time of sunrise and sunset is around 5 a.m. and 7 p.m. respectively, the period between these two hours was taken into account and during the time outside this period because of absence of sunlight, the radiation intensity was zero and hence was not considered in the calculations. Thereafter, as per radiation intensity in each hour, using the related equation, the production power () of the equivalent hour was calculated in watt per hour. Asthe present research studies the production power during the 31 days of Khordad, for each hour of the mentioned period the average production power for the same hour throughout the 31 days was used. Thereafter, the average production power for every hour during the month of Khordad was multiplied by the equivalent unit price in Rials before and after implementation of the targeted subsidies plan and finally the achieved amount was multiplied by the number of days, i.e., 31 and hence the price for each hour in Rials during the month of Khordad was determined. Next, in order to calculate the price in Rials during the studied hours, the sum of all hours of the period in Rials during Khordad was calculated. The resulting figure demonstrates the produced electricity for the related period in Rials. Finally, a comparison was made between the prices of consumed electricity before and after implementation of the subsidies plan.

RESULTS AND DISCUSSION

Based on the solar cells output curve (Figure 3), with increase in solar radiation intensity, the output increases as well. At the beginning of the curve, with the slightest increase in radiation, the output increases significantly. After a certain amount of radiation (K_s), with increase in radiation, the output increases slightly. Based on this curve, the sensitivity of the output to temperature is less than 2%. Therefore, changes in temperature in modeling of solar cells can be overlooked.

In conclusion, production power of solar cells is formulized based on radiation as follows

P pv (R i) = {(“ (S)/Ks (Ri) = 2 Ri< Ks @ (S.Ri) Ri> Ks @ Pn Ri>Rn)} (1)

Where (Pp) is the production power of the solar cell, (R) is the solar radiation intensity, (the constant output achieved in high radiation intensities and (Pn) the nominal solar production powerin radiations above (R) It needs to be mentioned that the solar cell output for high radiations is considered to be 7%. Moreover, the following values have been considered: k_s=300 and R_n=420 (Rastegar et al, 2011).

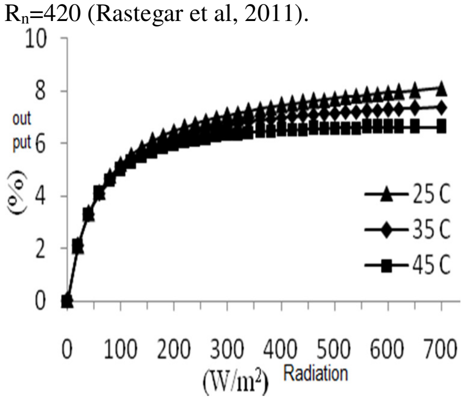

Fig. 3: Solar cell output based on radiation intensity

The radiation intensities are available for each 24 hours and for all days of the year. Since the solar radiation is repeated, the mean intensity for a period of time (T) for every hour can be used for the study.

$$R_h = \sum_{D=1}^{T} R^D \qquad (2)$$

Where $R_h$is the radiation intensity in the h^{th} hour and on the D^{th} day and $R_h$is the mean intensity of the h^{th} hour during the T day period. It should be mentioned that the value of T has been considered to be 365 for a one year period. The mean radiation for 24 hours can be achieved from equation 2. In the present research, the hours of the day with radiation intensities above zero have been studied. Therefore, during the month of Khordad there was only radiation intensity during these hours. Table 1 demonstrates production power for radiation intensity P_{PV} (R_1) during different hours of the day. In the last row, the average production power of different hours has been calculated for the 31 days of Khordad.

Table 1: Production power of solar cells for radiation intensity P_{PV} (R_1) based on watt-hour per square meter during different hours in the 31 days of the month of Khordad

Hour	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Day	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	*10^5	
1	0.0001	790.29	2.2330	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.2750	0.2018	0
2	0.0001	630.37	2.4780	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.4150	0.1569	0
3	0.0002	050.47	2.6110	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	1.7646	0.3140	0
4	0.0006	350.83	2.2330	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6110	0.3140	0
5	0.0001	480.13	1.2559	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6390	0.3191	0
6	0.0004	880.35	2.6040	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.8000	0.1243	0
7	0.0006	780.56	2.6320	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.6048	0.3473	0
8	0.0011	480.60	2.6390	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.4920	0.5111	0
9	0.0006	800.51	2.5550	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.2610	0.1848	0
10	0.0011	730.59	2.6740	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.6664	0.1383	0
11	0.0076	100.12	0.1016	0.26	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.5320	0.1932	0
12	0.0006	040.37	2.6180	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.0049	0.0560	0
13	0.0011	710.47	2.5340	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.7729	0.0785	0
14	0.0011	050.47	2.5970	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.0631	0.0004	0
15	0.0011	390.46	2.6040	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.5410	0.1210	0
16	0.0008	530.42	2.5270	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.7510	0.4906	0
17	0.0011	160.43	2.5690	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6670	0.4066	0
18	0.0015	080.45	2.6110	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6110	0.4705	0
19	0.0015	730.45	2.5970	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.8070	0.6430	0
20	0.0011	080.45	2.5900	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.7160	0.5462	0
21	0.0015	080.45	2.5830	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.9400	0.8691	0
22	0.0019	420.50	2.5970	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.7440	0.4705	2.3
23	0.0008	600.05	0.7900	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	0.7814	0.4838	0
24	0.0019	080.45	2.6040	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.4990	0.2572	0
25	0.0028	500.52	2.5970	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6180	0.3360	9.3
26	0.0006	730.34	2.3100	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.5550	0.4127	0
27	0.0008	490.32	0.7476	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.9120	0.6507	2.3
28	0.0008	3600.3	2.5830	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6320	0.4771	2.3
29	0.0011	110.51	2.6530	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.7300	0.6119	2.3
30	0.0006	040.37	1.2451	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.6880	0.0655	0
31	0.0008	440.44	2.5060	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.5200	0.1932	2.3
avrage	0.0010	0.4093	2.3414	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.2323	0.2973	0.1

In Abarkuh the rate of each kilowatt hour of electricity for household consumption in the year2010 – 2011 before and after implementation of the targeted subsidies plan was 164.54 Rials and 233.81 Rials, respectively (Yazd Province Electricity Company, 2011).

The total amount of production power of electricity in every hour during the month of Khordad has been demonstrated in Table 2. For example, the average production power of solar cell at 10 a.m. during one month is as follows:

$$294\times \frac{164}{54} = \frac{48374}{76}$$

The price of produced electricity at 10 am on one day prior to implementation of the targeted subsidies plan (in Rials):

$$\frac{48374}{76} \times 31 = \frac{1499617}{56}$$

The price of produced electricity at 10 am. in the month of Khordad prior to implementation of the targeted subsidies plan (in Rials):

$$294 \times \frac{233}{81} = 68740$$

The price of produced electricity at 10 am.in the month of Khordad after the implementation of the targeted subsidies plan (in Rials):

$$68740 \times 31 = \frac{2130944}{34}$$

The price of produced electricity at 10 am.in the month of Khordad after the implementation of the targeted subsidies plan (in Rials).

Table 2: Produced electricity amount during different hours of one month

Hour	Production power during the month of Khordad(Kwh/m^2)
5	3.1
6	1547.83
7	7258.34
8	9114
9	9114
10	9114
11	9114
12	9114
13	9114
14	9114
15	9114
16	9114
17	6920.13
18	921.63
19	0.003
Total production power from one solar cell(Kwh/m^2)	98677.03

Table 3: Comparison of electricity production in Rials prior to and after implementation of the targeted subsidies plan

Total production power from one solar cell during one month of Khordad98677.03 (Kwh/m^2)	Rate of each kw/h of household consumed electricity (in Rials)
16236318.52 Rials	164.54 (Prior to the targeted subsidies plan)
23306124.73 Rials	233.81 (After the targeted subsidies plan)

Table 3 shows that the Rial value of the produced electricity resulting from one solar cell in the Abarkuh area during the month of Khordad has risen significantly after implementation of the subsidies targeted plan. Considering that there is no possibility for utilization of other sources of production of electricity in the region, optimized usage of the solar radiation source for production of electricity becomes evident more than any other place.

Considering the targeted subsidies plan and global increase in energy prices, it is evident that the amounts of produced electricity and the resulting financial and environmental benefits are more than ever taken into consideration. Moreover, by proper utilization of potentials of desert areas and in particular electricity generation through solar cells all capacities of these areas can be appropriately used.

After implementation of the targeted subsidies plan in the country we have been facing increase in prices of energy carriers, including electricity, and on the other hand, in the Iran desert area solar energy is almost the sole source of electricity generation. Hence, it is suggested that required attention should be given to this God-given abundant source of energy.

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