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The effect of photovoltaic industry on the two variables of temperature and wind and possible impact on dust storm in Tehran province

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ABSTRACT

Introduction: Recently, the industry of launching solar power plants in arid/semi-arid regions has developed. A considerable part of Iran is covered by dry/semi-arid areas, which are exposed to severe wind erosion. Considering the occurrence of dust in these areas, this study investigated the possible impact of the photovoltaic industry on the prevention of dust storms.

Materials and methods: The effect of solar power plant construction on atmospheric variables and its possible effect on the occurrence of dust were investigated in Tehran province. The criterion is to compare the monthly average wind and temperature respectively at the height of 10 and 2 m inside and outside the power plant (obtained from the TerraClimate database for 2020 and 2021) on the western side and at the closest point to the power plant.

Results: The monthly average of wind and temperature respectively at the height of 10 and 2 m in 2020-2021 decreased inside of the power plant with respect to the outside of that. Significant differences were observed on temperature and wind inside and outside of the power plant during the peak heat in the summer, which increase with increasing temperature. The maximum of differences of monthly average of wind and temperature variables inside and outside of the power plant for Pars Ray Energy Bahar, Tehran Wastewater and Sohail Power Plants respectively are (0.5 °C, 0.55 m/s), (0.6 °C, 0.3 m/s), and (0.7 °C, 0.3 m/s).

Conclusion: The photovoltaic industry can change the effective solar radiation, and possibly decrease the occurrence of dust storms by weakening wind power.

Introduction

The desert photovoltaic industry has developed quickly in recent years. A large part of Iran is covered by desert areas, which are exposed to severe wind erosion. The Natural Resources and Watershed Management Organization plans to manage these areas with desertification operations, including the construction of windbreaks, plantations, and water runoff management. One of the related actions is the use of solar energy. The areas that have suitable factors for the construction of a solar power plant are approved by the Renewable Energy

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and Electricity Energy Efficiency Organization (SATBA) and prepared by the Natural Resources Organization. Iran has about 300 sunny days, and in addition, the intensity of sunlight in our country is higher than in many countries, which will make the use of solar power plants more affordable [1]. Therefore, this radiation and proper access to sunlight can be used well, so that now solar power plants with a production capacity of 10 MW have been operated in the Isfahan, Kerman, Yazd, and Tehran provinces.

Many studies have been done on the impact of dust on the photovoltaic industry [1-5] and on the different techniques for cleaning the surface of panels from dust and polluting issues [1-3]. The operation of photovoltaic panels in converting solar energy into electricity is highly dependent on environmental conditions such as solar radiation, ambient temperature, wind, humidity, atmospheric pollution, and other atmospheric characteristics. Because areas with high radiation potential for installing solar panels are often areas with dry and semi-arid climates, the effect of dust occurrence in these areas strongly affects the performance of solar panels. Therefore, studies have been conducted in Iran regarding the way dust stays on the surface of solar panels and which may affect this process [2]. Also, much research has been conducted regarding the effect of dust and pollution in the atmosphere on the performance and efficiency of solar panels. Before 2008, the research studies in this field were very limited. The effect of dust on the performance of photovoltaic panels diminishes the work efficiency [1, 6-8]. Also, dust type also affects the performance and efficiency of photovoltaic panels, and it cannot be related only to the duration of exposure in the environment [9]. Therefore, this research fully discusses the problem of dust accumulation on the surface of photovoltaic panels and the severity of the problem. In addition, the research presents the cleaning techniques, and their applicability is also evaluated. Many techniques have been used to remove dust accumulation on the surface of photovoltaic panels, including manual and self-cleaning methods. However, from the presented review it is concluded that there is a strong need to develop new cleaning methods, especially for the Middle East and North Africa region [10].

To show the impact of the photovoltaic industry on the prevention and control of sandstorms, a recent study [11] has been conducted. In this study analyzed the effect of the solar power plants on the prevention and control of sandstorms through continuous observation of air temperature, wind speed, and the air pressure inside and outside the solar power plant in the desert area. The results of this study showed that the launch of a solar power plant in the Gobi desert area can effectively change the solar radiation and adjust the thermal balance and weakening of the power for the occurrence and development of sandstorms. Also, rain collecting can help to make plants grow. However, there have been many trees have been planted in the deserts of northwest China (Gabi), but few have survived, and their effect on controlling sandstorms is not significant.

The driving force behind the occurrence and development of sandstorms is strong winds, which are created due to heat imbalance on the surface. The photovoltaic industry converts solar energy into electrical energy. Theoretically, the photovoltaic industry influences reducing dust storms. So the question raised here is, how does the photovoltaic industry reduce dust storms? What is the role of the photovoltaic industry in reducing dust storms?

Materials and methods

Study region

Since there is a direct relationship between energy consumption and industrial and construction developments, the topic of the energy crisis is known as the main problem of the current century. This problem has caused an increase in the attempt at renewable energies. Fig. 1 shows Iran's solar atlas, which the basis for choosing is the World Bank atlas. Based on studies results to identify high potential sites and evaluate renewable energy resources and consolidated evaluation, prioritization, and determining the share of clean energy in Tehran province have been prepared by the Ministry of Energy [12]. Several solar power plants were built in different areas of Tehran province which are now in the operational stage. Fig. 2 shows the geographical location of the three largest power plants in Tehran. Tehran province with the center of Tehran city has an area of about 12981 km2 in the latitude range of 34 to 36.5 degrees north and longitude of 50 to 53 degrees east. Due to its geographical location, there are different weather conditions in different areas of Tehran province. Dry areas such as Qazvin plain, desert areas of Qom and central, and dry areas of Semnan province, which are adjacent to Tehran province, head to the hot and dry air, and in some cases winds, which may cause dust storms to occur in Tehran region. The Alborz mountain range and the wet and humid west winds also moderate the climate of the Tehran region, but they do not deactivate the effect of the heat of the dry desert areas. Tehran province has also, three humid, semi-humid, and cold climates in the northern highlands of the province. The semi-humid, moderate and near cold climates are in the foothill slopes but dry and semi-arid climates are in altitudes of less than 1000 m. The southern regions of Tehran province, such as Varamin and Shahryar, have been categorized in this climate.

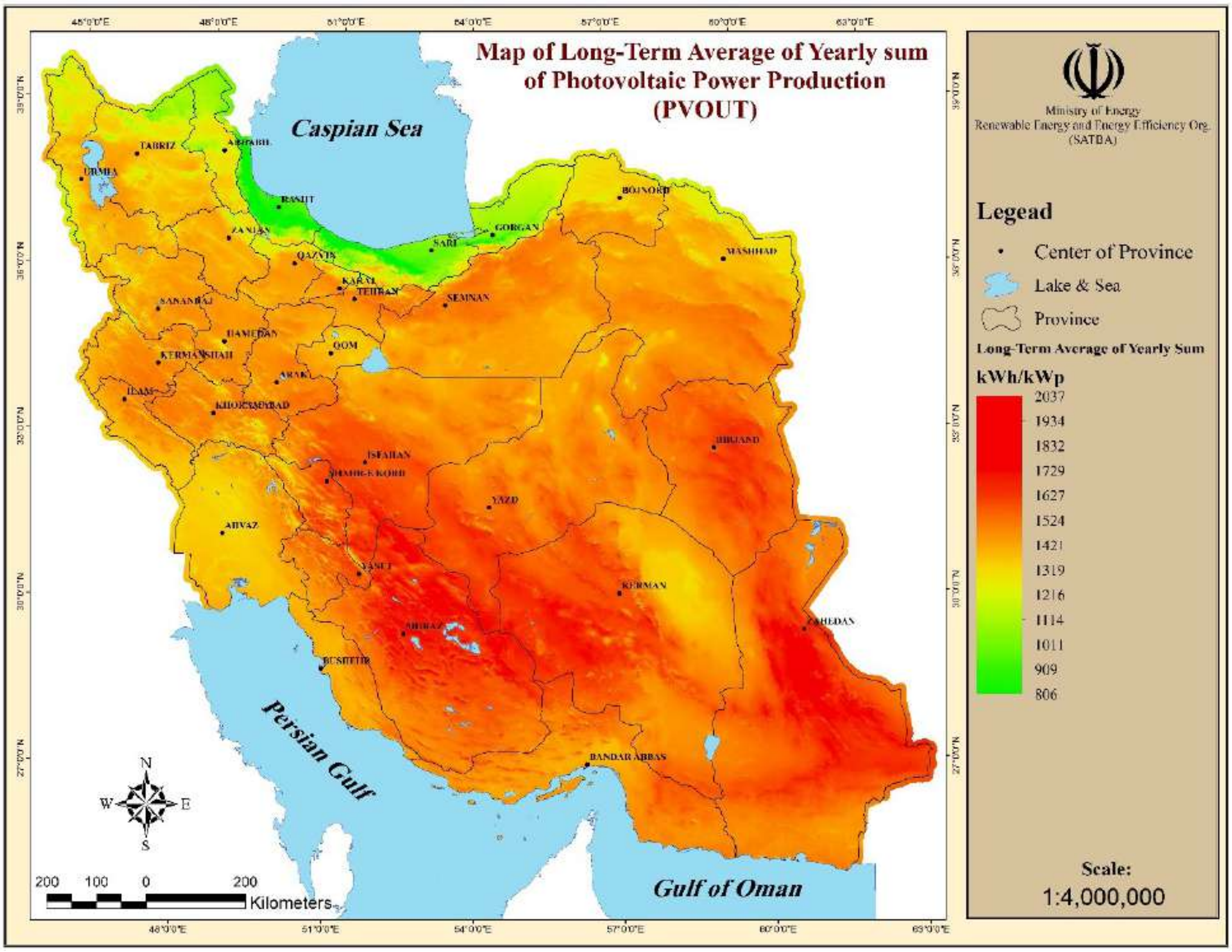

Fig. 1. Solar Atlas (taken from the website of the Ministry of Energy, Renewable Energy and Electricity Efficiency Organization [13]

These power plants are, Pars Energy Bahar power plant located in the southern area of Tehran (urban) with a capacity of 10 MW (power plant number 1), Tehran Wastewater Power Plant (power plant number 2) with a capacity of 5 MW in the central region of Tehran province and the power plant No. 3 named Soheil renewable energy power plant with a capacity of 8.4 MW located in Damavand area of Tehran province. The latest one was set into operation in 2016 [13].

In this section, it is necessary to provide an overview of the number of dust storms in Tehran province. Observational data to determine the number of dust storm occurrences has been available since 2007 in all stations of Tehran province, Fig. 3 shows the number of dust storm occurrences in the period from 2007 to 2021 in each month and in 5 stations that these stations are in both north and south of Tehran province. According to the observation data from Islamic Republic of Iran Meteorological Organization (IRIMO), the southern regions of Tehran, which are in arid and semi-arid climates, have the highest number of dust storms per year, which mostly occur in the summer season (May, June, July, and August). The most number of reported dust storms have occurred in Imam Khomeini airport and Shahriyar areas as shown in Fig. 3. According to Fig. 3, the maximum of the number of dust storms is 78 cases that occurred in Shahriyar on June 2007-2021.

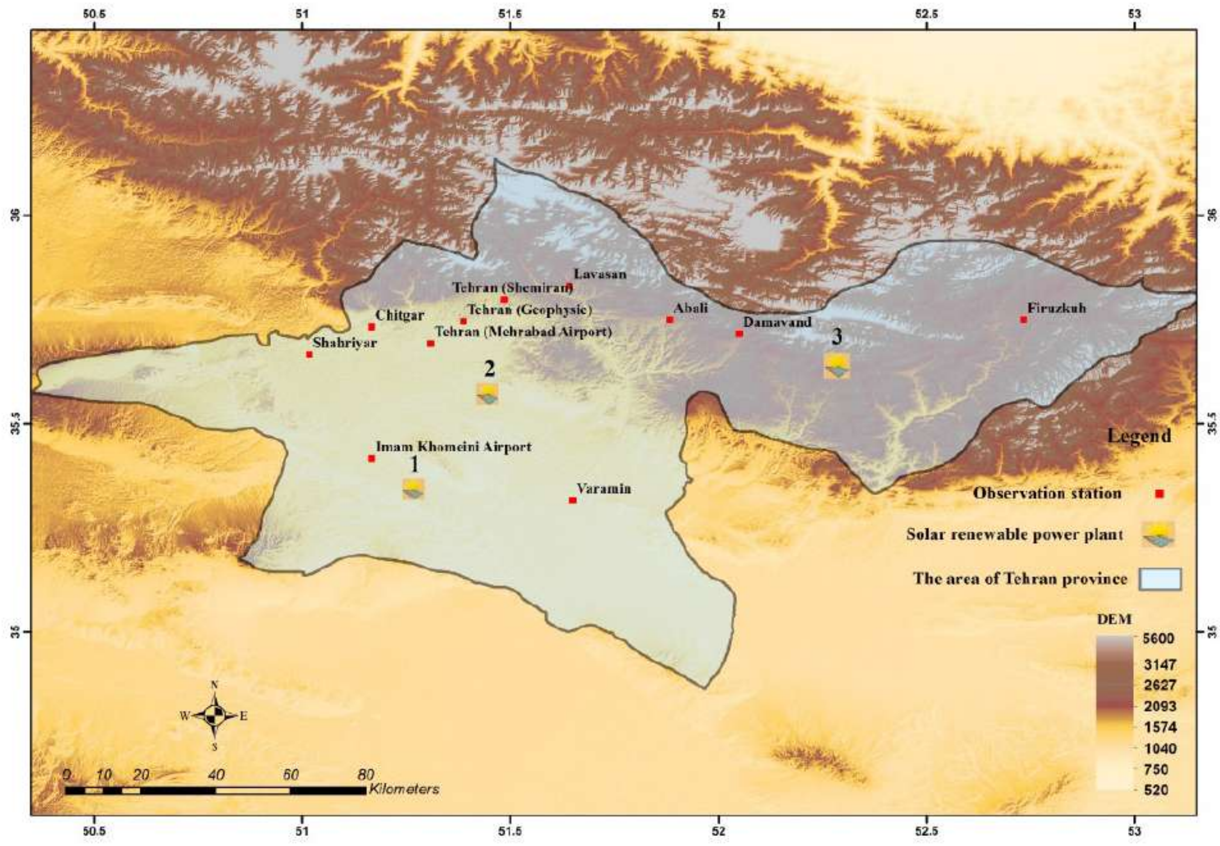

Fig. 2. Location of the largest solar power plants in Tehran Province: 1. Pars Ray Energy Bahar Power Plant, 2. Tehran Wastewater Power Plant, 3. Sohail Power Plant, and location of observation stations in Tehran

Data analysis and methods

In this study, to investigate the effect of solar power plant construction on the wind field and temperature, and as a result, the impact on the occurrence of dust phenomenon in the study area, the information of temperature and wind speed variables near the ground surface inside and outside the power plant is needed. Due to the lack of this information inside and outside of the power plant at the same time and the low density of observation data, the TerraClimate database has been used.

TerraClimate database is available to the public through an unrestricted data tank hosted by the University of Idaho's Northwest Knowledge Network [14]. This high spatial resolution dataset (1.24°, ~4 km) is globally available. The full list of TerraClimate datasets is provided in Table 1.

These data are available in https://www.climatologylab.org/terraclimate.html.

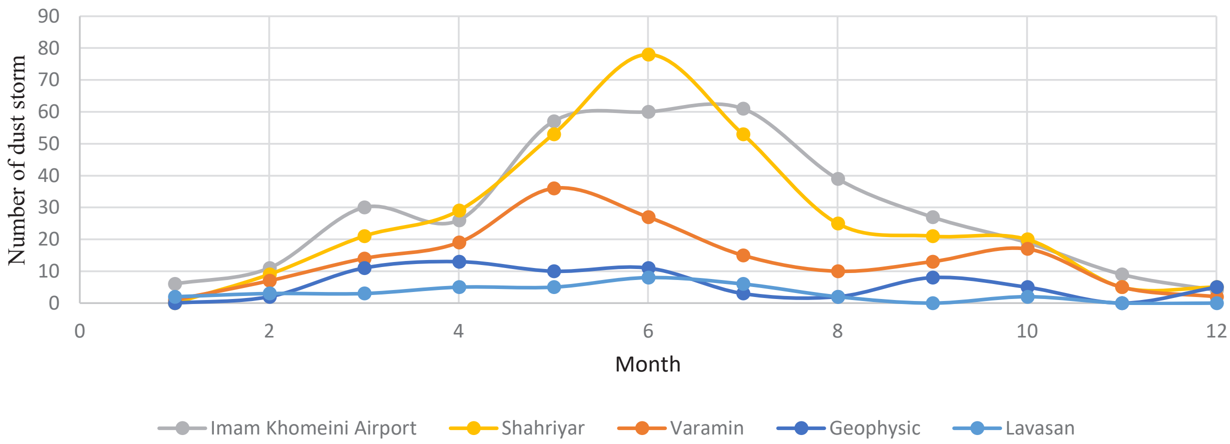

Fig. 3. The number of dust storm occurrences in the period from 2007 to 2021 in each month and in 5 stations in Tehran Province based on the observation data from IRIMO

Table 1. Datasets provided by TerraClimate are available monthly and time varying from 1958 and produced at a 1/24° spatial resolution

Dataset	Variables
Essential climate variables	2-m maximum temperature, 2-m minimum temperature, 2-m vapor pressure, 10-m wind speed, downward solar radiation flux at the surface, accumulated precipitation
ET_0	Reference Evapotranspiration
Water balance variables	Runoff, actual evapotranspiration, climate water deficit, soil moisture, snow water equivalent

The other datasets details are accessible from [15]. In this study, the monthly average of the wind speed and temperatures at a level of 10 and 2 m above the ground respectively, are obtained from the TerraClimate database for the last two years (2020 and 2021). These data were used to compare the effect of launching a solar power plant inside and outside the power plants. The point outside the power plant is considered in the west of the solar power plant, and the position of this point outside the power plant in each of the three power plants is shown in Figs. 4 a, b, and c.

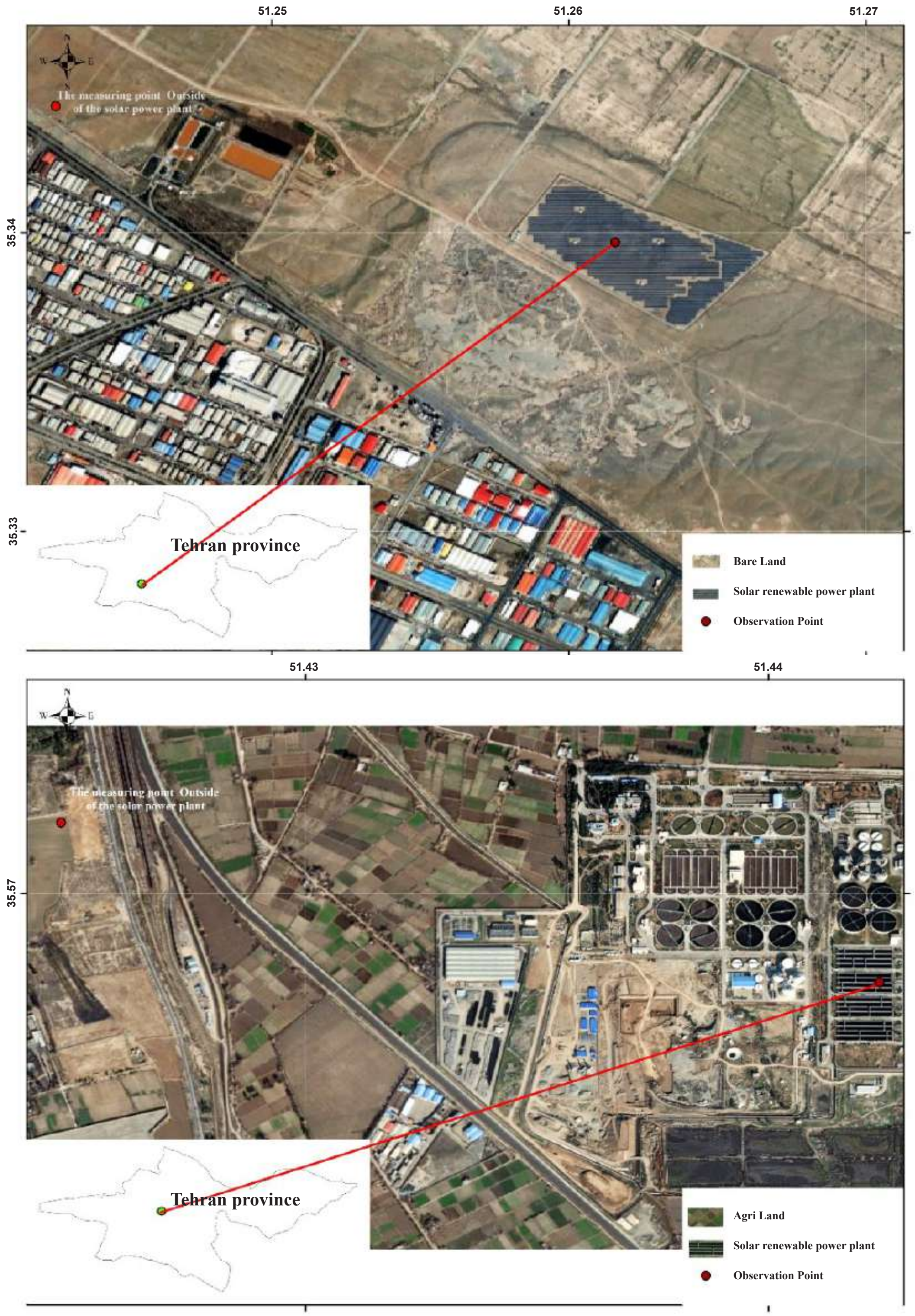

Fig. 4. The location of each of the three solar power plants and the investigated point outside the power plant located to the west of it: a) Power plant No. 1, b) Power plant No. 2, and c) Power plant No. 3

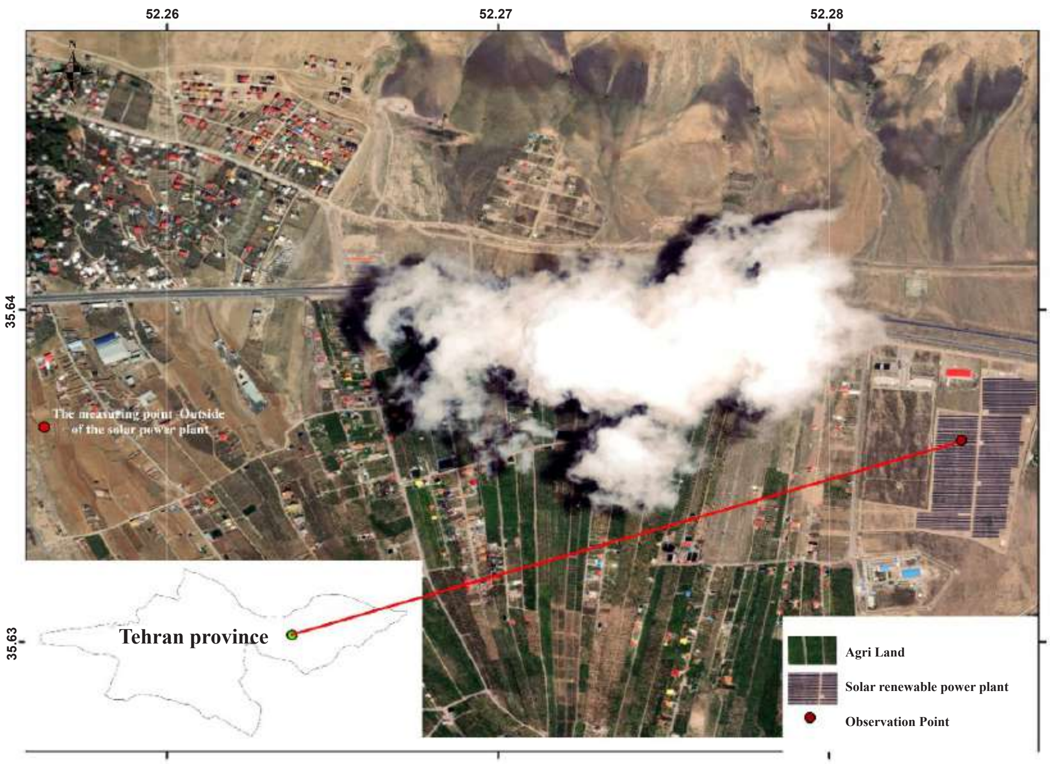

Fig. 4. The location of each of the three solar power plants and the investigated point outside the power plant located to the west of it: a) Power plant No. 1, b) Power plant No. 2, and c) Power plant No. 3

The calling and processing of the mentioned data were done in the web programming environment of Google Earth engine [16]. Earth Engine is a platform for scientific analysis and visualization of geospatial datasets, for academic, non-profit, business, and government users. Earth Engine hosts satellite imagery and stores it in a public data archive that includes historical earth images going back more than forty years. The images, ingested on a daily basis, are then made available for global-scale data mining. Earth Engine also provides APIs and other tools to enable the analysis of large datasets.

In order to evaluate the data extracted from the TerraClimate database in the statistical period from 2001 to 2021, using statistical parameters MSE (Mean Square Error), RMSE (Root Mean Square Error), MAPE (Mean Absolute Percentage Error), r (Correlation Coefficient), MAE (Mean Absolute Error), R^2 (Coefficient of Determination) and SSE (Sum od Squares Error) the monthly average for 21 years of the variables of average daily temperature at the height of 2 m and average daily wind speed at the height of 10 m in the region of the Tehran province for observation data (The location of observation stations is shown in Fig. 2) and the same variables from TerraClimate database (Table 2) was analyzed and reviewed, and the results of this review are shown in Table 3. The equations of these statistical indicators are shown in Eq. 1. MSE and R^2 are respectively square of RMSE and r indexes.

Table 2. Monthly average for 21 years (2001-2021) of the variables of average daily temperature at a height of 2 m and average daily wind speed at a height of 10 m in the region of the Tehran province from observation and TerraClimte data

Month	Mean_Temp_Observation (^{0}C)	Mean_Temp_TerraClimate (^{0}C)	Mean_Wind_Observation (m/s)	Mean_Wind_TerraClimate (m/s)
JAN	5/0	4/8	2/3	1/7
FEB	7/5	7/6	3/0	2/4
MAR	12/8	11/8	3/5	3/5
APR	17/8	16/3	3/5	3/2
MAY	23/7	21/9	3/8	3/4
JUN	29/4	27/3	3/4	3/6
JUL	31/7	30/3	3/2	3/7
AUG	30/5	28/9	2/8	3/1
SEP	26/6	24/9	2/7	2/9
OCT	19/9	18/9	2/5	2/5
NOV	11/4	11/5	2/2	2/1
DEC	6/5	6/2	2/0	1/6

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(T_i - O_i)^2}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}(\frac{O_i - T_i}{O_i})^2$$

$$r = \frac{\sum_{i=1}^{n}(T_i - \bar{T})(O_i - \bar{O})}{[\sum_{i=1}^{n}(T_i - \bar{T})^2]^{1/2}[\sum_{i=1}^{n}(O_i - \bar{O})^2]^{1/2}} \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|T_i - O_i|$$

$$SSE = \sum_{i=1}^{n}(T_i - O_i)^2$$

Where n is the number of stations, O_i is the Observation data value, and T_i is the TerraClimate data value.

Results and discussion

Evaluation results of TerraClimate data

In this research, considering investigating the effect of solar power plant construction on atmospheric variables and, due to the lack of observation data (monthly average temperature and wind speed variables near the ground surface inside and outside the power plant), the TerraClimate database has been used and according to this matter that the TerraClimate data are not observational data, these data were evaluated for the statistical period 2001 to 2021, and the results of this review are shown in Table 3, Which these results are telling good correlation and showing acceptable error.

Table 3. Results of evaluation the data extracted from the TerraClimate database in the statistical period from 2001 to 2021 (Table 2), using statistical indicators

Correlation and error coefficients	Mean_Temp	Mean_Wind
MAE	1/067	0/300
MSE	1/622	0/130
RMSE	1/273	0/361
MAPE	5/240	10/780
r(XY)	0/999	0/874
R^2	0/998	0/764
SSE	19/460	1/560

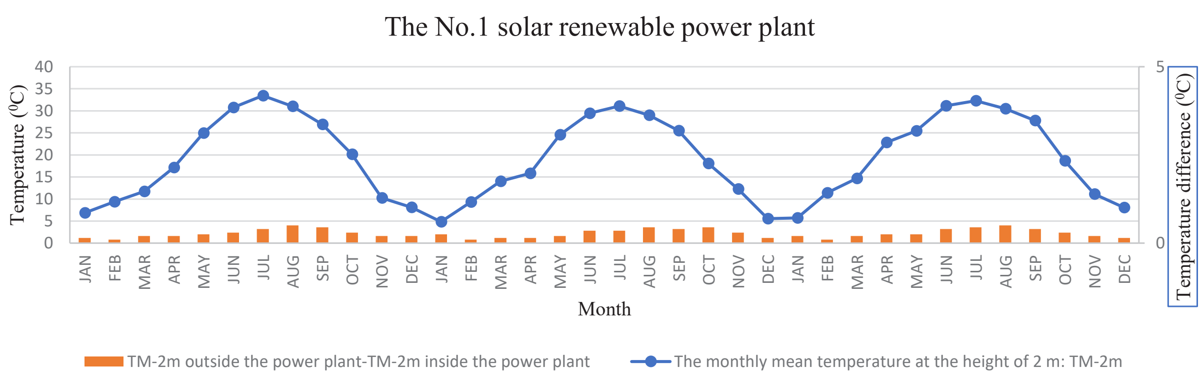

Fig. 5. Monthly average air temperatures at 2 m for the No.1 solar renewable power plant for the years 2020 and 2021

The function of balancing surface heat of the photovoltaic panel

The results of the average monthly temperatures at a level of 2 m inside and outside each of the three solar power plants in 2020 and 2021 are shown in the Figs. 5-7. The monthly average temperatures inside and outside the solar power plant No. 1 at the level of 2 m (Fig. 5) are 19.06 and 19.340C, respectively, which is a very significant difference ($p<0.01$). The average monthly temperature at the height of 2 m inside and outside this power plant has a significant positive correlation ($r=0.78$) with their average difference ($p<0.01$).

In solar power plant number 2, the monthly average temperature inside and outside the power plant at a height of 2 m (Fig. 6) is 18.4 and 18.010C, respectively, and this difference is very significant ($p<0.01$). The average monthly temperature at the height of 2 m inside and outside this power plant has a significant positive correlation ($r=0.86$) with their average difference ($p<0.01$).

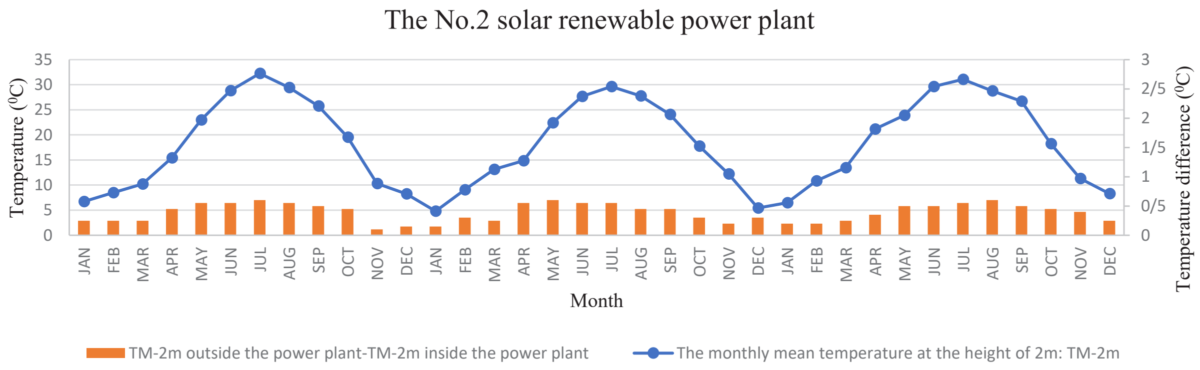

Fig. 6. Monthly average air temperature at the height of 2 m for the No.2 solar renewable power plant for the years 2020 and 2021

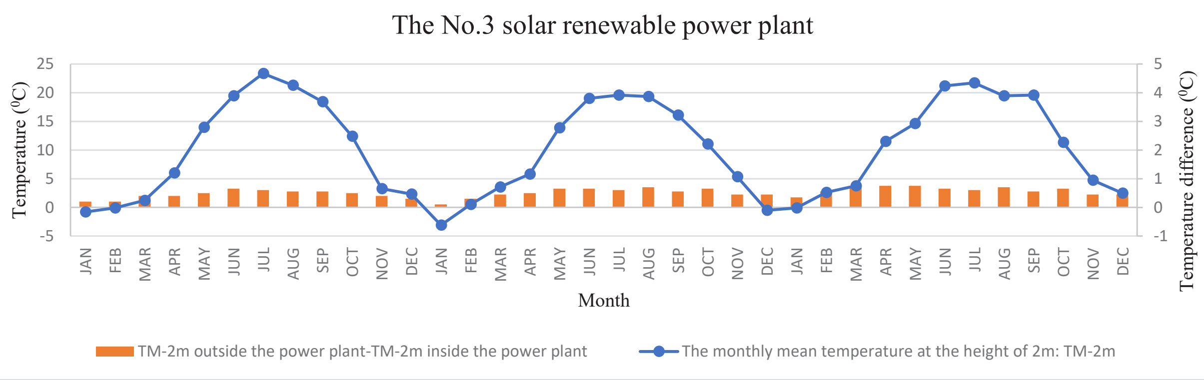

Fig. 7. Monthly average air temperature at the height of 2 m for the No.3 solar renewable power plant for the years 2020 and 2021

The monthly average temperature inside and outside solar power plant number 3 at 2 m (Fig. 7) are 10.2 and 10.70C, respectively, which shows a very significant difference ($p<0.01$). The average monthly temperature at 2 m inside and outside this power plant has a significant positive correlation ($r=0.72$) with the average monthly temperature difference at the same height inside and outside the power plant ($p<0.01$).

The function of the photovoltaic panel over monthly average wind speed and as a result reduce the possibility of a dust storm

In addition to converting solar radiation and balancing surface heat, photovoltaics reduce wind speed and stabilizes sand [11]. Therefore, in this research, the changes in the average wind speed value at the level of 10 m in the years of 2020 and 2021 inside the solar power plant have been investigated and compared to outside the plant. The results of this study are shown in Figs. 8 to 10. The average monthly wind speed at a height of 10 m inside solar power plant No. 1 is significantly lower than outside the power plant ($p<0.01$). The average monthly wind speed difference inside and outside power plant No. 1 is less than 0.24 m/s. The average monthly wind at the height of 10 m inside and outside this power plant has a significant positive correlation ($r=0.72$) with the average monthly average wind difference at the same height inside and outside the power plant ($p<0.01$) (Fig. 8).

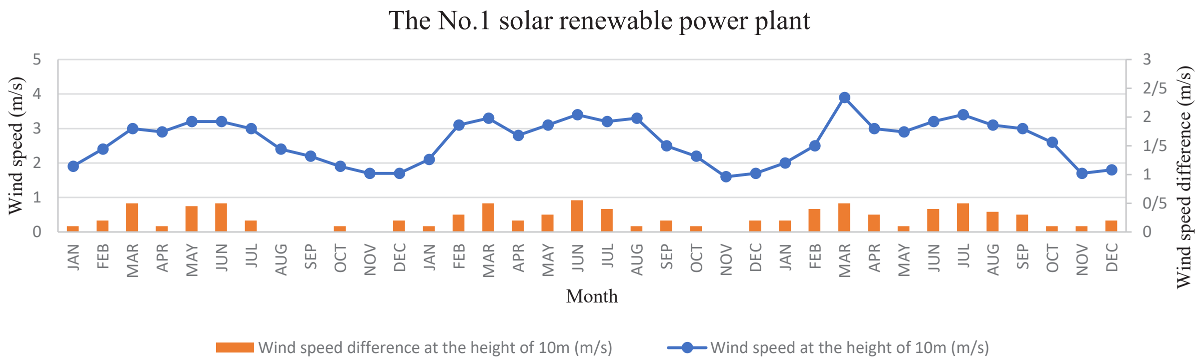

Fig. 8. Monthly average wind speed at the height of 10 m for the No.1 solar renewable power plant for the years 2020 and 2021

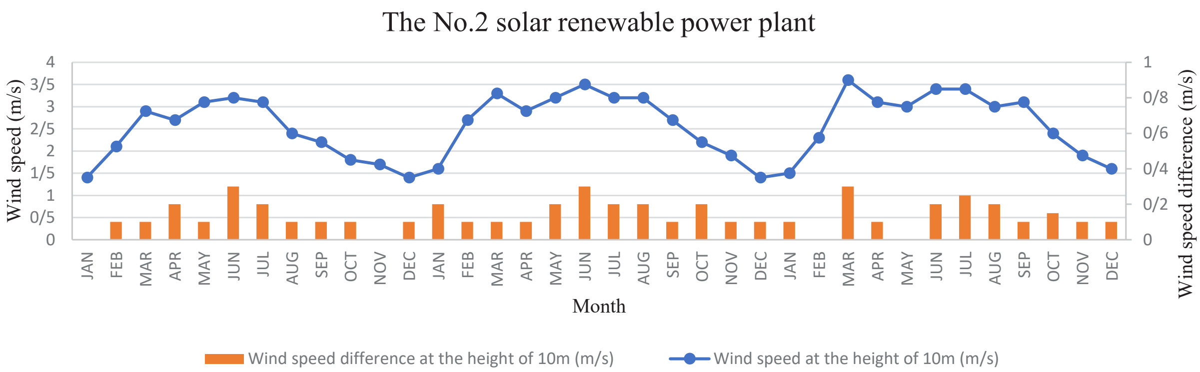

Fig. 9. Monthly average wind speed at the level of 10 m for the No.2 solar renewable power plant for the years 2020 and 2021

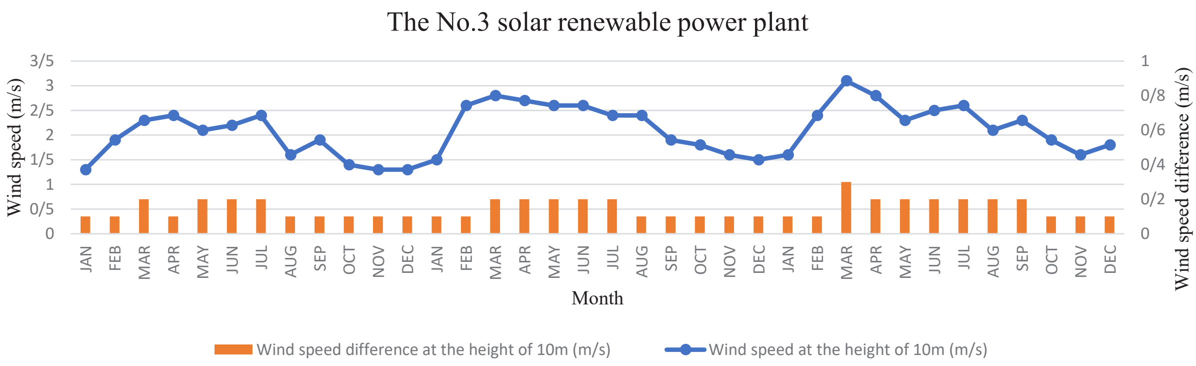

Fig. 10. Monthly average wind speed at the height of 10 m for the No.3 solar renewable power plant for the years 2020 and 2021

In Fig. 9, the trend of monthly average wind changes at the height of 10 m during the two years 2020 and 2021 inside and outside power plant No. 2 is shown. The results show that the average monthly wind speed at the height of 10 m inside solar power plant No. 2 is significantly lower than outside the power plant ($p<0.01$). The average monthly speed difference inside and outside this power plant is about 0.14 m/s. The average monthly wind at the height of 10 m inside and outside power plant No. 2 has a significant positive correlation ($r=0.55$) with the average monthly average wind difference at the same height inside and outside the power plant ($p<0.01$).

The average monthly wind speed at a height of 10 m outside solar power plant No. 3 is significantly higher than inside the power plant ($p<0.01$) (Fig. 10). The average wind speed difference inside and outside power plant No. 3 is less than 0.15 m/s. The average monthly wind speed at the height of 10 m inside and outside this power plant has a significant positive correlation ($r=0.75$) with the average monthly average wind difference at the same height inside and outside the power plant ($p<0.01$).

Conclusion

Photovoltaics in arid and semi-arid areas, which are vulnerable to dust storms, especially during the hot season, have a significant ecological purpose in preventing dust storms by converting solar radiation, regulating the thermal balance of the soil surface, and weakening the power of dust storms (i.e., wind). The development of the photovoltaic industry in arid and semi-arid regions not only has significant economic benefits but also has the ecological function of preventing and controlling soil on the surface and does not require the occupation of cultivated land. In the region of Tehran province, especially in the hot season, the number of dust storms increases due to strong convective motions and strong winds during the peak of heat in the afternoon. So, with the launching of a solar power plant, in addition to reducing electricity energy and water consumption during the peak, it is possible to reduce the probability of dust storms occurrence by reducing the temperature and because of convective motions and lowering the wind speed. In this study, to investigate the effect of solar power plant construction on atmospheric variables, due to the lack of atmospheric information inside and outside of the power plant because of the low density of the observation station (IRIMO), the information of monthly average temperature and wind speed variables near the ground surface (inside and outside the power plant) from TerraClimate data has been used for the last two years (2020 and 2021). Considering that the TerraClimate data are not observational data, in order to evaluate this database, several statistical parameters in the statistical period from 2001 to 2021 were used. The results of this section are telling good correlation and show an acceptable error. Examining the monthly average graphs of wind and temperature variables respectively at the height of 10 and 2 m shows the decrease of these variables inside of the power plant with respect to the outside of the power plant in the two years under study. Also, this study showed meaningful and significant differences between the monthly average of wind and temperature variables respectively at the height of 10 and 2 m inside and outside of the power plant. It is interesting to note that during the peak of heat, i.e., in the summer season, these differences increase with the increase in temperature.

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Competing interests
The authors declare that there are no competing interests.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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