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Solar energy in Iran: Current state and outlook

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ABSTRACT

This paper introduces the resource, status and prospect of solar energy in Iran briefly. Among renewable energy sources, Iran has a high solar energy potential. The widespread deployment of solar energy is promising due to recent advancements in solar energy technologies. Therefore, many investors inside and outside the country are interested to invest in solar energy development. Iran's total area is around 1600,000 km^2 or 1.6×10^{12} m^2 with about 300 clear sunny days in a year and an average 2200 kW-h solar radiation per square meter. Considering only 1% of the total area with 10% system efficiency for solar energy harness, about 9 million MW h of energy can be obtained in a day. The government's goal on 2012 was to install 53,000 MW capacity plants for electricity generation. To reach this goal, it was assumed that the new gas-fired plants along with the hydroelectric and nuclear power generating plants could be financed by independent power producers including those of foreign investment. Based on the fifth 5 year Socio-economic and Cultural Development Plan, the private sector was expected to have a share of at least 270 MW in renewable energy development. The existing small capacity solar energy plants are in Shiraz, Semnan, Taleghan, Yazd, Tehran and Khorasan. Based on the specified available solar trough technology, solar area, average solar hours and average solar direct irradiation, the technical potential of solar electricity was estimated to be 14.7 TWe. Under the current energy policies, the combined solar, wind and geothermal power plants are economically viable. These huge RES's potential can be realized assuming the availability of technology, investment capital, human expertise and the other resources along with a long-term driven renewable energy policy. Due to high growth rate of electricity demand in Iran, the nominal installed capacity has increased by 8.9% per annum during 2001–2007. In the reference scenario, the share of RES in total installed electricity capacity is expected to be about 2% in 2030. It is expected that the cumulative RES installed capacity will reach 2.8 GW in 2030. This requires more than 2800 million US dollar investment during 2010–2030.

Contents

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1. Introduction

Solar energy is a potential clean renewable energy source. Solar power generation demand increases worldwide as countries strive to reach goals for emission reduction and renewable power generations [1]. Solar energy can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications [2]. In 2005, global solar markets reached US $11.8 billion, up 55% on 2004. Solar installations provided 15 GW in 2010 versus 2.7 GW in 2006 [3,4]. Worldwide total PV installations represented 1.8 GW in 2000 and 71.1 GW in 2011 with a growth rate of 44%. Global cumulative PV installations reached about 106 GW [5]. Mainly Japan, Germany, the UK, China, Spain and Italy have produced electricity with PV based power [6]. In 2012, European capacity for PV electricity was 17.2 GW, and it was 22.4 GW in 2011. It is expected 48 GW by 2017 [7]. With about 37,007 MW (MW) of solar PV power installed in 2013, world solar PV power capacity increased about 35% to 136,697 MW. It is expected global PV installations to slow from over 20% annual growth in 2013 and 2014 to 16% next year, or 53 GW [8]. The total global solar power capacity will grow from 98 GW in 2012 to 308 GW in 2018 [9]. The high potential locations for solar power plants are United State of America south west, Mediterranean European countries, Middle East and Near East, Iran and India deserts, Pakistan, China and Australia [9–14].

The first steps of employing renewable resources in Iran were taken in 1994, and since that time, attention to this subject has significantly increased among authorities and society [15]. The 4th development program proposed that 500 MW (without considering hydro power) should be supplied from renewable resources (% 1 of total energy consumption), with a private sector share of 270 MW. In a 20-year Iranian development outlook, this share should reach 10% by 2025 [16]. Iran is rich in oil, gas and other fossil energy resources. Yet it has opted to turn to renewable energy [17]. The renewable energy sources (solar electric, wind, geothermal, biomass and small and low-impact hydro) are the suitable candidates for electricity production with minimum environmental impacts [18]. The world energy consumption by fuel type shows that the share of renewable energy is increasing rapidly and this trend will continue in the future. Only 1% of worldwide energy sources depend on renewable energy sources [19]. Several scientists have studied the status and perspectives of renewable energy sources especially solar energy in different countries [20]. In the case of Iran, there is a strong political will to develop the renewable energy resources and harness the potentials. The energy resources investigated and applied in Iran are wind power, solar thermal, geothermal, photovoltaic, biomass, biogas, hydrogen energy and fuel cells [21–24]. Iran embarked on a push to add 5 GW of renewable wind and solar capacity to the grid by 2018. 400 MW of projects have already begun construction and 900 MW of RE contracts have been signed. The bulk of the total 5 GW comprises wind power projects, but 500 MW has already been earmarked for solar PV, with some projects already permitted licenses to commence construction or enter into power purchase agreements. Currently, the Iranian grid generates 70 GW of power, and demand is growing at 5 GW per year as the economy blossoms and citizens begin to consume more [25]. To meet that growing demand, wind power has joined large-scale hydro power in the renewable fast lane (the latter of which currently accounts for 11 GW of Iran's energy generation), but demand for solar PV energy is increasing boosted by a domestic desire to transition to a more sustainable and environmentally friendly energy source. The level of PV capacity in Iran's renewable energy mix is increasing [26]. Iran is apparently planning to spend $60 million on solar power projects at 2014 [26]. That represents a pretty significant uptick in the country's investment into solar energy-up from just $12 million last year (2013), the focus is reported to be on rural areas that are otherwise completely dependent on diesel-powered generators- a good strategy, remote rural areas are certainly one place where solar PV really shines. In the next five years, Iran plans to boost national solar energy production to 5 thousand MW, 25 times what it is now [25,26].

2. Iran's energy status

Iran has huge reserves of both natural gas and oil [25,26]. Iran holds nearly 10% of the world's crude oil reserves and 13% of OPEC reserves [26]. About 70% of Iran's crude oil reserves are located onshore, with the reminder mostly located offshore in the Persian Gulf [25,26]. Iran also holds proved reserves in the Caspian Sea, although exploration has been at a standstill. Iran is the second-largest proved natural gas reserve holder in the world, behind Russia. Iran holds 17% of the world's proved natural gas reserves and more than one-third of OPEC's reserves. Iran's largest natural gas field, South Pars, is estimated to hold roughly 40% of Iran's gas reserves [22,23]. Furthermore, Iran also is the only country with huge hydrocarbon reserves which has the potential to increase its output massively, since its current production levels are well below its maximum potential.

The combined hydrocarbon energy reserves composed of natural gas and oil in Iran is almost equal to that of Saudi Arabia's and more than the Russia's total hydrocarbon energy reserves. As the energy resource is concerned, Iran has the fifth largest oil reserves and the second largest natural gas reserves in the world (Figs. 1 and 2) [27–30].

Iran is one of the most energy intensive countries of the world with per capita energy consumption of 15 times that of Japan and

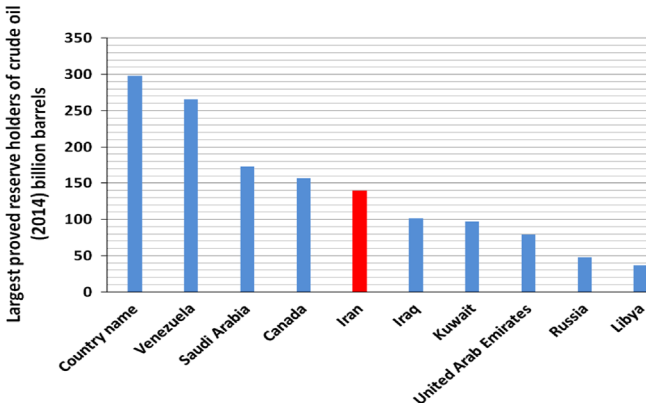

Fig. 1. Iran holds the world's fifth-largest proved crude oil reserves [25].

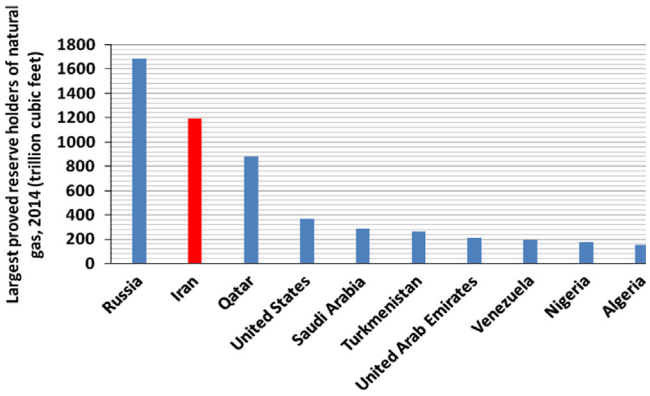

Fig. 2. Iran is the second-largest proved natural gas [25].

10 times that of European Union [25,26]. Also due to huge energy subsidies, Iran is one of the most energy inefficient countries of the world, with the energy intensity three times higher than the global average and 2.5 times the middle eastern average [31,32]. Iran's total primary energy consumption, share by fuel, 2012–2013 has been indicated at Fig. 3. Iran energy balance flow has shown in Fig. 4. With its heavy dependence on oil and gas revenues, Iran continues to explore for new sources of natural gas and oil. Iran has recently focused its energy sector on the exploration of the South Pars offshore natural gas fields in the Persian Gulf [33]. Iran has become self-sufficient in designing, building and operating dams and power plants and it has won a good number of international bids in competition with foreign firms [34]. The power generation capacity of Iranian thermal power plants has reached over 173 TW h in 2007, accounting for 17.9% of power production in the Middle East and African region. The natural gas has been the main energy in Iran in 2007, comprising over 55% of energy needs, while oil and hydroelectricity accounted for 42 and 2%, respectively. The region's energy need increased by 26.8% until 2012 since 2007 [34].

Iran's domestic consumption and production have steadily grown together since 1984 and it is still heavily reliant on traditional thermal energy sources of electricity, with a small fraction being produced by hydroelectric plants. The consumption has steadily risen and it is expected to rise at about 6% per year for the coming decades (Fig. 5) [25]. Accordingly, the Iranian energy sector must focus its efforts on meeting this continuing demand. Today Iran ranks 19th of the largest producer and 20th of the largest consumer of electricity in the world. A research work conducted by the Ministry of Energy indicated that about 15,000–20,000 MW of capacity could be added to the existing capacity for the next 20 years [35,36]. Iran has put greater emphasis on participation of domestic and foreign investors in electricity generation sector during recent years, with projects underway to add 40,000 MW h more capacity to the national grid [37]. It is estimated that about 18.5% of the electricity generated in Iran is wasted before it reaches its consumers due to technical problems. Iran is among the top ten manufacturers of gas turbines with a capacity of 160 MW [38]. Iran has acquired self-sufficiency of over 80% in constructing hydraulic turbines and over 90% in producing gas turbines. Within the next few years, Iran can join the list of countries that produce power plant technology. Iran has achieved the technical expertise to set up hydroelectric, gas and combined cycle power plants. Iran is not only self-sufficient in power plant construction but has also concluded a number of contracts on implementing projects in neighboring states [39]. Electricity generation by fuel in Iran at 2012 has been shown in Fig. 6.

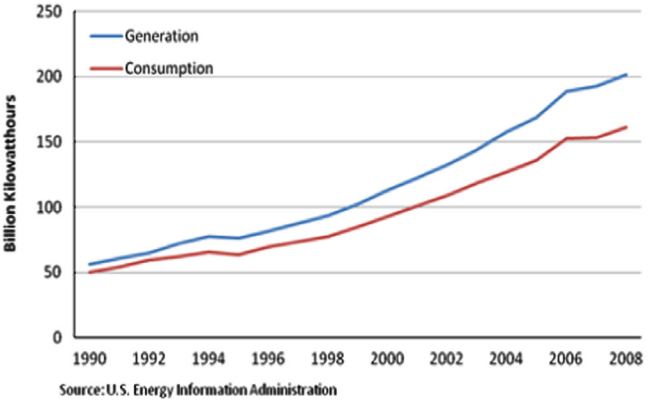

Fig. 5. Iran electricity generation and consumption, 1990–2008 [25].

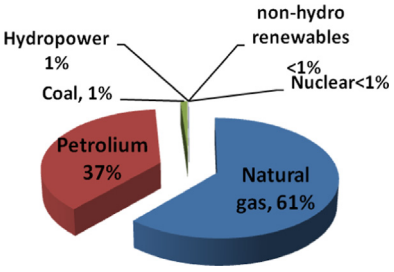

Fig. 3. Iran's total primary energy consumption, share by fuel, 2012–2013 [25].

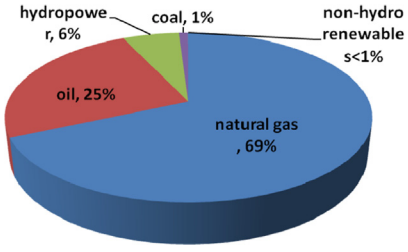

Fig. 6. Iran electricity generation by fuel, 2012 [25].

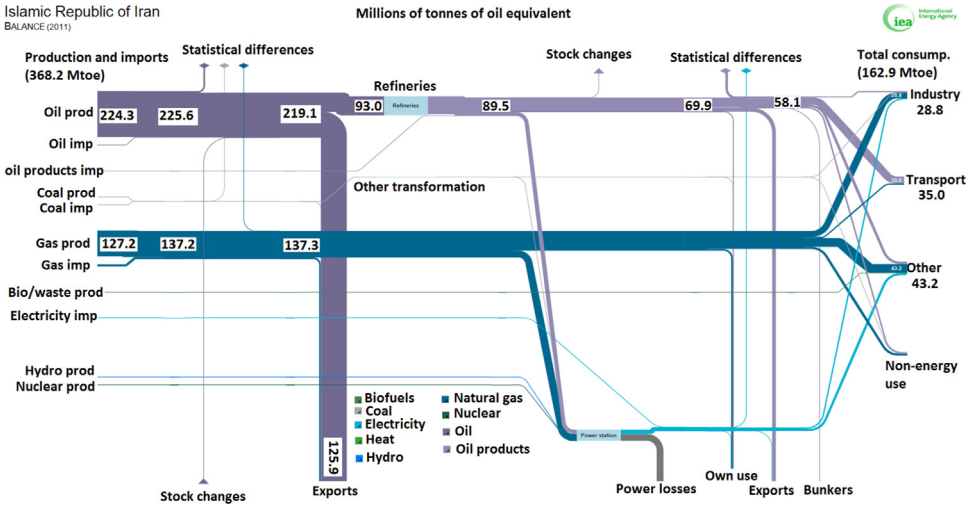

Fig. 4. Iran energy balance flow [25].

The nuclear and hydroelectric power may not be under focus for the time being, but they are part of an overall strategy to meet electricity demands. The electricity sector is also heavily subsidized and mostly state owned companies control the power distribution, transmission and generation [40]. In order to meet the demands of the electricity sector, however, Iran is beginning to look into private investment. The private companies in Iran have generated 14,440 MW of electricity in 2009 [40]. By 2004 the addition of new hydroelectric stations and the streamlining of conventional coal- and oil-fired stations increased the installed capacity to 33,000 MW [41]. Of this amount, about 75% was based on natural gas, 18% on oil, and 7% on hydroelectric power. However, in 2004, Iran opened its first wind-powered and geothermal plants, and the first solar thermal plant was to come online in 2009 [41]. Iran has recoverable coal reserves of nearly 1.9 bn short ton. The country produces about 1.3 m short ton of coal annually and consumes about 1.5 m short ton, making it a small net importer of coal [42]. Demographic trends and intensified industrialization have caused electric power demand to grow by 8% per year. The government's goal of 53,000 MW of installed capacity by 2010 is to be reached by bringing on line the new gas-fired plants financed by independent power producers, including those with foreign investment backing, and by adding hydroelectric and nuclear power generating capacity. It has also been estimated that Iran has the potential to produce at least 6150 MW h of electricity by Wave power from its coastline on Persian Gulf alone [43]. Iran is also experimenting the electricity generation from organic wastes and plans to build power plants using sewage and organic waste of domestic and industrial origin as fuel. Another area in which there is ongoing research is the assessment of Iran's tidal power potential. Having about 300 clear sunny days a year and an average of 2200 kW h solar radiation per square meter, Iran has a great potential to tap solar energy [44,45].

3. Solar energy in the world

It expected global PV installations to slow from over 20% annual growth in 2013 and 2014 to 16% next year. The total global solar power capacity will grow from 98 GW in 2012 to 308 GW in 2018 [46,8]. New installations totaling 30.2 GW in 2012 took global solar power generating capacity to 100 GW by year-end, a 43.3% increase versus the end of 2011. Capacity has grown more than ten-fold over the past 5 years, with more than half of the growth in capacity in Europe, led by Germany (7.6 GW) and Italy (3.4 GW). Germany remains the world's leader for cumulative installed capacity (32.6 GW), and Italy (16.2 GW) comes in second. The top markets-Germany, Italy, China, the United States, and Japan—were also the leaders for total capacity [47,48]. Solar power gets the top prize for thrust with its 65.5% year-on-year increase (41.4 TW h), that took the combined contribution past the 100 TW h line to 104.5 TW h. It forecasts that non-hydro renewable energies, driven by solar power investments could generate 8% of gross electricity output in 2018. Gross renewable electricity output will continue to pick up speed in the medium term to 2018, rising by approximately 40% and forecasts installed renewable capacity increasing from 1580 GW in 2012 to 2350 GW in 2018 [49]. The solar power generating capacity has grown up by 73% in 2010, picking up the pace again after a brief slowdown in 2009 [50]. The total capacity grew by 16.7 GW to reach 40 GW, more than the double level in 2008. The capacity growth has averaged 39% over the past 10 year [51]. The solar capacity growth in 2010 was heavily concentrated in one country i.e. Germany. The strong policy support has driven unexpectedly the rapid growth in Germany over the past three years. The growth in 2009 was so strong that the government accelerated the planned reduction of tariff incentives in 2010, but this still did not dampen growth. A record of 7.4 GW new capacity was added in 2010; almost doubling the 3.8 GW of addition in 2009. The Germany accounted for 44.3% of global capacity growth in 2010. With 17.3 GW of capacity installed by the end of 2010, Germany has 43.5% of the world's solar capacity, more than four times its nearest rivals (Spain 3.9 GW and Japan 3.6 GW) [52]. Outside Germany, the main centers of growth in solar power capacity were Italy, the Czech Republic, Japan and the US. There are now seven countries with more than 1 GW of solar power installed in 2009 (France and the Czech Republic were the new joiners). Despite the rapid capacity growth, the share of solar power in total electricity generation remains low, at an estimated rate of 0.1% [53]. Total concentrated solar power capacity has been indicated at Table 1 [54–56].

The largest solar thermal power plants in operation are [7,25]:

1. "Solar Energy Systems" in the Mojave Desert of California, USA—354 MW.
2. "Solnova Solar Power Station" in Seville, Spain—150 MW.
3. "Andasol Solar Power Station" in Granada, Spain—150 MW.
4. "Extresol Solar Power Station" in Torre de Miguel Sesmero, Spain—100 MW.
5. "Palma del Río Solar Power Station" in Córdoba, Spain—100 MW.
6. "Manchasol Solar Power Station" in Ciudad Real, Spain—100 MW.
7. "Martin Next Generation Solar Energy Center" in Florida, USA—75 MW.
8. "Nevada Solar One" in Boulder City, Nevada, USA—64 MW.
9. 6 more solar thermal power plants in Spain have a capacity of 50 MW.

Table 1
Total concentrated solar power capacity (MWp) [54].

Country or region	Total 2005	Total 2006	Total 2007	Total 2008	Total 2009	Total 2010	Total 2011
World	354	355	438	494	896	1193	1707
European Union	0	0	11	62	384	638	1108
Spain	0	0	11	61	382	632	1102
United States	354	355	427	432	512	517	517
Algeria	0	0	0	0	0	0	25
Morocco	0	0	0	0	0	20	20
Egypt	0	0	0	0	0	0	20
Iran	0	0	0	0	0	17	17
Italy	0	0	0	0	0	4.7	4.7
Germany	0	0	0	0	0	1.5	1.5

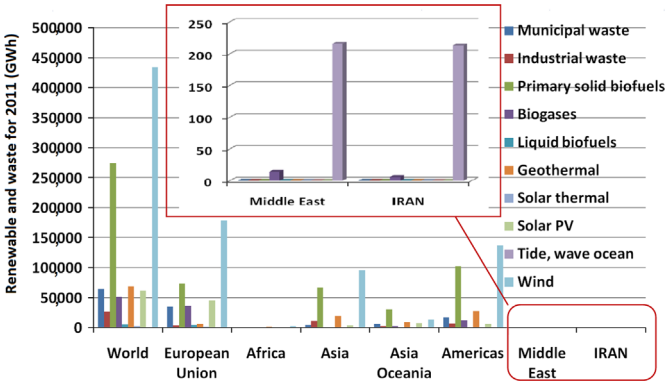

Fig. 7. Renewable and waste for 2011 (GW h) at different regions [25].

The largest solar photovoltaic (PV) power plants in the world are listed bellow [7,25]:

1. "Sarnia Photovoltaic Power Plant" in Canada—97 MW
2. "Montalto di Castro Photovoltaic Power Station" in Italy—84.2 MW
3. "Finsterwalde Solar Park" in Germany—80.7 MW
4. "Ohotnikovo Solar Park" in Ukraine—80 MW
5. "Solarpark Senftenberg" in Germany—78 MW
6. "Lieberose Photovoltaic Park" in Germany—71.8 MW
7. "Rovigo Photovoltaic Power Plant" in Italy—70 MW
8. "Olmedilla Photovoltaic Park" in Spain—60 MW
9. "Strasskirchen Solar Photovoltaic Park" in Germany—54 MW
10. "Puertollano Photovoltaic Park" in Spain—50 MW.

Table 2
Renewable energy power generation outlook [54–59].

	Photovoltaics			Concentrated solar power		
	2010	2035 Ref.	2035 Adv.	2010	2035 Ref.	2035 Adv.
North America	2.7	64.2	179.6	0.3	23.6	50.2
Latin America	0.1	2.3	6.8	0	0	0
Asia	5.5	161.3	420.6	0	5.9	9.9
Middle East	0.1	4	25	0	2.9	6.8
Europe	29.8	260.1	586.2	0.3	11.1	11.4
FSU	0	0	0	0	0	0
Africa	0.2	12.8	43.5	0	7.2	15.4
Oceania	0.6	20.3	40.8	0	0	0
Total	38.9	525.1	1303	0.6	50.8	93.7
Electricity output (TW h)						
North America	3	76	214	1	62	132
Latin America	0	2	5	0	0	0
Asia	6	168	435	0	16	26
Middle East	0	4	26	0	8	18
Europe	22	182	383	1	29	30
FSU	0	0	0	0	0	0
Africa	0	5	13	0	19	40
Oceania	0	10	20	0	0	0
Total	32	446	1095	2	134	246

4. Solar energy in the Middle East

Solar energy is one of the best renewable energy sources, for this reason different countries have formulated solar energy policies to reducing dependence on fossil fuel. The share of solar energy between renewable energies for different regions and countries of the world even at Middle East and Iran has been described at Fig. 7 [21–26].

In order to diffuse renewable energy substantially, research and development operations must be continued to lower costs and increase power generation efficiency, for example mainly Europe begun to diffuse Photovoltaics power generation very rapidly. Table 2 gives an outlook for solar energy- based power generation [54–59].

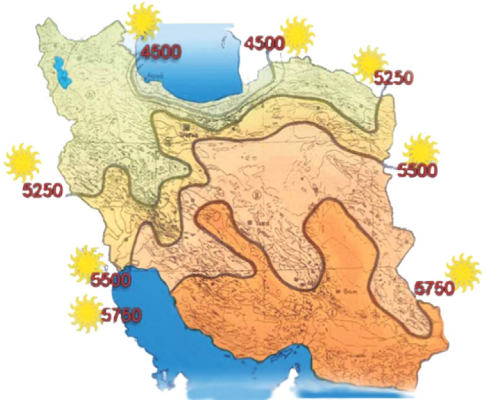

Fig. 8. Potential of solar energy in Iran [25,26].

Table 3
Renewable sources for electricity generation in different regions [54–59].

Country	Renewables electricity								
	Rene. El.	Hydroelectricity	Non-hydroelectric renewables	Non-hydroelectric renewables					
				Geothermal	Solar, tide, and wave			Wind	Biomass and waste
	Total renew.	Hydroelectric	Total non-hydroelectric renewables		Solar, tide and wave	Solar	Tide and wave		
World	4402.425	3471.621	930.804	67.532	58.742	58.185	0.557	446.334	358.196
North America	970.700	727.187	243.513	21.823	2.322	2.292	0.030	141.247	78.121
Central & South America	781.447	728.496	52.951	3.672	0.004	0.004	0.000	4.937	44.340
Europe	933.346	540.128	393.218	11.270	46.605	46.078	0.527	181.739	153.604
Eurasia	244.670	238.875	5.795	0.505	0.000	0.000	0.000	1.222	4.068
Africa	115.365	108.823	6.542	1.471	0.037	0.037	0.000	2.777	2.257
Asia & Oceania	1336.143	1107.947	228.196	28.792	9.564	9.564	0.000	114.126	75.714
Middle East	20.755	20.165	0.59	0	0.211	0.211	0	0.287	0.092
Bahrain	0.002	0	0.002	0	0	0	0	0.002	0
Iran	12.211	11.937	0.274	0	0.1	0.1	0	0.274	0
Iraq	4.099	4.099	0	0	0	0	0	0	0
Jordan	0.064	0.054	0.01	0	0	0	0	0.003	0.007
Kuwait	0	0	0	0	0	0	0	0	0
Lebanon	0.797	0.797	0	0	0	0	0	0	0
Oman	0	0	0	0	0	0	0	0	0
Palestinian	0	0	0	0	0	0	0	0	0
Qatar	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0
Syria	3.25	3.25	0	0	0	0	0	0	0
UAE	0.019	0	0.019	0	0.019	0.019	0	0	0
Yemen	0	0	0	0	0	0	0	0	0

The new and renewable energy sector is growing in strategic importance, particularly in the Middle East where energy demand is extremely close to outstripping supply and governments are looking for alternative sources of energy. Renewable sources used for electricity generation in different regions is showed in Table 3. The data from this table proves that the share of solar energy for electricity generation in Middle East and even for Iran is so little. As the region looks to preserve its main wealth of oil and gas, the development and implementation of renewable energy will continue to increase to cope with the region's escalating power demand. Countries in the region which have already implemented or are planning to implement new and renewable energies include Saudia Arabia, the UAE, Iran, Bahrain, Syria and Lebanon [54–67].

5. Solar energy in Iran

5.1. Current state

Ninety nine percent of energy production in Iran comes from oil and gas and only 1% from renewable energy resources. Since Iran has very rich fossil energy resources, little attention has been paid so far to explore alternative energy production. The majority

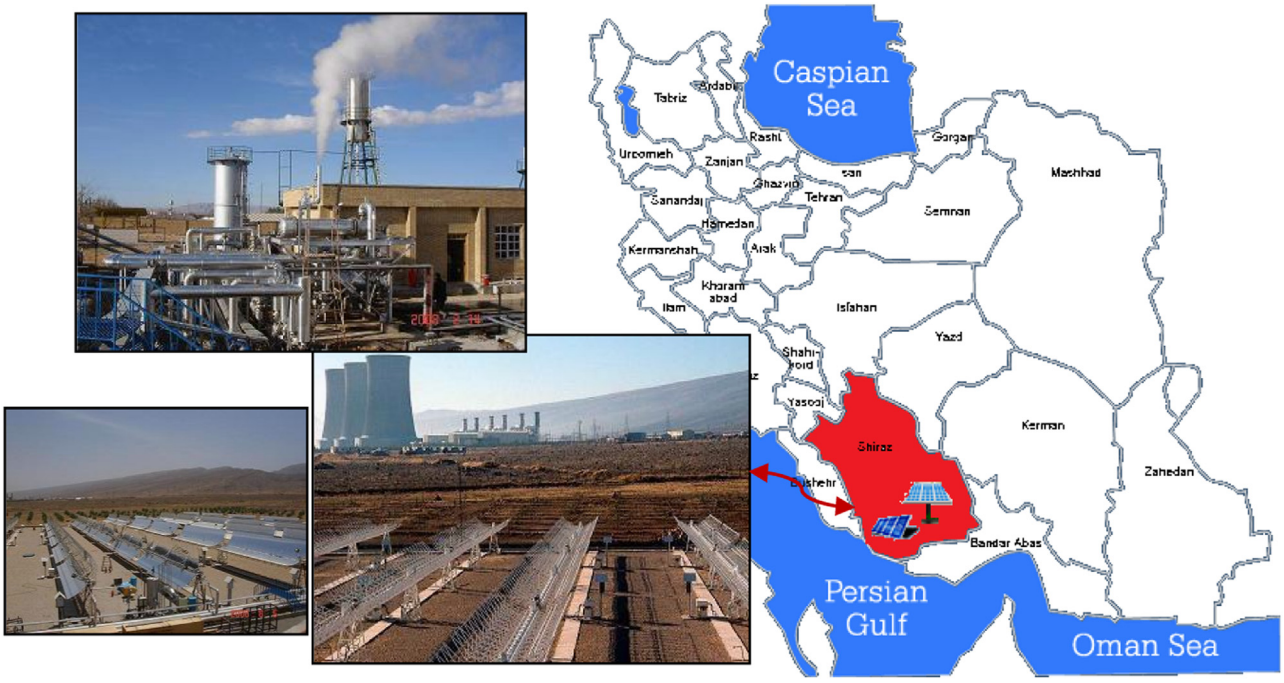

Fig. 9. Shiraz power plant, 250 MW [74,26].

Fig. 10. Yazd solar thermal power plant, 467 MW [67,26].

Table 4
The specifications of the Shiraz and Yazd power station [26].

Name	Location	Capacity	Type	Operational	Notes
Yazd solar thermal power plant	Yazd	467 MW	Integrated solar combined cycle	2009	Is the world's first integrated solar combined cycle power station using natural gas and solar energy and it is the largest solar power plant in the Middle East and the 8th largest in the world
Shiraz solar power plant	Shiraz	250 MW	Concentrating solar power	2009	Is Iran's 1st solar power station, currently being upgraded to 500 MW h

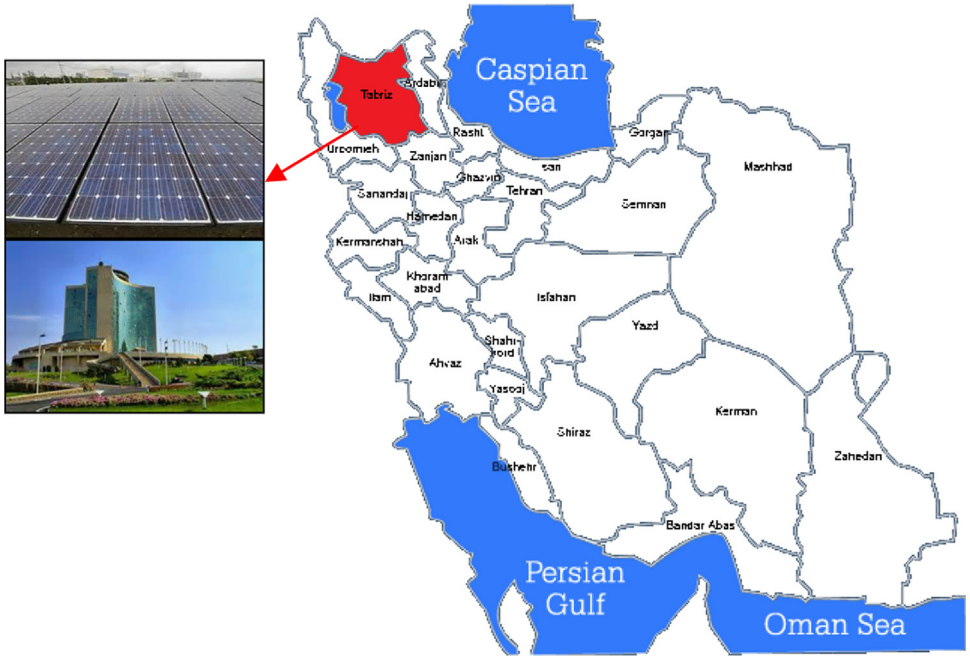

Fig. 11. Solar powerhouse of Tabriz with 5000 kW h capacity [82,26].

Table 5
The solar energy projects completed [74-86].

Project	Type of Tech.	State	Condition of completion	Capacity (kW)	Grid type	User
Solar power plant	PV	Semnan	Completed	27	Off-grid	AEOI
Solar power plant	//	Yazd	//	5	//	//
Develop. of solar power plant (Darbid Yazd)	//	Yazd	//	12	//	//
Develop. of solar power plant	//	Semnan	//	92	//	//
Photovoltaic	//	Khorasan	//	3.5	//	//
Shiraz power plant	Solar thermal	Fars	//	250	//	Univ./Ministry of energy
Solar lighting	//	Tehran	//	0.45	//	Ministry of Energy
Photovoltaic	PV	Tehran, Taleghan	//	30	//	Ministry of Internal affairs
Receiver system	Solar thermal	Tehran	//	1000	//	Ministry of Energy
Photovoltaic	PV	Tehran	//	4.5	//	Ministry of Energy
Solar water heater	Solar thermal	Yazd, Khorasan, Sistan and Isfahan	//	4312	//	//
Photovoltaic+ Solar lighting	PV	Evin hotel solar lighting+ solar rural electrification	//	12.6	//	AEOI
Rural electrification to 60 households	//	All of the country	//	50	//	Ministry of Energy
6 kW hybrid (Wind and solar)	//	Tehran, Energy deputy affairs building	//	6	//	//
Rural electrification to 634 households	//	All of the country	//	650	//	//

of country's income is from oil and gas which put extra pressure on its natural resources. Continuing the existing trend may lead to a path away from the goals of sustainable development set for the country. Therefore, the sustainability study should be of interest to decision-makers. The studies on the process of energy manufacturing shows that the production share of the renewable energies is still under 1%, although this share has increased over the last decade. Furthermore, over 50% of crude oil production and

petroleum products export, forces the economy to rely on natural resources. Iran is located in the world's Sun Belt and has an annual average of sun radiation about 20–30 MJ/m^2 that is even higher in the central regions (Fig. 8). Calculations have shown that the amount of actual solar radiation hours in Iran exceeds 2800 h per year [65–71]. Given the area of the country and solar radiation of the year, it is necessary to build more solar power plants for saving in excessive consumption of fossil energy [71–73].

Moreover, the sunny hours of the four seasons are 700 h during spring, 1050 h during summer, 830 h during autumn and 500 h during winter. Although Iran's solar potential is excellent, there was limited application to use this source of energy. One reason has been the fuel price for producing electricity and the other is the oil export, since 80% of Iran's income is based on oil and gas exports. Although the use of solar energy is traced back to ancient civilizations, it is still sensible to say that the technological harnessing of this energy source occurred only over the last four decades in Iran [54–60]. Besides thousands of small direct current individual photovoltaic units used in roads, highways, parks and communications, there are some solar photovoltaic units with a total installed capacity of around 650 MW. The solar thermal collectors, such as solar hot water panels, are commonly used to generate solar hot water for domestic and light industrial applications. The design and manufacture of solar water pumps, solar water distillation of various types, design and simulation of solar collectors of different types, solar refrigerators and solar air heaters are some of the other examples. Similar projects have also been carried out by some universities, research institutions, and also the Ministry of Energy research center [69–71]. Nowadays, solar powerhouses in Iran are mainly PV with the capacity of about 0.1% of whole reproducible capacity of the country which has been raised to be compared with the previous years. Some activities have also been carried out in the field of solar thermal applications in the country, launching the first phase of Shiraz solar thermal power plant with a capacity of 250 MW, is regarded as one of the most important projects [70–73]. A concentrating solar power (CSP) plant is situated in Shiraz, the Fars province which was becoming operational in 2008. It is a project aimed at developing technologies needed for larger solar power plants, and is currently being upgraded to the capacity of 500 MW (Fig. 9) [26,71–81].

The Yazd integrated solar combined cycle power station is another important solar project in Iran which is a hybrid power station situated near Yazd, which became operational in 2009 [71–81]. It is the world's first combined cycle power plant using solar power and natural gas. The plant has a capacity of 467 MW and uses solar energy to augment its steam generation by concentrating solar power technology (Fig. 10). Yazd integrated solar combined cycle power station at the start of 2010 was the eighth largest solar power plant in the world. Installation of nearly 18,000 solar water heaters was another activity in the field of household, official and commercial applications of solar energy. Moreover, about 77,000 m^2 of solar collectors were installed during Iran's third and fourth national development plan [71–81]. The specifications of the Shiraz and Yazd power station has been summarized at Table 4 [26,71–81].

30 kW Solar electricity photovoltaic projects were carried out in Darbid and Sarkavir powerhouses. Also solar powerhouse of Tabriz with 5000 kW h capacity has been added and the production of solar electricity was increased to 72,000 kW h in 2009 (Fig. 11).

Table 6
Electricity production supply from photovoltaic sites of Iran (1998–2012) (kW h) [43,74–87].

Year	Semnan site	Taleghan site	Yazd site	Total
1998	21,000	–	–	21,000
1999	20,000	–	–	20,000
2000	73,000	–	12,400	85,400
2001	96,000	–	14,100	110,100
2002	14,500	22,000	11,100	47,600
2003	63,450	45,000	10,800	119,250
2004	83,300	45,000	8,900	137,200
2005	25,000	10,000	18,000	53,000
2006	20,000	42,000	17,000	79,000
2007	24,000	32,000	15,000	71,000
2008	21,000	38,000	15,000	74,000
2009	22,000	38,000	15,000	75,000
2010	23,000	33,000	16,000	72,000
2011	24,000	38,000	14,000	76,000
2012	26,000	39,000	17,000	82,000

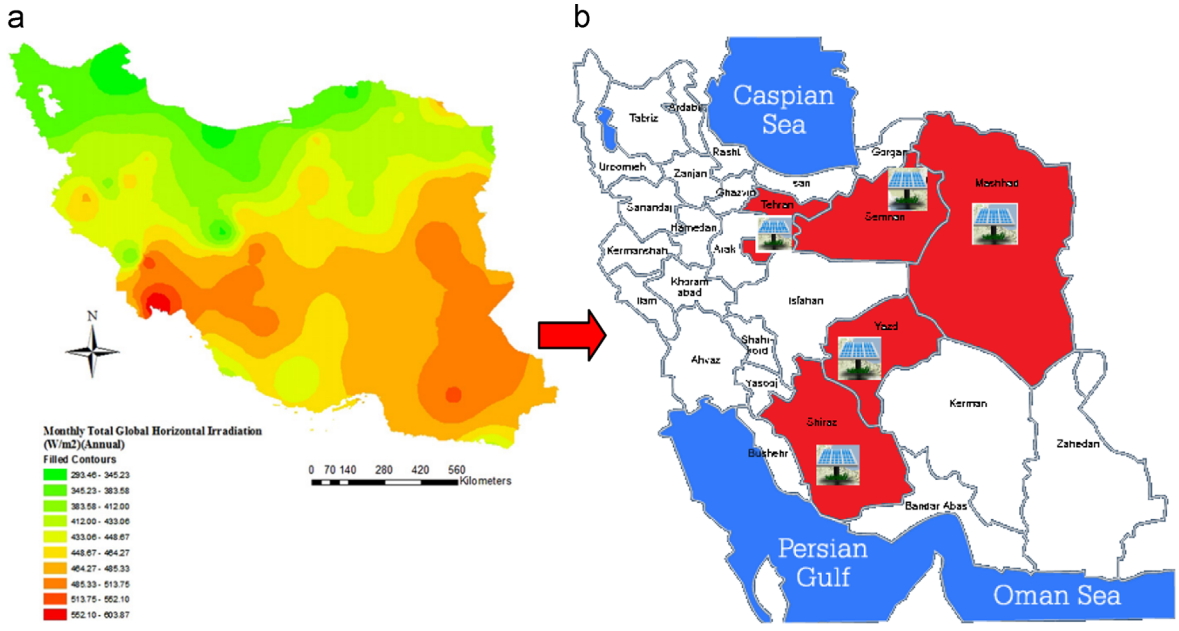

Fig. 12. (a) Annual average of total radiation on a horizontal surface [83], (b) The solar energy projects completed in Iran.

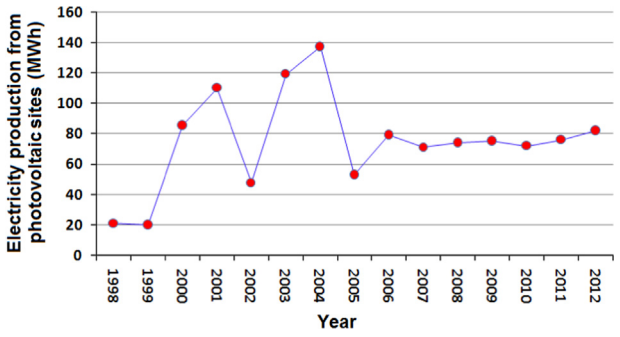

Fig. 13. Total solar electric generation in Iran from 1998 to 2012 [87,43].

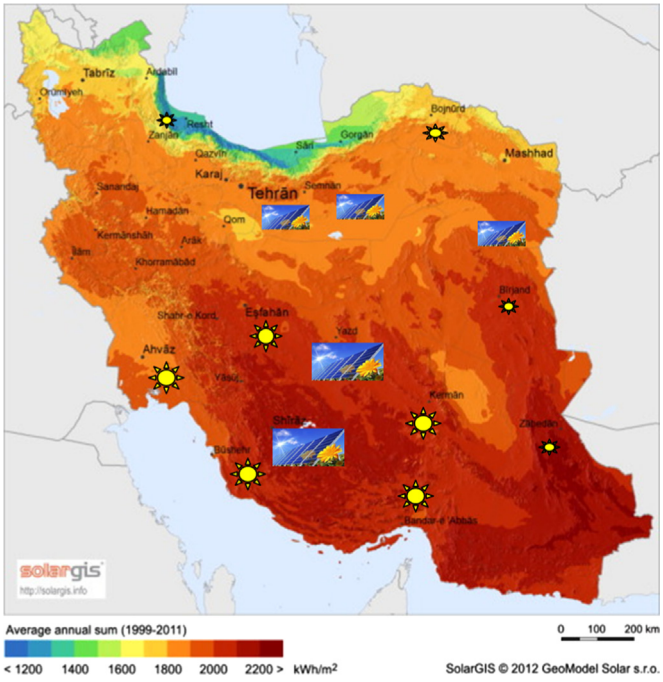

Fig. 14. Solar energy plants in Iran [25,26].

The solar energy projects completed have been listed at Table 5 and the provinces that these projects were carried out and completed have been indicated at Fig. 12. All of these projects was done based on the map for annual average of total radiation on a horizontal surface for the country. Among the incentive actions of government related to the solar energy projects, buying the produced electricity with incentive and guaranteed prices and paying loans can be mentioned. Iran has recently passed laws and incentives to encourage domestic and foreign investment in renewable energy projects. On the other hand, they consider a justifiable profit rate for reproducible projects. Setting-up international collaborative business venture between Iran renewable energy organization (SUNA) and private renewable energy sectors is proposed as an implementation strategy in Iran [26,74–86]. Table 6 and Fig. 13 show the energy production of photovoltaic sites between 1998 and 2012. The electricity production trend study shows 74% overall growth in 14 years and in 2012 the electricity production was equivalent to 44 barrels of oil.

Due to some technical problems in some plants, electricity production dropped in 2002 and 2005 (Fig. 13).

Solar energy plants are situated in Shiraz, Semnan, Taleghan, Yazd, Tehran and Khorasan. Some of the other projects were carried out by Iran Renewable Energy Organization (SUNA), such as Taleghan solar energy park, Design, fabrication and installation of 350 solar water heaters at Bushehr, Tabas, Yazd, Bojnoord, Zahedan and Isfahan. The SUNA experts are attempting to extend the utilization of solar energy at some rural zones of Kerman, Mazandaran and Zanjan cities (Fig. 14).

Iran officially inaugurated the country's biggest solar power plant on August 27, 2014 in Malard—which is located in Centeral Alborz province (Fig. 15). The peak power of the plant is 190 MW h per year. The facility has the capacity to produce 514 kW h per day of electricity (190,000 kW h of electrical power each year), which is two times more that the capacity of the country's 2nd biggest solar plant. Shiraz solar power plant's production capacity is 250 kW h/day [26].

The Iranian government has also apparently been installing large numbers of solar panels on rooftops around the country-everywhere from schools to government buildings-at over a 1000 new locations specially at rural areas (Fig. 16).

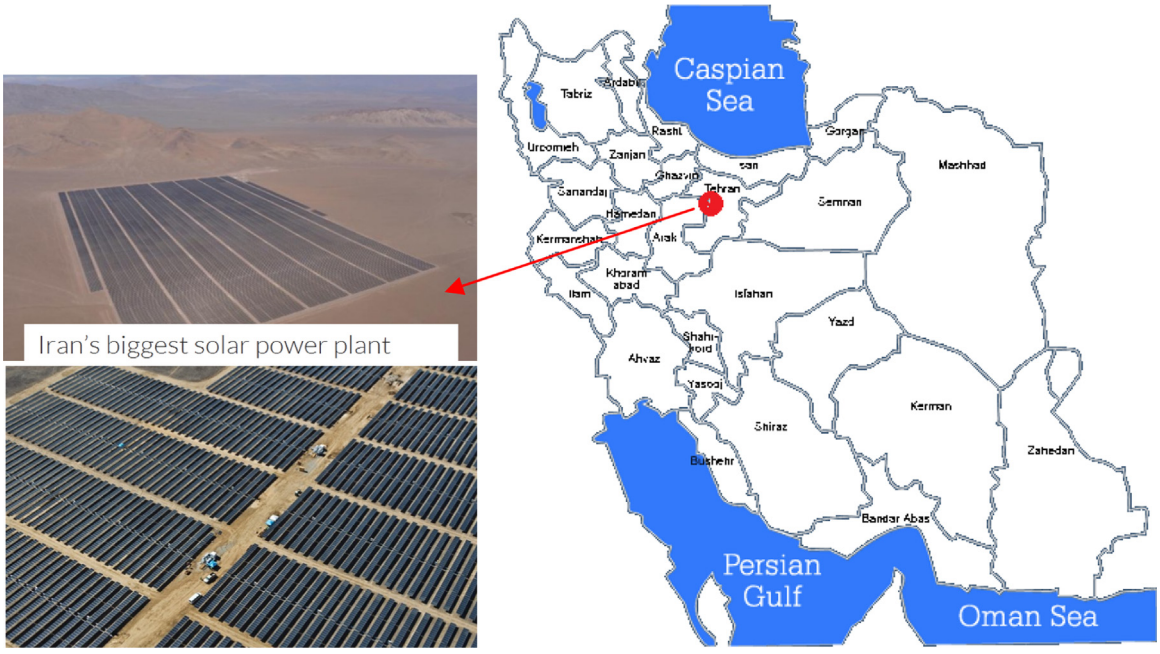

Fig. 15. Iran's biggest solar power plant in Malard-located in Centeral Alborz province [74,26].

Fig. 16. installing large numbers of solar panels on rooftops around the country-buildings-at over a 1000 new locations specially at rural areas [83,26].

Fig. 17. The largest solar power plant of the Iran based on DG technology in Kerman province [86,26].

5.2. Outlook of solar energy in Iran

Iran plans to construct some solar panels with the capacity to produce 485 MW of electricity. Iran now is the world's 14th biggest of solar power plants. The country's total potential for producing solar and wind energy is estimated to be around 40,000 GW h and 100,000 MW h [26]. Electricity production in Iran was about 212.8 (billion kW h) and electricity consumption was 206.7 (billion kW h) in 2012 [25,91]. Iran seeks to become a major regional exporter of electricity and has attracted more than $1.1 billion in investments for the construction of three new power plants. Iran currently trades power with Turkey, Armenia, Turkmenistan, Azerbaijan, Pakistan, Afghanistan, Syria and Iraq. Iran has plan to install over 5 GW of new renewable energy capacity by the year 2018, enough to power as many as two million homes, 25 times what it is now. While a large portion of the new capacity will surely be via wind energy, 500 MW of it will be via solar energy, as the portion of funding has been set aside for solar already [88]. A number of renewable power plants with the capacity to produce 500 MW h of electricity will be connected to the country's national grid by next year (2015). Over the past 14 years only some renewable power plants with the capacity to produce only 95 MW h of electricity have come on stream [89]. The power generation capacity in Iran has grown by 7% annually during the past 10 years, adding that the figure has averaged 3.5% across the world. Several contracts have been signed for the construction of power plants to generate 1000 MW of electricity from wind and solar power [90]. Iran has also instituted a "feed-in tariff", a policy mechanism that guarantees a fixed price for renewable power, and which has been responsible for dramatic growth of renewable energy in several European countries. In addition, the government is offering to cover up to 50% of the cost

of installing residential PV arrays. The country recently passed a number of new laws intended to encourage and support domestic and foreign investment into renewable energy projects there. Iran will be able to double its energy production by March 2015 [57]. The new power plant is aimed at producing electricity based on Distributed Generation (DG) technology. Distributed Generation (DG) is electricity generation that occurs at or near the point of use that includes many renewable energy options such as photovoltaic cell, wind turbines, biomass generation, fuel cells, microturbines and small onsite diesel and gas generators. Solar thermal technologies and demand side management technologies, aimed at reducing energy consumption, are sometimes included in the slightly broader concept of DG. DG clean power offerings focus on the use of solar renewable energy, provide electric generation options in transmission congested areas, improve energy supply options and help reduce energy consumption [57]. The largest solar power plant of the country based on DG technology will be established in Kerman province (72 MW h of electrical power each year) (Fig. 17).

6. Conclusion

The following conclusions are drawn from this paper:

1- Although Iran is rich in oil, gas and other fossil energy resources, yet it has opted to turn to renewable energy sources.
2- Iran's total area is around 1600,000 km^2 or 1.6×10^{12} m^2 with about 300 clear sunny days in a year and an average 2200 kW-h solar radiation per square meter.
3- Considering only 1% of the total area with 10% system efficiency for solar energy harness, about 9 million MW h of energy can be obtained in a day.
4- The Iran's existing small capacity solar energy plants are in Shiraz, Semnan, Taleghan, Yazd, Tehran and Khorasan.
5- Taking advantage of Iran's 300-odd days of sunshine a year, make its vast sun-kissed lands one of the best spots on earth to host solar panels.
6- Due to high growth rate of electricity demand in Iran, the nominal installed capacity has increased by 8.9% per annum during 2001–2007. Assuming a flat growth rate of 5% per annum, the nominal installed electricity capacity will reach to 139,298 MW in 2030.
7- In the reference scenario, the share of RES in total installed electricity capacity is expected to be about 2% in 2030. It is expected that the cumulative RES installed capacity will reach 2.8 GW in 2030.

This requires more than 2800 million US dollar investment during 2010–2030. More than 60% of this investment will be likely allocated to small hydro, 20% to geothermal, and 10% to solar and wind electricity projects.

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