International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-018-1779-7

REVIEW

Potential of solar energy in Iran for carbon dioxide mitigation

A. Shahsavari[1] · F. T. Yazdi[1] · H. T. Yazdi[2]

Received: 24 May 2017 / Revised: 9 November 2017 / Accepted: 11 May 2018

Abstract

The majority of power plants installed in Iran are normally using the cheapest and most available fuels as input energy sources (e.g., natural gas and oil). Iranian fossil-fueled power plants annually emit nearly 180 million tons of carbon dioxide (CO_2), which contribute to global warming. On the other hand, the use of renewable energy for producing the needed electricity significantly reduces the greenhouse emissions and polluting gases. Therefore, the environmental and health costs of producing electrical energy using fossil fuels are significantly higher than renewables, which are often unseen. Among the best available renewable energy sources, Iran benefits from high solar insolation with around 300 clear days annually and also large areas of available land. This shows that the solar systems utilization in Iran will be very economical. Despite this vast potential, Iran's solar market has remained undeveloped. The installed capacity of solar energy was around 17.3 megawatts (MW) by 2015, while each kilowatt-hour of solar electricity could save around 715 g of CO_2. The utilization of solar energy technologies is increasing around the world, which are due to technological progress, policy changes, the urgent need to reduce reliance on carbon-intensive energy sources like coal, oil and natural gas and the need to reduce greenhouse gases emission to the atmosphere. In conclusion, production of electrical and any other type of useful energy using solar systems can protect the environment. Thus, to achieve a sustainable future they should be employed as much as possible and wherever it is possible.

Keywords Greenhouse gas emissions · Electricity production · Fossil fuels · Renewable energies

Introduction

Increasing population and rising standards of living for many people in developing countries have caused remarkable growth in energy demand (Chaianong and Pharino 2015). Currently, fossil fuels are the world's primary energy source. The burning of fossil fuels is responsible for approximately 90% of the anthropogenic carbon dioxide (CO_2) emissions that produced each year (IEA 2015a; Moutinho and Robaina 2016). Consequently, atmospheric CO_2 concentrations have risen from 280 parts per million by volume (ppmv) in the eighteenth century to more than 400 ppmv in 2015. Carbon dioxide is the main greenhouse gas that plays the most important role in recent climate change (EPA 2016a; NOAA 2013; NASA 2017). Climate change has direct and indirect impacts on the public health: negative extreme weather events, heat waves, the spread of infectious diseases and negative effects on air and water quality as well (EPA 2016b). It is estimated that the direct damage costs of climate change to health will be between 2 and 4 billion US dollars each year by the year 2030 worldwide (WHO 2016).

In 2014, the power generation sector consumed about 42% of global energy. It is estimated that the share of power generation will increase to 45% by 2030 (BP 2016). Conventional power plants produce greenhouse gases such as CO_2, NO_x and SO_2, which are known contributors to global warming. Nowadays, the power sector has identified as main culprit of GHG emissions worldwide. Electricity and heat sectors produced, nearly two-thirds of the global CO_2 emissions in 2014, which accounted for about 42% emissions from electricity generation sector specifically increased by 50% from 2000 to 2014 (IEA 2015a).

In addition, generation of electricity by combusting fuels also emits air pollutants that are harmful to public health as well as the environment (NREL 2016). Air pollution

Editorial responsibility: M. Abbaspour.

✉ A. Shahsavari
amir.shahsavari@mail.um.ac.ir

1 Faculty of Natural Resources and Environment, Ferdowsi University of Mashhad, Mashhad, Iran

2 Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

Published online: 07 June 2018

imposes remarkable costs to the economy and creates negative impacts on the environment (IEA 2016a). According to the World Health Organization (WHO), around 7 million people died due to air pollution worldwide in 2012, so air pollution is now the largest single environmental health risk around the world (WHO 2014; NRDC 2017; Lambrechts and Sinha 2016; Chandrappa and Kulshrestha 2015). It is, therefore, essential to go for eco-friendly sources of energy for the improvement in the future electricity production. There are various technologies to reduce emissions on the planet, especially renewable technologies with different performances.

Renewable energies are clean and therefore do not produce significant greenhouse and net carbon emissions. Utilization of renewables for electricity production plays a significant role in power sector mitigating emissions (IEA 2015a; IRENA 2016a). Furthermore, they will not deplete natural resources and have minimal, if any, negative impacts on the environment compared with fossil fuels. Doubling the renewable share contributes to achieving a carbon-free energy system in the next years. It would also reduce the challenges of energy security worldwide and risks to human health and the environment. Nowadays, renewable energy technologies can become more cost-competitive option than other energy sources in order to generate power (IRENA 2016a). In 2015, renewable sources accounted for more than 24% (5830 terawatt-hours) of all global electricity generation (NREL 2015), and it is expected to generate more than 60% of electricity through non-fossil sources in the world by 2050 (Grundy 2008). Therefore, on average, every 1 gigawatt (GW) of extra renewable energy capacity mitigates 3.3 million tons CO_2 per annum (Sharma et al. 2012). During 2011 to 2050, the emissions can be reduced to almost 500–30 g/kWh by using low-carbon technologies (IEA 2014a).

Solar energy is considered as a clean and renewable source of energy and easily accessible to mankind and can be used for generating electricity or heat. The utilization of solar energy technologies like photovoltaics (PVs) for the everyday electricity production has many advantages for human and the environment including avoids consuming resources and degrading the environment via polluting emissions, toxic substances and oil spills (Omer 2008). Solar energy is widely available all over the world, but it provides a small fraction of the global current energy mix. In 2015, approximately 2% of the global electricity was generated using PV. In recent years, solar PV power technology is growing rapidly around the world and is projected to play a significant role in the future electricity generation mix (IRENA 2016b). PV systems installed by the end of 2013, generated 160 terawatt-hours (TWh) of clean electricity, so avoiding almost 140 million tons of CO_2 emission annually. The capacity of the installed PV 4600 GW would avoid more than 4 gigatons (Gt) of carbon dioxide emission per year in 2050 (IEA 2014b).

Iran is one of the largest countries in the Middle East, and its population is growing and reached more than 79 million people in 2015 and is projected to increase by 92 million in 2050 (UN 2015). This country holds the second largest natural gas reserves and the fourth largest oil reserves worldwide (EIA 2015). In this country, the majority of power generation units are using conventional fuels such as natural gas and oil (IEA 2016b). Thermal power stations using fossil fuels (i.e., coal, oil and natural gas) produce particulates, oxides of sulfur (SO_x), nitrogen oxides (NO_x), carbon and negligible amounts toxic metals such as mercury and arsenic (Mishra 2004). This situation not only increases the amount spent fossil fuels but also raises the level of greenhouse gases (mostly carbon dioxide) emissions of Iran. In this country, power-generating capacities from conventional supplies, particularly natural gas, have continuously increased for a decade. Iran faces a fast-growing demand for production of electricity, and an annual average growth rate of electricity generation has been 5% in the last 10 years (Tavanir 2015). CO_2 production is directly related to electricity consumption. Therefore, a practically unchanged carbon content in the energy mix and growth in population and energy demand in power sector caused a dramatic increase in CO_2 emissions, which is indicated in Fig. 1. In recent years, Iran generally experienced a constant growth of emissions, due largely to burning of fossil fuels and population growth. Burning fossil fuels released 321 million metric tons of carbon dioxide in the year of 2000. While in 2014, CO_2 emissions increased by 646 million tons, two times more than the level of CO_2 emissions in 2000, as illustrated in Fig. 1 (Enerdata 2015b). Increasing CO_2 emissions from fossil-fueled power generation sectors in Iran, which have led the amount of GHG emissions, has passed the Kyoto Protocol (KP) limitations (Hosseini et al. 2013). The increase in CO_2 emissions in Iran has caused one of the ten greatest carbon producers worldwide and also in the Middle East's top contributor to atmospheric carbon dioxide (IEA 2015a; Enerdata 2015a; Nejat et al. 2015).

In the future, power generation sectors should meet basic requirements in all the three principles of sustainable development (i.e., ecology, economy and society), mainly: (1) reduce negative impacts on human and environmental health, (2) cut down the emissions of GHGs in order to mitigate climate change, (3) reduce indirect costs and support a sustainable economy, (4) it should be safe, affordable, secure and locally acceptable (Treyer et al. 2014). Solar energy can be a promising technology to assist CO_2 mitigation and help transform Iran into a sustainable society. If we are serious about reducing carbon pollution and other pollutants due to traditional energy consumption, then renewable energies must be a part of the solution. Furthermore, as fossil fuels

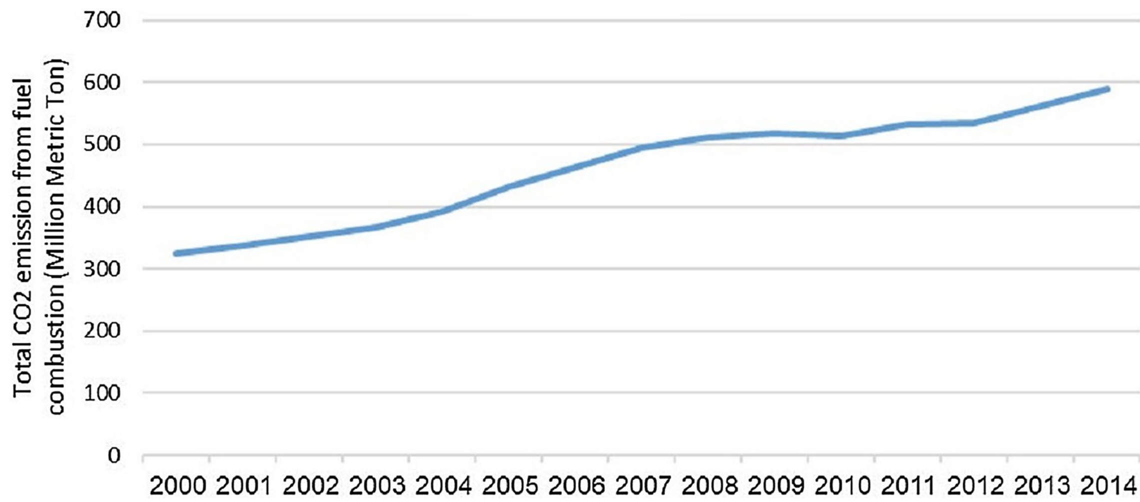

Fig. 1 CO_2 emission

are set to decline in the years to come, it is important to us move toward renewable and sustainable energy sources.

This review paper has discussed the potential of solar energy in Iran, solar energy technologies, advantages of solar energy utilization, sustainability indicators of renewable technologies, sources used for electricity generation in Iran, the emissions level from Iranian fossil-fueled power plants, the current status of solar energy utilization in Iran and barriers for better solar energy utilization.

Solar energy potential in Iran

Solar energy as a renewable energy is free radiant light and heat from the sun that is restrained using various technologies to produce electricity and heat for homes and businesses. Harnessing just 25% of the sunlight that strikes the Earth's surface could meet all current energy needs on a global scale (Souvik et al. 2016). Iran is geographically strategic, because it is located in Southwest of Asia, Middle East region, which has a broad desert surfaces and cloudless skies. This country is very favorable for renewable energy with a large-scale land area of 1,648,195 km^2, the Alborz Mountains and the Caspian Sea in the north, the deserts in the east and the Persian Gulf in the south; it comprises a large variety of natural environments. Solar energy has very different potentials in each region of Iran. Figure 2 shows the potential areas of solar energy resource in Iran. As shown in Fig. 2, Iran is endowed with rich solar energy resource. Close to one-quarter of the country's lands are deserts, which receive daily solar irradiation of about 5.5 kWh/m^2/day, and on average, it has 300 sunny days per annum. Some of the regions of Iran are particularly well suited for solar energy utilization. In many regions, particularly the central and southern regions, solar radiation is intrinsic in quantity, which makes beneficial utility. The central and southern regions of Iran like Yazd, Fars and Kerman provinces have high solar irradiation with a DNI (direct normal irradiation) of about 5.2–5.4 kWh/m^2/day (IPG 2016). The annual average sunny hours of Iran are around 2900. The obtained energy will be five times higher than the yearly gross electricity production in Iran if only 1% of these regions are covered with solar collectors. By considering the area of Iran, the total amount of radiation is approximately 3.3 million TWh annually, which is 13 times more than the total energy consumption in this country (Gorjian and Ghobadian 2015). Therefore, there is a good opportunity to generate clean energy in the country through direct sunlight by solar systems.

The solar energy technologies

The applications of solar energy have been categorized into two major groups: concentrating solar power (CSP) and photovoltaic technologies (PVs) (Hernandez et al. 2014; U.S Department of Energy 2013). CSP converts solar radiation to produce heat by hundreds or thousands of mirrors to concentrate sunlight onto receivers that collect solar energy which can then be used to produce electricity. It is used primarily in very large power plants and is not suitable for residential utilization (Kannan and Vakeesan 2016; U.S Department of Energy 2013). CSP technologies will require a direct normal irradiance (DNI) of 5 kWh/m^2/day

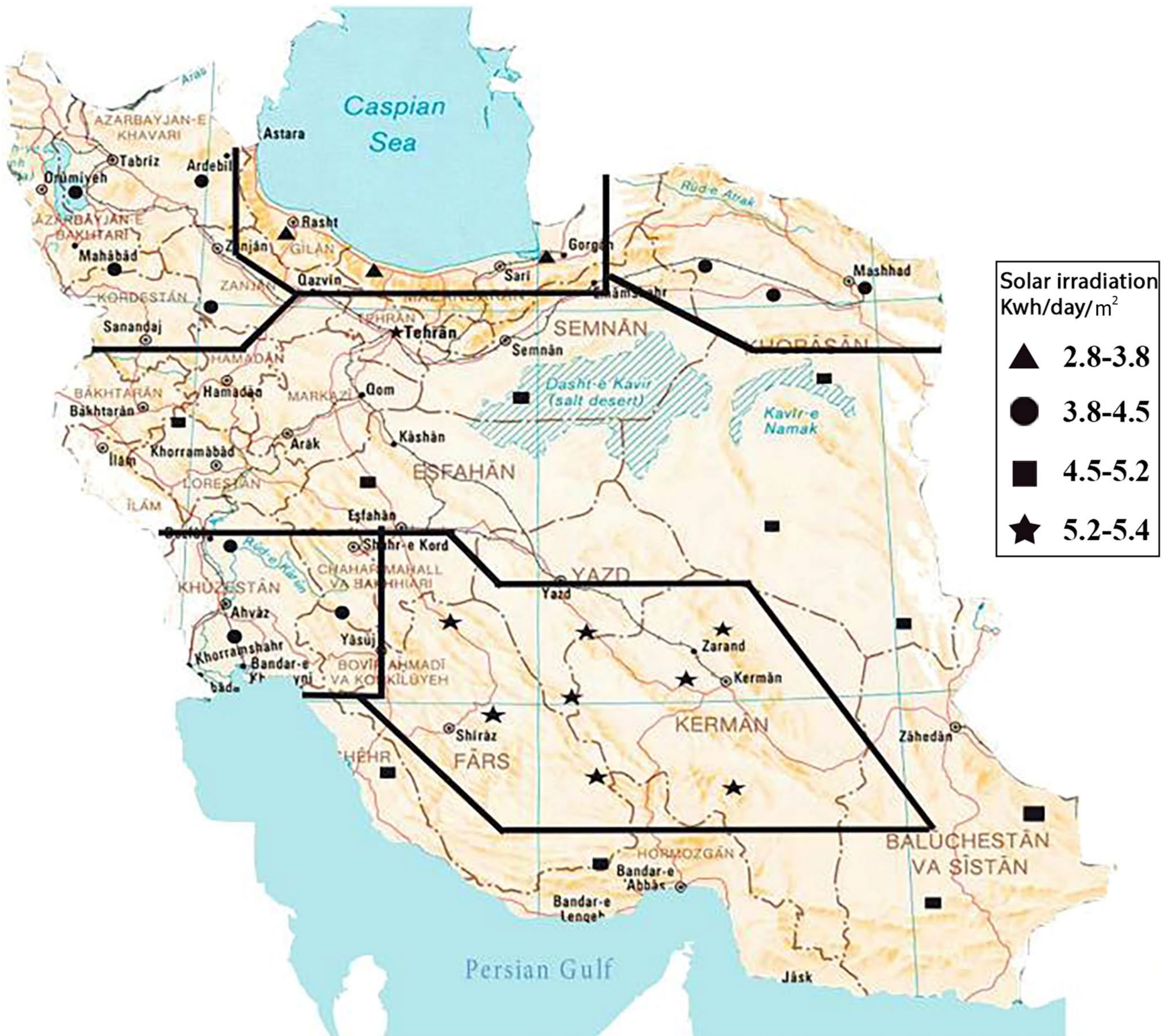

Fig. 2 The daily average of solar radiation in Iran

in order to concentrate the sun's energy to drive traditional steam turbines or engines that produce heat and electricity and be economic (IRENA 2015). A network of concentrated solar power (CSP) plants could supply source of electricity similar to fossil fuel or traditional nuclear power plants, and at costs comparable to photovoltaic (PV) or offshore wind. A CSP plant is a potential source of renewable electricity in arid areas. A CSP plant uses the renewable source of the sun and does not produce pollutants such as fossil fuel power plants (Hangera et al. 2016). Besides efficiency of concentrated solar power, the main advantage of using CSP is that these technologies involve a thermal intermediary and, therefore, can be readily hybridized with fossil fuels and in some cases adapted to use thermal storage (Devabhaktuni et al. 2013).

Today, all types of PV systems are widely utilized in a variety of applications. PV systems can be utilized to meet almost any electric power need, both small and large scales. These systems are divided into two main types: grid-connected and off-grid applications (Kannan and Vakeesan 2016; Department of Energy Solar Energy Technology Basics 2016). Photovoltaic installations may be ground-mounted (i.e., built on the ground) or built on the roof of a building, known as roof-mounted photovoltaic systems (Devabhaktuni et al. 2013). As photovoltaic power generation becomes more affordable, the photovoltaics utilization for grid-connected applications is increasing. Solar PV system is well suited to off-grid electricity production applications, especially in dry desert areas and semiarid regions, where homes are often not served via the nearest utility and where costs of electricity production through other sources are high, so people can save money through setting up their own solar system (Bahadori and Nwaoha 2013). Nowadays, photovoltaic (PV) system due to their benefits (i.e., abundance, renewability and pollution free) acts as the promising alternative sources of energy around the world. (Devabhaktuni et al. 2013). Electricity generated from renewable energy sources has usually minimal environmental impact and is vast, ubiquitous and virtually inexhaustible, which is why it is attracting new investment. During 2015, 161 billion US dollars or higher than 56% of total new investment in renewable power and fuels was just in the solar power sector (excluding hydropower > 50 MW). Investment in solar power plants was 12% higher than in 2014. Industrialized countries such as Japan, Italy and Germany dominated investment in small-scale solar power until 2014, but, emerging economies (e.g., China and India), Chile, South Africa and other developing countries and ramped up deployment of utility of solar PV and CSP.

Advantages of solar energy utilization

Diversification of fuel sources is important to address environmental issues (e.g., climate change and resources limitation). Solar energy is obviously environmentally advantageous relative to any other energy source with least negative impacts on the environment. The major direct or indirectly derived benefits of solar energy technologies are the following (Solangib et al. 2011; Bahadori and Nwaoha 2013):

- No emissions of greenhouse gas (mainly CO_2) or toxic gasses (SO_2, NO_x and particulates).
- Improvement in quality of water resources.
- No noise production during power production.
- Reduction in transmission lines from electricity grids.
- The increase in regional or national energy independence.
- Diversification and security of energy supply.
- Acceleration of rural electrification (especially in developing countries).
- Reclamation of degraded lands.

In view of the limited fossil fuel reserves in the world, energy security and climate change concern, it is expected that renewable energy sources, particularly solar energy, will play an important role in world's energy mix in the future. Unlike fossil fuel resources, renewable sources like solar, wind, hydropower and geothermal cannot be depleted. In contrast, the fossil energy sources are depleting very fast and can be diminished via extraction and consumption. The use of solar energy has extra positive implications such as reduction in the GHG emissions, particularly CO_2 and prevention of toxic air pollutants (SO_2, NO_x and particulates). Unlike conventional fuels, solar energy does not release any pollutants into water and does not consume water during electricity production, so it might seem a favorable energy source, while the most common types of conventional power plants (e.g., natural gas, oil, coal and nuclear) require much water for generating electricity. Water consumption is crucial and is a great concern, in particular for countries like Iran. Solar energy produces electricity very quietly because of their noise-free design, while conventional power plants and some renewables (e.g., wind and hydro) produce noise (Aman et al. 2015).

Solar energy technologies have the advantage of being harnessed in rural or remote locations that are not connected to the local network. Solar modules do not suffer with the noise problem. Additionally, solar panels can be installed on top of many rooftops and on pasture or unused lands as well (Castillo et al. 2016).

Sustainability indicators of renewable energy technologies

Renewable energy technologies play an important role in reduction in greenhouse gas emissions and mitigation of climate change which are the main aims of the global climate policy. The widespread of RE technologies (including hydroelectric power, solar, wind, biomass and geothermal) not only would help to avoid the negative environmental impacts, also can create remarkable extra socioeconomic benefits (e.g., reducing local air pollution and safety risks, supporting energy access and improving security of energy supply) (Pfeiffer and Mulder 2013).

Greenhouse gases emissions

As discussed earlier, electricity generation sector is the main source of greenhouse gases emission. Table 1 shows CO_2 emissions (g/kWh) of the major forms of electric power generation. Carbon footprint is utilized to find the total amount of greenhouse gases produced directly and indirectly during the whole lifecycle (i.e., cradle to grave) of a process or product, usually expressed in equivalent tons of CO_2. The total greenhouse gas emissions are expressed as grams of CO_2 equivalent per 1 kWh of energy generated (Aman et al. 2015; Amponsah et al. 2014). However, carbon footprints of renewable technologies depend on several factors such as operating conditions and country of its manufacture. We should mention that renewable technologies also have a

Table 1 Greenhouse gas emissions expressed as CO_2 equivalent for individual energy generation technologies (Weisser 2007, IEA 2003)

Energy source	g CO_2_e/kWh range
Coal	950–1250
Gas	360–575
Oil	700–800
Nuclear	2.8–24
Photovoltaic	43–73
Onshore Wind	8–30
Offshore Wind	9–19
Hydro	1–34
Biomass	35–99

carbon footprint value, in particular during the construction phase.

From Table 1, the emissions are found to vary widely depending on technology. It is obvious that CO_2 emissions from fossil-fueled power sectors far exceed those of the renewable technologies and nuclear power stations. A significant fraction of CO_2 emissions produced by coal-fired power stations. Table 1 indicates the greenhouse gas emissions by various fossil fuels and renewables as well as nuclear for electricity generation. Coal-fired power plants emit between 950 and 1250 g of CO_2 for every kilowatt-hour of electricity. For an oil-fired power, CO_2 emissions per unit of electricity range between 700 and 800 g of CO_2/kWh. In comparison with coal and oil, gas-fired power stations are known to have the lowest relative carbon dioxide emissions per kWh, which ranged from 360 to 575 g of CO_2/kWh. Compared with fossil-fueled power plants, nuclear power plants do not release GHGs when they produce electricity, which ranged from 2.8 to 24 g of CO_2/kWh. Accordingly, for every kilowatt-hour of electricity generated, a solar PV system emits ranged low of around 43 to a high of 73 g of CO_2/kWh over the whole GHG life cycle [depending on the type of photovoltaic (PV) cells]. While an onshore wind turbine emits between 8 and 30 g of CO_2 per kilowatt-hour, for an offshore wind turbine it is between 9 and 19 g of CO_2/kWh. A hydropower plant emits between 1 and 34 g of CO_2 per kilowatt-hour. Between 35 and 99 g of CO_2 per kilowatt-hour of electricity generated comes from biomass use (Weisser 2007, IEA 2003).

For fossil-fueled power plants, the largest part of emissions arises during the operation of the power station and burning fossil fuels for electricity production (World Energy Council 2004; Fthenakis and Kima 2011; Weisser 2007), while the majority of greenhouse gas emissions from renewables occur typically during equipment manufacturing stages and construction of their supporting infrastructure (Weisser 2007; IEA 2003). Nuclear power plants and some renewable energy technologies (i.e., wind and solar) do not directly emit CO_2 (IEA 2015a, c). The CO_2 emissions of wind power depend on the amount of material and work needed to build the wind turbines (World Energy Council 2004; Evans et al. 2009). The GHGs from a nuclear fuel cycle are due to the fossil fuel-based energy and electricity needed to uranium mining, processing the fuel and for the construction, waste byproducts, materials of fuel cycle facilities as well as decommissioning (World Energy Council 2004; NEI 2017). It has been found out that nuclear-based power electricity production emits fewer emissions to the atmosphere, but the dumping of the hazardous wastes and radioactive substances threat all forms of life (Varun et al. 2011). Emissions from any type of solar systems are lower than those from fossil fuels because solar energy technologies do not require fuel to operate. For photovoltaics power, the majority of emissions are the result of electricity usage in manufacturing process (Evans et al. 2009; Fthenakis et al. 2008; Fthenakis and Kima 2011; IEA 2003). Overall, renewable energy technologies result in some CO_2 emissions, albeit far less than coal, oil and natural gas. As a result, replacing generation from fossil fuels with nuclear or renewables would lead to reduce greenhouse gas emissions.

Environmental externalities of fossil fuels and renewable technologies

Using conventional fuels for electricity production has negative impacts on climate, human health, forests, crops, structures and biodiversity, which are typically defined as externalities (El-Guindy et al. 2013; RETD 2006; Streimikiene and Alisauskaite-Seskiene 2014). Climate change and air pollution make out the most important environmental costs and that the costs are primarily associated with the energy production phase (RETD 2006).

Electricity generation via the traditional methods causes two major problems. One of the major problems is global warming and also depletion of reserves of fossil fuels that will no more be available after the year in 2050 (Baharoon et al. 2016). In recent years, a series of evaluation studies have carried out to estimate the external costs of various power-generating technologies (Hohmeyer and Ottinger 1994; ATSE 2009; Akella et al. 2009; El-Guindy et al. 2013; Streimikiene and Alisauskaite-Seskiene 2014). The maximum, minimum and mean of external costs for each technology are summarized in Table 2. From this table, it is clear that externalities from coal and oil far exceed those of the “renewables” and are three times more than gas. The wind energy has the lowest external costs of electricity production. Overall, hydro and wind have the lowest mean of external cost, with only about 0.1 and 0.4 cents/kWh, respectively. Photovoltaics also have low mean of external cost, with average reported about 0.5 cents/kWh. The mean of external cost from the nuclear power station is fair at

Table 2 The range of external cost estimates for various sources of power generation (US c/kWh) (El-Guindy et al. 2013)

US c/kWh	Coal	Oil	Gas	Nuclear	Hydro	Wind	Solar	Biomass
Min	4	3	0.49	0.2	0.03	0.001	0.25	0.08
Max	9.5	9	3	1.5	1	0.25	0.6	3.5
Mean	5.4	5.9	1.7	0.6	0.4	0.1	0.5	1.3

0.6 cents/kWh. For combustion-based generation units (e.g., coal, oil, natural gas and biomass power plants), mean of the external cost is different, very high for oil with 5.9 cents/kWh and relatively low for biomass with 1.3 cents/kWh. The external cost of coal and natural gas is 5.4 and 1.7 cents/kWh, respectively (El-Guindy et al. 2013).

It is obvious if the externalities costs for each kWh generated from conventional power plants were added to the current average price of electricity it can be easily stated that some renewable energy technologies are financially competitive with fossil fuels projects. Fossil fuels produce negative environmental externalities at the local level (e.g., local air pollution) and also at the global level (e.g., GHG emissions), while solar energy technologies do not emit various emissions, so it would be unfair to compare solar energy technologies with conventional fuels without consideration of their externalities (Timilsina et al. 2011).

Therefore, power stations will play a significant role in reducing such emissions by the use of alternative electricity production such as solar power. Reaching parity between the benefit from non-renewable energies saving plus a remarkable reduction in the air pollutants and CO_2 emissions sets the point on which costs for society become beneficial.

Price of electricity generation

Currently, renewable energies are the excellent cheap resources for power generation. Table 3 shows the price for electricity production from conventional fuels and renewable sources as well. This table compares the range of costs for electricity generation in dollars per kilowatt-hour for both non-renewable and renewable energies.

The range costs for electricity generation for fossil fuel (i.e., coal, oil and natural gas), biomass and hydro are \$0.045–\$0.14/kWh, \$0.03–\$0.14/kWh and \$0.04–\$0.12/kWh, respectively. Among all renewable energy sources, photovoltaic system has the widest range of cost for generating electricity, which varies significantly by country or region, type of solar cells as well as electricity cost to manufacture panels. The cost of PV-generated electricity ranged from \$0.11 and \$0.12/kWh in South and North America to over \$0.30/kWh in Central America and the Caribbean. The onshore wind had the lowest cost ranged from \$0.06 to \$0.09 per kilowatt-hour, while offshore wind has a range of cost from \$0.11 to \$0.17/kWh of electricity generation. Geothermal and CSP have the same range costs per kilowatt-hours. Geothermal exhibits lower range in price variations with \$0.05–\$0.10/kWh, while the range costs for CSP are from \$0.20 to \$0.25/kWh.

If damage to public health of conventional fuels in power generation sector takes into account of economic terms, along with the environmental externalities relating to CO_2 emissions (assuming \$20–\$80/ton of CO_2), the cost of fossil fuel-fueled power generation increases by \$0.01–\$0.13/kWh, depending on technology and the country (IRENA 2015). Despite rapid declines in the costs of solar energy systems in recent years, cost competitiveness remains a significant obstacle to the development of these technologies.

Current power infrastructure in Iran

By the year of 2012, Iran had 400 power plant units. The capacity of the installed fossil fuel power plants has increased to almost 70% during 2005–2013, which had reached to 70 GW (Wikipedia 2016), while by the beginning of 2015, the total installed electricity capacity was 74,103 MW (more than 74 GW) with additions of 943 MW of new installed electricity capacity from different sources, with 1.3% growth rate compared with 2014. The total system generation in 2015 was 280,688 GWh, as given in Table 4 (Tavanir 2015). Today, in Iran, 100% of all urban areas have access to electricity through a mass network, while almost 1.1 million people in rural or remote areas of Iran did not have access to electricity in 2013 (REN 21 2016). In March 2015, close to 97 villages below 20 households did not have access to the national grid that results in 99.8% electrification rate for Iran's villages. The electrification of rural and remote areas has been a long-term target in

Table 3 The price of electricity generation by renewable technologies (IRENA 2015)

Technology	USD/kWh
Photovoltaic	0.11–0.30
Onshore wind	0.06–0.09
Offshore wind	0.10–0.17
Hydro	0.04–0.12
Geothermal	0.05–0.10
Biomass	0.03–0.14
Fossil fuel (coil, natural gas, oil)	0.045–0.14
CSP	0.20–0.25

Table 4 Electricity generation capacity and generation in Iran in 2015 (Tavanir 2015)

Sources	Capacity (MW)	Capacity share (%)	Generation (GWh)	Generation share (%)
Combined cycle	18,493	25.0	100,936	36
Steam	15,829	21.4	86,968	31
Gas turbines	26,870	36.2	75,424	26.9
Hydropower	11,278	15.2	14,087	5
Nuclear	1020	1.4	2950	1.1
Others (wind, solar, diesel)	612	0.8	324	0.1
Total	74,103	100	280,688	100

various Five-Year Development Plans (FYDPs) (Tavanir 2016). The majority of electricity (95%) generates using fossil fuels, mainly natural gas (almost 70%) (Energypedia 2017). Electricity consumption in this country is three times higher than the global average of electricity consumption (Farhangnews 2016). Thus, annually, Iran should generate the capacity of about 5 GW to supply the demand in the next years (Tavanir 2015; SUNA 2015). In this country, generating electricity is one of the major primary energy-consuming sectors, which consumes around 27% of the whole natural gas supplied via the country. Thermal power plants, which have the largest share in electricity production, are classified into three major types: steam cycle that works through burning residual fuel oil (RFO) or heavy fuel oil (HFO) or coal or natural gas, gas turbine that consumes natural or diesel and combined cycle gas power plants that generate electricity by burning natural gas (Aghasi 2015; CEC 2016). Note that 36% of the electricity in this country produces by combined cycle power plants, 31% produces from steam power plants and 26.9% is produced by conventional gas turbine power plants that work through burning of fossil fuels, while the remaining 6.2% is produced by hydropower, nuclear, wind, solar and diesel power plants in 2015, as illustrated in Table 4. In 2015, total installed nameplate capacity of fossil-fueled power plants (combined cycle, gas turbines and steam) reached 61,192 MW, while the total capacity of hydropower and nuclear power stations reached 11,278 and 1020 MW, respectively. In 2015, some renewable power plants and diesel power stations with total capacity 612 MW produced only 324 GWh of electricity, as is shown in Table 4. Fuel consumption by power plants in Iran was 58,424 million cubic meters of gas, 6083 million liters of gasoline and 6946 million liters of fuel oil. The produced energy by thermal power plants has grown by 2.9% and reached to 263,393 GWh, while the energy produced by hydropower, nuclear plants and renewables declined 7.1%, reached to 17,296 GWh in the beginning of 2015 (Tavanir 2015).

Energy saving and development of renewable energies, particularly solar and wind are important integrated elements of Iranian energy policy. The Iranian government has planned that the renewable energy resources supply 5% of the national generation of electricity in 2020 (SUNA 2016a). By the end of 2025, the government of Iran intends to increase the nominal capacity of all power plants from 74 GW to more than 120 GW, while renewable resources could supply a part of this capacity (SUNA 2016b). To achieve such objectives, the government of Iran should formulate and implement policies and laws, which stimulate private investment (local and foreign) for the establishment of power- and energy-generating units.

Emissions level of Iranian electricity generation systems

This section illustrates the direct emissions per kilowatt-hour of electricity generated from fossil fuel power plants. The emission factors of the electricity production depend on kinds of the power plants and load level (World Energy Council 2004; Wiser et al. 2016; Donateo et al. 2015). Different types of pollutants are released from a combustion power system: carbon oxides (CO_2 and CO), hydrocarbons, primary and secondary aerosols, sulfur dioxide (SO_x), nitrogen oxides (NO_x), etc. In countries where conventional fuels are the major source of electricity production, the emissions are larger than in countries utilizing fewer conventional fuels in power production sector (World Energy Council 2004).

In Iran, electricity production sector is responsible for about 28% of the total national energy-related CO_2 emissions, the most concentrated source of greenhouse gases in the country. The high share of fossil fuels in Iran's electricity mix, together with the rising energy demand, has led to a steady increase in GHG emissions, reaching 180 million metric tons (Mt) CO_2 in 2013. Besides CO_2, there are other pollutants emitted by fossil fuel power stations, such as CO, SO_2, suspended particulate matter (SPM) and other GHGs, such as methane (CH_4) and nitrous oxide (N_2O). The assumed values of the emission levels of CO_2 and for the other pollutant emissions are reported in Table 5. In Iran, the total average amount of carbon dioxide (CO_2) emitted per kilowatt-hour (CO_2-eq/kWh) when generating electricity with fossil fuels was 767.5 g/kWh and for other pollutants

Table 5 Pollutant and GHG emissions indicators in Iran power sector by power plant types, 2013 (g/kWh) (Ministry of Energy 2013)

Power plants types	C	CH_4	CO_2	SPM	CO	SO_3	SO_2	NO_x
Ministry of energy								
Steam	259.02	0.03	949.73	0.21	2.40	0.04	9.75	2.36
Gas	237.42	0.02	870.53	0.15	0.10	0.02	0.79	2.67
Combined cycle	135.50	0.01	496.83	0.10	0.08	0.01	0.46	3.03
Diesel	261.62	0.05	959.26	0.36	0.00	0.09	5.69	1.88
Private sector								
Steam	274.68	0.03	1007.15	0.24	0.21	0.05	10.67	3.45
Gas	219.24	0.02	803.88	0.16	0.08	0.03	1.27	2.89
Combined Cycle	140.18	0.01	513.99	0.11	0.05	0.02	0.42	2.31
Large industries	311.53	0.01	1142.28	0.68	0.48	0.00	0.05	2.45
Total average	209.3	0.02	767.5	0.2	0.7	0.03	3.9	2.9

such as C, CO, SO_2, CH_4, SPM, SO_3 and NO_x, it was 209.3, 0.7, 3.9, 0.02, 0.2, 0.03 and 2.9 g/kWh, respectively, in 2013. This poses a noticeable risk to the human health, due to high levels of atmospheric pollution from combustion of fossil fuels. All fossil fuel-fired electric power stations, including combined cycle power plants, steam and gas turbines emit greenhouse gases at various levels. Although diesel generating plants always have a minimal role in electricity production in Iran, the greenhouse gases emissions (i.e., methane and carbon dioxide) from diesel power plants are remarkable compared with other types of power plants (i.e., combined cycle, steam and gas turbines) (Ministry of Energy 2013).

Present status of solar energy in Iran and the Middle East

Globally, the Middle East is among the most promising areas with high direct solar irradiation (Wilson Center 2012). Despite this excellent potential, installing solar power technologies in the majority of countries in the Middle East is very low compared with the developed countries. As shown above, Iran's potential for use of solar energy is extremely high, having a great solar irradiation and high electricity demand. In spite of the fact that, the country depends heavily on fossil fuels for its electricity production. While today, solar power has emerged as a main actor in the electricity production sector in many countries. The installed solar power capacity in countries of the Middle East at the end of 2015 is indicated in Fig. 3. The diffusion of renewable technologies in Iran has been found to be very low for solar energy systems. In this country, besides thousands of small-scale photovoltaic (PV) systems utilized in communications, parks, roads and highways, the total installed solar power capacity has just reached to 17.3 MW by 2015. In the Middle East, Israel's solar power market continued to grow and installed approximately 772 MW, the United Arab Emirates (UAE) was the second largest market for solar energy in the region with 133 MW, Jordan (24 MW), Saudi Arabia (24 MW), and all other countries (Bahrain, Lebanon, Qatar and Kuwait) were far behind in terms of solar power installation and below the 10 MW market by 2015, as is stated in Fig. 3 (IRENA 2016c). Data in Fig. 3 demonstrated that some countries such as Israel and UAE, besides non-renewable power plants, have developed solar energy technology in order to increase electricity generation capacity in their countries. In Iran, the rate and capacity of energy production from solar energy technologies, however, is still very low compared with the fossil fuels such as natural gas and oil and other alternative sources such as hydropower.

There are two known solar power plants in Iran, Arak solar power plant with the nameplate capacity of 1 MW and Shiraz solar power plant with the nameplate capacity of 500 kW with a fuel type of solar radiation specified. In addition, there are several solar power plants already installed in Iran by the end of 2015, which are listed as follows:

- Arak solar power plant that 392 solar panels used in this power plant with a nameplate capacity of 1 MW,
- Shiraz solar power plant is a concentrating solar power (CSP) plant with a nameplate capacity of 250 kW, which will increase to 500 kW in the near future.
- Yazd solar combined cycle power plant with a nameplate capacity of 467 MW, including two gas units with a nameplate capacity of 159 MW for each unit and one steam unit with the nameplate capacity of 143 MW as well as a solar unit with nameplate capacity of 17 MW.
- Mashhad solar power station with a nominal capacity of 432 kW (Najafi et al. 2015).
- Tabriz solar hybrid power plant (solar and wind) with a nominal capacity of 50.4 kW.
- Semnan PV power station with a nominal capacity of 97 kW.
- Taleqan PV power station with a nominal capacity of 30 kW (SUNA 2015).

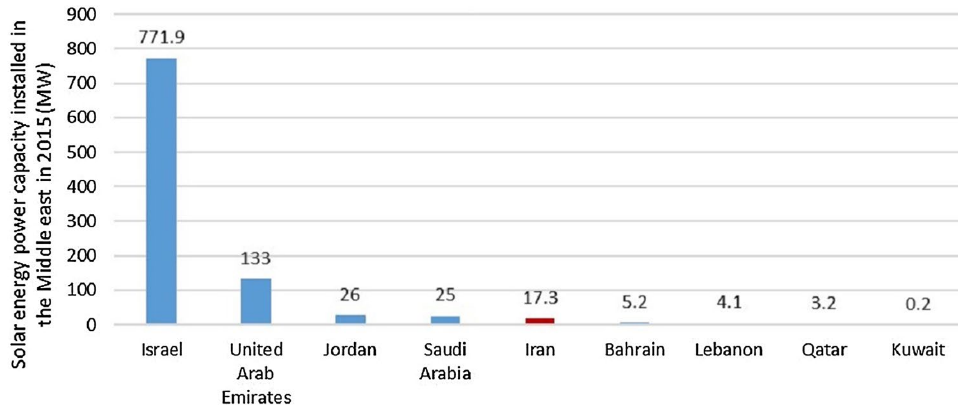

Fig. 3 Solar energy

- Birjand PV power station with a nameplate capacity of 20 kW (Farsnews 2013).
- Mallard solar power station with a nameplate capacity of 514 kW (Barghnews 2014).

In recent years, Iran has made steps to decrease its dependency on fossil fuels and use its enormous renewable energy potential for power generation. The Iranian government has started to add 5 GW of wind and solar power capacity to its power grid by the year 2018 (REN 21 2016; Najafi et al. 2015). The main part of the total 5 GW includes wind power plants, but 500 MW has previously been started for solar photovoltaic (PV) and also the government recently has given permission for the construction of some other projects (Najafi et al. 2015). Currently, concentrated solar power (CSP) plants with the capacity of 7.5 GW are under construction and also 8.5 GW under development (Tofigh and Abedian 2016). In 2016, for the first time, tariffs of the purchase price of renewable generated electricity have been represented based on variable rates. The average rate of purchase price of electricity by the Iranian government is 4000 Iranian Rials[1] per kWh (more than 11 cents/kWh) for the solar power plants (SUNA 2015).

Barriers to solar energy development

However, solar energy as other renewables has an enormous potential to meet the energy demand, but solar energy technologies face significant barriers. This section shows that some of the most common challenges constraining solar energy deployment in the world, especially in Iran, include relatively high prices, less efficiency of solar systems, environmental impacts of solar panels manufacturing, land-use requirements for solar power plants and inadequate government or policy support. Several barriers that have prevented penetration of solar energy are listed as follows:

- Two main barriers to developing solar energy usage are price and efficiency, but its price and efficiency are rapidly changing. Solar installations are costly, but after that, the electricity consumption is free (Kannan and Vakeesan 2016; IRENA 2016d). The cost of installing solar panels is expected to decline further in coming years, while fossil fuels prices will likely increase. The crystalline silicon module global average prices could decline from 0.72 to 0.52 USD/Watt in 2015 and from 0.46 to 0.28 USD/Watt by 2025 (IRENA 2016d).
- The low energy-generating efficiency of PV cells is one of the main barriers. On average, the efficiency of solar photovoltaic panels is from 5% to 15%, depending on solar panel types by 2014 (Chaharsooghi 2015). A typical 3 × 6 solar PV cell (78 × 156 mm) can generate almost 0.2 kWh in 1 h of bright sunshine. The sun would need to shine brightly on such a cell for 185 h to supply the same energy as a gallon of gasoline. A gallon of gasoline has potential to generate almost 37 kWh of energy. In the future, if electric costs rise due to either depletion of fossil fuels or policies such as carbon taxes, the installation of solar systems would become even favorable in terms of avoided electricity generation costs (Timmons et al. 2014).
- Another obstacle to implementing of solar energy technologies is daily fluctuations of solar radiation by sunset and clouds. The performance of photovoltaic (PV) panels is affected through the shading effect due to clouds and therefore the output from solar panels changes.
- The PV manufacturers use some toxic materials, corrosive liquids as well as explosive gases in the production cycle of PV cells. The presence and amount of those substances differ with the type of cell. Yet, nitrogen trifluoride (NF_3) is used in production lines of thin film and flat screens to clean the coating systems. Consequently,

[1] One dollar (US) was equal to 35,000 Iranian Rials.

the remainder of this gas can release into the atmosphere. NF_3 is 17,000 times more harmful than carbon dioxide to the environment. Lead often utilizes in the silicon wafer-based modules by many manufacturers in the cell metallization layer. Cadmium telluride (CdTe) thin-film modules contain cadmium (Cd) and copper (Cu), and indium selenide (CIS) solar cells contain selenium, which is toxic and harmful to the environment. However, it is essentially used in severe control methods that reduce the emission of hazardous materials in solar cell production lines (Wirth 2016). But, these negative environmental impacts are not remarkable when compared with conventional energy sources.

- One of the main barriers is the environmental impacts associated with solar power panels, particularly CO_2 emissions from the manufacturing process. These emission levels are lower than emissions of natural gas-fired power station (Edenhofer et al. 2011). The most energy-intensive phase (60% of CO_2) is silicon extraction and purification. Although the present footprint of the solar power is considerably comparing to other renewable energies, future technologies for producing PV cells (e.g., thin film) will reduce the silicon use and consequently will reduce the carbon footprint (Parliamentary of Office Science and Technology 2006).
- Another form of environmental impact is land use. This is not an issue for roof-mounted PV systems and solar thermal, but it can be a problem for large-scale PV and also for CSP. For CSP plants, it is environmentally sensitive land. Land-use impacts of installed PV systems depend on the type of applications (decentralized and centralized). Providing much of the community's electricity through solar PV systems would require a remarkable amount of space. Several factors such as geographical situation and system efficiency affect PV land requirements for large central electricity generation (Hohmeyer and Ottinger 1994). A 1 MW solar PV power plant would require about 2.2–12.2 acres of land, with a capacity-weighted average of 6.9 acres of land per megawatt, while concentrating solar power plants (CSP) require approximately 2.0–13.9 acres of land area per megawatt, with a capacity-weighted average of 7.7 acres of land per megawatt, but this environmental issue can reduce with increasing module efficiencies (Sean et al. 2013).
- Fossil fuels receive different kinds of subsidies, provided via different channels. The adverse effects of fossil-fueled subsidies are that they damage the competitiveness of emission-free renewable sources. Fossil fuels subsidies hinder investment in renewable energy technologies, increasing reliance on fossil fuels (IEA 2015b). So, shifting existing subsidies away from fossil fuels and toward renewable energies is important.
- A lack of cost-reflective electricity tariffs, compounded by regulatory, political and institutional barriers, has deterred widespread solar investment in many countries.
- The lack of skill, training, expertise in repair and maintenance of the solar systems is one of the main problems of establishing solar power stations in remote locations.
- An extra barrier in 2015 was low oil and gas prices, which make solar less attractive and less competitive compared with fossil fuels in many countries by continuing system payback periods (Novacheck and Jeremiah 2015).

Discussion

The combustion of fossil fuels in order to generate electricity emits a variety of pollutants and greenhouse gases (e.g., CO_2 and NO_x), which contribute to climate change. The average direct emissions from power plants based on oil, natural gas and coal are significantly higher than emissions from renewable energy technologies. As mentioned above, electricity generation by fossil fuels has the largest carbon footprint with higher than 1000 gCO_2eq/kWh, while renewable technologies have carbon footprint less than 100 gCO_2eq/kWh. Reduction in environmental pollutants, particularly GHG emissions, is an international challenge and will require involvement from emitters and manufacturers and require cooperation across borders. It is expected that the limiting the increase in total GHG levels in the atmosphere can reduce the probability of dangerous climate change. Therefore, increased use of renewable energy technologies is a central measure in accomplishing these objectives.

In Iran, currently, CO_2 emissions caused by the human activities have grown so rapidly. In this country, 646 million tons of CO_2 equivalents was emitted, by 2014 (Fig. 1). The majority of electricity production comes from burning fossil fuels, in particular natural gas, and the minority of it comes from renewable energies and nuclear; no significant solar energy system is used for electricity production (Table 4). Electricity generation through burning fossil fuels emits 180 Mt CO_2-eq in Iran per year. Furthermore, the combustion of fossil fuels for electricity production is the main source of local air pollution. SO_2, NO_x and $PM_{2.5}$ are some of the main pollutants (Table 5). Consequently, in this country, an important source of CO_2 emissions and other pollutants could be from fossil-fueled power plants. These results highlight the importance of reducing the share of fossil-fueled power plants in the electricity mix of Iran which would lead to substantial reduction in greenhouse gases impacts and global warming, since increasing global temperatures might have serious consequences not only on the environment but on the human welfare (Streimikiene and Alisauskaite-Seskiene 2014). Global average surface temperature has raised by almost 0.4–0.8 °C over the past century. Consequently, this phenomenon has increased global mean sea levels at an average annual rate of 1–2 mm over the past decades. A global average temperature increase of only 1 °C could have serious consequences. Arctic sea ice has declined by 40% and decreased in extent by 10–15% in summer season since the year 1950s (Panwara et al. 2011, Wei et al. 2011). Declining sea ice will cause sea levels to increase which destroys beautiful scenery and the habitats of penguins and polar bears. One of the harmful effects of global warming is droughts, which cause loss of agricultural crops, damage to plants, reduction in fresh water supply for irrigation and other essential uses, and so will tend to induce famines around the world, particularly in poor countries. Life in the oceans is not only threatened by climate change. Ongoing global ocean acidification is another serious problem of carbon dioxide emissions. When carbon dioxide dissolves in the oceans, carbonic acid is formed. As a result of higher ocean temperature and acidity of dissolved CO_2, highly sensitive corals reef in the ocean are dying (Kalogirou 2004; Bose 2010).

Problems with energy production and consumption are related not only to climate change, but also to environmental concerns such as air pollution, acid rain, ozone depletion, forest and land degradation, and radioactive substances as well. The most significant effects of atmospheric pollutants are their negative impacts on human health (Kalogirou 2004). Exposure to gaseous air pollutants such as CO, SO_x, NO_x and particulate matters (PM_x) threatens public health in both the short and long term during normal plant operations. Human toxicity and particulate matter formation from coal combustion are significant contributors to public health (Treyer et al. 2014). The atmospheric pollutants emitted via combustion of coal, and natural gas for electricity generation is associated with breathing problems, heart attacks, neurological damage as well as cancer (Union of Concerned Scientists 2013). Additionally, both SO_2, and NO_x lead to acid precipitation and smog. Therefore, replacing fossil fuels with renewable energies, particularly solar energy can reduce premature mortality and it reduces overall healthcare costs. If humanity is to accomplish a bright energy future with negligible environmental impacts, these issues should be taken into account simultaneously.

Fossil fuel energies have different externalities including unfavorable human health impacts and various environmental problems such as climate change that usually are not accounted for in the retail price (Owen 2006). Increasing concentration of CO_2 and other pollutants in the environment imposes enormous costs on the societies. In the energy sector, the potentially most significant externalities (i.e., the local and global environmental and health damages caused by the use of fossil fuels) are typically not priced by the market. Although these costs are not borne by the energy supplier or consumer, they are paid for by society as a whole, for instance, through higher healthcare costs, increased natural disaster costs, lower labor productivity, reduced life expectancy and premature mortality (IRENA 2015). Public health effects present in the form of epidemic diseases and premature death (i.e., morbidity and mortality) that account for well over 90% of all external costs. Other costs arise through impacts on agriculture production, costs to materials and negative impacts on ecosystems and habitats. Climate change impacts are important, but their valuation is vaguer than that of local air pollution. Damages from climate change, associated with the high GHG emissions from fossil fuel-based electricity production, also have considerable costs. The external effects of energy consumption are related to air pollution and climate change which is in the order of $2.2 trillion to $5.9 trillion per annum, in the world. In the European Union (EU) alone, the external costs of air pollution ranged from 330 billion US dollars to 940 billion US dollars in the year 2010 (IRENA 2016e). As mentioned in Sect. 5, the external cost of fossil fuel-fired power generation is significantly higher than renewable energies (Table 2). But, the results can differ from country to country according to various factors, for example, the utilize of various technologies that could imply various emission factors, or according to the characteristics of the specific sites that could vary in the population density, income or transport distances (El-Guindy et al. 2013). For example, in 2005, electricity generation by natural gas produced 0.74 billion US dollars in damages (0.16 cent/Kilowatt-hour), mainly from air pollution. The European Union cost of generating electricity without these external costs averages around

4 cents/Kilowatt-hour. In fact, if the external costs were incorporated, the EU cost of generating electricity from coal would double and that from gas would rise by about 30% (World Nuclear Association 2017). In Iran, the social cost of air pollutants and greenhouse gases that release by Iranian power plants was about 102,974 billion Iranian Rials (more than 2.94 billion dollars) (about 28% of the total social cost) in 2011. The social cost related to GHG emissions and air pollutants from power production sector is remarkable (only for carbon dioxide is more than 295,000 Iranian Rials per ton that means \$8.5/ton CO_2). In this country, producing only 1% of electricity from renewable energy sources could reduce CO_2 emissions by 0.07% in short term and 0.31% in long term (Sadeghi et al. 2013). In the USA, the use of fossil fuel for electricity generation could lead to loss of hundreds of billions of dollars of economic value per year through premature mortality and other health problems, work days lost and direct costs to the national healthcare system. For coal and oil, these costs are greater than the common retail price of electricity generation, illustrating the magnitude of the externality (Machol and Rizk 2013). Curbing emissions of GHG through better energy-use choices can result in improved health, especially through reduced air pollution that can offer many benefits when compared to the non-renewable energies. It has been found out that replacing carbon-intensive energy sources with solar energy reduces work days lost and premature deaths, and it reduces healthcare costs. In the USA, from 2015 to 2050, solar power reduces GHG emissions and air pollutants by around 10%, providing a central value of about 250 billion US dollars (Wiser et al. 2016). Thus, since the external costs for electricity generation are not reflected in their price, it is difficult to compare the costs of solar electricity with nuclear or fossil fuels electricity.

Utilization of solar energy, as the cleanest form of energy, does not deplete natural resources, does not require extraction or transportation, does not require water to operate and thus does not pollute water resources, does not emit remarkable greenhouses and is infinite and free. However, some toxic substances are broadly utilized in solar panels manufacturing (Aman et al. 2015; Fthenakis et al. 2008). Although there are no carbon emissions associated with electricity production through solar energy utilization, there are emissions associated with various stages of the photovoltaics life cycle, including the raw material mining and extraction, materials production, module manufacture and also production of systems/plants and their components (Hairata and Ghoshb 2017). The major sources of the greenhouse gas (GHG) emissions for photovoltaic life cycles are electricity and fuel utilization during the photovoltaic materials and module assembly. Since PV does not need fuel to operate, emissions from any type of PV system are expected to be lower than those from conventional energy systems. A reduction in CO_2 emission is the most significant environmental benefit from solar energy utilization. Negative impacts of solar energy technologies are usually minor, and they can be minimized through improvements in module efficiency, less silicon mass per module, increasing lifetime and lower use of fossil fuel electricity for the production process (WNA 2011; Weisser 2007). In the last 10 years, the efficiency of average commercial wafer-based silicon modules increased from around 12 to 17% (Super-mono 21%). Record efficiencies confirm the potential for further efficiency raises at the production level (ISE 2017). It is also important to mention that solar photovoltaic technology is a fast-improving technology among renewables. Therefore, there is a great need to increase the solar energy technologies and help Iran to meet its sustainable development goals.

The diffusion of renewable energy technologies (RETs) in many countries is very low. Many of mentioned barriers were more relevant to many countries in around the world, but a number were relevant to Iran. Globally, many barriers such as solar panels costs and the efficiency of solar cells as well as using some toxic materials in solar cells manufacturing are restricting the use of solar energy technologies. The cost of harvesting solar is high compared with that of fossil fuel-fired power generation options (Table 3). Policy and regulatory incentives, improvements in technology and also oversupply of installation components are driving the reduction in solar technologies costs (World Energy Council 2016). The potential to generate electricity from solar energy utilization depends on the amount of solar irradiation, the area of suitable land and the efficiency of solar power systems. It was found that centralized photovoltaic and solar thermal plants would only be practical in areas with high level of radiation about 1050 kWh/m^2/year, for PV and 1450 kWh/m^2/year for solar thermal (IEA 2003). Iran has a sunny sky characterized by long, hot, dry summers and available desert lands. The country is abundantly endowed with almost all forms of renewable energy sources, particularly solar energy. Renewable sources such as solar energy can present viable options to bridge burgeoning power demand–supply gap in Iran. Solar radiation resources vary greatly depending on location worldwide (Singh 2013). In some climatic conditions make solar less economical than in others. But, in Iran, due to its location (with over 300 days of sunshine, solar radiation of 5.2–5.4 kWh/m^2/day), solar radiation is one of the highest recorded in the world (Fig. 2). Therefore, the potential for all types of solar technologies exists. Since Iran contains vast deserts, land use for solar power plant construction does not act as an important barrier. In the country, the availability of large unused land has a great potential for producing solar energy. Richness of oil and gas reserves (Najafi et al. 2015) and low oil and gas prices are the main reasons that have led to undeveloped solar energy generation in this country. Additionally, a lack of enough knowledge about solar technologies, lack of national infrastructure, existing subsidies for fossil fuel technologies and lack of policy backing are other obstacles for the diffusion of solar energy utilization in Iran.

To overcome the mentioned barriers, cost reduction and increasing the efficiency of solar cells are key areas of focus in research and development (R&D) programs in the globe. Technology improvements could increase solar panel output and efficiency, and improvements in energy efficiency can reduce lifecycle carbon emissions.

Moreover, the increase rates of deployment of renewables (particularly solar energy) need supportive government policies.

Some recommendations for promotion of renewable energies, particularly the solar energy in Iran, are given as follows:

- Providing a reliable policy framework for investors is crucial.
- Some new motivations have to determine to make it a competitive energy source for the conventional power stations.
- The Iranian government should spot the applicability and importance of solar energy usage.
- The Iranian government should emphasize on establishment of training institutes to ensure availability of engineers, teachers, scientists and installers of solar energy systems.
- To promote the widespread and large-scale implementation of solar power plants to mitigate environmental pollutants emission, more awareness and understanding of solar power benefits in Iran is needed.

Additionally, Iran's new commitment at the twenty-first session of the Conference of the Parties (COP 21) is another reason that can motivate the utilization of renewables such as solar energy into its energy mix, as a strong instrument to mitigate greenhouse gas emissions in this country. Therefore, there is an urgent need for transition from fossil-fueled energy systems to one based on renewable resources, particularly solar energy to decrease dependence on limited reserves of fossil fuels and to mitigate climate change.

Conclusion

In the present study, environmental impacts of fossil fuels consumption for electricity production have been dealt and potential solution in terms of the appropriate renewable energy technologies, particularly solar energy has discussed.

During the past couple of decades, the risk and certainty of environmental degradation due to the burning of fossil fuels have become more obvious. Growing environmental problems such as air pollution and global climate change is due to the environmental impact of human activities grown significantly. In Iran, the increased usage of fossil fuels for electricity production has resulted in increased production of greenhouse gases, particularly CO_2 that are responsible for global warming.

Solar energy is an attractive climate change mitigation option and appropriate in enabling low-carbon development in Iran, where has nearly 300 sunny days per year. Since Iran is well placed to harness its enormous solar potential, solar energy integration into energy production mix would lead to a steady decline in GHG emissions as well air pollutants. So countries like Iran, which has a high potential of solar energy should use this free and available energy source for a significant portion of its electricity production.

External effects are high in the case of air pollution from non-renewable energy sources utilization. Renewable energy sources can compete with conventional fuels if the external cost of conventional fuels utilization takes into account. As a result, due to avoiding environmental pollution, utilization solar energy source for energy production is profitable.

Although there are a few disadvantages such as low efficiency of solar panels, the high cost of installing these technologies and also energy requirements and CO_2 emissions for the production of PV modules, in the future, improvement in the efficiency of solar panels, reduction in the amount of material used in the solar cell systems will reduce the energy demand and greenhouse gas emissions.

Overall, renewable technologies mainly solar energy integration into energy production mix could bring long-term economic and environmental benefits from reduced externalities. Utilization of renewable sources is critical for sustainable development and should be implemented through all possible means. This is required not only for today's generation but for the next generation as well.

Acknowledgements The authors would like to thank the Renewable Energies Organization (SUNA) and the Ministry of Energy of Iran for permission to publish the data. Also, authors are grateful to anonymous reviewers for their detail reviews and suggestions which helped the manuscript in its betterment.

References

Aghasi A (2015) Iranian electrical production and consumption system modeling: a theoretical study for investigation of possible scenarios. Int J Smart Electr Eng 4(1 (Winter)):7–13. https://doi.org/10.1109/ipsc.2015.7827741

Akella AK, Saini RP, Sharma MP (2009) Social, economical and environmental impacts of renewable energy systems. Renew Energy 34:390–396. https://doi.org/10.1016/j.renene.2008.05.002

Aman MM, Solangi KH, Hossain MS, Badarudin A, Jasmon GB, Mokhlis H, Bakar AHA, Kazi SN (2015) A review of Safety, Health and Environmental (SHE) issues of solar energy system. Renew Sustain Energy Rev 41:1190–1204

Amponsah NY, Troldborg M, Kington B, Aalders I, Hough RL (2014) Greenhouse gas emissions from renewable energy sources: a review of lifecycle considerations. Renew Sustain Energy Rev 39:461–475

Australian Academy of Technological Sciences and Engineering (ATSE) (2009) The hidden costs of electricity: externalities of power generation in Australia

Bahadori A, Nwaoha Ch (2013) A review on solar energy utilization in Australia. Renew Sustain Energy Rev 18:1–5

Baharoon DA, Rahman HA, Fadhl SO (2016) Publics' knowledge, attitudes and behavioral toward the use of solar energy in Yemen power sector. Renew Sustain Energy Rev 60:498–515

Barghnews Agency (2014) Solar power plant of Mallard, the largest Iran's solar power plant. http://barghnews.com/fa/news/7177. Accessed 05 Nov 2017

Bose BK (2010) Global warming: energy, environmental pollution, and the impact of power electronics. IEEE Ind Electr Mag 4(1):6–17. https://doi.org/10.1109/mie.2010.935860

BP, Energy Outlook – 2016 Edition (2016). https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2016.pdf. Accessed 10 Jan 2017

Castillo CP, Silva BF, Lavalle C (2016) An assessment of the regional potential for solar power generation in EU-28. Energy Policy 88:86–99

Chaharsooghi SK (2015) Iran's energy scenarios on a 20-year vision. Int J Environ Sci Technol 12:3701–3718

Chaianong A, Pharino Ch (2015) Outlook and challenges for promoting solar photovoltaic rooftops in Thailand. Renew Sustain Energy Rev 48:356–372

Chandrappa R, Kulshrestha UC (2015) Sustainable air pollution management: theory and practice. Springer, Berlin

Commission for Environmental Cooperation (CEC) knowledge network (2016) Fossil fuels used to generate electricity. http://www2.cec.org/site/PPE/fossil-fuels. Accessed 04 May 2017

Department of Energy's National Renewable Energy Laboratory (NREL) (2015) Renewable energy data book. www.nrel.gov/docs/fy17osti/66591.pdf. Accessed 08 May 2016

Devabhaktuni V, Alam M, Depuru SSSR, Green RC II, Nims D, Near C (2013) Solar energy: trends and enabling technologies. Renew Sustain Energy Rev 19:555–564

Donateo T, Licci F, D'Elia A, Colangelo G, Laforgia D, Ciancarelli F (2015) Evaluation of emissions of CO_2 and air pollutants from electric vehicles in Italian cities. Appl Energy 15:675–687. https://doi.org/10.1016/j.apenergy.2014.12.089

Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Kadner S, Zwickel T et al (2011) Renewable energy sources and climate change mitigation: special report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

El-Guindy R, Maged E, Mahmoud K (2013) Environmental externalities from electric power generation. The Case of RCREEE Member States. http://www.rcreee.org/sites/default/files/rcreee_rs_environmentalexternalitiesfromelectricpowergeneration2013en.pdf. Accessed 10 Nov 2016

Enerdata Yearbook (2015a) Global energy statistical yearbook 2016. CO_2 emissions from fuel combustion. https://yearbook.enerdata.net/electricity-domestic-consumption-data-by-region.html#CO2-emissions-data-from-fuel-combustion.html. Accessed 10 Sept 2016

Enerdata Yearbook (2015b) Global energy statistical yearbook 2015. CO_2 emissions from fuel combustion. Available from https://yearbook.enerdata.net/co2-fuel-combustion/CO2-emissions-data-from-fuel-combustion.html. Accessed 3 Feb 2016

Energy Information Administration (EIA) (2015) Iran. https://www.eia.gov/beta/international/analysis_includes/countries_long/Iran/iran.pdf. Accessed 19 June 2015

Energypedia (2017) Iran energy situation. https://energypedia.info/wiki/Iran_Energy_Situation. Accessed 15 Apr 2017

Environmental Protection Agency (EPA) (2016a) Causes of climate change. https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases. Accessed 09 Oct 2016

Environmental Protection Agency (EPA) (2016b) Climate change indicators: health and society. https://www.epa.gov/climate-indicators/health-society. Accessed 07 Dec 2016

Evans A, Strezov VJ, Evans T (2009) Assessment of sustainability indicators for renewable energy technologies. Renew Sustain Energy Rev 13:1082–1088

Farhangnews Agency (2016) Why is the Iranian record electricity consumption? http://www.farhangnews.ir/content/196709. Accessed 09 Dec 2016

Farsnews Agency (2013) The 20 kW solar power plant of Birjand University launched. http://www.farsnews.com/newstext.php?nn=13910708001080. Accessed 13 May 2017

Fraunhofer Institute for Solar Energy Systems (ISE) (2017) Photovoltaic report. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf. Accessed 10 June 2017

Fthenakis VM, Kima HCh (2011) Photovoltaics: life-cycle analyses. Sol Energy 85(8):1609–1628

Fthenakis VM, Kim HCh, Alsema E (2008) Emissions from photovoltaic life cycles. Environ Sci Technol 42(6):2168–2174. https://doi.org/10.1021/es071763q

Gorjian Sh, Ghobadian B (2015) Solar thermal power plants: progress and prospects in Iran. Energy Procedia 75:533–539

Grundy P (2008). Shell energy scenarios to 2050

Hairata MK, Ghoshb S (2017) 100 GW solar power in India by 2022—a critical review. Renew Sustain Energy Rev 73:1041–1050

Hangera S, Komendantovaa N, Schinkec B, Zejli D, Ihlal A, Patta A (2016) Community acceptance of large-scale solar energy installations in developing countries: evidence from Morocco. Energy Res Soc Sci 14:80–89

Hernandez RR, Easter SB, Murphy-Mariscal ML, Maestre FT, Tavassoli M, Allen EB, Barrows CW, Belnap J, Ochoa-Hueso R, Ravi S, Allen MF (2014) Environmental impacts of utility-scale solar energy. Renew Sustain Energy Rev 29:766–779

Hohmeyer O, Ottinger RL (1994) Social costs of energy. Springer, Berlin

Hosseini SE, Mahmoudzadeh Andwari A, Wahid MA, Bagheri Gh (2013) A review on green energy potentials in Iran. Renew Sustain Energy Rev 27:533–545. https://doi.org/10.1016/j.jafrearsci.2015.06.002

International Energy Agency (IEA) (2003) The potential of solar electricity to reduce CO_2 emission

International Energy Agency (IEA) (2014a) Energy technology perspectives, 2014. https://www.iea.org/media/news/2014/ETP14_factsheets.pdf. Accessed 05 June 2016

International Energy Agency (IEA) (2014b) Technology roadmap. Solar photovoltaic energy. https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf. Accessed 10 Nov 2016

International Energy Agency (IEA) (2015a) Key trends in CO_2 emissions from fuel combustion. Available from https://www.green4sea.com/wp-content/uploads/2017/02/IEA-Key-CO2-Emissions-Trends-2016.pdf. Accessed 10 Mar 2016

International Energy Agency (IEA) (2015b) Energy and climate change. https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf. Accessed 02 Feb 2016

International Energy Agency (IEA) (2015c) CO_2 emissions from fuel combustion

International Energy Agency (IEA) (2016a) Key world energy statistics. http://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf. Accessed 10 Feb 2017

International Energy Agency (IEA) (2016b) Energy and air pollution. World Energy Outlook Special Report. http://www.worldenergyoutlook.org/airpollution/. Accessed 10 Jan 2017

International Persian Group (IPG) (2016) Opportunities to construction renewable energy power plants in Iran. Solar energy map for Iran. http://ipg-co.com/services/opportunities-to-construction-renewable-energy-power-plants-in-iran.html. Accessed 11 Dec 2016

International Renewable Energy Agency (IRENA) (2015) Renewable power generation costs in 2014

International Renewable Energy Agency (IRENA) (2016a) RE map: roadmap for a renewable energy future, 2016 Edition. http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf. Accessed 10 Mar 2017

International Renewable Energy Agency (IRENA) (2016b) Summer of solar. http://www.irena.org/Quarterly/IRENA_Quarterly_2016_Q3.pdf. Accessed 10 Mar 2017

International Renewable Energy Agency (IRENA) (2016c) Featured dashboard-capacity and generation. http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=18. Accessed 11 Mar 2017

International Renewable Energy Agency (IRENA) (2016d) IRENA quarterly 2016 Q3. www.irena.org. Accessed 10 Apr 2017

International Renewable Energy Agency (IRENA) (2016e) The true cost of fossil fuels

Iran Renewable Energy Organization (SUNA) (2016a) History, objectives and missions. http://www.suna.org.ir/en/history. Accessed 29 Jan 2017

Iran Renewable Energy Organization (SUNA) (2016b). http://www.suna.org.ir/en/privatesectorrequirements/planningdevelopment/strategicenergyplanning. Accessed 29 Jan 2017

Iran's Ministry of Energy (2013) Deputy for power & energy affairs-power & energy planning department. Iran and world energy facts and figures

Iran's Ministry of Energy (2015) Tavanir holding company of Iran. Detailed statistics of Iran electricity production industry

Iran's Ministry of Energy (2016) Tavanir holding company of Iran. Rural power statistics in 2015. http://amar.tavanir.org.ir/. Accessed 10 Mar 2017

Kalogirou SA (2004) Environmental benefits of domestic solar energy systems. Energy Convers Manag 45:3075–3092

Kannan N, Vakeesan D (2016) Solar energy for future world: a review. Renew Sustain Energy Rev 62:1092–1105

Lambrechts J, Sinha S (2016) Microsensing networks for sustainable cities. Springer, Berlin

Machol B, Rizk S (2013) Economic value of U.S. fossil fuel electricity health impacts. Environ Int 52:75–80

Mishra UC (2004) Environmental impact of coal industry and thermal power plants in India. J Environ Radioact 72:35–40

Moutinho V, Robaina M (2016) Is the share of renewable energy sources determining the CO_2 kWh and in come relation in electricity generation? Renew Sustain Energy Rev 65:902–914

Najafi G, Ghobadian B, Mamat R, Yusaf T, Azmi WH (2015) Solar energy in Iran: current state and outlook. Renew Sustain Energy Rev 49:931–942

National Aeronautics and Space Administration (NASA) (2017) A blanket around the Earth. https://climate.nasa.gov/causes/. Accessed 10 July 2017

National Oceanic & Atmospheric Administration (NOAA) Research (2013). https://www.esrl.noaa.gov/gmd/news/7074.html. Accessed 03 May 2017

National Renewable Energy Laboratory (NREL) (2016) A retrospective analysis of the benefits and impacts of U.S. renewable portfolio standards. https://emp.lbl.gov/sites/all/files/lbnl-1003961.pdf. Accessed 10 Apr 2017

Nejat P, Jomehzadeh F, Taheri MM, Gohari M, Majid MZA (2015) A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). Renew Sustain Energy Rev 43:843–862

Novacheck J, Jeremiah XJ (2015) The environmental and cost implications of solar energy preferences in Renewable Portfolio Standards. Energy Policy 86:250–261

Nuclear Energy Institute (NEI) (2017) Life-cycle emissions analyses. https://www.nei.org/Issues-Policy/Protecting-the-Environment/Life-Cycle-Emissions-Analyses. Accessed 10 Apr 2017

Omer AM (2008) Energy, environment and sustainable development. Renew Sustain Energy Rev 12:2265–2300

Owen AD (2006) Renewable energy: externality costs as market barriers. Energy Policy 34:632–642

Panwara NL, Kaushikb SC, Kotharia S (2011) Role of renewable energy sources in environmental protection: a review. Renew Sustain Energy Rev 15:1513–1524

Parliamentary of Office Science and Technology (2006) Carbon footprint of electricity generation

Pfeiffer B, Mulder P (2013) Explaining the diffusion of renewable energy technology in developing countries. Energy Econ 40:285–296

REN 21 (2016) Renewables 2016, global status report. http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf. Accessed 10 Mar 2017

Renewable Energy Organization of Iran (SUNA) (2015) Activities in the field of solar energy. http://www.suna.org.ir/fa/sun/projects. Accessed 02 Nov 2015

Renewable Energy Technology Deployment (RETD) (2006) Renewable energy costs and benefits for society

Sadeghi H, Noori-Shirazi M, Biyabani-Khameneh K (2013) Role of electricity generation from renewable sources in reducing greenhouse gases: an econometric approach. Iran's Energy J 17(3):11–20

Sean O, Clinton C, Paul D, Robert M, Heath G (2013) Land-use requirement for solar power plants in the United States. National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy13osti/56290.pdf. Accessed 10 Dec 2016

Sharma NK, Tiwari PK, Sood YR (2012) Solar energy in India: strategies, policies, perspectives and future potential. Renew Sustain Energy Rev 16:933–941

Singh GK (2013) Solar power generation by PV (photovoltaic) technology: a review. Energy 53:1–13

Solangib KH, Islam MR, Saidur R, Rahim NA, Fayaz H (2011) A review on global solar energy policy. Renew Sustain Energy Rev 15:2149–2163

Souvik S, Sourav G, Ayanangshu D, Joyjeet S, Sourav D (2016) Renewable energy scenario in India: opportunities and challenges. J Afr Earth Sci 122:25–31. https://doi.org/10.1016/j.jafrearsci.2015.06.002

Streimikiene D, Alisauskaite-Seskiene I (2014) External costs of electricity generation options in Lithuania. Renew Energy 64:215–224

The Natural Resources Defense Council (NRDC) (2017) New report: 7 million people died from air pollution in 2012. https://www.nrdc.org/experts/emily-davis/new-report-7-million-people-died-air-pollution-2012. Accessed 04 June 2017

The United Nations New York (2015) A world population prospects

The World Energy Council (2016) World energy resources. https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf. Accessed 11 Jan 2017

The World Nuclear Association (2017) Externalities of electricity generation. Available from: https://www.world-nuclear.org/information-library/economic-aspects/externalities-of-electricity-generation.aspx. Accessed 09 May 2017

Timilsina GR, Kurdgelashvili L, Narbel PA (2011) A review of solar energy markets, economics and policies. The World Bank Development Research Group Environment and Energy Team. October 2011

Timmons D, Harris J, Roach B (2014) The economics of renewable energy. Global Development and Environment Institute, Tufts University, Medford

Tofigh AA, Abedian M (2016) Analysis of energy status in Iran for designing sustainable energy roadmap. Renew Sustain Energy Rev 57:1296–1306

Treyer K, Bauer Ch, Simons A (2014) Human health impacts in the life cycle of future European electricity generation. Energy Policy 74:31–44

U. S Department of Energy (2013) Office of energy efficiency and renewable energy. Solar energy technology basics. https://energy.gov/eere/energybasics/articles/solar-energy-technology-basics. Accessed 11 Oct 2015

Union of Concerned Scientists (2013) Benefits of renewable energy use. http://www.ucsusa.org/clean-energy/renewable-energy/public-benefits-of-renewable-power#.WdvOQmiCzDc. Accessed 10 Jan 2017

Varun G, Prakash R, Bhat IK (2011) Energy, economics and environmental impacts of renewable energy systems. Renew Sustain Energy Rev 13:2716–2721

Wei Y, Wu G, Liu L, Zou L (2011) Energy economics: CO_2 emissions in China. Springer, Berlin, p 321

Weisser D (2007) A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy 32:1543–1559

Wikipedia (2016) List of power stations in Iran. https://en.wikipedia.org/wiki/List_of_power_stations_in_Iran. Accessed 10 July 2016

Wilson Center (2012) Solar energy potential. https://www.wilsoncenter.org/sites/default/files/Border_Solar_Romero_0.pdf

Wiser R, Millstein D, Mai T, Macknick J, Carpenter A, Cohen S, Cole W, Frew B, Heath G (2016) The environmental and public health benefits of achieving high penetrations of solar energy in the United States. Energy 113:472–486

World Energy Council (2004) Comparison of energy systems using life cycle assessment

World Health Organization (WHO) (2014) 7 million premature deaths annually linked to air pollution. http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/. Accessed 11 Dec 2015

World Health Organization (WHO) (2016) Climate change and health. http://www.who.int/mediacentre/factsheets/fs266/en/. Accessed 05 Mar 2016

World Nuclear Association (WNA) (2011) Comparison of lifecycle greenhouse gas emissions of various electricity generation sources. http://www.worldnuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf. Accessed 09 Sept 2017