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Renewable energy management and market in Iran: A holistic review on current state and future demands

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ABSTRACT

There are abundant renewable energy sources in Iran such as wind, solar, geothermal, biomass. However, Iran is fully dependent on fossil fuels for industrial, residential and transportation sectors. It results in the country to be in top 10 producers of greenhouse gases (GHGs) into the atmosphere. GHGs can be controlled by incorporating renewable sources to produce energy. Therefore, renewable energy resources are becoming more attractive to develop sustainable energy development in Iran. However, the transformation from traditional fossil fuel infrastructures to advanced renewable technologies needs many considerations, such as strategic and core planning. In this regard, this paper covers the current state of Iran's energy market focusing on both fossil fuels and renewable energy resources. A general review is offered over the renewable energy production status in Iran and the production potentials. Finally, in conclusion, a comparisons are made over the current state, plans and also potential opportunities of Iran over each sort of energy production.

1. Introduction

Iran (Islamic Republic of Iran) is located in the West Asia, surrounded by Caspian Sea, Azerbaijan, Turkmenistan, Armenia, Pakistan, Afghanistan, Iraq, Persian Gulf, Oman Gulf and Turkey. The country owns total area of 1.65 million km^2, and a population over 80 millions people including 49.6% females and 50.6% males [1]. The population is distributed mainly in cities with urban citizen number of ca 54 million. Generally, Iran has a hot, dry climate characterized by long summers and short, cold winters. ran is one of the largest economies in the Middle East and North Africa (MENA) with an estimated gross domestic production (GDP) in 2015 of $393.7 billion [2]. Iran's economy is characterized by a large hydrocarbon sector, small-scale agriculture and services sectors, and a noticeable state presence in manufacturing and financial services [3]. Although there are many great resources of income holistically, urbanization and balanced population distribution have drawn Iran into many challenges and dilemmas such as environmental hazards and seasonal drought [4–6].

As one of the rapid developing countries in West Asia, Iran's government seek the country to become a developed nation in the near future. To realise this vision, economic growth has to propel from being an agricultural- and commodity-based ecosystem to a manufacturing and service-based one. On the other hand, both its population and economy are expanding each year, so its energy demand increases correspondingly. This increasing demand should be accompanied by sustainable development in the economy and raising welfare of the Iranians [7,8]. Fossil-based energy sources, and in particular oil and natural gas, have been the major contributing fuels for the power sector in Iran, while the economic enhancement and societal advancements are appurtenant reliable energy sources. The challenging issue is how to achieve sustainability, i.e. to ensure the security and reliability of energy supply while taking the environmental consequences of energy production into account. Globally, the power generation has been a major contributor of GHG emissions [9], as most electricity generating plants use fossil fuels. In Iran, GHG emissions increased rapidly in the past few decades, [2,10], while the country has committed to the Kyoto Protocol [11], and has a vision to implement low-carbon economy and to reduce GHG emissions. Therefore, it is essential for the country to intensify the applications of renewable energy resources. It is worth mentioning that there is an enormous potential for using renewable energies and power production from renewable energy sources in Iran,

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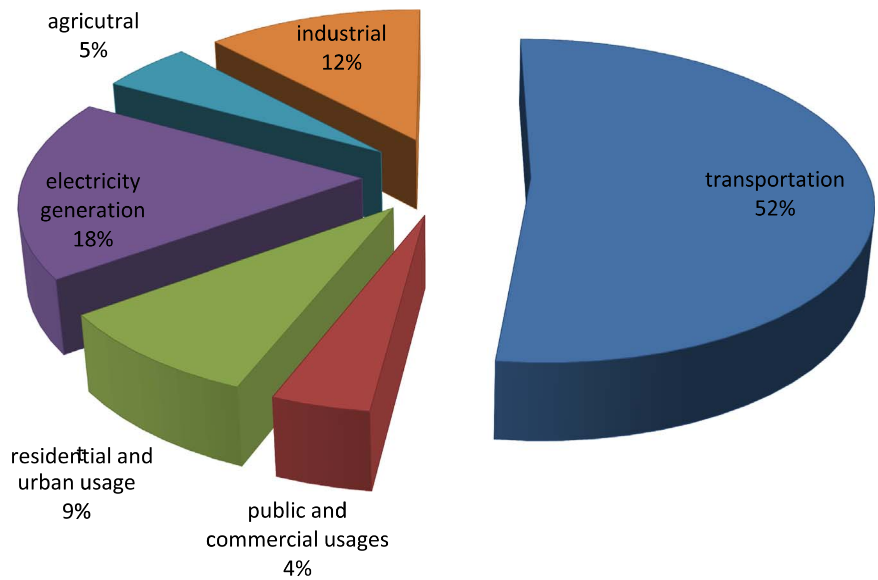

Fig. 1. Various energy consuming sectors and their related shares form Iran's total energy consumption (adopted from [30]).

and it had a positive trend in the last decade.

The aim of this study is to clarify the extent of non-renewable and renewable energies in Iran, and potentials of sustainable energy carrier. A brief review over Iran's energy market covering both non-renewable and renewable energy carriers is first performed. Furthermore, the limitations of developing renewable and sustainable energy carriers (RSE) are discussed to reach to a lower GHGs emissions.

2. Iran's current state of energy

Different aspects of Iran's energy market is covered in previous studies [4,12–17]. The country's energy consumption passed 1493.21 million barrels oil equivalent per year, which places Iran among the fast-developing countries [12]. Residential and commercial sectors, transportation, industrial sector and agricultural activities are the first four and major energy-consuming sectors in Iran. Currently, the largest energy demand is in transportation sector (Fig. 1). The government tried to increase the shares of alternative energy resources in the energy carrier mix by reducing the share of crude oil from 54% in 2001 to 44% in 2008. However, it resulted in practice to higher share of natural gas, that is still a fossil fuel [18].

There are four major energy carriers in Iran as crude oil, natural gas, coal and hydropower. Even though there are considerable coal resources, there is no significant supply for coal-based energy industries in the overall energy mix of Iran.

2.1. Crude oil

Iran owns 28 operating fields of crude oil and natural gas. To be more specific, 18 fields contain specifically crude oil, and four field contain gas resources. The remaining others field have both crude oil and natural gas. Many of the fields have not been explored yet. In fact, there are more than 102 oil fields and 205 oil reservoirs identified in Iran, from which only a small share are in operation [19]. Meanwhile, some of the oil and gas fields are shared with other neighbors that extract more oil and gas than Iran does. Iraq takes advantage of the shared resources two times more than Iran. There are even reservoirs shared with Qatar, of which, despite the neighbor, Iran has not started to extract hydrocarbons yet. Another fact is that current extraction technologies are rather old. Only 25% of accessible crude oil could be extracted with the aforementioned technology and enhanced facilities and techniques such as gas injection are crucial for higher production rates [19]. Table 1 summarizes the amount of crude oil handled by

Table 1
Different crude oil extraction and refinery companies in Iran and their working capacity.

	Company name	Production capacity (thousand barrels per day)
Crude oil extraction companies	Manategh e nafatkhiz jonub	3075
	Falatghare Iran	706
	Manategh emarkazi (onshore)	151
	Arvandan	84
Refinery companies	Abadan	350
	Bandar Aabbas	320
	Tehran	220
	Isfehan	200
	Arak	150
	Tabriz	110
	Shiraz	40
	Lavan	20
	Kermanshah	15

Iran.

It is worth mentioning that even there exist great infrastructures and the country stands on the fourth stage among the oil producing countries, the demands for the energy carriers are not satisfied yet which has turned Iran into an importer of processed petroleum products and exporter of raw crude oil. Another influencing factor for Iran is the depletion in crude oil production due to the prolonged operation age of the mature wells and consequently lowered wells' pressure [20].

2.2. Natural gas

The government of Iran had a strategy to increase the share of natural gas in domestic energy mix and increase the export of crude oil [19]. It resulted in consumption of natural gas to meet an annual growth of 10.7% since 2000 [21]. Being the second producer of world's natural gas, Iran plays an important role in the field. Six available liquefied natural gas (LNG) plants are all fed with reserves owned by Pars Jonoobi field. Unlike some of the industrialized countries, Iran does not rely on coal as the main fuel due to the fact that coal involves in only 0.21% of energy consumption in the country. Main reserves considered are located in Yazd and Kerman provinces producing more than 64% of the country's coal. Based on modelling the energy

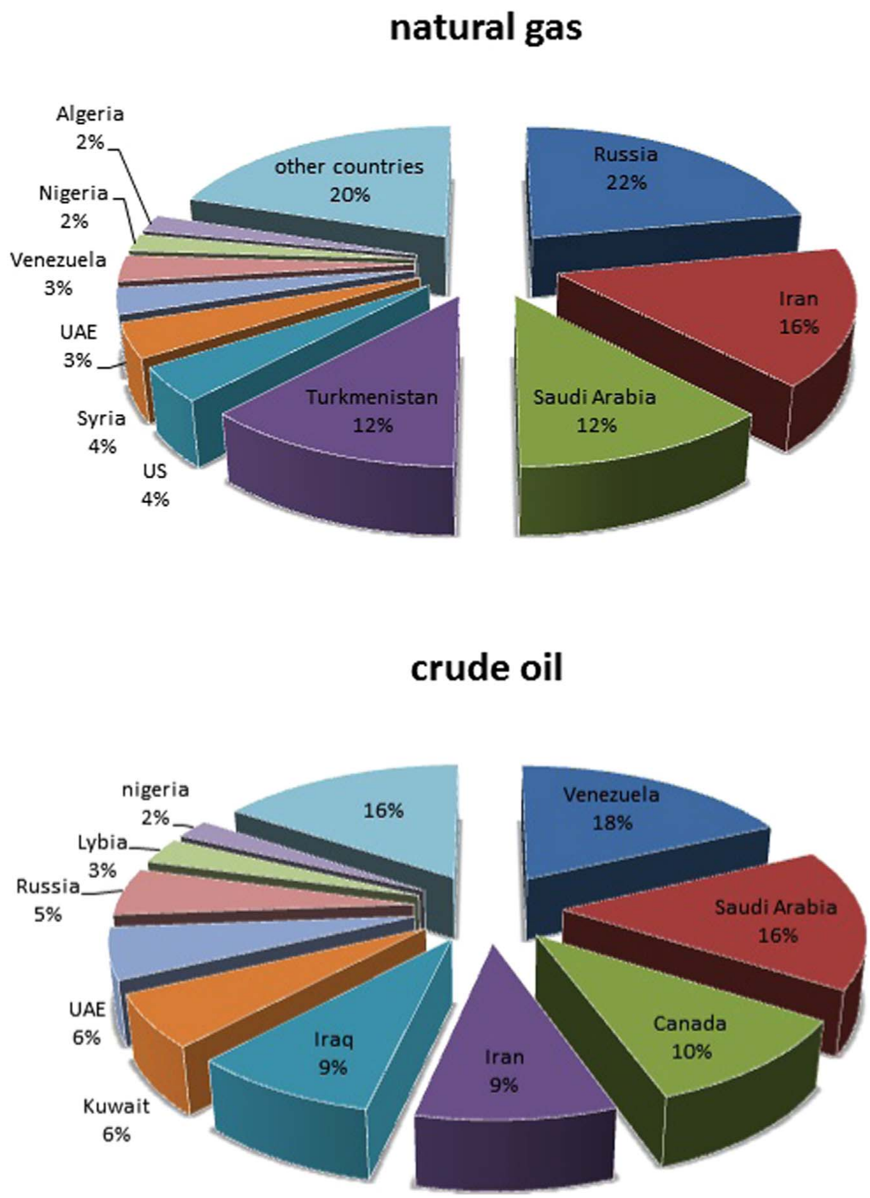

Fig. 2. Comparison of Iran's natural fossil resources with other countries.

production trends, it was claimed that Iran's fossil fuel productivity starts to fall down in 2019 [4]. Based on a report published in world's energy outlook (WEO) published by International Energy Agency (IEA), world's natural gas and crude oil resources might be fully finished in next 59 and 39 years, respectively [22]. This means that Iran owns a short range of time to reconfigure its energy policy. Even if the accuracy of the aforesaid predictions was wrong, it would be wise to start to reform the old habits as the resources are limited for sure. Even though the abundant reservoirs of Persian nation lessens the possibility of RSEs, Iran tends to produce more than 5000 MW electricity out of renewable energy resources [19]. Fig. 2. shows Iran's natural fossil resources shares compared to other countries.

2.3. Coal

Globally, around 30% of primary energy demands are provided by coal, and about 40% of the electricity of world is produced by coal (https://www.iea.org/topics/coal/). According to the BP Statistical Energy Survey in 2010, the coal consumption of Iran was about of 1. 36 million tonnes oil equivalent. There are three main operating and processing plants which placed in Kerman Province and the Alborz Mountains at Zirab and Shahroud (http://petropadpars.ir/Mining.htm). Most of the coal in the country is produced from the underground mine and is used in steel industry. The annual coal production of Iran is preserved on 1.5 Mt from relatively small underground mines in the Kerman and Alborz coalfields. A major coal-sector investment was accomplished to develop the Tabas Coalfield to produce 1.5 Mt/y of coking coal from a new longwall operation. Kerman Coal company owns several coal operations within the country, namely Eshkli coal mine which has proven reserves of 16, 887,500 t and produces 360,000 t of coal per year; Hamkar coal mine which has proven reserves of 6,970,380 t and produces 259,000 t; Hashouni with proven reserves of 25.9 Mt and an annual production of 240 000 t; Hojedk with proven reserves of 817,000 t and annual production of 68,000 t; Kamsar with proven reserves of 874,000 t and an annual production of 120,000 t (http://petropadpars.ir/Mining.htm). In world the coal has great contribution to generating the electricity, and its consumption is still growing. For example, the percentage contribution of coal was increased from 9.7% (in 1995) to 48.3% (in 2012) (https://www.eia.gov/coal/annual/pdf/acr.pdf). Although coal is the cheapest and most abundant fossil source, the large amount of CO_2 is emitted when coal is burned (around 200 pounds per million British thermal units (Btu) of energy) (https://www.eia.gov/tools/faqs/faq.cfm?id=73 & t=11). Therefore, increasing GHGs emission threaten anthropogenic vita and the global warming has caused policy makers to initiate to remark moving towards an agreement that would charge power plants for CO2 emission and if this occurs, the days of cheap energy and electricity from coal will be ended [23,24].

3. Iran's renewable energy resources

3.1. Hydropower

Iran has managed to build great dams with total hydropower capacity of 7704 MW, while other dams with 7000 MW are projected or under construction. Iran has plan to increase its hydropower generation capacities to 36 GW [25]. There are more than 44 hydropower plants, while six plants with +1000 MW capacities produce more than 90% of the current available hydropower electricity in Iran. It is worth mentioning that due to the inherent nature of the technology, hydropower includes the least greenhouse gas production among the four main energy supplying resources. The growth rate of hydropower industries was reported to be 27.5%, nine times more than global measures during the 4th Iran's development plan [25]. Besides the electricity generation, there are many other socioeconomic, geological and agricultural advantages considered for the constructed dams (flood control, irrigation water supplies, and job opportunities in different sectors).

3.2. Wind power

Increments over economic, social and environmental awareness of wind power utilization resulted in the technology incorporation growth [26]. With respect to accelerated rate reported, a 1,900,000 MW wind power production is projected for 2020. The country's overall potential for wind assisted energy production is estimated to be 100,000 GW by Iran Renewable Energy Organization (SUNA) [27]. There are numbers of wind farm sites in Iran, namely, Manjil, Guilan and Binalood in Razavi Khorasan Province. The total capacity of Iran's wind power driven energy is estimated to be around 6500 MW [26]. This is while the last nominal installed sites' capacity was not more than 3400 MW annually [28]. Projection of wind-assisted power generation by 2020 is reported to be 100,000 MW [26]. Even though the capacity of wind-assisted power generation sites is negligible in comparison with other energy resources, governmental development programs tend to be aimed to higher the production rate. This might be due to the fact that Iran owns many lands being potentially suitable for wind farm sites. Investigations have led to the formation of wind maps of Iran showing 26 regions including 45 potential locations (Fig. 3) [26,29]. Moreover, the former ministry of energy took great steps for promotion of the wind power including preparing wind atlas of Iran using 53 synoptic stations all over the country.

Iran's trend in wind power generation had a significant growth over last decade. Reports offer the numbers as follow: 25 MW in 2004, 32 MW in 2005, 47 MW in 2006 and 130 MW in 2009 [26]. This is however far away from the ministry of energy's projection. Consequently, massive research and operational efforts must be carried out to reach to an acceptable share of the planned goal. Fortunately, the great research works have so far been conducted on different dimensions of wind power in Iran, where provinces and city's capability (i.e. Tehran [30], Zahedan [31], Mah-shahr [32], Semnan [33], Chabahar, Kish, Salafchegan [34], Tabriz, Ardabil [35], Kerman [36], Binalood [37], north and south Khorasan [38], Yazd [39], Zarrineh [40], Mil-e-Nader in Sistan and Baluchestan [41] and shahrbabak [42]) were considered. In such reports, the necessity of developing infrastructure especially in the case of manufacturing turbines were highlighted [28,43]. The possibility of the offshore sites for obtaining wave energy was also studied by Mostafaeipour [44]. However, such technology has challenges such as higher capital investments in comparison with onshore wind sites, underwater cabling and difficult installation. Positive and negative environmental impacts were also pointed out. Being situated in the vicinity of densely populated coastal areas, Persian waters own moderate wind resources which could contribute significantly in local and regional power supplies [44].

3.3. Biomass

Biomass is playing an important role in current world's energy market. The only current highly incorporated biomass in Iran is wood as a traditional fuel [12]. Forests have a share of approximate 7% (11 million ha) of the lands in Iran. This is while more than 52% of the lands in the country is dedicated to pasture and agriculture [12]. It is worth mentioning that a considerable amount of the biomass residues are burned (19.6 million tonnes annually) based on the reports of Kim et al. [45]. Ministry of Agriculture of Iran reports that 22% of the total land with potential of agricultural activities in Iran is not currently under any operation or use due to the lack of water supplies [46]. The data provided could be an incentive for assessing the capabilities of Persian posture and arable lands to cultivate non-edible seeds. The products could be used for second generation biofuel productions.

3.4. Biogas

One of the major sources to produce renewable energy is biogas as which can be used directly to provide heating, electricity or car fuel. Any biological material including forest, agricultural and crop residuals, food industry wastes, municipal solid waste (MSW), livestock waste, municipal sewage and industrial organic waste can be used as a source of biomass. Resources for biomass consist carbohydrate polymers and/or proteins that are transformed into methane by anaerobic digestion process [47]. Anaerobic digestion (AD) of organic wastes to produce biogas would profit society by providing a clean fuel from renewable materials [48]. There is a good potential to substitute this renewable energy with fossil fuel-derived energy, and consequently, the environmental impacts including global warming and acid rain are decreased [49,50]. In the digestion process, hydrolysis of polymers occurs to obtains sugars, amino acids and long chain fatty acids. These materials are then converted to volatile fatty acids, hydrogen and acetic acid in the next step by acidogens and acetogens. In the final step hydrogen, carbon dioxide and acetate are converted to carbon dioxide and methane by methanogenic bacteria. Methane (50–70%) and carbon dioxide (30–50%) are two main components of biogas produced with a small amount of other gases such as H_2S. Biogas has a heating value of around 21–24 MJ/m^3 [51,52]. Iran has good potential to produce energy from biomass resources equal to about 15 million tonnes or 140 million barrels of crude oil equivalent [53]. Production and application of biogas in Iran have a long history, but the growing is not significant. A bath in Isfahan (Sheikh Bahai bath) was the first documented commercial plant to use the biogas produced from sewage to warm up the water (1530–1622). The first biogas production digester of Iran was established in Niaz Abad at Lorestan province in 1975 by using the livestock waste of the village (http://www.suna.org.ir). Recently, some pilots for biogas production have been started up and operated by academic and research centers in Iran. Shiraz biogas plant has an overall energy production capacity of 1060 kW. The plant is able to convert 4 million m^3 biogas into electricity and generate 7189 MWh of electricity per year [54]. Mashhad biogas plant was constructed with a total capacity of 650 kWh in the old municipal waste landfill. This plant can deliver 4 million kW to the power network per year by using around 2 million m^3 biogas produced. Currently, two units of this plant with a capacity of 330 kW are supplying electricity for 600 families in Mashhad, and the rate of electricity production will be increasing to 1 MW in the near future (http://www.suna.org.ir). The

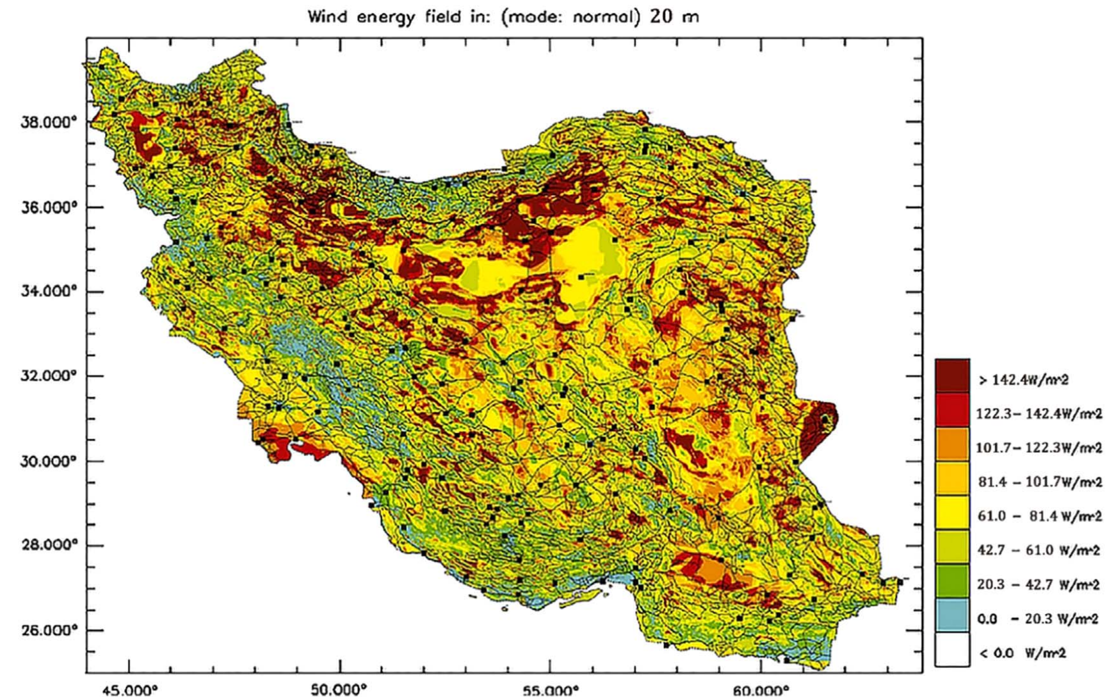

Fig. 3. Iran's wind energy field [35,38] (with permission from Elsevier, copyright 2015).

biogas plant in Saveh is the first biogas reactor of Iran which can produce energy from solid and liquid organic wastes including 175 t of municipal solid waste, 27.4 t of refinery sludge, 13.7 t of domestic sludge and 12 t of slaughterhouse waste. The rate of biogas and electrical energy production of this plant is about 6930 m^3/day and 4850 MWh/year, respectively [54]. Isfahan biogas plant with a capacity of around 1 MW is the first unit of sewage biogas in Iran. As the authorities in biomass office of SUNA claim, more than 7 million kWh electricity is added to the network by this plant. There is an excellent potential to produce biogas in Isfahan landfill (about 225,000 m^3 per day) and then to generate electricity. Two biogas combustion motors with a nominal generating power equal to 620 kW can generate 1200 kW electricity per hour [55]. A biogas plant with total capacity of 5 MW connected to the municipal wastewater treatment was constructed in Tehran in 2011. Currently, this plant is working with 40% of its total capacity and produces 2 MW electricity [54]. The potential of biomass sources in Iran is enough good and estimated to be 132 million tonnes (oil equivalent) in the form of agricultural and forest wastes, municipal wastes, livestock wastes, sewage and industrial wastes. It is predicted that Iran has the potential to produce about 16, 000 million m^3 which is approximately 320 petajoule of energy.

3.5. Urban wastes

A proper waste management could contribute to energy supply by different technologies. Many cities' residents face the barrier of controlling wastes and leftovers of daily life [56]. The waste production has been intensified by many factors such as escalation of economic activities, lifestyle change and steep growing rate of urbanization (world's population would reach to 7.2 billion with two third of them living in cities) [56–58]. High costs of waste handling and the lack of knowledge of the diversity of the affecting factors have hindered the management of human life redundant materials [59]. Moreover, the landfilling problems causing many pollutions of water resources and air (based on the chemical and biological activities) raises another series of individual calamities [60]. Controlling the solid wastes could effectively enhance the greenhouse gas emissions as the landfill gases are comprises of nearly 50% CO_2 and 50% CH_4. It is worth mentioning that about 20% of anthropogenic methane (produced by human beings) emissions are resulted from landfills [60]. The wastes are mainly divided into two sub-sections of solid waste and waste water. There are many efforts put on converting recyclable portions of municipal solid wastes (MSW) into accessible energy. Wastewaters could also be considered as an energy carrier. In fact, the alternative usages of waste waters could go further to thermal energy generation [61]. High-temperature energy recovery through thermal plants, hydrothermal carbonization, incineration, plasma treatment, anaerobic digestion and gasification are some of the process routes considered for the power generation scenarios [62–69]. Most common route is, however, the digestion and biogas production which could result in heat and power generation individually or simultaneously in a combined heat and power generation system (CHP) [20,70,71]. Other technologies like incineration and gasification power plants have not been developed significantly yet. There are a few plants owning these technologies, however many challenges have been experienced for suitable development of these plants. In order to go with one certain process, some of the influential parameters like the waste production rate, distribution of the waste producers, process efficiency and lifecycle assessment studies of each method should be investigated. There are also possibilities of process integration and co-processing of waste to energy processes with other industrial production processes [72–74]. A study of twenty-three developing countries or those who are in transition which included Iran shows that average MSW production rate is near 0.77 kg per person per day with a current recovery rate of only 5–40% [58]. The production rate is slightly higher for Iran with the value of 0.888. This is while the possible recyclable share goes up to 70% with 17–80% organic materials [58]. The annual municipal wastewater production rate in Iran has to be reported to be 4.6 billion m^3 [54]. Considering the great amount of waste production in Iran, great opportunities of energy production and material recovery could be turned out of environmental risks. According to a conference paper, the potential of energy production from the municipal wastes in Iran is equal to 15 and 2 million crude oil barrels for MSW and urban wastewaters respectively [55]. Even though there are numerous wastewater treatment plants and solid waste centers, only a few centers take advantage of waste-to-energy production processes. Rather than the

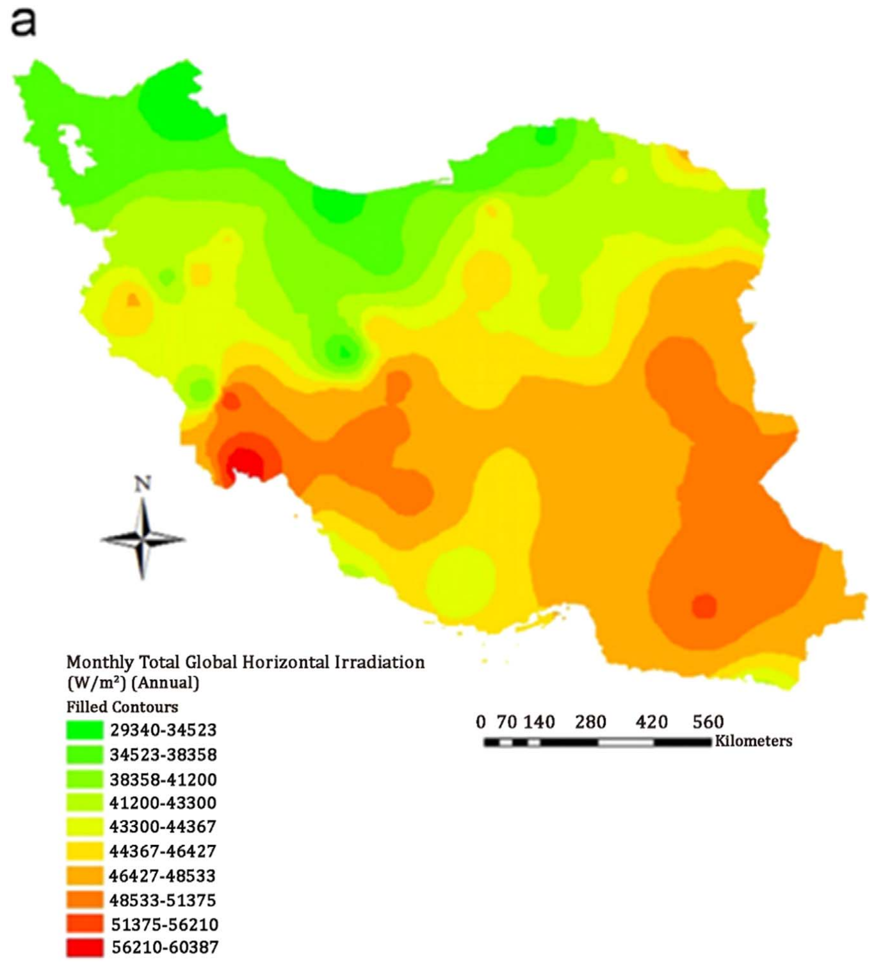

Fig. 4. Average radiation on a horizontal surface [76] (with permission from Elsevier, copyright 2015).

ancient practical usages of Persian scientists from the concept (Sheikh Bahai's bath building) there exist five main biogas production plants are currently being run in Iran namely, Tehran, Shiraz, Mashhad, Saveh and Isfahan plants [54] and some other plants unreported or under construction. All the main biogas production plants are fed with solid wastes, wastewaters and sewages of the urban population. The minimum potential of biogas production in Iran is estimated to be around 40 million m^3 per year (previous conference). Consequently, 170,666 MWh of electrical energy and 742,000 Gj per year of thermal energy could be extracted from the potential (previous conference). It was reported that biogas sites with the total capacity of 11.5 MW under construction while there are other projects at the stage of contracting with an accumulated capacity of 11.5 MW [25].

3.6. Solar assisted energy production

Being located at a great geographical position, Iran owns great potentials for producing energy with the assistance of photovoltaic (PV) solar cells and thermal solar facilitated technologies. By taking advantage of GIS maps and weather statistics, the annual average irradiation map of Iran is presented in Fig. 4. Clearly one could conclude that, except southern coastal line, central and southern regions of Iran are suitable areas for solar cells [75]. Findings of Alamdari et al. was confirmed by the solar irradiation harnessing potential investigation using solar maps and comparing 5 MW PV plants in 50 different cities of Iran [76]. Besarati et al. reported the same findings while introducing Bushehr bearing the highest solar capacity factor (26.1%) and Anzali owning the lowest capacity factor (16.5%). Based on the these scenario, more than 6110 t of CO_2 would be saved from emitting into Iran's environment [76]. More recently 'new configurations' of each technology and integrated forms of introduced systems are also under attention [77–80]. Various solar irradiation intensities and angles offer a board range of available energy differing from 5.4 kW h/m^2 in the south to 2.8 kW h/m^2 in the north during the daylight. Considering the facts that Iran owns 300 shiny days a year and average irradiation per square meter reaches to 2200 KW h, Iran stands in a great position to take advantage of solar-assisted power production systems [27].

Based on Najafi and his coworkers' estimations, based on incorporation of only 1% of Iran's area and installing facilities with just 10% efficiency Iran would be capable of harnessing more than 9 million MW solar-assisted power each day [27]. Rather than small and distributed solar units in parks, streets and highways for general usages of lighting and urban life, Iran owns a few solar power plants with formerly installed capacity of 650 MW. The capacity is assigned to six main solar power plants: Shiraz, Mashhad, Yazd, Semnan, Talaghan and, the biggest one, Alborz (Fig. 5).

These solar-assisted power plants own technologies varying from simple PV systems to concentrated solar power (CSP) plants (Shiraz) and combined solar power technology (Yazd). Researches on new integrated solar-assisted processes show that Shiraz, Kerman and Yazd are three locations of CSP sites which unfortunately all suffer from a scarcity of water resources [81]. Considering the finalization of power-house constructions and variations in production capacities, 74% growth in electricity power generation was reported accumulatively from 1998 to 2012 (Fig. 6). The country's overall potential for solar energy production is estimated to be 40,000 GW by Iran Renewable Energy Organization (SUNA) [27]. Considering the growth in plant

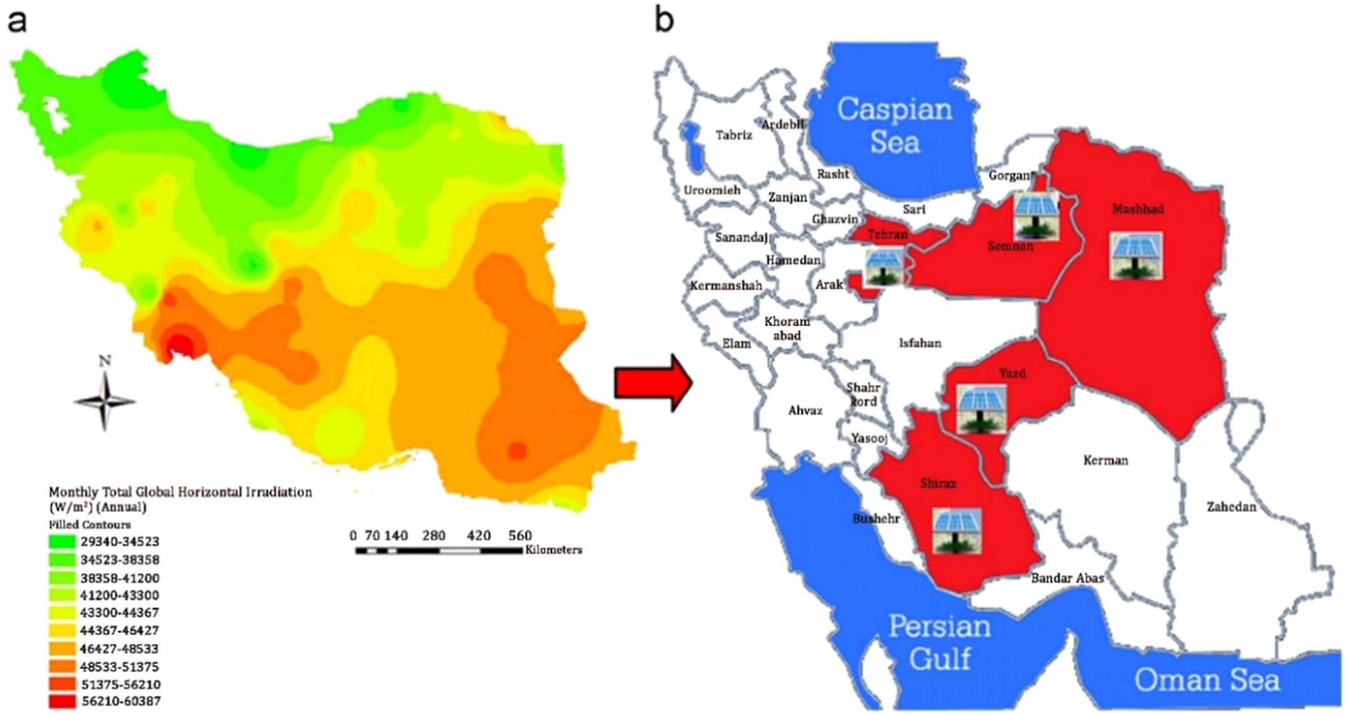

Fig. 5. Different locations of Iran solar assisted powerhouses [36] (with permission from Elsevier, copyright 2015).

installation which owned a gradual growth of 8.9%, Iran could reach to a nominal capacity of 139,296 MW annual solar-assisted power productions in 2030. A more comprehensive review of the solar power generation status of Iran could be found elsewhere [27].

3.7. Geothermal energy

An excellent source of renewable and sustainable energy which has not been focused so far in Iran is the one stored in the Earth's crust. Based on the researchers claim 1% of the stored geothermal energy is comparable to an amount of energy equal to 500 fold of current fossil fuel energy capacity of the world [82]. Even though the stored energy exceeds far beyond human's needs, only a small fraction of current energy demands is met by the resource, and that is due to the high costs of drilling and explorations [82]. Considering the fact that Iran is located on the geothermal belt, there exist high potential of geothermal energy production. Meshkinshahr, the main geothermal power site of Iran owns a capacity of 55 MW. The project is intended to be upgraded to a 200 MW CHP plant by the end of Iran's 5th development plan [25]. Technically, the area is known as Sabalan geothermal field. However, this is not the only potentially proper place for the geothermal sites. Damavand, Sahand and Khoy-Makuareas were also proposed as probable lands owning same characteristics [83,84]. Fig. 7 shows the distribution of potential geothermal sites in Iran [85]. Efforts are ongoing in order to achieve a better understanding of the field's structure [82,86–89]. It is worth mentioning that with all the obvious benefits of the introduced technology, based on the estimations and as a result of technological barriers and availability of other renewable energies, geothermal energy will not have any significant role in Iran's future energy mix [83].

3.8. Heat pump

Heat pumps are considered as another renewable energy technology which incorporates a process fluid and electricity to draw thermal energy from a low-temperature source [90]. These technologies are capable of offering heat to a higher temperature sink (and refrigeration of the heat source). Main heat sources (in heating applications) or sinks (in cooling applications) consist of outdoor/indoor air, river/lake/sea water, ground and waste heat [90,91]. Heat pumps consist of the

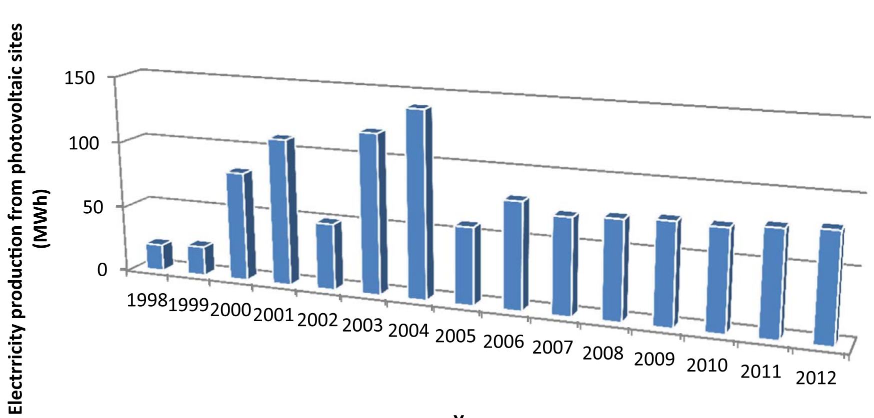

Fig. 6. Growth in electrical power generation in Iran from 1998 to 2012 (adopted from [82]).

Fig. 7. Possible sites for geothermal plants (Adopted from [86]).

Table 2
Detail information of heat pump projects developed in Iran.

Name of project	Year	Location	Area (m^2)	Capacity (Kw)	COP	Coil
Established by National Iran Gas company						
Gahan Jamezghan	2012	Qom	100	10	4–4.2	Open
Gahan Jamezghan	2012	Qom	60	10	3.8–4	Vertical
Gahan Jamezghan	2012	Qom	70	10	3.8–4	Vertical
Ghanavat	2013	Qom	300	33	3.9–4.2	Vertical
Edaray Gaz Gom	2013	Qom	50	6.67	4–4.2	Slinky
Established by SUNA						
Taleghan 2	2010	Ghazvin	50	7	4–4.1	Vertical
Taleghan 2	2010	Ghazvin	40	5	3.9–4	Slinky
Taleghan 2	2010	Ghazvin	30	3.5	3.8–4.1	Slinky
Taleghan 1	2006	Ghazvin	45	5	3.9–4	Vertical
Rasht	2006	Gilan	50	5	4–4.1	Slinky-Vertical
Ahvaz	2006	Khozestan	45	5	3.5–3.8	Slinky
Bandar abbas	2006	Hormozgan	50	5	3.6–3.8	Slinky

evaporator (i.e. outdoor unit) to evaporate the process fluid, a compressor to compress the fluid and increase its temperature, a condenser (i.e. indoor unit) to release heat by condensing, and an expansion valve to reduce the pressure and temperature of the process fluid to below the level of outside air temperatures in order to restart the cycle. The power demanded such a process be supplied by the electric energy to run the compressor and circulate the fluid. Common applications for heat pumps could be listed as air-conditioning, refrigeration and space heating in the buildings [91–93] while other applications can be hot water supply in the buildings, cold storage warehouses and process heat and steam for some industrial applications. Heat pumps are classified as highly energy-efficient technologies as they are capable of supplying three to six units of thermal energy for each unit of energy consumed. The economics and market penetration of heat pumps have significantly improved [92]. This technology has a good contribution to CO_2 emissions reduction. Furthermore, heat pumps can be considered as renewable technologies because they mostly use the renewable sources and contribute significantly to penetrate in renewable energy field [94]. Some geothermal heat pump pilot projects have been introduced by the Renewable Energy Organization of Iran (SUNA) on behalf of power ministry in order to reduce the power load [95]. More ever some other pilot projects have been instructed by the National Iranian Gas Company (NIGC) on behalf of the Petroleum Ministry for heating the houses that are located in villages or cities that are far from the gas network in Iran [95]. The first geothermal heat pump (GHP) was installed in Meshkin Shaher city next to the geothermal field in Sabalan Mountain. This GHP has been applied for heating for eight months and cooling for two months. The second GHP was installed in Taleghan and has been used for 3 months of cooling and 5 months of heating, the third was installed in Rasht city for 4 months of cooling and 5 of months heating, the fourth was installed in Ahvaz for 7 months of cooling and 2 months of heating and finally the fifth was installed in Bandar Abbas city for 8 months of cooling. These projects were undertaken to determine the feasibility of GHP application in different climate conditions. The detail technical information of all heat pump pilot projects developed in Iran has been

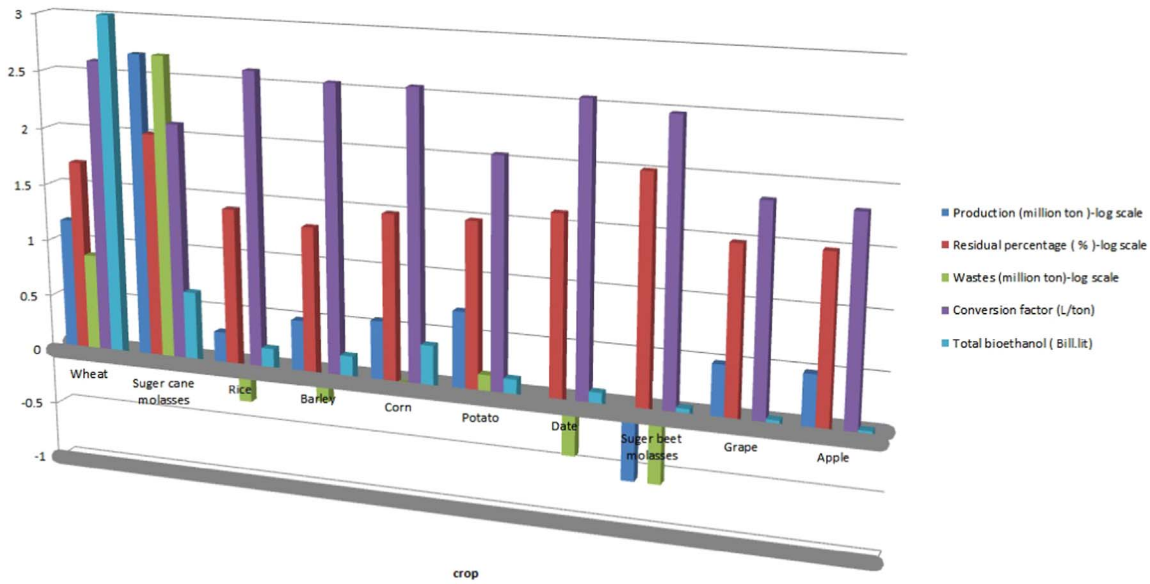

Fig. 8. Potential bioethanol production in Iran from agricultural wastes (adopted from [10,25]).

collected in Table 2 [95,96]. One of biggest obstacles in heat pump technology is the high initial cost. Another one can be insufficient recognition of the heat pump benefits. Moreover, it is also essential to spread the information on benefits of heat pumps and persuade research for reduction costs and improving efficiency.

3.9. Marine energy

"Ocean energy systems" cover all sort of possible technologies which could lead to energy formation out of many related renewable resources such as tides, waves, currents, temperature gradients and concentration gradients [97]. Among the aforesaid resources, wave energy is under certain attentions. One of the significant wave energy's plus points is that, in comparison with solar resources or other conventional renewable energy forms, it has a great density of energy. The amount of energy depends on wave's configuration (height and length). Based on estimations and considering open ocean waves, the energy is said to be near 107 MW [97]. Tidal energy is estimated to be around 100 GW around the world [98]. Biggest ocean project is constructed for Korea in 2011. Other players in the field of ocean-driven energy (mostly tidal) are US, Canada, France and UK [97]. Many researches have been conducted over the capabilities of marine and wave energy potentials of Iran [98–103]. Oman Sea bear an acceptable level of wave energy, 12.6 kW/m. The value, however, is less for Persian Gulf (6.1 kW/m) due to the fact that it is far from the open ocean waters [98]. Investigation of the wave pattern of the Persian Gulf along with numerical modelling was performed by Kamranzad et al. [104]. Even the patterns were driven out and higher energy intensity seasons were reported to be autumns, variations in seasonal weather patterns led to the demand for observation for a longer period. The Caspian Sea owns sustainable wave resources (average energy equal to 5–14 kW/m based on [105] and 16.6 kW/m based on [98] with a maximum energy of 19 kW/m). The fact that the Caspian Sea is isolated by neighbor countries from ocean waters creates a great safe condition for energy sites [98]. Alamian and his coworkers evaluated the possibilities for extracting wave energy from Caspian sea from the technological point of view [105]. The study holistically covered all aspects like Caspian Sea's geological characteristics and current models along with all the possible technologies and operating costs for energy harnessing. The most suitable energy converters based on the characterizations were reported to be point absorbers. Uremia Lake is also introduced to have great potentials of saline gradient power generation. Despite all the capabilities no certain report exists on the nominal or actual capacity of Iran's wave and ocean power harnessing.

3.10. Biofuels

Different rates of bio-based fuels are currently available categorized based on their state of the material (biogas and liquid biofuels) [106] or feed resources (1st to 4th generation biofuels). More conventional types of biofuels could be listed as bioalcohols (methanol and bioethanol), biodiesel and biohydrogen. Based on each biofuel, recent trends and commercialization efforts would be discussed here.

3.10.1. Bioethanol

A diverse range of agricultural seeds offer an ideal opportunity to the bioethanol production industries in Iran. The main resource is reported to be sugar beet molasses and sugar cane with 500 million liters approximate production volume [46]. The more important resources after sugar residuals could be named as wheat, cone and rice [15]. For instance, based on FAO's reports, 30% of rice plants are wasted after taking the seeds. As each tonne of residual rice could be turned into 400 l of bioethanol, Iran is capable of reproducing 200 million liters of the bio-based fuel [15]. Considering the reported 17–20% agricultural products turned into residuals and their annual amount of productions (17.86 million tonnes), Iran is capable of producing more than 4.91 billion liters bioethanol a year [46]. Fig. 8 shows the potential bioethanol production volumes from Iran agricultural waste resources (based on agriculture ministry of Iran's report).

3.10.2. Biodiesel

Just like bioethanol, biodiesel could be generated out of many feedstocks like fresh crops oil, used and waste cooking oil, etc. based on the FAO's reported Iran's rate of cooking oil consumption is 1.5 million tonne per year. About 20% or 0.3 million tonne turns to waste oil is delivered to wastewater systems. The estimated amount, if turned into biodiesel, is sufficient for supplying the demand for Iran's B10 requirements till 2026 [15]. Rather than waste cooking oil resource, Iran owns excellent edible oil sources. Fars, Golestan and Khorasanrazavi are three main edible seed providers of Iran. Different crops like soybean, canola and cotton along with other edible oil resources such as olive, sunflower and sesame have the potential to own a share of biodiesel production feedstock [46,107]. Fig. 9 shows the estimated proportion of each resource in Iran's biodiesel produc-

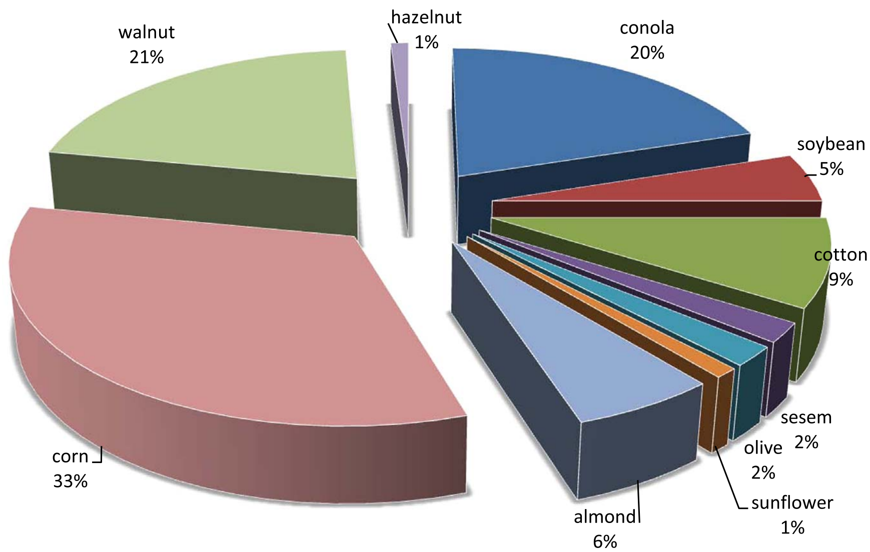

Fig. 9. Estimated share of each resource in Iran's biodiesel production (adopted from [101]).

Table 3
Iran's 4th development plan's renewable energy objectives [115] (with permission from Elsevier, copyright 2015).

RSE source	Wind power	Geothermal	Hydropower (small scale)	Solar thermal water	Biomass	Photovoltaic	Fuel cell	Total
Capacity (MW)	250	100	80	17.25	26.6	3	1	477.75

tion [107].

Fish waste oil is mentioned to be also a potential feed for biodiesel production [108,109]. The project, however, is claimed to be at its infancy steps and would be proceeded with a higher pace in case of governmental incentives and supports were provided [109,110]. Algal resources are another sustainable feedstock for biodiesel production. About 50% of an Algae's weight is comprised of oil. 30 fold higher oil production in each acre in comparison with current conventional energy crops is reported to be one of the main advantages of the Algae [111]. Different species from soil and water were collected from various locations. Many researches from Tehran, Tarbiat Modares and Shiraz universities have conducted main algal biodiesel researches [111]. While the feasibility of large-scale algae cultivation and biodiesel production were assessed [112], many efforts have been focused on small-scale productions and bioreactor technologies [113,114]. Considering natural advantages of the Caspian Sea and parts of Persian Gulf for proper cultures and great CO_2 resources near the locations, in the case of sufficient governmental policies and supports, considerable opportunities of new resources would be created.

4. Debate over Iran's renewable energy state

Iran has started the systematic planning for RSE production since 2005 with preparing the first drafts of renewable energy scenarios of Iran through the 4th national development plan. The projection is to supply 1% of the demanded energy of the whole country from renewable energy sources. The longer projected goal is providing 10% of the energy mix from the same resources by the end of 2025. The organization in charge planning, renewable energy organization of Iran (SUNA) by the assistance of the world bank and with the operational and specialized power of its specialized committee, Renewable Energy Initiative Council (REIC) revealed the initial headlines [115]:

– Support and corroboration of the private sector to incorporate economically viable renewable energy sources.
– Endorsement and affirming the researches and research-based technologies bearing the potential of competitiveness among the matching and synonymous options.
– Sustainable and accessible energy supplement to poorer areas and isolated lands.

One of the operational decisions aligned with the initial aforesaid strategy makings was to purchase the renewable energy based electricity from the private sector with a 3 fold higher expenses [115]. Road map planning, budget allocation and reconsideration, easing the path for science-based technical companies and supporting tax tariffs and incentives are other resulted activities so far. Table 3 offers the objectives deemed for the 2005–2009 period.

As it is evident no direct planning aimed the biofuel development to any extent, unfortunately, it worth noting that an average achievement of 38% was reported for the adverted period [115]. Table 4 summarizes the energy market of Iran with attention to both renewable and non-renewable sources. Fig. 10 also demonstrates the potential energy production out of renewable and non-renewable resources. Obviously the country owns great renewable resources so that the lack of geographical opportunities of RSE development is way unreasonable. Based on Fadai et al.'s claim there are five main stimulating factors: 1. Lack of dynamic strategic management team, 2. Non-effective policies, 3. Non-optimal utilization of human resources, 4. Problems in the administrative and policy-making structure of Iran's renewable energy system and 5. The unbalanced proportion between goal settings and management powers [115]. As a matter of fact, not only the technological enhancement and management creativities are crucial for the case of Iran; there is a great demand for prioritizing criteria in the field. In other words, a complete range of possible policies and probable measures needs to be considered and assessed through a systematic decision making i.e. multi criteria approaches like analytical hierarchy process (AHP) to come to a reasonable general policy [116–121]. There are also samples of strength-weakness-opportunities-threats (SWOT) analysis in assessing the bioenergy planning [122–127].

There are some sustainability indicators assessing the state of countries regarding the energy mix they claimed. Infrastructures such as harvesting technologies, transportation and storage capabilities

Table 4
Summary of Iran's current state, projections and capacities for each energy carrier and renewable resource.

Energy carrier		RSE	Current rate of use	Share in current energy mix (%)	IRI's plan for development	Estimated possible capacities		Ref.
Crude oil		Limited resource	500,000 barrel per day	48	2450,000 barrel per day by 2025	136 billion barrel		[14,19,128]
Natural gas			396 million cubic meter per day	49	538million cubic meter by 2030	36.6 trillion cubic meter		[14]
Coal			2.7 million tone	1	–	1.2 billion tones		[14,129]
Solar energy		Renewable and sustainable	650 MW	–	139,296 MW by 2030	40,000 GW		[14,27]
Wind			3400 MW	–	100,000 MW by 2020	100,000 GW		[26,27]
Geothermal			55 MW	–	200 MW	–		[25]
hydropower			7704 MW	2	7200 MW	36 GW		[14,25]
Urban waste (biogas)	Solid waste		1800 kW	–	23 MW	15 million barrel crude oil per year	170,666 MWh electrical energy, 742,000 Gj per year thermal energy	[14,25,55]
	Waste water					2 million barrel crude oil per year		[25,55]
Biomass			–	–	–	–		–
Marine energy			–	–	–	–		–
Biodiesel			–	–	–	300,000 l per year (only from waste cooking oil)		[130]
Bioethanol			–	–	–	4.91 billion liter per year		[46]

should inevitably be a part of data gathering for an efficient policy making system [18]. Some of the items would be discussed here, and the rest would be postponed to a more detailed study.

4.1. Global warming, air pollution and GHG emission

Energy consumption distribution patterns on the Earth is sparse and as reported by Zhang [131] only 0.3% of these energies is transported to the higher levels of contacting environments by atmospheric and ocean circulations. Referencing to Zhang and his coworkers claim, based on the higher mean value of energy consumption (1.5 W m^{-2}) in comparison with lower expected amounts, temperature variations were observed in different continents ranging from 0.8 K in Canada to 1 K in Eurasia [131]. Even though there are great efforts on climate change research in Iran on one side [128,132–134] and the benefits of biofuels and generally renewable energies are proven on the other side [135] there is no significant research or report elucidating the relations between the two sides in Iran.

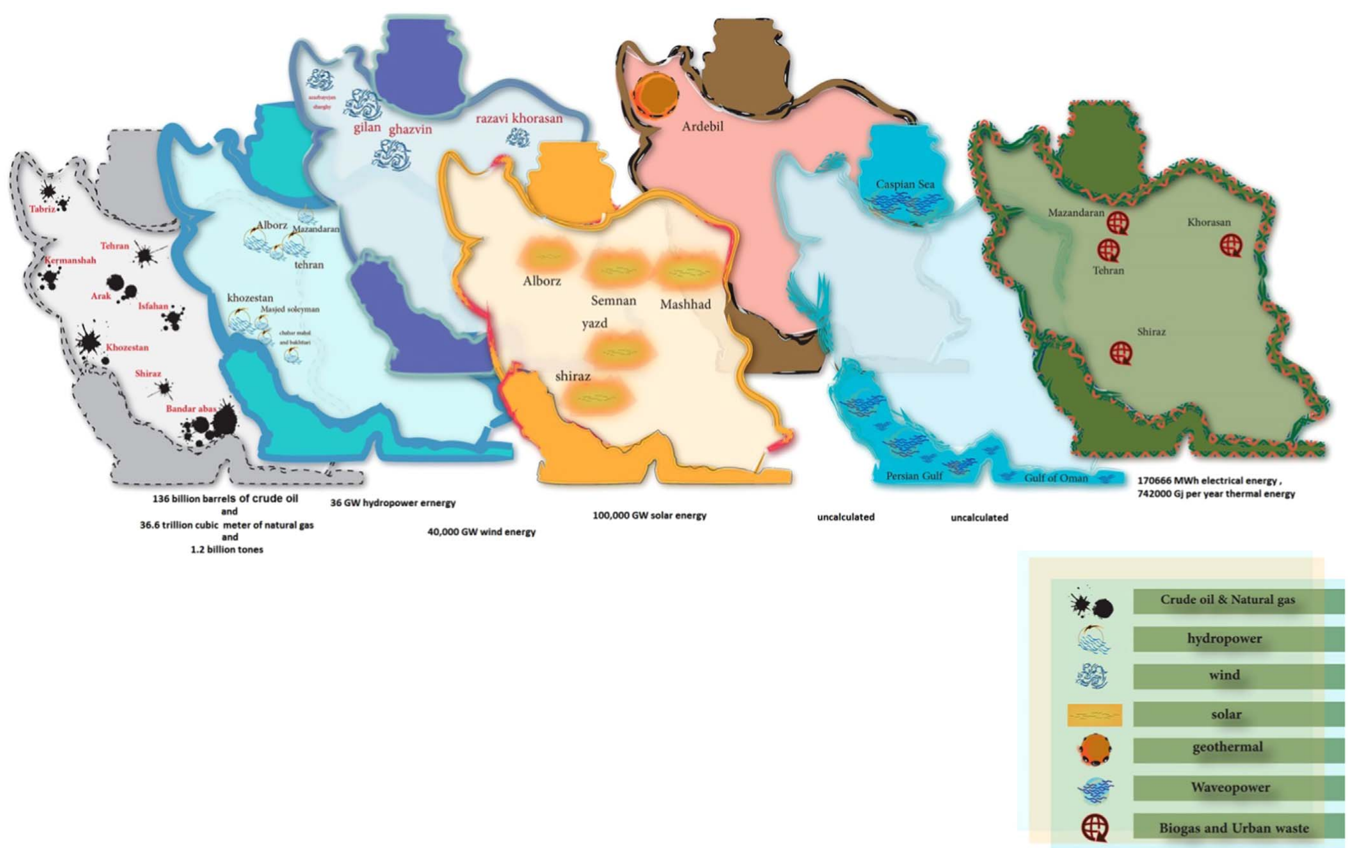

Fig. 10. Potential energy production out of different energy resources in Iran.

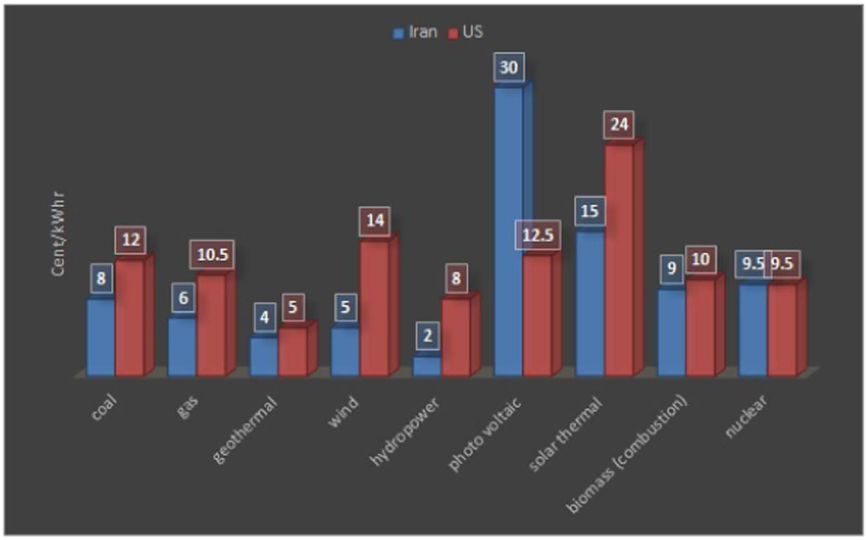

Fig. 11. Comparison of Energy production cost in Iran and US from different resources (http://barghnews.com/fa/news/5796/; http://regulatory.moe.gov.ir/; http://www.hydropower.org.ir/).

4.2. Land use

Investigation of the agriculturally abandoned lands into persistent cultivation of feedstock plants bears many advantages [136]. While on the one hand this could lead to the minimization of biofuel vs. food competition, it could, on the other hand, improve the wildlife habitat, increases carbon sequestration in soil and enhance water quality [136]. The best choices to supply biomass for bioenergy production are local lands [137] as the importation of the feedstocks, or final products could impose extra expenses. In order to identify the effect of biofuel resource supply intensity on the wetlands i.e. lands suited for the agriculture sector, database over the availability of the lands and their vulnerability to cultivations are needed. There exist numbers of research-based effort reporting such databases regarding the biofuel production vs. land use issues [18,138–144]. According to Mellilo et al. there is no concrete proposal for biofuel production land-usage as there are many concerns about the practicality of the designed systems. Based on Schleupner et al. [145] investigations with the assistance of geographical information systems (GIS) 70% of Europe wetlands have solely been wasted during the last century while the other 30% is well protected. However, the remaining areas need to be extended intensively in order to meet the ambitious targets set in biofuel production policies. [146]. However, the idea has not limited the planning anyway. An important factor to be considered is the efficiency of lands in feedstock cultivation. In other words, field-level costs with respect to geological aspects and conversion characteristics of the energy crops or other cellulosic resources are critical factors to be considered. Another side of the coin to be considered is the technical efficiency and intensity of agricultural activates. A stable food market relying on a successful agriculture including the higher yield of crops and sufficient livestock feed conversion leads to the availability of more arable lands for energy crop harvesting [137]. In order to assure a safe condition for food security, every country needs to provide statistical data revealing the amount of food consuming and agricultural and demographical trends in the future. Only, in that case, the quantity of extra lands available for biofuel feedstock preparation would be determined.

4.3. Business viability factors for investors

Based on what was briefly reviewed above, the crucial governmental and private sector's investment in renewable energy is undeniable. However, there are not enough data supporting the viability of the renewable energy sources. In fact, there should exist more efforts on data analysis and the preparing convincing documents to show the attractiveness of the field. Understanding the different necessary aspects of business models in renewable energy area could result in an enhanced appetite for investors and financiers to take part in the business [147]. Aslani and his coworker discussed different sides of successful business model aligned for the renewable energy sector (strategic side, technology side, resources side, feasibility analysis side, stockholder side, market and customer side and value production side) [147]. While a fruitful model should be able to cover all the key areas, it should satisfy the consumer and market demands.

4.4. Production costs and savings

Another issue to take into consideration is the expenses of production of each energy carrier. Due to the availability of the former conventional fossil fuels, it is inevitable that the expenses are currently lower for this kind of energy carriers. On the other hand, it is worth mentioning that not all the alternative energy carriers are produced on the same scale. The differences in the production scale and the geological availability of the resources in each country are the affecting parameters on the final costs of the energy production. Based on the US department of annual energy outlook 2015 [148], currently, the hydropower, nuclear and geothermal resources are cheaper ways of energy provision while natural gas owns the same position in the fossil fuel resources. Solar thermal plants are the most expensive with a final cost of $0.24 per kW/h. These costs are driven out by calculating many factors considering the fixed and operating costs of the production, loses through transportation, etc. Fig. 11. Depicts the energy production costs in Iran and offers a comparison with the same expenses in the US. While a meaningful difference could be seen in almost all the sources, the first resulted conclusion could be that Iran owns a cheaper energy production infrastructure. Technically comparing two regions might not be fair due to the aforesaid reasons. Hydropower and geothermal are the two alternative energy production methods with the lowest expenses with 2 and 4 cents per kWh respectively. Natural Gas-fired plants are the most convenient conventional method of energy production with the lowest emission among the fossil-based power plants.

It is worth mentioning that according to many resources, calculating the energy production costs, both with the conventional fossil fuels and new alternative energy resources is more complicated and many other factors should be brought into consideration [149–151]. Each method of production should be evaluated precisely and in details.

Indirect costs, environmental costs and social costs are among those factors which have to be considered. For instance, for the case of hydropower, the following items cold be noted as indirect expense imposing factors: environmental damages caused by the dames (leakage of underground water to the surrounding lands), immigration over the displacement of the water resources, dam destruction and related hazards and risks. Regarding biofuels, while there are general ideas over the profitability of the bioethanol and biodiesel, with respect to lower taxes and lower energy expenses [152,153], a clear calculation over the capacities and the production costs (direct and indirect) of biofuels in Iran has not been offered yet. This is while most of the renewable energy production of Iran has been focused on the hydropower plants, other forms of alternatives are suffering from lack of attention and receiving adequate investments. This is while the country is paying huge expenses from released dust which dam production is one reason for (http://forsatnet.ir/news/report/). While few studies have been published over this debate [154,155], it seems crucial to conduct economic studies, life cycle assessments and life cycle environmental impacts of biofuels to reach to a clarified scenario. By considering the different culture of consumption in Iran and considering that the conventional fossil fuels are resourceful and accessible to the country, staying on fossil fuels seems cheaper. This is while none of the indirect, social and environmental costs are considered in the calculations. Accordingly, there have to be detailed studies considering all the aspects to clarify if using each of the alternative forms of energy production is saving money or wasting it.

5. Conclusion

It could not be highlighted more that one-dimension economic condition, i.e. non-renewable energy-based program is sentenced to fail in case the sustainability and reliability of the resource is exposed to risks. In other words to avoid sick environment and unorganized society, perpetual poverty, migration of intellectuals, unemployment and many other problems [4], the fossil fuel oriented economy of Iran must have capable alternatives. As one of the main suppliers of fossil fuel energy carriers, Iran, besides 19 other countries, has taken part in the production of more than 75% of CO_2 of the world [43,156]. The current energy consumption trends led Iran to pass the red lines of Kyoto protocol and turned it to be the 10th great producer of carbon dioxide [46]. While the RSE resources are being advertised globally, there are still concerns about the trueness of biofuels being green [110] and about the dominance of their advantages over the drawbacks [157–161]. Based on many measures, the development process both from technical and planning aspects need to be enhanced to a stipulated level. The main concerns are attributed to the effects on the agriculture sector, and land uses as the second priority after technological and strategic planning for large-scale biofuel production while developing g non-edible resources (second and third generation biofuels) [110,162,163]. All the offered statistics and analysis aim to implement the necessity of developing bioenergy farms, algal pounds and bio-refineries to bring biological fuels to petrol stations and deliver it to energy consuming end-users. Since there is no official report revealing any systematic approach is available from the governmental sector of Iran, science-based efforts are inevitable. Future researches could be aimed to find the priorities, proper feedstocks, supply chains, side effects on different sectors and future perspectives.

References

[1] Mohebbi M, Mohebbi Z. Demography of race and ethnicity in iran. the international handbook of the demography of race and ethnicity. Springer; 2015. p. 353–66.

[2] Arouri ME, Youssef AB, M'henni H, Rault C. Energy consumption, economic growth and CO 2 emissions in Middle East and North African countries. Energy Policy 2012 30;45:342–9.

[3] Esfahani HS, Mohaddes K, Pesaran MH. Oil exports and the Iranian economy. Q Rev Econ Financ 2013;53:221–37.

[4] Bakhoda H, Almassi M, Moharamnejad N, Moghaddasi R, Azkia M. Energy production trend in Iran and its effect on sustainable development. Renew Sustain Energy Rev 2012;16:1335–9.

[5] Pacione M. Problems and planning in third world cities (Routledge Revivals). Routledge; 2013.

[6] Yarahmadi S, Etemad K, Hazaveh AM, Azhang N. Urbanization and non-communicable risk factors in the capital city of 6 big provinces of iran. Iran J Public Health 2013;42:113.

[7] Tofigh AA, Abedian M. Analysis of energy status in Iran for designing sustainable energy roadmap. Renew Sustain Energy Rev 2016;57:1296–306.

[8] Bahrami M, Abbaszadeh P. Development a scenario-based model for Iran′ s energy future. Renew Sustain Energy Rev 2016;62:963–70.

[9] Amponsah NY, Troldborg M, Kington B, Aalders I, Hough RL. Greenhouse gas emissions from renewable energy sources: a review of lifecycle considerations. Renew Sustain Energy Rev 2014;39:461–75.

[10] Songolzadeh M, Soleimani M, Takht Ravanchi M, Songolzadeh R. Carbon dioxide separation from flue gases: a technological review emphasizing reduction in greenhouse gas emissions. Sci World J 2014;2014.

[11] Alizadeh R, Majidpour M, Maknoon R, Salimi J. Iranian energy and climate policies adaptation to the Kyoto protocol. Int J Environ Res 2015;9:853–64.

[12] Mohammadnejad M, Ghazvini M, Mahlia T, Andriyana A. A review on energy scenario and sustainable energy in Iran. Renew Sustain Energy Rev 2011;15:4652–8.

[13] Hamzeh Y, Ashori A, Mirzaei B, Abdulkhani A, Molaei M. Current and potential capabilities of biomass for green energy in Iran. Renew Sustain Energy Rev 2011;15:4934–8.

[14] Najafi G, Ghobadian B, Tavakoli T, Yusaf T. Potential of bioethanol production from agricultural wastes in Iran. Renew Sustain Energy Rev 2009;13:1418–27.

[15] Ghobadian B. Liquid biofuels potential and outlook in Iran. Renew Sustain Energy Rev 2012;16:4379–84.

[16] Ghobadian B, Najafi G, Rahimi H, Yusaf T. Future of renewable energies in Iran. Renew Sustain Energy Rev 2009;13:689–95.

[17] Avami A. Assessment of optimal biofuel supply chain planning in Iran: technical, economic, and agricultural perspectives. Renew Sustain Energy Rev 2013;26:761–8.

[18] Dicks MR, Campiche J, Ugarte D, Hellwinckel C, Bryant HL, Richardson JW. Land use implications of expanding biofuel demand. J Agric Appl Econ 2009;41.

[19] Abbaszadeh P, Maleki A, Alipour M, Maman YK. Iran's oil development scenarios by 2025. Energy Policy 2013;56:612–22.

[20] Watkins P, McKendry P. Assessment of waste derived gases as a renewable energy source–Part 1. Sustain Energy Technol Assess 2015;10:102–13.

[21] Azadi AK, Yarmohammad MH. Analysis of Iran's crude oil export future capacity. Energy Policy 2011;39:3316–26.

[22] Birol F. World energy outlook 2010. International Energy Agency; 2010.

[23] Kharecha PA, Hansen JE. Implications of “peak oil” for atmospheric CO_2 and climate. Glob Biogeochem Cycles 2008;22.

[24] Hansen J, Sato M, Kharecha P, Beerling D, Berner R, Masson-Delmotte V. et al. Target atmospheric CO2: Where should humanity aim? ArXiv preprint arXiv:08041126; 2008.

[25] Nejat P, Morsoni AK, Jomehzadeh F, Behzad H, Vesali MS, Majid MA. Iran's achievements in renewable energy during fourth development program in comparison with global trend. Renew Sustain Energy Rev 2013;22:561–70.

[26] Najafi G, Ghobadian B. LLK1694-wind energy resources and development in Iran. Renew Sustain Energy Rev 2011;15:2719–28.

[27] Najafi G, Ghobadian B, Mamat R, Yusaf T, Azmi W. Solar energy in Iran: current state and outlook. Renew Sustain Energy Rev 2015;49:931–42.

[28] Alamdari P, Nematollahi O, Mirhosseini M. Assessment of wind energy in Iran: a review. Renew Sustain Energy Rev 2012;16:836–60.

[29] Abbaspour M, Atabi F. A mathematical model to evaluate wind energy potential in Iran. World renewable energy congress; 1994.

[30] Keyhani A, Ghasemi-Varnamkhasti M, Khanali M, Abbaszadeh R. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. Energy 2010;35:188–201.

[31] Mostafaeipour A, Jadidi M, Mohammadi K, Sedaghat A. An analysis of wind energy potential and economic evaluation in Zahedan, Iran. Renew Sustain Energy Rev 2014;30:641–50.

[32] Nedaei M, Assareh E, Biglari M. An extensive evaluation of wind resource using new methods and strategies for development and utilizing wind power in Mah-shahr station in Iran. Energy Convers Manag 2014;81:475–503.

[33] Mirhosseini M, Sharifi F, Sedaghat A. Assessing the wind energy potential locations in province of Semnan in Iran. Renew Sustain Energy Rev 2011;15:449–59.

[34] Mohammadi K, Mostafaeipour A, Sabzpooshani M. Assessment of solar and wind energy potentials for three free economic and industrial zones of Iran. Energy 2014;67:117–28.

[35] Fazelpour F, Soltani N, Soltani S, Rosen MA. Assessment of wind energy potential and economics in the north-western Iranian cities of Tabriz and Ardabil. Renew Sustain Energy Rev 2015;45:87–99.

[36] Mostafaeipour A. Economic evaluation of small wind turbine utilization in Kerman, Iran. Energy Convers Manag 2013;73:214–25.

[37] Mostafaeipour A, Sedaghat A, Ghalishooyan M, Dinpashoh Y, Mirhosseini M, Sefid M, et al. Evaluation of wind energy potential as a power generation source for electricity production in Binalood, Iran. Renew Energy 2013;52:222–9.

[38] Saeidi D, Mirhosseini M, Sedaghat A, Mostafaeipour A. Feasibility study of wind energy potential in two provinces of Iran: north and South Khorasan. Renew

Sustain Energy Rev 2011;15:3558–69.
[39] Mostafaeipour A. Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. Renew Sustain Energy Rev 2010;14:93–111.
[40] Mohammadi K, Mostafaeipour A. Using different methods for comprehensive study of wind turbine utilization in Zarrineh, Iran. Energy Convers Manag 2013;65:463–70.
[41] Tizpar A, Satkin M, Roshan M, Armoudli Y. Wind resource assessment and wind power potential of Mil-E Nader region in Sistan and Baluchestan Province, Iran–Part 1: Annual energy estimation. Energy Convers Manag 2014;79:273–80.
[42] Mostafaeipour A, Sedaghat A, Dehghan-Niri A, Kalantar V. Wind energy feasibility study for city of Shahrbabak in Iran. Renew Sustain Energy Rev 2011;15:2545–56.
[43] Moghaddam NB, Mousavi SM, Nasiri M, Moallemi EA, Yousefdehi H. Wind energy status of Iran: Evaluating Iran's technological capability in manufacturing wind turbines. Renew Sustain Energy Rev 2011;15:4200–11.
[44] Mostafaeipour A. Feasibility study of offshore wind turbine installation in Iran compared with the world. Renew Sustain Energy Rev 2010;14:1722–43.
[45] Kim S, Dale BE. Global potential bioethanol production from wasted crops and crop residues. Biomass- Bioenergy 2004;26:361–75.
[46] Hosseini SE, Andwari AM, Wahid MA, Bagheri G. A review on green energy potentials in Iran. Renew Sustain Energy Rev 2013;27:533–45.
[47] Hrubant G, Rhodes R, Sloneker J. Specific composition of representative feedlot wastes: chemical and microbial profile [USA]. United States Agricultural Research Service North Central Region ARS-NC (USA) no 59; 1978.
[48] Gupta P, Singh RS, Sachan A, Vidyarthi AS, Gupta A. A re-appraisal on intensification of biogas production. Renew Sustain Energy Rev 2012;16:4908–16.
[49] Chynoweth DP, Owens JM, Legrand R. Renewable methane from anaerobic digestion of biomass. Renew Energy 2001;22:1–8.
[50] Tomei M, Braguglia C, Mininni G. Anaerobic degradation kinetics of particulate organic matter in untreated and sonicated sewage sludge: role of the inoculum. Bioresour Technol 2008;99:6119–26.
[51] Taiganides E. Animal waste management and wastewater treatment. Netherlands: World Animal Science; 1987.
[52] Dimpl E. Small-scale electricity generation from biomass. Part II: Biogas, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)-HERA; 2010.
[53] Noorollahi Y, Kheirrouz M, Asl HF, Yousefi H, Hajinezhad A. Biogas production potential from livestock manure in Iran. Renew Sustain Energy Rev 2015;50:748–54.
[54] Maghanaki MM, Ghobadian B, Najafi G, Galogah RJ. Potential of biogas production in Iran. Renew Sustain Energy Rev 2013;28:702–14.
[55] Asl ART, Malekiha M, Movassaghi K, Adani F. New method for biogas generation from municipal wastewater treatment plant of Isfahan City, Iran. Eurasia 2014Waste Management Symposium Istanbul, Turkey.
[56] Shrestha ME, Sartohadi J, Ridwan MK, Hizbaron DR. Converting urban waste into energy in Kathmandu Valley: barriers and opportunities. J Environ Prot 2014;2014.
[57] Minghua Z, Xiumin F, Rovetta A, Qichang H, Vicentini F, Bingkai L, et al. Municipal solid waste management in Pudong New Area, China. Waste Manag 2009;29:1227–33.
[58] Troschinetz AM, Mihelcic JR. Sustainable recycling of municipal solid waste in developing countries. Waste Manag 2009;29:915–23.
[59] Guerrero LA, Maas G, Hogland W. Solid waste management challenges for cities in developing countries. Waste Manag 2013;33:220–32.
[60] Mustafa SS, Mustafa SS, Mutlag AH. Kirkuk municipal waste to electrical energy. Int J Electr Power Energy Syst 2013;44:506–13.
[61] Frijns J, Hofman J, Nederlof M. The potential of (waste) water as energy carrier. Energy Convers Manag 2013;65:357–63.
[62] Arena U. Process and technological aspects of municipal solid waste gasification. A review. Waste Manag 2012;32:625–39.
[63] Ojha A, Reuben AC, Sharma D. Solid waste management in developing countries through plasma arc gasification-an alternative approach. APCBEE Procedia 2012;1:193–8.
[64] Zhang Q, Dor L, Fenigshtein D, Yang W, Blasiak W. gasification of municipal solid waste in the plasma gasification melting process. Appl Energy 2012;90:106–12.
[65] Lu X, Jordan B, Berge ND. Thermal conversion of municipal solid waste via hydrothermal carbonization: comparison of carbonization products to products from current waste management techniques. Waste Manag 2012;32:1353–65.
[66] Khalid A, Arshad M, Anjum M, Mahmood T, Dawson L. The anaerobic digestion of solid organic waste. Waste Manag 2011;31:1737–44.
[67] Appels L, Lauwers J, Degrève J, Helsen L, Lievens B, Willems K, et al. Anaerobic digestion in global bio-energy production: potential and research challenges. Renew Sustain Energy Rev 2011;15:4295–301.
[68] Bosmans A, Vanderreydt I, Geysen D, Helsen L. The crucial role of waste-to-energy technologies in enhanced landfill mining: a technology review. J Clean Prod 2013;55:10–23.
[69] Kwon EE, Castaldi MJ. Urban energy mining from municipal solid waste (MSW) via the enhanced thermo–chemical process by carbon dioxide (CO2) as a reaction medium. Bioresour Technol 2012;125:23–9.
[70] Farhad S, Hamdullahpur F, Yoo Y. Performance evaluation of different configurations of biogas-fuelled SOFC micro-CHP systems for residential applications. Int J Hydrog Energy 2010;35:3758–68.
[71] Ryu C, Shin D. Combined heat and power from municipal solid waste: current status and issues in South Korea. Energies 2012;6:45–57.
[72] de Queiroz Lamas W, Palau JCF, de Camargo JR. Waste materials co-processing in cement industry: ecological efficiency of waste reuse. Renew Sustain Energy Rev 2013;19:200–7.
[73] Lam CHK, Barford JP, McKay G. Utilization of municipal solid waste incineration ash in Portland cement clinker. Clean Technol Environ Policy 2011;13:607–15.
[74] Pan S-Y, Chiang A, Chang E, Lin Y-P, Kim H, Chiang P-C. An innovative approach to integrated carbon mineralization and waste utilization: a review. Aerosol Air Qual Res 2015;15:1072–91.
[75] Alamdari P, Nematollahi O, Alemrajabi AA. Solar energy potentials in Iran: a review. Renew Sustain Energy Rev 2013;21:778–88.
[76] Besarati SM, Padilla RV, Goswami DY, Stefanakos E. The potential of harnessing solar radiation in Iran: generating solar maps and viability study of PV power plants. Renew Energy 2013;53:193–9.
[77] Tian Y, Zhao C-Y. A review of solar collectors and thermal energy storage in solar thermal applications. Appl Energy 2013;104:538–53.
[78] Parida B, Iniyan S, Goic R. A review of solar photovoltaic technologies. Renew Sustain Energy Rev 2011;15:1625–36.
[79] Chow TT. A review on photovoltaic/thermal hybrid solar technology. Appl Energy 2010;87:365–79.
[80] Jamel M, Rahman AA, Shamsuddin A. Advances in the integration of solar thermal energy with conventional and non-conventional power plants. Renew Sustain Energy Rev 2013;20:71–81.
[81] Enjavi-Arsanjani M, Hirbodi K, Yaghoubi M. Solar energy potential and performance assessment of CSP plants in different areas of Iran. Energy Procedia 2015;69:2039–48.
[82] Sadeghi B, Khalajmasoumi M. A futuristic review for evaluation of geothermal potentials using fuzzy logic and binary index overlay in GIS environment. Renew Sustain Energy Rev 2015;43:818–31.
[83] Najafi G, Ghobadian B. Geothermal resources in Iran: the sustainable future. Renew Sustain Energy Rev 2011;15:3946–51.
[84] Noorollahi Y, Yousefi H, Itoi R, Ehara S. Geothermal energy resources and development in Iran. Renew Sustain Energy Rev 2009;13:1127–32.
[85] Yousefi H, Ehara S, Noorollahi Y. Geothermal potential site selection using GIS in Iran. In: Proceedings of the thirty-second workshop on geothermal reservoir engineering; 2007.
[86] Ghaedrahmati R, Moradzadeh A, Fathianpour N, Lee SK, Porkhial S. 3-D inversion of MT data from the Sabalan geothermal field, Ardabil, Iran. J Appl Geophys 2013;93:12–24.
[87] Torbehbar AK, Sattari SM. Geochemistry and isotope study of discharged geothermal fluids, NW Sabalan geothermal field, NW Iran. Geochemistry 2015;19:25.
[88] Porkhial S, Salehpour M, Ashraf H, Jamali A. Modeling and prediction of geothermal reservoir temperature behavior using evolutionary design of neural networks. Geothermics 2015;53:320–7.
[89] Sharifi R, Moore F, Keshavarzi B. Potential health risks of arsenic, antimony and mercury in the Takab geothermal field, NW Iran. Int J Environ Stud 2014;71:372–90.
[90] Sivasakthivel T, Murugesan K, Thomas HR. Optimization of operating parameters of ground source heat pump system for space heating and cooling by Taguchi method and utility concept. Appl Energy 2014;116:76–85.
[91] Self SJ, Reddy BV, Rosen MA. Geothermal heat pump systems: status review and comparison with other heating options. Appl Energy 2013;101:341–8.
[92] Diczfalusy B, Taylor P. Technology roadmap, energy-efficient buildings: heating and cooling equipment. Paris, France: International Energy Agency; 2011.
[93] Sarbu I, Sebarchievici C. General review of ground-source heat pump systems for heating and cooling of buildings. Energy Build 2014;70:441–54.
[94] Taylor P. Energy technology perspectives 2010 – scenarios and strategies to 2050. Paris: International Energy Agency; 2010. p. 74.
[95] Taghaddosi M, Porkhial S Geothermal heat pump in Iran.
[96] Saffarzadeh A, Porkhial S, Taghaddosi M. Geothermal energy developments in Iran. In: Proceedings of the 2010 world geothermal congress; 2010. p. 25-29.
[97] Bilgili M, Ozbek A, Sahin B, Kahraman A. An overview of renewable electric power capacity and progress in new technologies in the world. Renew Sustain Energy Rev 2015;49:323–34.
[98] Zabihian F, Fung AS. Review of marine renewable energies: case study of Iran. Renew Sustain Energy Rev 2011;15:2461–74.
[99] Fadaeenejad M, Shamsipour R, Rokni S, Gomes C. New approaches in harnessing wave energy: with special attention to small islands. Renew Sustain Energy Rev 2014;29:345–54.
[100] Naghiloo A, Abbaspour M, Mohammadi-Ivatloo B, Bakhtari K. Modeling and design of a 25 MW osmotic power plant (PRO) on Bahmanshir River of Iran. Renew Energy 2015;78:51–9.
[101] Rashid A, Hasanzadeh S. Status and potentials of offshore wave energy resources in Chahbahar area (NW Omman Sea). Renew Sustain Energy Rev 2011;15:4876–83.
[102] Rashid A. Status and potentials of tidal in-stream energy resources in the southern coasts of Iran: a case study. Renew Sustain Energy Rev 2012;16:6668–77.
[103] Saket A, Etemad-Shahidi A. Wave energy potential along the northern coasts of the Gulf of Oman, Iran. Renew Energy 2012;40:90–7.
[104] Kamranzad B, Etemad-Shahidi A, Chegini V. Assessment of wave energy variation in the Persian Gulf. Ocean Eng 2013;70:72–80.
[105] Alamian R, Shafaghat R, Miri SJ, Yazdanshenas N, Shakeri M. Evaluation of technologies for harvesting wave energy in Caspian Sea. Renew Sustain Energy Rev 2014;32:468–76.
[106] Demirbas A. Competitive liquid biofuels from biomass. Appl Energy 2011;88:17–28.
[107] Ardebili MS, Ghobadian B, Najafi G, Chegeni A. Biodiesel production potential

from edible oil seeds in Iran. Renew Sustain Energy Rev 2011;15:3041–4.
[108] Yahyaee R, Ghobadian B, Najafi G. Waste fish oil biodiesel as a source of renewable fuel in Iran. Renew Sustain Energy Rev 2013;17:312–9.
[109] Avami A. A model for biodiesel supply chain: a case study in Iran. Renew Sustain Energy Rev 2012;16:4196–203.
[110] Avinash A, Subramaniam D, Murugesan A. Bio-diesel – a global scenario. Renew Sustain Energy Rev 2014;29:517–27.
[111] Najafi G, Ghobadian B, Yusaf TF. Algae as a sustainable energy source for biofuel production in Iran: a case study. Renew Sustain Energy Rev 2011;15:3870–6.
[112] Moazami N, Ashori A, Ranjbar R, Tangestani M, Eghtesadi R, Nejad AS. Large-scale biodiesel production using microalgae biomass of Nannochloropsis. Biomass- Bioenergy 2012;39:449–53.
[113] Tabatabaei M, Tohidfar M, Jouzani GS, Safarnejad M, Pazouki M. Biodiesel production from genetically engineered microalgae: future of bioenergy in Iran. Renew Sustain Energy Rev 2011;15:1918–27.
[114] Najafi G, Ghobadian B, Yusaf TF. Biofuel from microalgae: alternative, sustainable and renewable fuel. In: Proceedings of the 10th international conference on sustainable energy technologies (SET 2011): University of Southern Queensland; 2011.
[115] Fadai D, Esfandabadi ZS, Abbasi A. Analyzing the causes of non-development of renewable energy-related industries in Iran. Renew Sustain Energy Rev 2011;15:2690–5.
[116] Lanjewar PB, Rao R, Kale A. Assessment of alternative fuels for transportation using a hybrid graph theory and analytic hierarchy process method. Fuel 2015;154:9–16.
[117] Ren J, Manzardo A, Mazzi A, Zuliani F, Scipioni A. Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multicriteria decision-making. Int J Life Cycle Assess 2015;20:842–53.
[118] Haddad M, Fawaz Z. Evaluation of microalgal alternative jet fuel using the AHP method with an emphasis on the environmental and economic criteria. Environ Progress Sustain Energy 2013;32:721–33.
[119] Nwokoagbara E, Olaleye AK, Wang M. Biodiesel from microalgae: the use of multi-criteria decision analysis for strain selection. Fuel 2015.
[120] Ziolkowska JR. Evaluating sustainability of biofuels feedstocks: a multi-objective framework for supporting decision making. Biomass- Bioenergy 2013;59:425–40.
[121] Mendes PA, Barros AK, d'Avila LA, Antunes AM. Multicriteria mapping of stakeholder preferences for the sustainability of the Brazilian program for biodiesel production and use. Environ Progress Sustain Energy 2013;32:1262–70.
[122] Lokesh AC, Mahesh NS, Gowda B, White P. Sustainable biofuel strategy in Karnataka state a review. Manag Environ Qual: Int J 2015;26:288–300.
[123] Zhu L, Hiltunen E, Antila E, Huang F, Song L. Investigation of China's bio-energy industry development modes based on a SWOT–PEST model. Int J Sustain Energy 2015;34:552–9.
[124] Soimu O. A SWOT analysis of bio-energy production in Republic of Moldova. Procedia-Soc Behav Sci 2014;149:896–900.
[125] Richel A. Green chemistry and the biorefinery: a SWOT analysis for the European region. Meeting Cornell University-University of Liege; 2014.
[126] Dogan N. The place OF renewable energy sources in energy sector in Turkey: SWOT analysis1. IIB Int Referee Acad Social Sci J 2015;17:118.
[127] Chen W-M, Kim H, Yamaguchi H. renewable energy in eastern Asia: renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, South Korea, and Taiwan. Energy Policy 2014;74:319–29.
[128] Ghorbani A, Rahimpour HR, Ghasemi Y, Zoughi S, Rahimpour MR. A review of carbon capture and sequestration in Iran: microalgal biofixation potential in Iran. Renew Sustain Energy Rev 2014;35:73–100.
[129] Ghorashi AH, Rahimi A. Renewable and non-renewable energy status in Iran: art of know-how and technology-gaps. Renew Sustain Energy Rev 2011;15:729–36.
[130] Abbaszaadeh A, Ghobadian B, Omidkhah MR, Najafi G. Current biodiesel production technologies: a comparative review. Energy Convers Manag 2012;63:138–48.
[131] Zhang GJ, Cai M, Hu A. Energy consumption and the unexplained winter warming over northern Asia and North America. Nat Clim Change 2013;3:466–70.
[132] Roshan G, Ghanghermeh A, Nasrabadi T, Meimandi JB. Effect of global warming on intensity and frequency curves of precipitation, case study of Northwestern Iran. Water Resour Manag 2013;27:1563–79.
[133] Yousefi M, Khoramivafa M, Mondani F. Integrated evaluation of energy use, greenhouse gas emissions and global warming potential for sugar beet (Beta vulgaris) agroecosystems in Iran. Atmos Environ 2014;92:501–5.
[134] Tabari H, Somee BS, Zadeh MR. Testing for long-term trends in climatic variables in Iran. Atmos Res 2011;100:132–40.
[135] Dhillon R, von Wuehlisch G. Mitigation of global warming through renewable biomass. Biomass- Bioenergy 2013;48:75–89.
[136] Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, et al. Beneficial biofuels – the food, energy, and environment trilemma. Science 2009;325:270.
[137] Fischer G, Prieler S, van Velthuizen H, Berndes G, Faaij A, Londo M, et al. Biofuel production potentials in Europe: sustainable use of cultivated land and pastures, Part II: Land use scenarios. Biomass- Bioenergy 2010;34:173–87.
[138] Lapola DM, Schaldach R, Alcamo J, Bondeau A, Koch J, Koelking C, et al. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proc Natl Acad Sci 2010;107:3388–93.
[139] Matondi PB, Havnevik K, Beyene A. Biofuels, land grabbing and food security in Africa. Zed books; 2011.
[140] Ravindranath N, Manuvie R, Fargione J, Canadell J, Berndes G, Woods J. et al. Greenhouse gas implications of land use and land conversion to biofuel crops. Biofuels: environmental consequences and interactions with changing land use. In: Proceedings of the scientific committee on problems of the environment (SCOPE) International biofuels project rapid assessment; 2008. p. 22–5.
[141] Hellmann F, Verburg PH. Impact assessment of the European biofuel directive on land use and biodiversity. J Environ Manag 2010;91:1389–96.
[142] Qin Z, Zhuang Q, Chen M. Impacts of land use change due to biofuel crops on carbon balance, bioenergy production, and agricultural yield, in the conterminous United States. GCB Bioenergy 2012;4:277–88.
[143] Rathmann R, Szklo A, Schaeffer R. Land use competition for production of food and liquid biofuels: an analysis of the arguments in the current debate. Renew Energy 2010;35:14–22.
[144] Mattison EH, Norris K. Intentions of UK farmers toward biofuel crop production: implications for policy targets and land use change. Environ Sci Technol 2007;41:5589–94.
[145] Schleupner C, Schneider UA. Effects of bioenergy policies and targets on European wetland restoration options. Environ Sci Policy 2010;13:721–32.
[146] Melillo JM, Reilly JM, Kicklighter DW, Gurgel AC, Cronin TW, Paltsev S, et al. Indirect emissions from biofuels: how important?. Science 2009;326:1397–9.
[147] Aslani A, Mohaghar A. Business structure in renewable energy industry: key areas. Renew Sustain Energy Rev 2013;27:569–75.
[148] Sieminski A. Annual energy outlook 2015. US Energy Information Administration; 2015.
[149] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proc Natl Acad Sci 2006;103:11206–10.
[150] Hohmeyer O. Social costs of energy consumption: external effects of electricity generation in the Federal Republic of Germany. Springer Science & Business Media; 2012.
[151] Hohmeyer O, Ottinger R. Social costs of energy: present status and future trends. Springer Science & Business Media; 2012.
[152] De Gorter H, Just DR. The social costs and benefits of biofuels: the intersection of environmental, energy and agricultural policy. Appl Econ Perspect Policy 2010:4–32.
[153] De Gorter H, Just DR. The welfare economics of a biofuel tax credit and the interaction effects with price contingent farm subsidies. Am J Agric Econ 2009;91:477–88.
[154] Mohammadshirazi A, Akram A, Rafiee S, Kalhor EB. Energy and cost analyses of biodiesel production from waste cooking oil. Renew Sustain Energy Rev 2014;33:44–9.
[155] Rajaeifar MA, Ghobadian B, Safa M, Heidari MD. Energy life-cycle assessment and CO 2 emissions analysis of soybean-based biodiesel: a case study. J Clean Prod 2014;66:233–41.
[156] Parker L, Blodgett JE. Greenhouse gas emissions: conflicting situations. Conflicting perspectives. Congressional Research Service, The Library of Congress; 2005.
[157] Koh LP, Ghazoul J. Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. Biol Conserv 2008;141:2450–60.
[158] Crutzen P, Mosier A, Smith K, Winiwarter W. Interactive comment on "N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" by PJ Crutzen et al. Atmos Chem Phys Discuss 2007;7:S5146–S5148.
[159] Pimentel D, Marklein A, Toth MA, Karpoff MN, Paul GS, McCormack R, et al. Food versus biofuels: environmental and economic costs. Hum Ecol 2009;37:1–12.
[160] Smith KA, Searchinger TD. Crop-based biofuels and associated environmental concerns. GCB Bioenergy 2012;4:479–84.
[161] Zainura NZ. Biofuel: advantages and disadvantages based on life cycle assessment (LCA) perspective. J Environ Res Dev 2013;7:1444.
[162] Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: the challenge of feeding 9 billion people. Science 2010;327:812–8.
[163] Sheehan JJ. Biofuels and the conundrum of sustainability. Curr Opin Biotechnol 2009;20:318–24.