A Review of Renewable and Sustainable Energy Potential and Assessment of Solar Projects in Iran

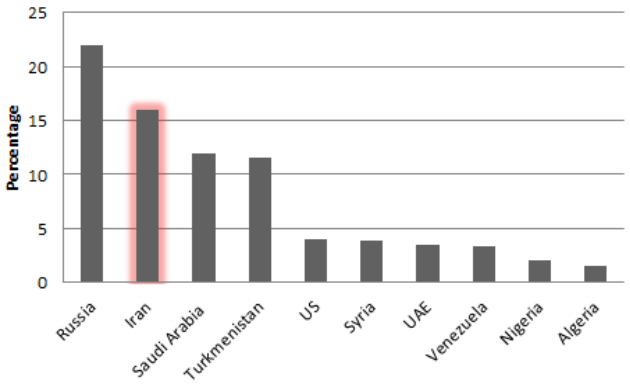
Shayan Fathi and Arash Mirabdolah Lavasani

***Abstract*—Using renewable energy is one of the most promising paths towards the sustainable development, especially in oil dependent economy nations like Iran. In present study, recourses, status and prospect of solar energy in Iran was investigated. Among renewable energy sources, Iran has a high solar energy potential with more than 300 clear sunny days in a year and average 2300 kW-h solar radiation per square meter. Considering just 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. Iran had a plan to install 53,000 MW capacity plants for electricity generation. The existing small capacity solar energy plants are in provinces of Shiraz, Taleghan, Yazd, Semnan, Khorasan and Tehran. Based on the specified available solar through technology, solar area, average solar hours and average solar direct irradiation, the technical potential of solar electricity was estimated to be 14.7 TWe. 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 electricity capacity will reach 2800 MW in 2030 and it needs more than 2800 million US dollar investment among 2010-2030.**

***Index Terms*—Renewable energy, solar energy, electricity, Iran.**

I. Introduction

Developing country Iran is located in the Middle East, has the area of 1,648,195 km^2 and the population of around 78 million. The most land area of Iran is classified as arid and semi-arid with an average anneual rainfall of 228 mm and with average temperature of 19-38 ℃ in summer and 10-25 ℃ in winter [1]. Today the energy of the world is mostly provided by different kinds of fossil fuels like oil, coal and natural gas. Around 66% of required electricity of the world is generated based on fossil fuels utilization. The economy of Iran relies on crude oil export strongly and the fluctuations of oil price impact on country's development [2]. Statistics show that Iran holds the fourth largest crude oil reserves and is the second largest natural gas reserves in the world [3]. Iran benefits enormous oil and natural gas reservoir as shown in Fig. 1. International Energy Agency has anticipated that natural gas and crude oil will be run out in the next 60.3 and 41.8 years, respectively; so it is expected that renewable and sustainable energy (RSE) will the most important energy source in future [4]. Electricity demand in Iran has been reported to be 50,000 MW which is around 80% of what has been generated by the fossil fuel consumption. It has been projected that Iran's electricity demand will be 200,000 MW in 2030 [5]. Recently, transition to the renewable and sustainable energy resources has been has been accepted as a crucial factor in energy mix and different programs for green energy development have been established by Renewable Energy Organization (REO) of Iran. Also Research Institute of Petroleum Industry (RIPI) formed Renewable Energy Initiative Council (REIC) to organize RSE development in Iran in 2008.



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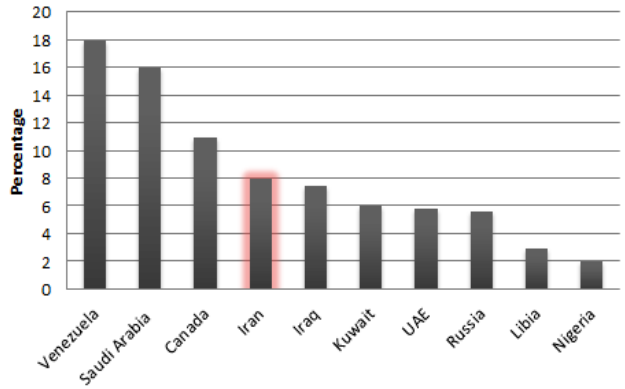

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Fig. 1. (a) Top 10 oil reservoir countries; (b) Top 10 natural gas reservoir countries [4].

Generation of 2000 MW energy has been planned based RSE resources' utilization until the year 2015 by Iranian government; therefore, some private companies signed contracts to establish biomass and wind power plant with 600 MW and 500 MW capacities respectively at 2010. In 2012, Iran dedicated €500 million from the National Development Fund (NDF) for green energy development. Furthermore, Renewable Energy Organization of Iran (SUNA) which is the state-sponsored supported by Ministry of energy works on solar energy development and its annual budget is around US$60 million [6]. One of the most advantages of using renewable and sustainable energy is decrease of greenhouse

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The authors are with the Mechanical Engineering Department, Islamic Azad University Central Tehran Branch, Iran (e-mail: nsky221@gmail.com).

gases (GHGs). GHGs are generated in the process of energy production, conversion, consumption and distribution in the world [7]. The increasing rate of GHGs generation due to exorbitant fossil fuel consumption has serious impact on human life and especially on Global Warning (GW) phenomena [8].

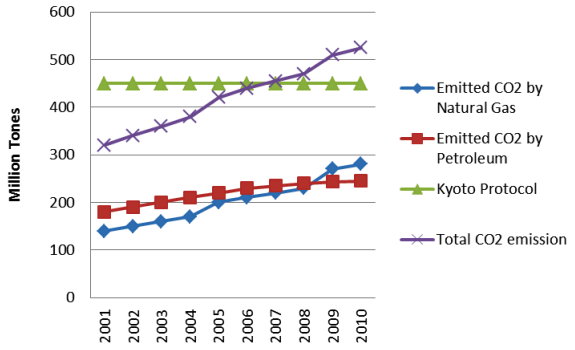
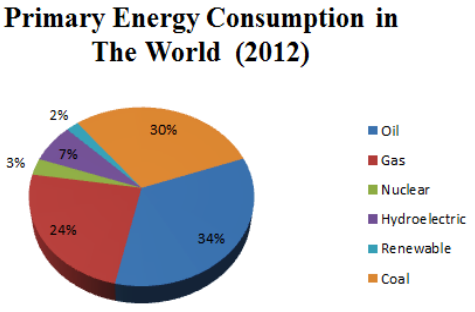


Fig. 2. The trend of CO_2 emission in Iran among 2001-2010 [8].

As the main part of energy demand in Iran has been proved by fossil fuels, Iran has become one of the 20 countries to have a contribution in 75% of GHGs generation [9]. Recently, the rate of CO_2 emission from different resources in Iran passed the Kyoto Protocol (KP) limitations and this country has been introduced as the 10th worldwide country in carbon dioxide generation as shown in Fig. 2 [10].

II. Energy Consumption in the World

Oil and natural gas are major primary energy resources in Iran. The main oil field is located in the southwest of the country and in the Persian Gulf. Although a majority of energy resources in Iran and other countries rely on oil and gas reservoirs, developed countries have investigated on renewable and sustainable energy resources. Primary energy consumption in the world and in Iran has shown in Fig. 3 [4].



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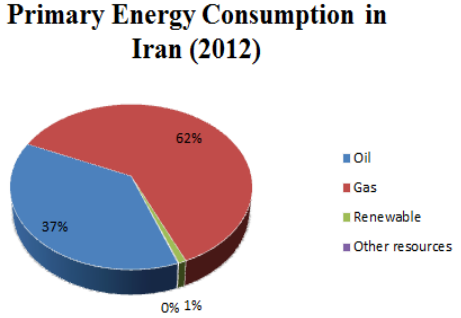

(b)

Fig. 3. Primary energy consumption of Iran and the world in 2012 [4].

III. Solar Energy in the World

The sun has produced energy for billions of years. Solar energy can be used for heat and electricity in two main methods. Photovoltaic (PV devices) change sunlight directly into electricity. Individual PV cells are grouped into panels and arrays of panels that can be used in a wide variety of applications ranging from single small cells that charge calculator and watch batteries, to systems that power single homes, to large power plants covering many acres. Hundreds of thousands of houses and buildings around the world have PV systems on their roofs. Covering 4% of the world's desert areas with photovoltaic could supply the equivalent of all of the world's electricity. The Gobi Desert alone could supply almost all of the world's total electricity demand.

New installations totaling 40.2 GW in 2014 took global solar power generating capacity to 180 GW by year-end, a 28.7% increase versus the end of 2013. Capacity has more than quadrupled in the past four years. The largest increments in 2014 were recorded in the Asia Pacific region as shown in Fig. 4; China added 10.6 GW, just ahead of Japan with 9.7 GW, together accounting for more than half of the growth in global solar capacity. The US provided the third largest addition (6.2 GW). Germany remains the world leader for cumulative installed capacity (38.2 GW), but China (28.2 GW) and Japan (23.3 GW) have both overtaken Italy to take second and third place. Solar power generation enjoyed another year of very rapid growth in 2014, with a 38% increase. Its overall share of global power generation remains low (0.8%), but that share has doubled in just two years. Solar is starting to have a noticeable impact in terms of sources of power generation growth, contributing nearly 15% of the growth of global power in 2014.

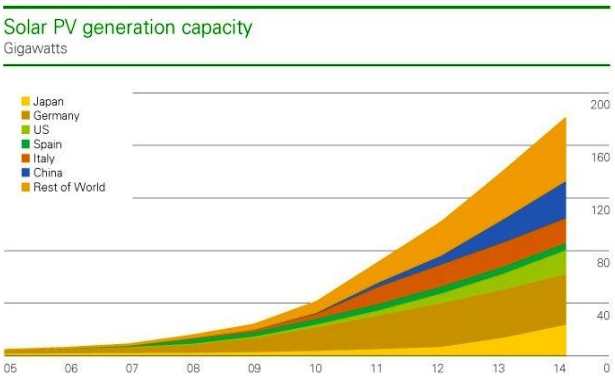

Fig. 4. Solar photo voltaic capacity in the world among 2006-2014 [4].

The total global solar power capacity will grow from 98 GW in 2012 to 308 GW in 2018 [11]. New installations totaling 30.2 GW in 2012 took global solar power generating capacity to 100GW 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 (7.6GW) and Italy (3.4GW). Germany remains the world's leader for cumulative installed capacity (32.6GW) and Italy (16.2GW) comes in second. The top markets-Germany, Italy, China, the United States, and japan were also the leaders for total capacity [12]. Solar thermal power plants generate electricity by concentrating solar energy to heat a fluid and produce steam that is then used to power a generator. Solar energy systems do not produce air

pollutants or carbon dioxide. On the other hand, the amount of sunlight that arrives at the earth's surface is not constant and it depends on location time of day, time of year and weather conditions [13]. Because the sun does not deliver that much energy to any one place at any one time, a large surface area is required to collect the energy at a useful rate (see Fig. 5). Total concentrated solar power capacity has been indicated at Table I.

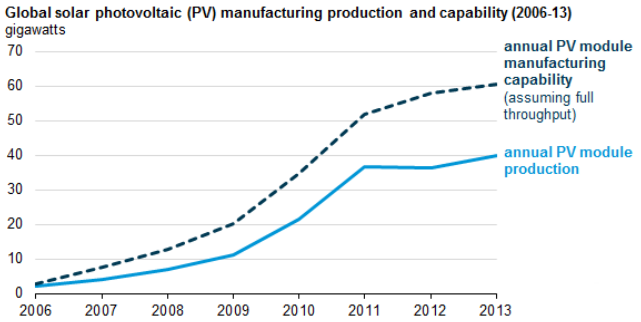

Fig. 5. Comparison between solar photovoltaic manufacturing capacity and production [4].

TABLE I: TOTAL CONCENTRATED SOLAR POWER CAPACITY (MW P)

Country or region	Total 2005	Total 2006	Total 2007	Total 2008	Total 2009	Total 2010	Total 2010
World	354	355	438	494	896	1193	1707
EU	0	0	11	62	384	638	1108
Spain	0	0	11	61	382	632	1102
USA	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

IV. SOLAR ENERGY IN IRAN

A. Current State

99% of energy production in Iran comes from oil and gas and just about 1% from renewable energy sources. Since Iran has rich fossil fuel recourses, little attention has been paid so far to explore alternative energy production. Iran is located in the world's Sun Belt and has an annual average of sun radiation about 20-30 MJ/m^2 and the amount of actual solar radiation hours exceeds 2800h per year. Moreover, the sunny hours of the four seasons are 700h during spring, 1050h during summer, 830h during autumn and 500h during winter (see Fig. 6) [14]. Many small direct current individual photovoltaic units used in highways, roads and parks, there are some solar photovoltaic units with a total installed capacity of around 650MW [15]. The solar thermal collectors, such as solar hot water panels, are commonly used to generate solar hot water for domestic industrial applications. Today, solar powerhouses in Iran are mainly PV with the capacity of about 0.1 % of whole reproducible capacity of the country (see Fig. 6). Some other activities in the field of solar thermal application have also been carried out, launching the first phase of Shiraz and Yazd solar thermal power plant with a capacity of 250 MW and 467MW respectively, is regarded as the most important projects in 2009 [16]. The Yazd integrated solar combined cycle power station is another solar project in Iran which is a hybrid power station situated in in Yazd province and became operational in 2009 [17]. It is the world's first combined cycle power plant using solar power and natural gas. The plant has a capacity of 467 MW. Yazd integrated solar combined cycle power station in 2010 was the eighth largest solar power plant in the world. Installation of 18,000 solar water heaters was another activity in the field of household, official and commercial applications of solar energy. Solar energy plants are situated in Shiraz, Semnan, Taleghan, Yazd, Khorasan and Tehran. 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 more than 350 solar water heaters as Bushehr, Tabas, Yazd, Bojnoord, Zahedan and Isfahan. Total solar electric generation in Iran has grown significantly and the most important photovoltaic sites are represented in Table II.

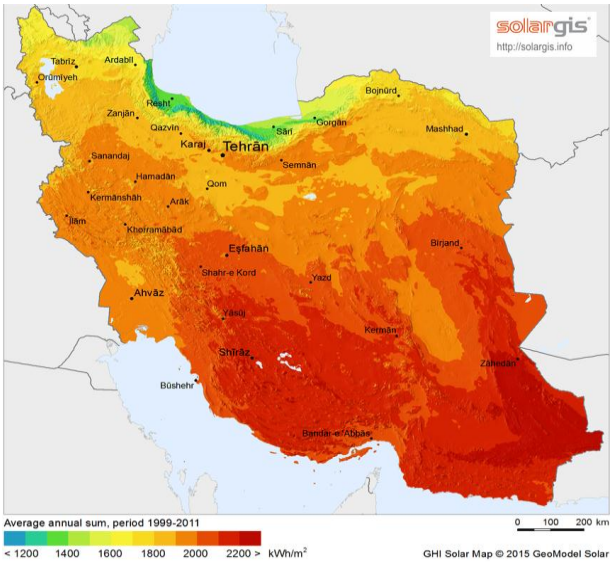

Fig. 6. Solar radiation map of Iran according to Solar GIS.

The electricity production shows 74% overall growth in 14 years and in 2012 the electricity generation was equivalent to 44 barrels of oil. Because of some technical problems in some pants, electricity production dropped in 2002 and 2005 (see Fig. 7). Iran officially inaugurated the country's biggest solar power plant on August 27, 2014 in Malard which is located in Alborz province. 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 (190,000kW h of electrical power each year), which is two times more that the capacity of the country's second biggest solar plant. Shiraz solar power plant's production capacity is 250 kW h/day [18] (see Fig. 8).

TABLE II: ELECTRICITY PRODUCTION SUPPLY FROM PV SITES OF IRAN (KW H) [20]

Year	Semnan site	Taleghan site	Yazd site	Total
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
2013	27,000	40,000	17,000	84,000

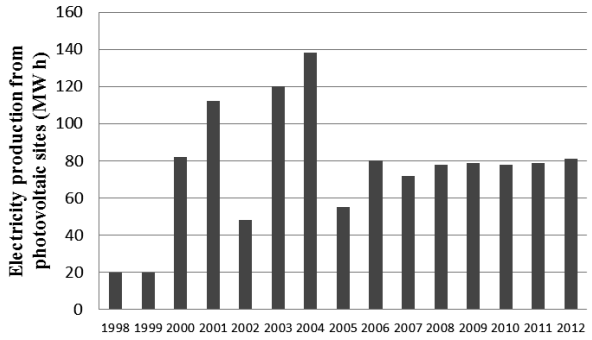

Fig. 7. Total solar electric generation in Iran between 1998 and 2012.


(a)


(b)


(c)


(d)

Fig. 8. (a) Iran's biggest solar power plant (Malard); (b) Shiraz solar power plant; (c) Yazd solar power plant; (d) Taleghan solar power plant [20].

B. Outlook of Solar Energy in Iran

Iran plans to construct some solar panels with the capacity to produce 458 MW of electricity [20]. Iran now is the world's 14th biggest of solar and wind energy is estimated to be around 40,000 GW h and 100,000 MW h [21]. Electricity generation in Iran was about 212.8 (billion kW h) and electricity consumption was 206.7(billion kW h) in 2012 [22]. 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 [23]. 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 in 2016. 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 [24]. The power generation capacity in Iran has grown by 7% annually during the past 10 years and several contacts have been signed for the construction of power plants to generate 1000 MW of electricity from wind and solar power [25]. Iran is offering to cover up to 50% of the cost of installing residential PV arrays and also supports domestic and foreign investments in renewable energy. 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 [26]. The solar energy projects completed have been listed at Table III. 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).

TABLE III: SOLAR ENERGY PROJECTS IN IRAN [17]

Project	Technology	State	Capacity (kW)
Solar power plant	PV	Semnan	27
Solar power plant	PV	Yazd	5
Develop of solar power plant	PV	Yazd	12
Develop of solar power plant	PV	Semnan	92
Photovoltaic	PV	Khorasan	3.5
Shiraz power plant	Solar thermal	Fars	250
Solar lighting	Solar thermal	Tehran	0.45
Photovoltaic	PV	Tehran, Taleghan	30
Receiver system	Solar thermal	Tehran	1000
Photovoltaic	PV	Tehran	4.5
Solar water heater	Solar thermal	Yazd, Isfagan, Sistan, Khorasan	4312
Photovoltaic& solar lighting	PV	Evin hotel+ Solar rural electrification	12.6
Rural electrification to 60 households	PV	The whole country	50
6kW hybrid (wind and solar)	PV	Tehran, Energy deputy affairs building	6
Rural electrification to 634 households	PV	The whole country	650

V. Conclusion

Although Iran is rich in oil, gas and other fossil energy resources, yet it has opted to turn to reneable energy sources. Iran's total area is 1.6×10^{12} m^2 with about 300 clear sunny days in a year and an average 2200kW-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 Iran's existing small capacity solar energy plants are in Shiraz, Semnan, Taleghan, Yazd, Tehran and Khorasan. Taking advantages 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. Due to the 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 139,300 MW in 2030. 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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Shayan Fathi was born in Tehran on April 12, 1987. He received the B.S degree in mechanical engineering from Parand Islamic Azad University, Iran and the M.S degree in mechanical engineering from Sharif University of Technology, Iran. He is currently a PhD student in Mechanical Engineering Department at Islamic Azad University Central Tehran Branch.

Arash Mirabdolah Lavasani was born in Tehran on 1971. He received the B.S degree in mechanical engineering from Khajeh Nasir Toosi University of Technology, Iran and the M.S degree in mechanical engineering from Shahid Bahonar University of Kerman, Iran and the PhD degree in mechanical engineering from Islamic Azad University, Science and Research Branch. He is currently an assistant professor of Mechanical Engineering Department at Islamic Azad University Central Tehran Branch.