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RENEWABLE ENERGY SOURCES

Energy Feasibility of Hybrid PV/Wind Systems with Electricity Generation Assessment under Iran Environment

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Abstract—The need for the use of renewable energy helps human beings transmit the world to future generations. People, farmers, and governments tend to use renewable energy to generate electricity for their own consumption. Among the many sorts of renewable energy resources available in Iran, wind energy and solar energy are the fastest growing and most attractive renewable energy resources for electricity production. In this study, wind and solar energy potentiality is evaluated for four cities in Iran including Ahvaz, Sirjan, Neyshabur and Tabriz. The numerical analysis utilized wind speed, solar radiation and temperature data measured in 2018 from Iran Meteorological Organization to study electricity generation for the four cities. The results show that electricity is generated by solar and wind energy for all four cities of Tabriz, Neyshabur, Ahvaz and Sirjan are 5444.56, 7642.49, 9335.89 and 8084.47 MW h, respectively. Using solar energy in Ahvaz and Sirjan cities and wind energy in Neyshabur and Tabriz cities are rational to generate electricity.

Keywords: electricity generation, renewable energy, energy potential, wind turbine, photovoltaic

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INTRODUCTION

Due to a rapid climate change in the world, global society needs to use renewable energy to produce electricity [1–7]. Iran neighboring the equator, with suitable average sunlight and wind speed per year, hence renewable energy resources like photovoltaic plate and wind turbine for generating electricity have a great potential as they are inherently stochastic in nature of Iran [8–11]. They are reliable power sources by itself in many locations [12, 13]. Many types of researches for electricity generation in Iran using solar energy [14, 15] and wind energy [16, 17] have been analyzed. An analysis of wind energy potential and economic evaluation in Zahedan, Iran, was studied by Mostafaeipour et al. [18]. Their results showed that the obtained wind power density was 89 W/m^2 and the turbines generated 2.5 kW in the region which was the most cost-efficient option [19]. The best comparisons between Iran and Middle East investigations were analyzed by the same research group [20]. Dabbaghiyan et al. [21] evaluated wind energy potentiality for different regions of Bushehr province in Iran. The results found that the yearly wind density for Borskhum was about 265 W/m^2 for winds at 40 m above ground level.

Khorasanizadeh, and Mohammadi [22] emprically tested a model to predict daily irradiance in different regions including Bandarabass, Isfahan, Kerman and Tabass. Asnaghi and Ladjevardi [23] presented a solar chimney which was presented to be constructed as the first national solar chimney in central regions of Iran. Results cleared that this power plant could generate electricity of 28 MW h/month [24–26]. Naderipour et al. [27] analyzed solar and wind power generation for different regions of Iran and also the cost of energy for per kW h. In a case study by Firozjaei et al. [28], the optimal feeding considering solar tariff the parameters including geographical, topographic and climate condition was evaluated. The results showed that irradiance potential was in the range of 380 to 578 W/m^2 in Iran. The optimal feeding considering solar electricity tariff varied from 0.0835 to 0.1272 $ for different regions in Iran and among these results, Ardebil and Kohkiluyeh and Boyer-Ahmad were considered as the riskiest and safest regions, respectively, for financiers in case of solar project.

In other countries, researchers have studied technology-economic analysis of solar PV. Ramadan and Elistratov [29] analyzed the technology-economic feasibility of installing a 300 kW grid-connected solar photovoltaic (PV) plant in Syria. Their results showed that the annual optimal tilt angle of PV modules was 25°, energy production was 493 MW h/year, the annual average performance ratio was 0.799 and the capacity factor was 18.7%. In addition, they showed that the solar power PV with 493 MW h/year could provide energy to 220 capita/year and save about 42.4 tons of oil equivalent yearly. Elistratoy and Ramadan [30] determined the energy potential of solar and wind resources in Syria. Their results showed that the average total gross and technical potential of solar energy were 345406 and 55265 TW h/year, respectively, and also the average wind power at the height of 50 m and the average total gross potential of wind energy in Syria were estimated as 32.2 TW and 273533 TW h/year, respectively.

Since Iran is a large country, it has a variety of climate conditions. Comparing previous works available in literature, it was found that no comparisons were made between north and south of Iran for electricity generation by using solar and wind energy. The objective of this study is to evaluate the feasibility of electricity generation in four cities (Ahvaz, Sirjan, Tabriz and Nyshabur) with different climate conditions and also assess the difference in renewable energy generation in these cities. The use of solar and wind power to generate electricity for all four cities was investigated based on the data available for the year of 2018. Therefore, in this study, a comparative evaluation regarding the potential of wind and solar renewable power generation for four cities in Iran country is presented so that based on the findings of this manuscript a detailed study can be performed to design and implement the hybrid wind-solar systems in these cities. The main highlights of the paper are as follows:

- Wind and solar energy potentiality in view of clean power generation for four cities in Iran (Ahvaz, Sirjan, Neyshabur and Tabriz).

- Using of real data of wind speed, solar radiation and temperature measured in 2018 from Iran Meteorological Organization to study electricity generation for theses four cities.

- Comparative evaluation of wind and solar power generation potential for these four cities.

- Assess which renewable energy source in a city has the best potential for power generation.

FEASIBILITY STUDY OF SOLAR AND WIND POWER PLANTS IN IRAN

Today, with the decline in fossil fuel consumption worldwide, the application of renewable energies is assumed to play a vibrant role in the world energy portfolio. The limited resources of fossil fuels and the problems associated with greenhouse gas emissions have made it increasingly clear that renewable energy is needed to be used. Conventional sources of traditional power plants are also limited, and the high variability in the cost of providing these resources has provided an important benchmark for the future of conventional electricity generation. Given the favorable potential of renewable energy in Iran, the rational development of these valuable, clean and free resources seems justified, as it can also be a step towards sustainable development goals. Energy resources are important elements of sustainable expansion. Having the optimal energy potential is one of the most important factors of economic growth in post-workforce industrial societies because of the energy importance for sustaining economic expansion, social security and convenience, improving the quality of life and security of society. However, this territory is constantly changing, and the future of these changes represents a reduction in costs and an expansion of its influence in the world energy market and the achievement of sustainable energy. Investing in solar and wind power industries is an investment in energy independence, and countries that can expand their solar infrastructure and electricity grid will be a step ahead of their rivals in competing for electricity generation and economic development. Solar and wind power have the greatest potential to meet the world future demand as one of the renewable sources, with much of the world's electricity generated by solar and wind technologies.

Iran should not only rely on fossil fuels but also must plan for the growth and development of energy resources. Iran is located in a region with about 300 days of sunshine over 60% of it and average irradiance of 4.5 to 5.5 kW h per day which is among the highest ranks of solar energy in different parts of the world. Moreover, according to the report of the World Wind Energy Organization, in 2008, Iran was ranked thirty-fifth in view of wind power generation and has a vast potential to generate wind power, as the Manjil region is considered as one of the windiest in Iran. Therefore, the application of solar and wind energy for a variety of reasons such as ease of accessibility and ease of converting to electrical energy, being environmentally friendly and renewable, is highly desirable. The use of renewable energy sources has become increasingly important in recent years. Due to the dispersed nature of many areas of Iran, grid-independent systems that utilize renewable energy resources are suitable options for electricity supply to grid-off regions. Moreover, accurate assessment of solar and

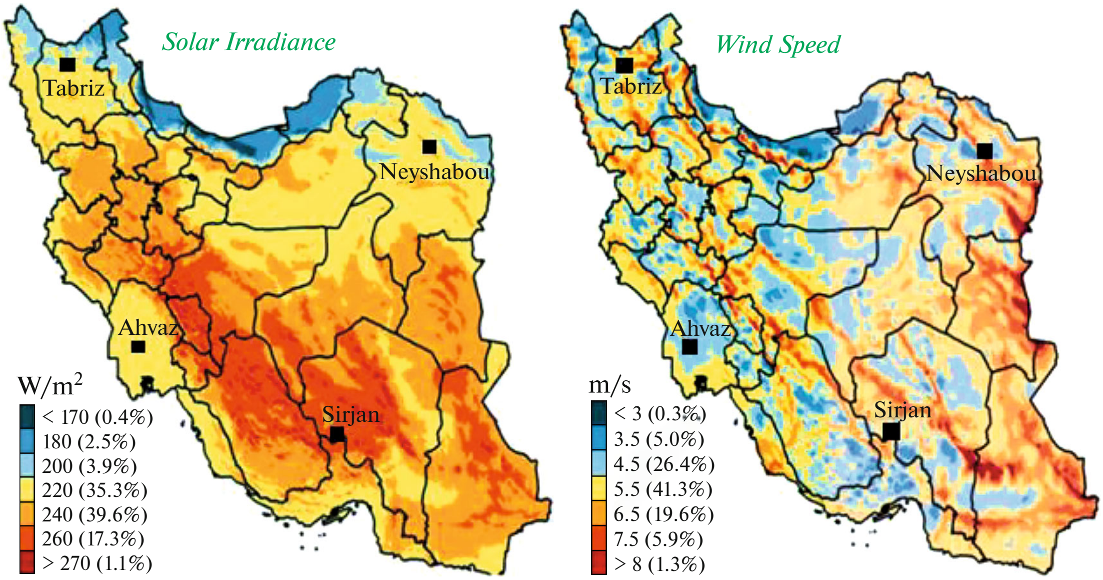

Fig. 1. Distribution of solar radiation and wind speed for four cities in Iran country [14].

wind energy potentiality in a particular region needs the application of solar irradiance data, temperature and wind speed of that region, and accurate calculation of the generation capacity based on these types of energy sources. The feasibility of constructing solar hybrid renewable-based power generation systems based on solar and wind energy sources in that geographical area is also required to better finding out the exact potentiality of this region in terms of energy production.

AREAS OF STUDY

Iran has a high capacity to deploy a variety of renewable energy sources. This large country is located in southwest Asia and the Middle East between latitudes 24° and 40° N, and longitudes 44° and 64° E with area of 1648195 km^2 and 84 million inhabitants in 2020. There are areas with different climates, such as dry, semi-warm and temperate. In this paper, as can be seen in Fig. 1, four cities: Ahvaz (southwestern Iran), Sirjan (southeast of Iran), Neyshabur (northeast of Iran), and Tabriz (northwest of Iran) are studied. The geographical and weather data for the four regions are presented in Table 1.

Ahvaz is known as the capital of Khuzestan province. This area is located at 31°19′ N and 48°40′ E and 12 m above the sea level. Sirjan is one of the cities of Kerman province, which is geographically located at 29°6′ N and 58°20′ E with 1760 m above the sea level. Neyshabour is one of the cities of Khorasan Razavi province which is located at 36°12′ N and 58°47′ E with 1250 m above the sea level. Tabriz is one of the cities of East Azarbaijan province which is located at 38°4′ N and 46°25′ E with 1351 m above the sea level. Distribution of solar and wind energy resources in these four cities in Iran country in Fig. 1.

The curves of the solar radiation and wind speed for each of the extracted areas of the Iranian Meteorological Organization for each month in 2018 are also presented in Figs. 2 and 3, respectively. For example, the average monthly temperature of Tabriz in 2018 is presented in Fig. 4.

Table 1. Geographic and weather information for the four regions in Iran

Region	Location	Weather	In 2018		
			average radiation intensity, W/(m^2 year)	average wind velocity, m/s	average ambient temperature, °C
Ahvaz	31°19′ N and 48°40′ E	Arid, desert, hot	26.22	3.88	700.66
Sirjan	29°6′ N and 58°20′ E	Dry, hot	17.45	4.67	633.25
Neyshabur	36°12′ N and 58°47′ E	Dry, cold	14.34	4.81	625.64
Tabriz	38°4′ N and 46°25′ E	No dry, cold	12.83	3.73	447.06

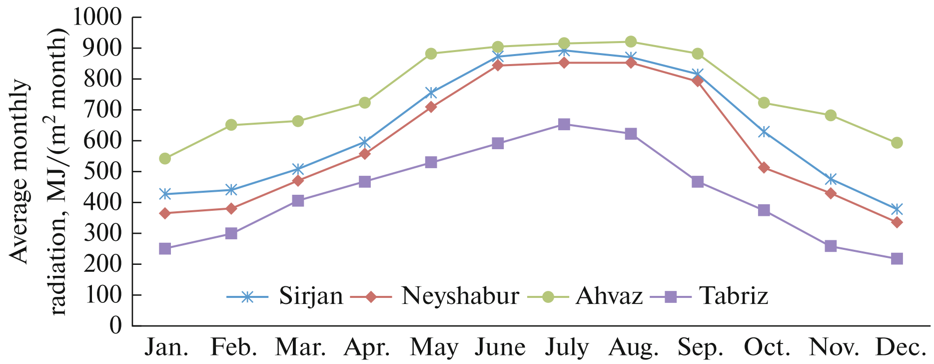

Fig. 2. Average monthly radiation for four cities.

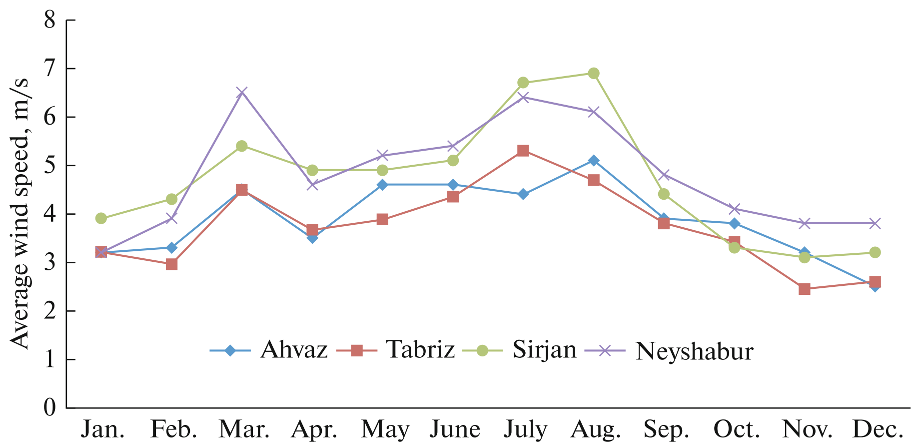

Fig. 3. Average monthly wind speed for four cities.

POWER GENERATION MODEL

For better analysis, it is better to study the mathematical equations of photovoltaic plate and wind turbine. In this section the mathematical modeling (MM) of the photovoltaic plate and wind turbine are described. In this study the PV and wind turbine are used to generate the power based on real data of solar radiation, wind speed and temperature of the four cities of Iran country. So the mathematical model of output power of PV based on solar radiation and temperature is presented in (1)–(14) and also the model of output power of wind turbine based on wind speed is written in (15), (16).

POWER GENERATION MODEL OF PV CELLS

The output power of a photovoltaic (solar cell) is obtained using the following equation [16]:

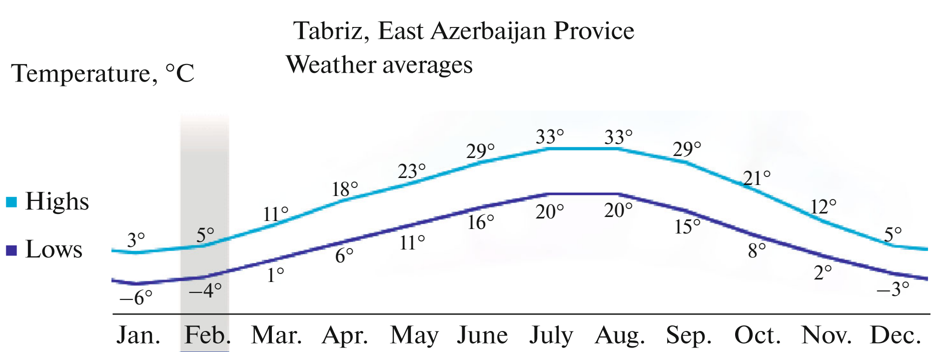

Fig.4. Average monthly temperature for Tabriz.

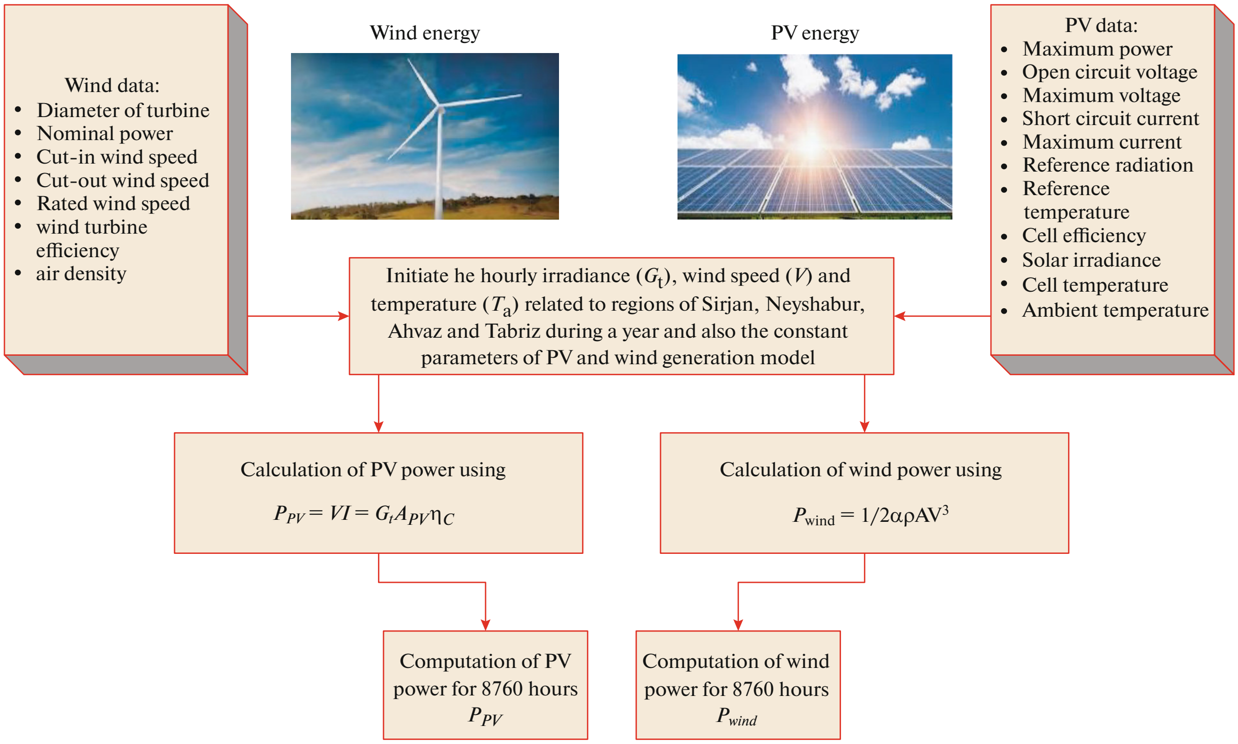

Fig. 5. Schematic of renewable resources power modelling.

$$P_{PV} = IV, \tag{1}$$

where I is the current (A) and V is the voltage (V) .

The unipolar photovoltaic current for a solar cell with a diode from an array is expressed as follows [26]:

$$I = I_L - I_D = I_L - I_0\left(e^{\frac{V+IR_s}{a}} - 1\right), \tag{2}$$

where R_s, a, I_L and I_D are the resistance series (Ω), curve fitting parameter, light current and diode current (A), respectively. The characteristics of products are supplied by the PV manufacturer with a data sheet (V values). Also, the current for 3 conditions is a set of reference conditions like short circuit, open circuit, and the maximum extracted power. The light current is equal to short-circuit current as

$$I_L = I_{SC}, \tag{3}$$

where I_{SC} is the short circuit current (A). The diode current reverse saturation is given by:

$$I_{0,ref} = I_{L,ref}\, e^{\frac{-V_{0C,ref}}{a_{ref}}}. \tag{4}$$

The values of I and V at maximum power point determined by the manufacturer must be replaced by Eq. (2) to calculate series resistance (R_s) as follows:

$$R_s = \frac{a\ln\left(1 - \frac{I_{mp}}{I_L}\right) - V_{mp} - V_{OC})}{I_{mp}}, \tag{5}$$

where the subscripts mp and oc denote the maximum point and open circuit, respectively. Equation (6) is a suitable approximation for the temperature impact on solar cells. The parameters in the above equations are expressed as:

$$I_L = \frac{G_T}{G_{T,ref}}\left(I_{L,ref} + \mu_{ISC}\left(T_C - T_{C,ref}\right)\right), \tag{6}$$

$$a = a_{ref}\frac{T_{C,ref}}{T_C}; \tag{7}$$

$$I_0 = I_{0,ref}\left[\frac{T_C}{T_{C,ref}}\right]^2 e^{\left[\frac{\epsilon N_s}{a_{ref}}\left(1 - \frac{T_{C,ref}}{T_C}\right)\right]}, \tag{8}$$

$$V_{0C} = V_{0C,ref} + \mu_{V_{0C}}\left(T_C - T_{C,ref}\right), \tag{9}$$

$$a_{ref} = \frac{\mu_{V_{0C}} T_{C,ref} - V_{0C,ref} + \epsilon N_s}{\frac{\mu_{ISC} T_{C,ref}}{I_{L,ref}} - 3}, \tag{10}$$

where G_T, T_C, N_s, ϵ and μ are the irradiation, cell temperature (K), number of cells, bandgap energy and temperature coefficient, respectively. It is clear that the temperature of solar cell in operating conditions

Table 2. Characteristics of wind turbine in this study [32]

Diameter of turbine, m	Nominal power, kW	Cut-in wind speed, m/s	Cut-out wind speed, m/s	Rated wind speed, m/s	AC voltage, V	Frequency, Hz
10	7	3	20	10	240	50

Table 3. Characteristics of photovoltaic module in this study [16]

Parameter	Maximum power, W	Open circuit voltage, V	Maximum voltage, V	Short circuit current, A	Maximum current, A	Reference radiation, W/m^2	Reference temperature, °C
Value	200.143	32.9	26.3	8.21	7.61	1000	25

should be determined. It is necessary to apply the energy balance for the cell. The module energy balance is obtained by:

$$\tau\alpha G_t = \eta_C G_t + U_L\left(T_C - T_a\right), \tag{11}$$

where τ, α, η_C, U_L and T_a are the transmittance absorbance product, fraction of the radiation incident absorbed on the surface of the cell, cell efficiency, loss efficient and ambient temperature (K), respectively. Considering nominal operating temperature (NOCT) at no load condition can be written as:

$$\tau\alpha/U_L = \left(T_{C,NOCT} - T_a\right)/G_{t,NOCT}. \tag{12}$$

The solar irradiances at NOCT and ambient temperature are 750 W/m^2 and 18°C, respectively.

The cell temperature is obtained by

$$T_C = T_a + \left(G_t \frac{\tau\alpha}{U_L}\right)\left(1 - \frac{\eta_C}{\tau\alpha}\right), \tag{13}$$

where the cell efficiency is determined by Eq. (14) as

$$\eta_C = \frac{VI}{G_t A_{PV}}. \tag{14}$$

In the above equation, A_{PV} is the PV area (m^2).

POWER GENERATION MODEL OF WIND TURBINE

Wind energy has been exploited for many purposes such as drying fruit, sailing, kite flying and electricity generation [27]. The power transmitted to a wind turbine is directly proportional to the area displaced by rotor, air density, and the wind speed that is calculated by

$$P_{wind} = \frac{1}{2}\alpha\rho A V^3, \tag{15}$$

where α is the wind turbine efficiency factor, A is frontal area (m^2), V is wind speed (m/s) and ρ is the air density (kg/m^3), which is obtained using ideal gas law as follows:

$$\rho = \frac{P}{R\overline{T}}, \tag{16}$$

where $\overline{T}$ is the equivalent air temperature per month (K), P is gas pressure, R is the gas constant of air, which is equal to 287 kJ/kg.

Characteristics of wind turbine and PV module that used in this study is presented in Tables 2, 3, respectively. It should be noted that a set of wind turbines as well as PV modules are used by the proposed program to generate energy.

MODELLING PROCESS OF RENEWABLE RESOURCES GENERATION

In this section schematic of renewable power modelling is presented. As shown in the below figure, based on solar radiation, wind speed and temperature data, as well as constant parameters related to each renewable energy source per hour, the generation capacity of PV panels and wind turbines is calculated. The study is intended hourly for one year. Therefore, the power of each renewable resource is determined based on the total power of 8760 h in a year.

RESULTS AND DISCUSSION

In this study four cities including Ahvaz, Sirjan, Tabriz and Nyshabur with different climate conditions are considered to comparative evaluation of clean power generation. The Ahvaz, Sirjan and Neyshabour have desirable potential of solar radiation according to Table 1 (These cities are known as tropical regions). Also the Sirjan and Neyshabour have suitable potential of wind speed. But the Tabriz city has not desirable potential of solar radiation and wind speed compared to other cities and this city is known as the cold region but generation of clean energy based on PV and wind resources can be one of attractive options for clean energy generation in this city. Therefore, choosing these cities with different climatic conditions to generate clean power has been one of the important motivations. The amount of electrical energy using solar and wind energy is calculated using FORTRAN 95 software. The main variables such as the intensity of solar radiation, ambient temperature, wind speed, and other parameters such as the number of solar planes

Table 4. Monthly generation of electricity by wind and solar energy in the four cities

City	Sirjan		Neyshabur		Ahvaz		Tabriz	
PV/turbines	PV	turbine	PV	turbine	PV	turbine	PV	turbine
month	MW h	MW h	MW h	MW h	MW h	MW h	MW h	MW h
Jan	410.1636	49.569	350.0784	40.672	521.64	40.672	239.568	40.7991
Feb	423.4944	54.653	364.5684	49.569	625.968	41.943	286.5832	37.6216
Mar	488.6028	68.634	452.3778	82.615	638.4874	57.195	389.298	57.0679
Apr	572.7414	62.279	535.4538	58.466	695.52	44.485	449.19	46.6457
May	727.3014	62.279	682.479	66.092	850.08	58.466	509.082	49.3148
Jun	840.5166	64.821	812.7924	68.634	871.1388	58.466	568.974	55.2885
Jul	858.9672	85.157	840.42	81.344	881.5716	55.924	628.866	67.363
Aug	838.1982	87.699	830.76	77.531	886.788	64.821	539.028	59.6099
Sep	785.6478	55.924	763.2366	61.008	850.08	49.569	449.19	48.298
Oct	605.5854	41.943	541.443	52.111	695.52	48.298	359.352	43.4682
Nov	457.4976	39.401	412.6752	48.298	656.88	40.672	247.9529	31.1395
Dec	362.733	40.672	321.5814	48.298	569.94	31.775	207.8252	33.046

Table 5. Electricity generation in 2018 by wind turbines and solar photovoltaic

City	Sirjan		Neyshabur		Ahvaz		Tabriz	
Resource	PV, MW h	Turbine, MW h	PV, MW h	Turbine, MW h	PV, MW h	Turbine, MW h	PV, MW h	Turbine, MW h
Value	7371.44	713.03	6907.86	734.63	8743.61	592.28	4874.90	569.66

and wind turbines are logged. For the wind turbine, the mean wind speeds for all four cities were included in the software. In this study, it is assumed that wind and solar devices are healthy and do not break down during the annual operation. Therefore, based on radiation, wind and temperature data, solar and wind power are obtained based on Eqs. (1) and (15), respectively. Of course, the amount of power generation is calculated based on the input data and the production model of each energy source. As can be seen in Fig. 1, the maximum wind speed among the four cities was 6.9 m/s for Sirjan. Moreover, the maximum amount of solar radiation for the city of Ahvaz is 911 W/m^2. As can be seen in Table 4, the amount of electricity produced using solar and wind energy per month is extracted for the four cities. The maximum amount of electricity generated by solar energy from Ahwaz is 886.78 MW h and the maximum amount of electricity generated by the wind energy from Sirjan is 87.69 MW h for the month of August.

As can be seen from Table 5, the electricity generated by wind and solar for Ahwaz in 2018 is 8743.61 and 592.28 MW h, respectively. Moreover, the electricity generated by wind and solar energy for Sirjan in 2018 is 7371.44 and 713.03 MW h, respectively. Moreover, electricity generated by wind and solar energy for Tabriz in 2018 is 4874.90 and 569.66 MW h, respectively. The electricity generated by wind and solar energy for Neyshabur in 2018 is 6907.86 and 734.63 MW h, respectively. The results show that the power generation based on solar power plant is logical and feasible in Ahwaz. The lowest amount of solar electricity produced by is for Tabriz of about 4874.90 MW h. The electricity produced for all four cities of Tabriz, Neyshabur, Ahvaz and Sirjan is 5444.56, 7642.49, 9335.89, and 8084.47 MW h, respectively.

CONCLUSIONS

Renewable energy sources such as solar and wind energy provide many advantages compared to the traditional applications of fossil fuels. Using wind and solar energy in order to generate electricity has been increased remarkably in recent decades in Iran. In this research, wind and solar energy potential and their characteristics are evaluated for four cities of Iran. Meteorological data for 2018 have been obtained from Iran Meteorological Organization. In this study same generators of solar and wind energy are used for all cities. The simulation results cleared that the more PV power generated in Ahvaz city due to perfect potential of radiation (more average radiation) and also lowest PV power generated in Tabriz due to weak radiation potential. Moreover, the obtained results showed that the maximum wind power is generated in Neyshabour and minimum wind power is related to Tabriz. The electricity generated by solar and wind energy resources for Tabriz, Neyshabur, Ahvaz, and Sirjan are obtained 5444.56, 7642.49, 9335.89 and 8084.47 MW h, respectively that it cleared the more generated power is belonging to Ahvaz and lowest generated power is related to Tabriz. Also Sirjan city after Ahvaz has more generated power with desirable potential of radiation and wind speed.

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