Wind Turbine Productivity and Development in Iran

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***Abstract*— This paper presents an overview of the status of wind energy productivity and development issues in Iran. It also presents a summary of the present global work on offshore energy, including the most recent works as well as potential offshore wind energy resource in Iran. The positive impacts of wind energy on the mitigation of climate change as well as opportunity to diminish energy dependency are indisputable. Wind energy helps decreasing import dependency, diversifying sources of production, and contributes to a sustainable development in many countries. Wind energy production is expected to increase in future and has experienced dramatic growth over the past decade in many countries worldwide. Offshore winds are generally stronger and more constant than onshore winds. Wind farms in real offshore sites, open seas with waves and water depth over 10 m, are now proposed in Persian Gulf, Caspian Sea and Gulf of Oman. This paper studies productivity and development of wind energy in Iran while setting out the developments that have taken place so far. There are many installed wind turbines in suitable regions like Manjil and Binalood in north, but there has not been any offshore wind installation yet in Iran. Also many suitable land sites have been identified for future installation of large wind turbines.**

Keywords-wind; turbine; offshore; development; Iran

I. INTRODUCTION

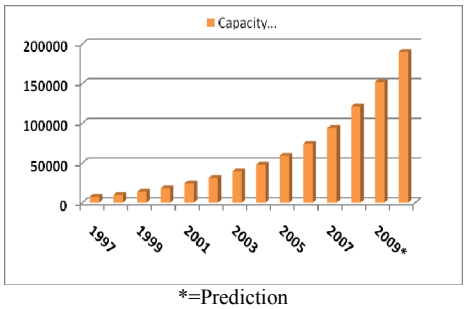
Energy is one of the essential inputs for economic development and industrialization. Fossil fuels are the main resources and play a crucial role to supply world energy demand. However fossil fuel reserves are limited and usage of fossil fuel sources have negative environmental impacts. Since the first oil crisis, renewable energy sources have gained in great importance due to their inexhaustibility, sustainability, ecological awareness and supply of energy security. So, renewable energy sources are expected to play an important role especially in electrical energy generation [1].

Among the renewable energy sources wind energy is currently viewed as one of the most significant, fastest growing, commonly used and commercially attractive source to generate electrical energy because of the mature and cost effective energy conversation system technology. So, electricity generation cost from wind energy system has become competitive with fossil fuel systems. Installed total wind power capacity has reached over 93 GW and installed wind power capacity generates more than 1% of the global electricity consumption. In recent years Weibull distribution has been one of the most commonly used, accepted, recommended distribution to determine wind energy potential and it is also used as a reference distribution for commercial wind energy software, such as Wind Atlas Analysis and Application Program (WAsP) [1, 2, 3, 4].

Germany is a leader in Europe on shifting from conventional to renewable sources of energy. As its land-based sites of wind energy are built to capacity [5, 6], Germany looks to the sea for further production possibilities. In the United States and Germany, offshore areas are generally considered public space, which makes offshore renewable energy development public in nature [7].

The wind energy sector has grown exponentially since the end of the 1990s, especially within the European Union (EU), and this has affected the employment levels of the regions involved [8].

Wind energy conversion systems for electricity generation and water pumping by direct mechanical means are techno-economically feasible in many locations of the country. The potential for wind power generation is estimated to be 6500 MW with the majority of the locations situated in the eastern and northern parts of the country. Manjil has winds that can result in as much as 1609 kWh/m^2 per year at the 40m elevation above ground. The recent installation of a 600 kW wind turbine promises a reasonable growth for this technology in Iran [12, 44].



*=Prediction

Figure 1. Total world installed capacity [10].

Based on a survey amongst the WWEA (World Wind Energy Association) member associations, a double digit

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growth for the wind energy market is expected despite the general economic crisis. Based on available figures from 11 of the top 15 countries representing over 80% of the world market, WWEA recorded 5374 MW new installed capacity in the first quarter of 2009, equaling an increase of 23% compared with last year in the same countries. WWEA keeps its previous prevision of a total installed capacity of 152000 MW worldwide by the end of 2009 (Fig. 1), which will mean a new record of over 30,000 MW newly installed capacity within one year. This represents a market growth of 25% compared with last year [9].

Offshore wind power has attracted attention around the world, and the development of offshore wind power development is to argue for a direction. At present, offshore wind power technology has become more and more mature and has entered the large-scale development phase [11]. In fact, contribution of the wind energy for production of electricity in Iran is very low [12]. The use of renewable energy has started to be an interesting issue for people and also governments in Middle East, especially in Iran where all different types of renewable energy sources (RES) are available and also possible to implement for gaining required energy [13]. Development in wind energy towards higher nominal power of the wind turbines is related to the moving of the turbines to better locations. First, there was a shift from onshore to offshore. Further, there have been studies toward moving from coast to the deep water, which requires floating windmills.

Onshore wind turbine technology is evolving rapidly driving the development of the offshore turbines with their own specific characteristics of reliability in the harsh environmental conditions of open seas [14, 15]. In Denmark for example, 20% of the electricity is produced from wind, and plans are towards reaching 50%. As space is becoming scarce for the installation of onshore wind turbines, offshore wind energy, when possible, seems as a good alternative [16]. There are many locations in many parts of Iran which are capable of harnessing wind energy. Recently, the wind atlas of Iran was prepared by Iranian Renewable Energy Organization (SUNA). But there has not been a proper effort toward offshore energy program yet.

II. GEOGRAPHIC PROFILE OF IRAN

Iran (Persia) is situated in south-western Asia and borders the three CIS states, the Republic of Armenia, the Republic of Azerbaijan, and the Republic of Turkmenistan, as well as the Caspian Sea to the north, Turkey and Iraq to the west, the Persian Gulf and the Gulf of Oman to the south, Pakistan and Afghanistan to the east [12,17].

With the total area of 1648195 km^2, Iran is located in the northern hemisphere in the east of Asia (one of the countries in the Middle East). The east meridian of 44.5 draws along the western most part of Iran and the east meridian of 63.8 draws along the eastern most part. Its land borders are with former Soviet States of Azerbaijan, Armenia and Turkmenistan, 2013 km to the north, Pakistan (978 km) and Afghanistan (945 km) to the east, Turkey (486 km) and Iraq (1609 km) to the west. Its water borders are with the Caspian Sea from the Astara river to the Gulf of Hosseinqoli (657 km) to the north, the Gulf of Oman in southwest from the Goatr to the Bandar-Abbas (784 km) and the Persian Golf from Bandar-Abbas to the mouth of Arvand Roud (125 km) to the south. Iran is 8731 km in circumference. Iran consists of the Iranian plateau (90% of its total area) with the exception of the coasts of the Caspian Sea and Khuzestan. It is considered a mountain country in which more than half of the area is covered with the mountain ranges, 1.4% by the desert and less than 1.4% by the arable land [38, 39, 43].

III. ALTERNATIVE ENERGY SOURCES

Iran's renewable energy consumption is low. With 9% of the world`s oil reserves and 15% of its natural gas reserves (80% of which have not been developed), Iran has an abundant supply of fossil fuel resources, which tends to discourage the pursuit of alternative, renewable energy sources. Iran's 1997 renewable energy consumption (including hydropower, solar, wind, tide, geothermal, solid biomass and animal products, biomass gas and liquids, and industrial and municipal wastes) totaled 106 trillion Btu, a 6% increase over the previous year. In an attempt to diversify its energy mix from a primarily oil-based economy, Iran is increasing its hydroelectric capacity. Several hydropower plants are currently in operation, and several more are under construction. In addition, Iran would like to increase its nuclear power usage in order eventually to meet 20% of the country's electricity demand, but international concerns about Iran's use of nuclear power for purposes other than electricity generation have limited the country's nuclear capacity [18]. Recently, Iran has paid a great attention towards harnessing wind energy from suitable sites with acceptable wind potential in different parts and locations. Unfortunately, there has not been a wind map for survey and installing the wind turbines yet. But, in 2006, Renewable Energy Organization of Iran (SUNA) started to complete the job in order to provide the national wind map or wind atlas. Solar energy is also another form of renewable kind which is available in most of the regions especially in central and southern parts of Iran. In order to provide a broad wind resource assessment over Iran, the wind characteristics must be studied in detail. Wind resource assessments can be divided into two main areas: regional assessment and micro sitting. Regional assessment is overall estimation of the mean energy content of the wind over a large area. Micro sitting is to position one or more wind turbines on a land in order to maximize the overall yearly energy output of a wind farm. During the last two years, many 40 meters towers have been installed in many provinces in order to provide wind information for Iranian wind atlas. A precise prediction of the wind speed at a given site is essential for the determination of regional wind energy resources. Because of aerodynamic reasons, the power output of a wind turbine is proportional to the third power of the wind speed. It is a fact that, especially

in complex terrain, wind energy content may vary significantly from one region to another. Therefore, wind data taken over many years are utilized to calculate wind climatology. European Wind Atlas [19] is a good example of this. Some other wind resource maps such as Wind Atlas of Russia [20] and the Irish Wind Atlas [21] also have been prepared. The whole area of renewable energy options needs further survey and examination. For example, wind energy is gaining more attention internationally, and countries such as India, South Africa, China, and many others have invested in large wind generators. Primary studies indicate that Iran has regions where wind and solar energies may be a viable alternative which must be considered [13].

IV. ENERGY CONSUMPTION IN IRAN

A major factor behind the suffocating air pollution in major cities is the dramatic rise in energy consumption. Iran's total energy consumption jumped from 1.6 quadrillion BTU in 1980 to 4.7 quadrillion BTU in 2000, which is a very high consumption rate. It should be noted that most of the consumption was accounted for by gasoline.

Overall, natural gas makes up about 50% of the energy consumed in Iran, with oil (48%) making up much of the rest and coal accounting for only 1%. Per capita energy consumption in 2400 was 73.8 million Btu, which is only one-fifth of the U.S. level of 351.1 million Btu, but is still on the increase. Iran's energy intensity (energy consumption per GDP dollar) at 39,265 Btu/$1995 remains above the level of most western countries, but it is below many countries in the former Soviet Union and the Middle East [18]. In 2000, US energy intensity was 10,919 Btu/$1995 which is almost one fourth of Iran.

TABLE I. ENERGY CONSUMPTION FOR IRAN FROM 1980TO 2000[13]

Year	Consumed energy (Quadrillion BTU)
1980	1.6
1982	1.6
1984	2.2
1986	2.4
1988	2.5
1990	3.0
1992	3.2
1994	3.5
1996	4.0
1998	4.5
2000	4.6

V. WIND ATLAS OF IRAN

It has been anticipated that Iran's wind atlas will be ready in 2010. Preliminary studies led to the identification of some different geographical locations in the country that are suitable for generating electricity from the wind energy, the Manjil Tunnel (Gilan-Manjil), Takestan, Shahriar, Tehran, Semnan, Khorasan, Neishabur, Sabzevar, Badqais in Khorasan Province, Mashhad all the way down to Khaf, Torbat Heidarieh, as well as the provinces of Ardebil, East and West Azarbaijan, Kordestan, Hamedan, Kermanshah, Ilam, Isfahan, Kerman, Fars and the regions located in the south parts of Sistan and parts of the southern coasts are capable of producing 6,500 megawatts of electricity generated from the wind energy. According to international and local renewable energy experts Iran possesses wind and other renewable energy resources which may be characterized as "world class", but the Iranian wind resource has not yet been mapped out in detail, and existing data is not easily available. During the project preparation the wind resources in the Manjil area were assessed based on existing data from a local meteorology station and found to be in line with Danish Class 1 / good European sites [22].

VI. CLIMATE OF IRAN

Iran has a complex climate, ranging from subtropical to sub polar. In winter, a high-pressure belt, centered in Siberia, slashes west and south to the interior of the Iranian Plateau, while low pressure systems develop over the warm waters of the Caspian, the Persian Gulf, and the Mediterranean. In summer, one of the lowest pressure centers in the world prevails in the south [22, 43].

Low pressure patterns in Pakistan generate two regular wind patterns: the Shamal, which blows from February to October north-westerly through the Tigris-Euphrates Valley, and the 120-day summer wind, which sometimes reaches velocities of 70 miles per hour in the Sistan region near the Pakistan frontier. Warm Arabian winds bring heavy moisture from the Persian Gulf. The gulf area, where the heat and humidity are unbearable, stands in sharp contrast to the Caspian coastal region, where moist air from the sea mingles with the dry air currants from the Alborz to create a soft nightly breeze. It is located within 25 to 40 degrees latitude and being under great near continental pressure. The near continental region means that the sun shines perpendicularly in regions in the afternoons. The dry air also goes to the two poles (the South Pole and the North Pole). The arid air that blows toward the North Pole passes over the Iranian territory that is situated in the northern hemisphere [22]. Iran's geographical situation is such that its low air pressures in comparison with high pressures in the north and northwestern regions produce strong air flows over it in general during the summer and winter months. During the winter months it is the difference in the air pressure between the atmospheres over Iran; center Asia as well as the Atlantic Ocean that causes cold winds from north and humid air flows from the Atlantic and Mediterranean from west. When these systems of air maldes collide with the humid air from the Mediterranean, cools off Iran producing snow over the country. During the summer Iran is also affected by winds from the Atlantic Ocean on the northwest and by the winds from the Indian Ocean from the southeast; of the well known winds from the east are the 120 day winds of Sistan

and lavas wind: the other local winds in the country include the north winds on the Persian gulf and Khoch wind in the Gorgan plain, Deez wind between cities of Mashhad and Nayshabour. Also there is Sham wind in Khuzestan province too [23, 43].

VII. GLOBAL INSTALLED WIND TURBINES AND ENERGY POTENTIAL

Today, the world's energy supply is largely based on fossil fuels and nuclear power. These sources of energy will not last forever and have proven to be contributors to our environmental problems [24].

A reliable supply of energy is essential to maintain and to improve human being's living conditions. Compared to the conventional coal-fired approach, renewable energy (RE) helps to mitigate the impacts of greenhouse gas emissions to a large extent .According to the Global Wind Energy Council (GWEC), the global cumulative installed capacity has reached 94 GW in 2007, which increased 31% than the previous year [25,26].

The status of wind energy is as a stable, profitable and low-risk investment. Although some wind energy projects are postponed due to financing challenges, the overall market development can still compensate such delays showing great signs of vitality. A substantial share of the slow down in some regions are a consequence of new regulations and bureaucratic delays that undermine the development of new wind parks rather than of financing difficulties [9].

The top five countries in terms of total installed wind capacity at the end of 2004 were Germany, Spain, USA, Denmark, and India; wind turbine manufacturers from these top five countries sold 94 percent of all wind turbines installed globally in 2004. Germany clearly stands out as having maintained the most sizable and stable market [27].

VIII. RECENT INSTALLED WIND TURBINES WORLDWIDE

The share of new installed capacity for USA and China with 31.62% and 23.83% respectively accounts for more than half of the other countries in the world for 2008 (Fig. 2). The USA and China took the lead, USA taking over the global number one position from Germany and China getting ahead of India for the first time, taking the lead in Asia. The USA and China accounted for 50.8 % of the wind turbine sales in 2008 and the eight leading markets represented almost 80 % of the market for new wind turbines. One year ago, still only five markets represented 80 % of the global sales. The pioneer country Denmark fell back to rank 9 in terms of total capacity, whilst until four years ago it held the number 4 position during several years. However, with a wind power share of around 20 % of the electricity supply, Denmark is still a leading wind energy country worldwide [10]. For the year 2008, USA was in top position following by Germany, Spain, China, India, Italy, France, UK, Denmark and Portugal. But Germany was in top position in 2007 [10].

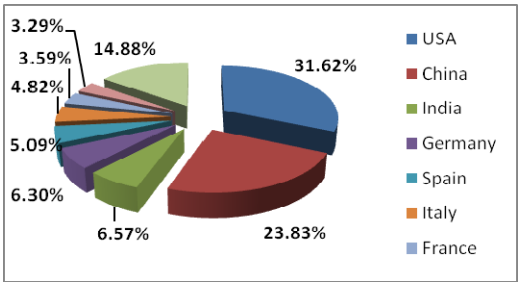

Figure 2. Share of countries new installed capacity for 2008 [10].

In terms of continental distribution, a continuous diversification process can be watched as well: In general, the focus of the wind sector moves away from Europe to Asia and North America. Europe decreased its share in total installed capacity from 65.5 % in 2006 to 61 % in the year 2007 further down to 54.6 % in 2008. Only four years ago Europe dominated the world market with 70.7 % of the new capacity. In 2008 the continent lost this position and, for the first time, Europe (32.8 %), North America (32.6 %) and Asia (31.5 %) account for almost similar shares in new capacity. However, Europe is still the strongest continent while North America and Asia are increasing rapidly their shares. The countries in Latin America and Africa counted for respectively only 0.6 % and 0.5 % of the total capacity and fell back in terms of new installations down to respectively only 0.4 % and 0.3 % of the additional capacity installed worldwide in the year 2008 [10]. Wind energy generating capacity in the US increased from about 2,500 MW in 1999 to about 21,000MW in mid 2008 and about 28,000 MW in early 2009. At the same time, the costs of installed utility- scale wind projects (in constant $/kW) declined until the early 2000s and then generally increased [28, 29, 30].

IX. WORLD OFFSHORE WIND ENERGY STATUS

The first offshore wind farm began operating in 1991; by the end of 2008 there were approximately 1500MW of installed capacity. By 2009 or 2010 the wind capacity in Europe is expected to grow by another 1500MW [33], and by 2015, the rate of growth of the European offshore industry is expected to be 1700 to 3000MW per year [31, 32]. The Danish government's tender to build in 2 blocks of the sea about 16MW of wind power demonstration was projected in 1997. And now they have been put into operation [11].

Key drivers for offshore wind energy success are various policy schemes that promote technology development and diffusion in countries such as Denmark, Germany, Spain, the US or India [34, 35, 36].

Because electricity is lost as it is carried long distances, we begin an evaluation of the world wind by looking at where

people use electricity. As a first-order approximation of where power is currently needed, NASA examines the earth at night. The image reveals that the electric-using population is concentrated in a few world areas and is mostly along the coasts [37].

There has not been any offshore wind turbine in Middle East yet. There is also potential for offshore wind farms in Persian Gulf, Gulf of Oman, Caspian Sea and Arabian Sea. Future research studies regarding this issue are necessary.

A. Offshore wind status in Iran

There are four different available locations for harnessing offshore wind such as: Persian Gulf (Fig. 3), Caspian Sea, Urmia Lake and Gulf of Oman.

There has not been a serious research about offshore wind energy development yet in Iran, mainly due to lack of technology, need for expensive crane vessels, high cost of investment and lack of offshore wind atlas. Iran has been trying to harness wind in areas with good potential, but offshore is not in priority yet.

The Persian Gulf, in the Southwest Asian region, is an extension of the Indian Ocean located between Iran and the Arabian Peninsula [45]. Historically and commonly it is known as the Persian Gulf. Ideally, offshore wind farms should be located in areas where winds blow continuously at high speeds. The new research identifies such areas and offers explanations for the physical mechanisms that produce the high winds [46]. There should be more research about accurate status of offshore wind in Persian Gulf and other Iranian waters like Caspian Sea, Gulf of Oman and Urmia Lake.

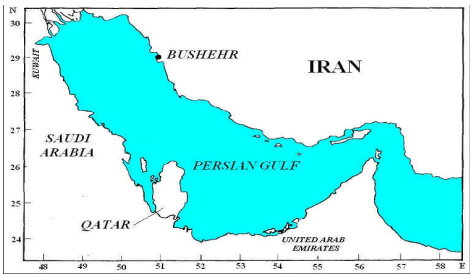

Figure 3. Persian Gulf map [19].

X. FLOATING WIND TURBINE CONCEPT

The average depth of the Persian Gulf is 36 meters; therefore there is not any need for floating wind turbine system. For Caspian Sea, there are some areas with depth of more than 1000m which is difficult and costly to use anchor in order to support the structure. But there are some areas in Caspian Sea with depth of less than 200 m, which are suitable for floating turbines. Depth of water in the Gulf of Oman is up to 300 m, which is also suitable for floating turbines too. But maximum depth of water in Urmia Lake is 12 m which is not necessary for floating turbines.

XI. SURVEY ON WIND ENERGY IN IRAN

Iran has a variable climate and a comparison among different areas shows the variety of climates. The rugged mountain ranges, located in the north, are too high for rain clouds to reach these regions, so the northern edge (the Caspian coastal plain) remains humid. In the southern part of the Caspian coast, the weather in mild and the annual precipitation, especially in Gilan province (western part of Caspian Sea) is more than the other regions. The average summer temperature is about 18 Degrees Centigrade, but the western part experiences the Mediterranean weather. The southern part which is influenced by the salt desert, the weather is mild and in the valleys it is very hot in summer [38, 40, 43].

In winter, it is mild in the valleys and it is subzero freezing. In the south, summer heat is accompanied by high humidity. The temperature sometimes reaches 54 Degrees Centigrade. Summer is usually hot and winter is mild. There is not much difference between the day and night temperatures. The Zagro Mountain, in the west, and Alborz Mountain ranges in the north, has left the interior part of the Iranian plateau arid. The northern and western foothills are influenced by the mild weather of the neighboring areas [38, 40, 43].

As we go from the west to the east and north to the south, the effect of humid winds declines and the heat goes up. In the central lowlands and in the east and south east of Iran the temperature is freezing in winter and it is very hot in summer. There is a sharp contrast between day and night temperatures [38, 40, 43]. Iran is surrounded by the rugged mountainous rims. It is located between the west and the east, the south (hot) and the north (mild), being affected by the main air currents coming from Asia, Europe, Africa, the Pacific and Atlantic Oceans. The determining factors are latitudes, the north and south poles, the elevation from the sea level, the presence of the mountains or plains, the sea, the lake, the pressure of the air, wind and precipitation [43]. Iran is located in the southwest of Asia, its central borders continue into the central Asia, the high mountain ranges, rimming it provides the country with a variety of climates [38, 39, 43].

The winds blowing from the Atlantic Ocean and the northeast, the central Asia, occur in winter and the winds coming from the Iceland, Scandinavia and the Pacific Ocean occur in summer and all the atmospheric currents are influenced by them.

Iran has been affected by following atmospheric currents [38, 41, 43]:

1- The main pressure center in the central Asia in winter.
2- The main pressure center in the Pacific Ocean in summer.
3- The west current blowing from the Atlantic Ocean and the Mediterranean especially in winter.
4- The northwest current in summer.

XII. FUTURE OF WIND ENERGY IN IRAN

Energy production market is a competitive one and the total amount of economically extractable power available from all sources.

Some countries have increased their wind generation capacity, setting an example for the other countries which have begun to take steps. Many of the economic developmental sources are located in Asia. The developing economy in Asia, including Iran, is capable of implementing most of the renewable sources of energies. Asian countries have been aware of their desperate need to generate electricity, using the non-fuel resources. The lake of power-supply in some rural areas enhances the development of the wind power generation [38, 41, 42, 43].

Regarding the prospect of the wind energy in Iran, it can be said that the use of the wind energy will lead to saving in fuel, bringing about the preservation of the oil products. It will also help to preserve the environment and leads us to the dynamic social and economical development.

The wind power generation will bring growth, development and job opportunities, finally when the wind energy technology is well-established, the economy will improve [43]. Future of wind energy in Iran is promising, because the national wind atlas was prepared recently. It shows many suitable locations for installation of wind turbines. It should be mentioned that it is possible to install small wind turbines in most of the regions in Iran.

XIII. PUBLIC'S ATTITUDES TOWARDS WIND POWER IN IRAN

In general, Iranians are interested to have renewable sources of energy like wind, solar, geothermal and other different kinds of environmentally friendly kinds of energy. For example people in city of Yazd which is located in central part of Iran and in middle of desert, have been using solar water heaters for many years. As a matter of fact, the access to fossil fuel is easy and inexpensive. But Iranian people as well as others would like to have clean energy for different purposes. There are many legal issues and problems towards wind turbine sites in many countries. But there have not been these kinds of problems in Iran yet. People are friendly with renewable energy establishment and legal issues are not important factors for Iran yet.

There has not been any survey in Iran regarding of the public attitude regarding of turbine installation in general. But people in Iran support any action which yields to cleaner environment. For instance there are many big installed turbines in city of Manjil in north of Iran, but there has not been any opposition movements or demonstrations regarding of turbine existence in the city. There has not been any plan about offshore wind turbine in Iran yet, but it is easy to predict the attitude of people regarding of this matter. People have shown their positive supports toward any kinds of renewable energy installations.

CONCLUSION

The contribution of wind turbines in the production of electric energy in Iran is very low, but it is possible to increase the share of wind energy for energy purposes. The government has paid a great attention to establish wind farms in different good locations in Iran, but there has not been an accurate map or wind atlas yet. Iran is also capable of manufacturing most parts of wind turbines in which the cost of manufacturing is lower than other countries. The national wind atlas of Iran was prepared in 2009 and many locations with good potential of wind energy were identified. There are many good locations in the southern part of Caspian sea, north eastern and also south eastern parts of Iran which could be good locations for wind farms.

There are many countries like Iran with offshore wind potential, but there has not been serious effort in this regard. As the best wind resources become developed onshore, there has been increasing effort toward offshore wind industries in Europe and North America. Despite the moderate wind resource found in Iranian waters, using existing technologies, offshore wind power can contribute a significant share to the country's electricity supply. The results indicated that Iran's offshore resources are promising, situated close to the densely populated islands and coastal cities along the coastlines of Persian Gulf, Caspian Sea and Gulf of Oman.

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