Effect of desert photovoltaic on sand prevention and control—taking Gansu Gulang Zhenfa photovoltaic DC field as an example

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Abstract. In recent years, the photovoltaic industry in desert and Gobi has developed rapidly. In order to reveal the effect of photovoltaic industry on sand prevention and control, this study was performed by taking GuLang Zhenfa photovoltaic DC field on the southern edge of Tengger Desert as an example. Through continuous observation of air temperature, wind speed and air pressure inside and outside the photovoltaic field, combined with the investigation of vegetation inside and outside the photovoltaic field in desert and Gobi of the central and eastern part of Hexi Corridor, this study analyzed the ecological effect of photovoltaic industry on sand prevention and control from three aspects: the balance of surface heat by the transformation of solar radiation of desert photovoltaic, the function of wind barriers and sand barriers of the photovoltaic DC field, and the effect of the photovoltaic DC field on vegetation. The results showed that the photovoltaic DC field in desert and Gobi had very significant ecological functions for desert prevention and control, and the ecological functions were mainly as follows: 1) the photovoltaic DC field could effectively transform solar radiation, adjust the thermal balance of the desert, and weaken the power (i.e., the gale) for the occurrence and development of sandstorms and sand flow; 2) the photovoltaic panel had a strong function of wind barriers, and its function of wind-proof and sand-fixing were several times that of sand barriers; 3) the rain-collecting effect of photovoltaic panel could promote the growth of plants. The development of photovoltaic industry in desert and Gobi not only has remarkable economic benefits, but also has the ecological function of sand prevention and control. China has a vast area of desert and Gobi, and there are broad prospects for the development of desert and Gobi photovoltaic industry. The photovoltaic industry in desert and Gobi is expected to become the third new way of sand prevention and control after afforestation and desertification control and sand fixation by sand barriers.

1. Introduction
China has a vast area of desert and Gobi, especially in the northwest, where sandstorms are frequent and wind-blown sand flow is active, therefore, the task of sand prevention and control is quite arduous. The economic losses caused by wind and sand hazards in China amounts to 54 billion RMB per year [1]. China has made remarkable achievements in sand prevention and control since the 1950s. There are generally two kinds of measures for sand prevention and control, one of which is biological sand control (i.e., afforestation and desertification control). However, due to the drought in desert areas,
there are many trees planted but few survive, and the effect of sand control is not very significant. The other is sand fixation by sand barriers. Although there are many kinds of sand barriers, sand barriers can only fix sand on the spot, and the amount of sand accumulation is easy to be saturated, which can only cure the symptoms but not the root causes. There are also defensive measures (i.e., the delineation of closed areas for protection). These sand control measures are the achievements of the 1950s and 1960s, and for decades there has been no new breakthrough in the technical means of sand prevention and control and can not adapt to the serious trend of desertification [2].

The Hexi Corridor of Gansu Province is a sandstorm-prone area and a key wind-sand hazard area in China. The east, north and west of the Hexi Corridor are successively surrounded by the three major deserts of Tengger Desert, Badain Jaran Desert and Kumtag. The area of interior desert and sporadic sandy land is 7.54×10² km², and the area of Gobi is 8.55×10⁴ km² [3]. The Hexi Corridor is rich in solar energy resources, also known as the "Three Gorges on land". By the end of 2016, Wuwei, Jinchang, Zhangye, Jiuquan and Jiayuguan in Hexi region had established 18 photovoltaic industrial parks in desert and Gobi, with photovoltaic generating capacity capacity reaching 422.4×10⁴ kW, which is only less than the 580.4×10⁴ kW in Qinghai [4]. By March 2020, the photovoltaic power output of Gansu had reached 628.84×10⁴ kW, accounting for 36.3% of the total generating capacity output of the province [5].

However, up to now, there are many reports on the control of sandstorm and desertification [6-10] and the study of light energy resources and their utilization potential [3, 11-15], but there are no reports on the ecological effects of the photovoltaic DC field at home and abroad, let alone the ecological functions of desert and Gobi photovoltaic DC field. Similar to the ecological function of the photovoltaic DC field, one is that some scholars have pointed out that desert photovoltaic has a potential positive effect on the ecological environment in desert areas [16], and the other is that the development of the photovoltaic DC field is conducive to reducing thermal power plants (i.e., reducing CO₂ and dust emissions of thermal power plants [17]). In addition, there is a research report on the wind and sand prevention design for the protection of the photovoltaic DC field [18].

Sandstorm is the most typical form of desertification [19]. The driving force for the occurrence and development of sandstorms is the gale, which is caused by the imbalance of heat on the surface. Photovoltaic industry converts solar energy into electric energy. Theoretically, photovoltaic industry has the effect of reducing sandstorms and sandstorms. So, in what way does the photovoltaic industry reduce sandstorms and sand flow? What is the role of photovoltaic industry in reducing sandstorms and sand flow? The Hexi Corridor is a sandstorm-prone area and a wind energy resource area in China. The photovoltaic industry has already reached a certain scale. By the end of 2016, 18 desert and Gobi photovoltaic industrial parks had been built in the Hexi Corridor of Gansu Province (Figure 1), with 107 photovoltaic enterprises, of which GuLang Zhenfa photovoltaic DC field is located in a typical desert zone. In view of this, this study took GuLang Zhenfa photovoltaic DC field as an example to make a preliminary analysis for discussion.

2. Research methods

2.1. The region of study

Gansu Gulang Zhenfa photovoltaic DC field is located in Gulang County, southwest edge of Tengger Desert. The average annual precipitation is about 180 mm and the evaporation is about 2500 mm. The annual number of wind-blown sand days is more than 30 days, and the main wind direction is NW. The photovoltaic DC field is rectangular, with a length of 2700 m from north to south and a width of 1410 m from east to west. There is a distance of 120 m between the first stage field and the second stage field. The center position of the photovoltaic field is 37°45'50''N, 103°07'40''E. The west and south sides of 3 km are oases, and the east and north sides are deserts (Figure 1). The dunes around the photovoltaic DC field are 1.5 m-3.0 m high, and the main plants are *Nitraria tangutorum*, *Artemisia arenaria*, *Agriophyllum squarrosum*, *Phragmites communis*, *Agropyron cristatum*, etc., and the total vegetation coverage is 8%-10%.
The field of the first stage is 1500 m wide from east to west and 800 m long from north to south, in which the south end is a light tracking rotary photovoltaic panel with a north-south length of 156 m; the second stage is 1400 m wide from east to west and 1760 m long from north to south, and the south end is a light tracking rotary photovoltaic panel with a north-south length of 390 m. The photovoltaic panel is arranged horizontally facing the south, with the row spacing about 5 m and the height about 2.5 m (Figure 1). The inclination angle ranges from 35° to 45°, and the height is 30-50 cm from the ground.

Figure 1. Location map of Gulang Zhenfa photovoltaic DC field

2.2. Observation analysis methods

The observation instrument adopted the CYA (CMII METEOROLOGICAL) series of Changchun Institute of Meteorology. The observation instrument and observation height were the same in the photovoltaic DC field and outside the photovoltaic DC field. The measuring point in the field was set in the open position in the center of the first stage field, and the distance of the instrument to the photovoltaic panel in the east, south, west and north directions was 8 m, 10 m, 9 m and 16 m respectively. The No.1 measuring point outside the field was located at 300 m west of the photovoltaic DC field, and the No.2 measuring point outside the field was located at about 1000 m west of the photovoltaic DC field (Figure 1). The meteorological factors were observed by CYA automatic weather station of Changchun Institute of Meteorology. The observation of temperature and wind speed were at the height of 10 m and 2 m, and the observation of total solar radiation, air pressure and air humidity were at the height of 2 m. The data of China Meteorological Science Data Sharing Service Network were used for precipitation and evaporation in various parts of the Hexi Corridor.

The observation equipment at the measuring point inside the field and the No.1 measuring point outside the field were installed on April 16, 2018. Since there were only two sets of observation equipment, the instrument of the No.1 measuring point outside the field was moved to the location of the No.2 measuring point outside the field on April 24, 2019.

Each observation equipment automatically observed and recorded data every minute. The observation began on April 17, 2018, there were 20160 groups of observed data in that month, 40320 groups in February 2019, and 43200 (30 d) and 44640 (31 d) groups in other months.

The calculation formula for solar radiation conversion by the photovoltaic panel:

\[
V = \frac{3600 \times E}{e \times \pi \times d}
\]  

(1)
In the formula, \( V \) is the volume of air (m\(^3\)), \( E \) is the monthly generating capacity (kWh), 3600 is the conversion coefficient converted from kWh to kJ, \( c \) is the specific heat capacity of air (kJ·kg\(^{-1}\)·\(^\circ\)C\(^{-1}\)), \( \rho \) is the air density (kg·m\(^{-3}\)), \( t \) is the decrease of air temperature (\(^\circ\)C), \( d \) is the number of days of the month.

Photovoltaic generating capacity was provided by Zhenfa photovoltaic DC field. Since the observation began on April 17, 2018, the relevant meteorological data analysis used data from May and beyond. The data were analyzed by SPSS17.0, and the significance of difference was tested by T-test of paired samples.

3. The function of the photovoltaic panel to reduce sandstorms and sand flow

3.1. The function of balancing surface heat of the photovoltaic panel

The first stage field of Gulang Zhenfa Photovoltaic Field covers an area of 124.80×10\(^4\) m\(^2\), and the second stage field covers an area of 248.16×10\(^4\) m\(^2\). From April 2018 to October 2019, the cumulative generating capacity of the first and second stages of photovoltaic DC field was 33980.55×10\(^4\) kWh, of which the first stage field generated 11047.61×10\(^4\) kWh and the second stage field generated 22932.94×10\(^4\) kWh (Figure 2). From May 2018 to April 2019 (1 year), the generating capacity of the first stage field was 6953.86×10\(^4\) kWh, and the generating capacity of the second stage field was 13993.80×10\(^4\) kWh. On average, the annual generating capacity of the first stage field was 55.72 kWh·m\(^{-2}\), and that of the second stage field was 56.39 kWh·m\(^{-2}\) (i.e., the annual generating capacity per unit area was basically the same).

![Figure 2. Photovoltaic generating capacity in 2018.4-2019.10](image)

From May 2018 to October 2019, the monthly average temperature at the height of 2 m in the photovoltaic DC field was 11.11\(^\circ\)C, and that outside the field was 10.99\(^\circ\)C. The results of T-test of paired samples showed that the temperature in the field was significantly higher than that outside the field (\( P < 0.01 \), Figure 3), and the average monthly temperature was 0.12\(^\circ\)C higher than that outside the field. The monthly average temperature at the height of 10 m in the field was 11.27\(^\circ\)C, and that outside the field was 11.41\(^\circ\)C. The air temperature in the field was significantly lower than that outside the field (\( P < 0.01 \), Figure 4), and the monthly average temperature was 0.13\(^\circ\)C lower than that outside the field.

The monthly mean temperature in the field and outside the field at the height of 2 m was significantly negatively correlated with the monthly mean temperature difference at the same height inside and outside the field (\( P < 0.01 \)), i.e., in cold winter, the temperature in the field was lower than that outside the field, and the lower the temperature, the more obvious the difference. However, the temperature in the field was higher than that outside the field from May to September, and the higher the temperature, the more obvious the difference (Figure 3). The monthly mean temperature in the field and outside the
field at the height of 2 m was also significantly negatively correlated with the monthly mean temperature difference at the same height inside and outside the field \( (P<0.01) \), i.e., the temperature at the height of 10 m in the field was lower than that outside the field, and the lower the temperature, the more obvious the difference (Figure 4).

In view of the fact that two summers were included in the above analysis, further analysis of the data from May 2018 to April 2019 showed that the monthly average temperature inside and outside the field at the height of 2 m was 8.07°C and 8.02°C respectively, and the difference was not significant. The monthly mean temperature inside and outside the field at the height of 10 m was 8.40 and 8.57°C respectively, and the difference was extremely significant \( (P<0.01) \).

**Figure 3.** Air temperature at the height of 2 m

**Figure 4.** Air temperature at the height of 10 m

From May 2018 to April 2019, the generating capacity of Gansu Gulang Zhenfa photovoltaic DC field was 20947.66×10⁴ kWh, with a monthly average of 1745.64×10⁴ kWh. The temperature inside the field at a height of 10 m was 0.17°C lower than that outside the field. Under the condition that photovoltaic generating capacity reduced the air temperature by 0.2°C, 0.3°C, 0.5°C and 1.0°C respectively, the daily average cooling air volume obtained by formula (1) was shown in the table below (Table 1). As can be seen from Table 1, the solar radiation converted by the average daily generating capacity from May 2018 to April 2019 was equivalent to reducing 5.87 km³ of air by 0.2°C, or 1.17 km³ of air by 1.0°C.

**Table 1.** Daily cooling air volume in terms of generating capacity and different cooling ranges

| Year & month | 2018 | 2019 | Mean |
|--------------|------|------|------|
| Air 0.2°C    | 6.24 | 6.03 | 6.71 |
| Air 0.3°C    | 6.71 | 6.03 | 6.05 |
| Air 0.5°C    | 4.59 | 6.05 | 5.88 |
| Air 1.0°C    | 4.64 | 5.65 | 4.80 |
| Air 1.2°C    | 6.58 | 7.29 | 5.87 |
| Volume (km³) | 0.3℃ | 0.4℃ | 0.5℃ | 1.0℃ |
|-------------|-------|-------|-------|-------|
| 0.3℃        | 4.16  | 3.12  | 2.50  | 1.25  |
| 0.4℃        | 4.02  | 3.01  | 2.41  | 1.21  |
| 0.5℃        | 4.48  | 3.36  | 2.69  | 1.34  |
| 1.0℃        | 4.02  | 3.02  | 2.41  | 1.34  |

3.2. The function of the wind barriers of the photovoltaic panel

It is known that sand fixation by sand barriers is the second type of sand fixation after afforestation and desertification control [2, 20]. In addition to converting solar radiation and balancing surface heat, photovoltaic has the sand-fixing function of sand barriers.

From May 2018 to October 2019, the monthly average wind speed at the height of 2 m in the field was significantly lower than that outside the field ($P<0.01$), and the average wind speed was 0.71 m·s⁻¹ lower than that outside the field. The monthly mean wind speed at the height of 10 m in the field was also significantly lower than that outside the field ($P<0.01$), with an average lower of 0.30 m·s⁻¹. The wind speed difference between inside and outside the field decreased from 2 m to 10 m (Figure 5, Figure 6). Excluding repetitive months, the internal and external differences of the field at the height of 2 m and that at the height of 10 m were extremely significant from May 2018 to April 2019 ($P<0.01$).

The period from March to May every year is the high incidence season of sandstorms in Hexi Corridor, which gradually decreases forward and backward. As can be seen from figures 5 and 6, the local gale is also mainly distributed in this season. From March to May in 2019, the difference of wind speed at the height of 10 m inside and outside the field increased from 0.30 m·s⁻¹ to 0.40 m·s⁻¹, and the difference of wind speed at the height of 2 m inside and outside the field increased from 0.71 m·s⁻¹ to 0.83 m·s⁻¹. The results showed that the positive correlation between the monthly average wind speed at the height of 2 m inside the field and the wind speed difference at the same height inside and outside the field was extremely significant ($P<0.01$). The positive correlation between the monthly average wind speed at the height of 10 m outside the field and the wind speed difference at the same height inside and outside the field was significantly positively correlated ($P<0.01$). The monthly mean wind speed at the height of 10 m in the field was significantly positively correlated with the wind speed difference at the same height inside and outside the field ($P<0.01$). The wind speed difference at the height of 2 m inside and outside the field was significantly smaller than that at the height of 10 m ($P<0.01$, Figure 7 and Figure 8). Inside the photovoltaic DC field, the difference between the wind direction at the height of 2 m and that at the height of 10 m had no significant correlation with the wind direction at the height of 10 m ($P>0.05$), but had a very significant correlation with the wind direction at the height of 2 m (Figure 7, $P<0.01$). Outside the field, when the observation instrument was moved from the No.1 measuring point outside the field to the No.2 measuring point outside the field, there was little difference between the wind direction at the height of 2 m and that at the height of 10 m, and the average wind direction at the height of 2 m was 0.25° smaller than that at the height of 10 m from May to October 2019.
Figure 5. Wind speed at the height of 2 m

Figure 6. Wind speed at the height of 10 m

Figure 7. Wind direction in the photovoltaic DC field
3.3. The rain-collecting effect of photovoltaic panels

It is known that the Hexi Corridor is an arid area, and the western end of the corridor is an extremely arid area, with rare precipitation and strong evaporation (Figure 9). The gale is the driving force for the formation of sandstorm and sand flow, and the pressure gradient is the driving force for the formation of the gale. The pressure gradient is caused by the imbalance of surface heat. The greater the pressure gradient is, the greater the wind speed will be. When the gale passes through the dry and exposed sand surface, the sand grains will be blown up, resulting in a gale sandstorm [20].

Figure 8. Wind direction outside the photovoltaic DC field

Figure 9. Precipitation and evaporation in various regions of the Hexi Corridor

The specifications of solar photovoltaic panels are generally 158 cm×88 cm, and the inclination angle is generally 35°-45° (a light tracking rotary photovoltaic panel). If the average is calculated according to 40°, the projection area of each photovoltaic panel is 0.98 m². The row spacing of the photovoltaic panel is 4.5 m-5.5 m, and the average is calculated by 5.0 m, then the projection degree of the photovoltaic panel per unit area is 24.2%. After landing on the photovoltaic panel, rainwater will fall to the ground along the inclined panel, so that the soil moisture content under the photovoltaic panel along the 80 cm width of the ground is increased by 30%-60% (i.e., the photovoltaic panel forms a rain-collecting surface (Figure 10)). Under the inclined edge of the photovoltaic panel along the ground, not only the density and height are high, but also the plant diversity is obviously increased. According to the investigation of Gulang Zhenfa photovoltaic DC field, Minqin Huaneng photovoltaic DC field, Zhangye Jiaxun photovoltaic DC field and four photovoltaic DC fields in Suzhou district, the average height of plant in the photovoltaic DC field was
18.2 cm, which was 6.4 cm higher than that in the periphery of the photovoltaic DC field. The average plant coverage increased by 16.62%, which was 9.6% higher than that outside the field; the average projected coverage of vegetation was 10.3%, which was 7.0% higher than that outside the field; and 7.1 plant species were 3.6 more than those outside the field (Figure 10).

Figure 10. The function of rain collecting of the photovoltaic panel

4. Discussion
1) The ecological functions of photovoltaic in desert and Gobi for sand prevention and control: first, it can transform solar radiation, adjust the thermal balance of desert and Gobi area, and reduce the driving force for the occurrence and development of sandstorms and sand flow (i.e., gale); second, photovoltaic panels also have the role of sand barriers to prevent wind and sand; third, photovoltaic can collect rain and promote plant growth. From May 2018 to April 2019, the generating capacity of Gansu GuLang Zhenfa photovoltaic DC field was 20947.66×10^4 kWh. At the temperature of 10 m, the average temperature inside the photovoltaic DC field was 0.17°C lower than that outside the photovoltaic DC field. According to the temperature reduction of 0.2°C, 0.3°C and 0.5°C by photovoltaic generating capacity, the solar radiation converted by the average daily generating capacity from May 2018 to April 2019 was equivalent to 0.2°C reduction of 5.87 km³ air or 0.3°C reduction of 3.92 km³ air. Although from the point of view of a single photovoltaic DC field, the extent of converting solar radiation and reducing near-surface air temperature is very limited, desert photovoltaic has the function of balancing desert near-surface heat and improving desert ecological environment [16], which is undoubtedly a new way of sand prevention and control that can be further studied and utilized and this function has been shown in desert photovoltaic areas. With the further development of desert and Gobi photovoltaic, this function will be recognized by extensive people.

2) The height of photovoltaic is generally more than 2.5 m, while in the sandy area of Hexi Corridor, except for artificial Haloxylon ammodendron forest and Caragana korshinskii, the height of most desert vegetation is not more than 30 cm-50 cm. Therefore, the height of photovoltaic panels against wind is 5 times higher than that of vegetation, and the unit area silhouette is also significantly larger than that of plants [21]. The sand barriers used in the sand area of Hexi Corridor are firewood sand barrier and plastic net sand barrier, whose height is generally 30 cm. The height of photovoltaic panel is more than 8 times that of firewood sand barrier, plastic net sand barrier and clay sand barrier. Therefore, the function of both in-situ sand fixation and blocking cross-border quicksand is far greater than that of sand-fixing barrier. The role of the photovoltaic DC field in reducing wind speed comes from two aspects: one is that photovoltaic converts solar radiation, reduces air temperature, causes the difference of air pressure inside and outside the DC field, and the air flow changes and decelerates when it passes through the uneven pressure field; the second is the function of photovoltaic equipment in blocking air flow.

3) In the observation period, two time periods can be compared simultaneously (i.e., the No.1 measuring point from May to October 2018 at 300 m from the photovoltaic DC field, and the No.2
measuring point from May to October 2019 at 1000 m from the photovoltaic DC field (Figure 1, Figure 8). By comparing the difference between the two measuring points outside the field and the measuring point in the field, we can see that there was an extremely significant difference in the air temperature difference between them at the height of 2 m ($P<0.01$), but there was no significant difference in the temperature difference between them at the height of 10 m ($P>0.05$).

4) First, although the temperature difference between inside and outside the field in Figure 3 and Figure 4 was little, the monthly observation data of each index was more than 40,000. Even if the instrument may have observation errors, the results reflected by such a large number of observation samples (i.e., the differences in air temperature and wind speed inside and outside the photovoltaic DC field) are completely credible. Second, from Figure 3 to Figure 8, we can see that the seasonal distribution of temperature, wind speed and wind direction inside and outside the photovoltaic DC field were quite regular, and such a large sample size was enough to reduce the possible errors in observation accuracy.

5) Why was the temperature of the river at the height of 2 m higher inside the photovoltaic DC field than that outside the photovoltaic DC except winter (Figure 3)? The main reason was the shielding effect of photovoltaic panels and the blocking of gas exchange. The air flow always flows from the place where the temperature is low (high pressure) to the place where the temperature is high (low pressure). The solar radiation in winter is relatively small and the temperature is quite low. The temperature difference between inside and outside the photovoltaic DC field at the height of 2 m was little (Figure 3) and the wind speed was also relatively minimal (Figure 5). Besides, the shielding effect of the photovoltaic panel was relatively weak. In other seasons, the wind speed was larger. With the increase of wind speed, the shielding effect of photovoltaic panel was enhanced and the gas exchange inside and outside the photovoltaic DC field was seriously blocked. The effect of photovoltaic panel on air convection is greater than that on reducing air temperature. As can be seen from Figure 3, when the temperature at the height of 2 m exceeded 7°C, the temperature inside the photovoltaic DC field was higher than that outside the photovoltaic DC field. Some scholars have pointed out that desert photovoltaic DC field will produce "photovoltaic heat island effect" during the day [22].

6) China has a large area of desert and Gobi and is rich in light energy resources. The development of photovoltaic industry in desert and Gobi not only has remarkable economic benefits, but also has the auxiliary function of sand prevention and control. With the development of society, there is an increasing number of energy consumptions. Photovoltaic and wind energy are green energy and the development of desert and Gobi photovoltaic industry is the direction of green energy industry in the future. At present, countries all over the world attach great importance to the development of photovoltaic industry. It is believed that in the near future, the problems of "high cost, low conversion rate" and "difficulty in grid connection" of photovoltaic will be solved. At the same time, the conversion rate of photovoltaic will be greatly improved, and the function of desert photovoltaic to balance desert surface heat will be further improved.

5. Conclusions
Desert photovoltaic has the remarkable ecological function of sand prevention and control. The ecological function of desert photovoltaic for sand prevention and control is mainly manifested in three aspects: the first is to transform solar radiation, adjust the thermal balance of sand surface and weaken the power of sandstorm and sand flow (i.e., the gale); the second is the function of wind barriers and sand barriers, whose function of wind-proof and sand-fixing were several times that of sand barriers; the third is that the rain-collecting effect of photovoltaic panels can promote plant growth.

The development of desert photovoltaic industry not only has significant economic benefits, but also has the ecological function of sand prevention and control, and does not need to occupy cultivated land, which is conducive to the protection of the national cultivated land "red line". China has a vast area of desert and Gobi, and there are broad prospects for the development of desert and Gobi
photovoltaic industry. Desert photovoltaic industry is expected to become the third new way of sand prevention and control after afforestation and desertification control and sand fixation by sand barriers.

Acknowledgment
This work is supported by the General Program of National Natural Science Foundation of China (41671528) and Key R & D Projects in Gansu Province (17YF1WA155).

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