Observational Study on the Impact of Large-Scale Photovoltaic Development on Soil Temperature

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Abstract. The two-year observation data of the three monitoring stations inside and outside Qinghai Gonghe Photovoltaic power plant from January 2019 to December 2020 was compared to analyze the characteristics of soil temperature changes inside and outside the photovoltaic power plant. The results showed that the photovoltaic power plant had the function of heat insulation and heat preservation, and had a greater impact on shallow soil. Specifically speaking, the photovoltaic power plant is the cold source in spring, summer and autumn, and the cooling effect on soil is the strongest in spring; the station offers insulation to the soil, and the impact of the station on soil temperature decreases as the distance from the center of the photovoltaic station increases.

1. Introduction
At present, the global energy structure is undergoing tremendous changes. Traditional fossil energy is unsustainable with a limited reserve and can cause serious pollution, so our focus is shifted to clean, low-carbon and renewable energy. Among them, solar energy has developed rapidly due to its wide distribution, cleanliness, and convenient access [1-3]. According to statistics, photovoltaic power generation will account for 12% of global power generation in 2030, and 33% in 2050 [4]. As a large country in the photovoltaic industry, China has a market share of about 46%, our newly installed capacity has ranked first in the world for five consecutive years, and our cumulative installed capacity has ranked first for three years in a row [5-6]. Qing Hai province, which is rich in solar energy and land resources, plays an important role in China’s clean energy system and it is also a major base of new energy industry. By the end of 2017, the photovoltaic power generation capacity of Qinghai has ranked first in China, and the number of photovoltaic power plants has ranked second in China. In 2018, it achieved 216 hours of continuous clean energy for power supply and reduced energy emissions to zero. It is no wonder to say that “China’s photovoltaic technology holds a special place in the world, and Qinghai’s photovoltaic technology holds a special place in China” [7-9].

In the construction of large-scale photovoltaic power plants, photovoltaic panels convert part of the solar radiant energy into electrical energy, which changes the local surface energy distribution. In addition, the photovoltaic panels have a certain impact on soil characteristics by shading the soil [10-14]. Nowadays, some researchers have compared the soil inside and outside the photovoltaic power plant through on-site observations and model simulation methods [15] and analyzed the impact of large-scale photovoltaic stations on soil environment. Yang Liwei et al. [16], for example, conducted actual measurement and research on the soil temperature inside and outside Golmud photovoltaic power plant and drew the conclusion that photovoltaic power plants have the function of heat insulation and preservation, they are cold resources in winter, and that the daily average temperature of each layer...
inside the station is lower than that outside. Zhao Pengyu et al. \cite{17} compared and analyzed the soil temperature in different areas of the photovoltaic power plant in Chengkou County, and drew the conclusion that the temperature of the surface soil decreased because of the photovoltaic power plant. The studies of Yin Daiying et al. \cite{18} have shown that large-scale photovoltaic power plant had a cooling effect on the soil temperature in the desert area of Gonghe Basin. Zhou Maorong et al compared and analyzed the nutrients in the soil of the established photovoltaic power plants in the Gobi area of Hexi Corridor, Gansu Province, and drew the conclusion that the engineering disturbance of photovoltaic power plants had no obvious impact on soil nutrients. Li Shaohua et al. used the sample site survey method and found that the photovoltaic power plants could increase the water content, organic matters and total nitrogen of the soil.

Based on this, the Qinghai Gonghe Talatan photovoltaic power plant was selected as the research area, and three field ecological environment element monitoring stations were set up in the photovoltaic power plant, transition zone and outside the station. A comparative analysis was conducted on the data from January 2019 to December 2020 to study the impact of photovoltaic power plants on the soil temperature in desert areas and to access the characteristics of soil temperature changes at different time scales, which laid foundation for study of local ecological effects of large-scale desert photovoltaic development \cite{19-20}.

2. Research Area and Method

2.1 Overview of the research area

The research site is in Talatan Photovoltaic Power Park in Gonghe County, Qinghai Province (hereinafter referred to as Gonghe Photovoltaic power plant). The geographical location is shown in Figure 1 (East longitude 100°26′0.67″-100°38′51.52″, North latitude 36°0′0.07″-36°12′50.91″, altitude 2700-3028 m). The study area has a plateau continental climate, with an average annual temperature of 4.1 °C, and an annual precipitation of 246.3 mm, mainly from July to September. The average evaporation is 1716.7 mm, the annual average wind speed is about 2.5 m/s, and the average annual number of windy days is 17.7~43.2 d\cite{21}. The soil type of Tara Beach is dominated by chestnut soil, and the thickness of the soil development layer is generally between 50 and 70 cm \cite{22}.

2.2 Research Method

There are three monitoring stations in this experiment. The first monitoring station (Station No. 1 in the demonstration base, hereinafter referred to as Inside Station) is built in the operation area inside the photovoltaic power plant. The latitude of the Inside Station is 100.567° E, the latitude is 36.131° N, and the altitude is approximately 2913 m. The second monitoring station (Station No. 2 in the transition area, hereinafter referred to as Transition Station) is built in the planned construction area, in the transition zone from photovoltaic sub-array to desert area and in the southwest direction of the Inside Station at a distance of 6.65 km. The latitude of the Transition Station is 100.507° E, the latitude is 36.096° N, and the altitude is about 2924 m. The third monitoring station (Station No. 3 in the control area, hereinafter referred to as Outside Station) is built in the off-side control area outside the power station, and in the northwest direction of the Inside Station at a distance of 8.17 km. The longitude of the Outside Station is 100.509° E, the latitude is 36.187° E, the altitude is about 2922 m, and the underlying surface is desert. The instruments used in the three monitoring stations were the same, and the Hydra soil temperature sensors were adopted. The installation height of the soil temperature sensor at each monitoring station is 10 cm, 20 cm, and 40 cm below the ground surface. Data were collected synchronously with CR1000X data collector, and the data were recorded every 30 minutes. The data used inside the power station, in the transition area and outside the station were collected from January 2019 to December 2020, in which the annual average daily value is represented by a 24-hour daily change process composed of the arithmetic mean value of the corresponding daily time value of the year.
3. Results and Analysis

3.1 Daily changes of soil temperature
The annual average daily changes of soil temperature at different depths of the three monitoring stations inside the photovoltaic power plant, in the transition zone, and outside the power station are shown in Figure 2. As is shown, the daily changes of the soil temperature at the depth of 10 cm and 20 cm below the surface ground have a sinusoidal trend, and the daily change of the soil temperature at the depth of 40 cm below the surface ground approaches a straight line. The daily variation of soil temperature inside the station is slower than that in the transition zone and outside the station, and the daily maximum and minimum values appear later.
Figure 2. Daily changes of soil temperature at different depth below the surface ground in 2019 and 2020 of the three monitoring stations

The daily average soil temperature of the three monitoring stations is shown in Table 1. According to the table, the soil temperature at all layers inside the station is lower than that in the transition area and outside the station, which can be contributed to the fact that the operation of photovoltaic power plant has changed the energy distribution on the ground and that the photovoltaic panels cover a large area of land. Therefore, the construction of photovoltaic power plant can reduce soil temperature and has a more obvious effect on shallow soil.

Table 1. Daily average soil temperature at different depth below surface ground of the three monitoring stations

| Monitoring station                  | Daily average soil temperature |            |            |            |            |            |
|------------------------------------|--------------------------------|------------|------------|------------|------------|------------|
|                                    | 10 cm                          | 20 cm      | 40 cm      | 2019       | 2020       | 2019       | 2020       |
| Inside Station                     | 6.42                           | 6.40       | 6.34       | 6.35       | 6.47       | 6.51       |
| Transition Station                 | 10.40                          | 10.27      | 10.33      | 10.24      | 9.82       | 9.78       |
| Outside Station                    | 9.85                           | 9.74       | 9.66       | 9.58       | 9.38       | 9.34       |
| Inside Station–Transition Station  | -3.98                          | -3.87      | -3.99      | -3.89      | -3.35      | -3.27      |
| Inside Station–Outside Station     | -3.43                          | -3.34      | -3.32      | -3.23      | -2.91      | -2.83      |

3.2 Annual changes of soil temperature

The annual changes and differences of soil temperature at different depths of the monitoring stations inside the photovoltaic power plant, in the transition zone and outside the power station are shown in Figure 3. The annual change trend of the soil temperature in the three monitoring stations are basically the same, showing a unimodal curve. The soil temperature at the depth of 10 cm and 20 cm below the surface ground at the Inside Station from March to October in 2019 and from March to October in 2020 is significantly lower than that in the Transition Station and Outside Station, indicating soil temperature
is reduced to some extend because of the construction of photovoltaic power plant. The reason is that photovoltaic power plant reduces the solar radiation received by the ground inside the station, which in turn reduces the soil temperature. The soil temperature at the depth of 10 cm below surface ground at the Inside Station from November to December, from January to February in 2019 and from November to December, from January to February in 2020 is higher than that at the Transition Station and Outside Station, which may be due to the insulation effect of photovoltaic panels.

Figure 3. Annual changes of soil temperature at different depths at the three monitoring stations

The annual difference in soil temperature refers to the difference between the average temperature of the hottest month and the average temperature of the coldest month in a year [19]. Table 2 shows that the annual difference in soil temperature at the depth of 10 cm is the largest, followed by 20 cm, and the smallest is at 40 cm, that is, the annual soil temperature difference at the three monitoring stations decreases with the increase of depths, which is related to the energy transfer of various layers of the soil caused by the annual change of solar radiation. The annual difference of soil temperature in each layer inside the station is significantly lower than that in the transition zone and outside the station, which is mainly due to the fact that the photovoltaic power plant has a heat preservation effect in the cold season and heat insulation effect in the warm season, resulting in a decrease in the annual temperature difference inside the station. The effect is more obvious in shallow layer.

Table 2. Annual soil temperature difference at different depths at the three monitoring stations

| Monitoring station       | Annual soil temperature difference |
|--------------------------|------------------------------------|
|                          | 10 cm 2019 2020 | 20 cm 2019 2020 | 40 cm 2019 2020 |
| Inside Station           | 18.62 17.18     | 17.99 16.80     | 17.47 16.59     |
| Transition Station       | 25.70 26.44     | 24.53 24.53     | 22.47 22.47     |
| Outside Station          | 25.68 24.23     | 22.37 21.42     | 20.10 18.94     |
3.3 Vertical change characteristics of soil temperature

Due to the exchange of heat in the soil layers at different depths, the soil temperature has certain characteristics in the vertical distribution. Figure 4 shows the vertical changes of soil temperature at the three monitoring stations in the four seasons in 2019 and 2020. According to the figure, the vertical changes of soil temperature at the three monitoring stations are similar. In spring and summer, as the depth increases, the soil temperature drops and energy is released from the top soil to the deep soil. In autumn and winter, as the depth increases, the soil temperature rises, and energy is released from the deep soil to the shallow soil [19]. Among them, the vertical transmission gradient of the soil temperature inside the photovoltaic power plant is weaker than that in the transition zone and outside the station, that is, the vertical change of the soil temperature in the station is smaller.

Figure 4. Average seasonal changes of soil temperature at different depths at the three monitoring stations

Figure 5 shows the vertical changes of the soil temperature difference at the three monitoring sites in 2019 and 2020. According to the figure, the soil temperature at the three monitoring stations differs greatly in spring and summer, followed by winter, and the temperature difference is the smallest in autumn. In spring, summer and autumn, the soil temperature difference between the Inside Station and
the Transition Station (the average soil temperature inside the station minus the average soil temperature in the transition area) and the soil temperature difference between the Inside Station and Outside Station (the average soil temperature inside the station minus the average soil temperature outside the station) are below 0℃, which means the soil temperature at all layers inside the station is lower than that in the Transition Station and Outside Station. In winter, the soil temperature difference between the Inside Station and the Transition Station and the soil temperature difference between the Inside Station and Outside Station are above 0℃, which means the soil temperature at all layers inside the station is higher than that in the Transition Station and Outside Station, and the soil temperature difference at the Inside Station and Transition Station is larger than that at Outside Station. It can be concluded that the photovoltaic power plant is a cold source in spring, summer and autumn, and the cooling effect on soil is the strongest in spring, and weakest in autumn. This is mainly because that photovoltaic power plants convert solar radiant energy into electrical energy, which reduces the solar radiation received by the ground surface, thereby reducing the heat transmitted downward. As the distance from the photovoltaic center increases, the cooling effect decreases. In winter photovoltaic power plants increase the temperature of the soil in winter, which is probably because the heating effect of the photovoltaic panels is more obvious in winter and the panels have insulation function by covering the ground surface. As the distance from the photovoltaic increases, the insulation effect decreases. Therefore, the photovoltaic power plant has played a role in insulation and heat preservation of the soil.

![Figure 5. Average seasonal soil temperature difference changes at different depths at the three monitoring stations](image)

Figure 5. Average seasonal soil temperature difference changes at different depths at the three monitoring stations
4. Conclusions
(1) The soil temperature at the Inside Station is lower than that at the Transition Station and Outside Station. In 2019, the photovoltaic power plant reduced the average temperature of the soil at the depth of 10 cm, 20 cm, and 40 cm by 34.82%, 34.34%, and 31.05% respectively; in 2020, the photovoltaic power plant reduced the average temperature of the soil at the depth of 10 cm, 20 cm, and 40 cm by 34.30%, 33.71% and 30.32% respectively.

(2) The monthly average temperature of the soil at the depth of 10 cm, 20 cm, and 40 cm at the Inside Station is significantly lower than that at the Transition Station and Outside Station from March to October. The annual soil temperature difference of different soil layers at the Inside Station is lower than that at the Transition Station and Outside Station.

(3) The vertical changes of the soil temperature at the Inside Station, Transition Station and Outside Station are similar, and the vertical gradient of soil temperature in summer and autumn is smaller. In spring, summer and autumn, photovoltaic power plants are cold sources. In winter, photovoltaic power plants have a certain thermal insulation effect on the soil.

In this research, we only conducted two years of field monitoring experiment, but the impact of large-scale photovoltaic power plants on the environment is a slowly changing process. In addition, the impact of photovoltaic power plants on soil temperature can be different in different regions and based on different underlying surface characteristics. Therefore, long-term observations are needed to study the impact of the construction of photovoltaic power plants on soil temperature in desert areas.

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