

## ORIGINAL RESEARCH ARTICLE

# Analysis and evaluation of solar energy resource change characteristics in the Wanshan Island area

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## ABSTRACT

The total solar radiation and insolation hours in Wanshan Island were analyzed by linear regression analysis, distance level analysis method, 5-year sliding average method, and Mann-Kendall test method. The results showed that the total solar radiation in Wanshan Island showed a slight upward trend, and the total monthly solar radiation showed a unimodal distribution, with the highest in July and the lowest in February. The number of annual sunshine hours showed a weak downward trend, and the number of monthly sunshine hours showed a double-peak distribution, with the highest in July and the lowest in March. The analysis and evaluation of solar energy resources in the Wanshan Island area show that the annual average of total solar radiation in the Wanshan Island area is 4,996.25 MJ/m<sup>2</sup>, belonging to a resource-rich area. The indicator of the stability of solar energy resources is 3.7, which belongs to the resources of more stable areas.

**Keywords:** Total Solar Radiation; Hours of Sunshine; Solar Energy Resources; Wanshan Island

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## 1. Introduction

Since entering the 21<sup>st</sup> century, China's energy system is changing into a modern energy structure that is economical, efficient, clean, diversified, and safe and has gradually entered a stage of sustainable development, green and low-carbon energy development<sup>[1]</sup>. With unlimited reserves and ubiquitous properties, and its use has the advantages of cleanliness and economy, solar energy is internationally recognized as one of the most competitive future energy sources<sup>[2]</sup>, and is also an important part of distributed energy resources.

At present, solar photovoltaic power generation technology has matured and has been widely used worldwide<sup>[3]</sup>, and the primary task of photovoltaic power plants is to analyze and grasp the characteristics of local solar resource changes.

In this paper, the total solar radiation and sunshine hours of the Wanshan Island area are analyzed and studied, which provides a reference for the development and utilization of solar energy resources on the island and related scientific research<sup>[4,5]</sup>.

## 2. Data selection and analysis methods

The Wanshan Island area has a subtropical oceanic climate with no severe cold in winter and abundant rainfall. Solar radiation observations are carried out at the Tai Tam Shan Meteorological Station in Macau,

which is located at a longitude of 113°33' east, the latitude of 22°09' north, and altitude of 110 m.

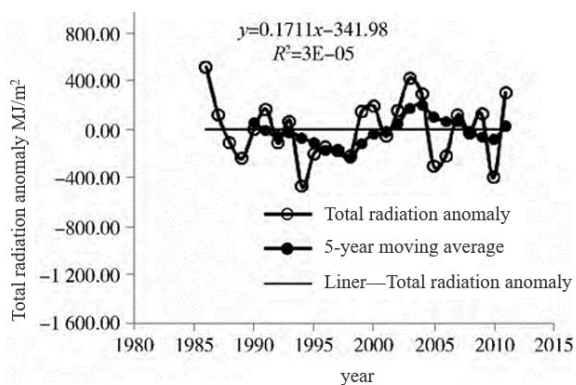
The main data in this paper are the total solar radiation of the Tai Tam Shan Meteorological Station from 1986 to 2011 and the monthly sunshine hours from 1981 to 2011 (the meteorological data in this article are from the Macao Geophysical and Meteorological Bureau).

Firstly, the linear regression analysis and distance analysis method were used to analyze the trend of total solar radiation and insolation hours in the region, and then the multi-year change characteristics of total solar radiation and sunshine hours in the region were verified and analyzed by the 5-year moving average method and the Mann-Kendall (M-K) rank correlation test. Finally, according to the solar resource assessment method, the solar energy resources in the Wanshan Island area are evaluated<sup>[6]</sup>.

### 3. Characteristics of the change in total solar radiation

#### 3.1 Analysis of inter-annual changes

Statistical analysis of the total solar radiation data in the Wanshan Island area from 1986 to 2011 shows that the total solar radiation average in the Wanshan Island area in the past 26 years is 4,996.25 MJ/m<sup>2</sup>, of which the highest value appeared in 1986 at 5,512.70 MJ/m<sup>2</sup> and the lowest value appeared in 1994 as 4,526.44 MJ/m<sup>2</sup>. The interannual variation of total solar radiation in the Wanshan Island area is shown in **Figure 1**.

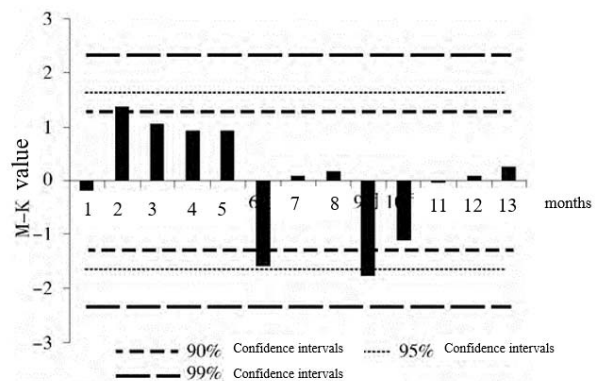


**Figure 1.** Annual variations of global solar radiation in Wanshan Islands area.

From **Figure 1**, it can be seen that: (1) The total solar radiation in the Wanshan Island area is in a

weak upward trend, with an increase of only 1.711 MJ/m<sup>2</sup>/10a; (2) From the 5-year sliding average to the parity, there was a clear downward trend before the end of the 1990s, and then recovered in the late 1990s, which is basically consistent with the trend of total solar radiation in South China<sup>[7]</sup>, also in line with the climatic background of “global dimming” to “global lighting” in this period<sup>[8]</sup>; Since the beginning of this century, the total annual solar radiation has shown a state of fluctuation up and down, but the magnitude of the rise is slightly greater than the magnitude of the decline; (3) From the perspective of total solar radiation in different eras, the period in the late 1980s belonged to the high-value zone, which was higher than the multi-year average; In contrast, the total solar radiation in the 1990s was lower than the multi-year average; Since the beginning of this century, total solar radiation has rebounded, slightly above the multi-year average.

The sequence of total solar radiation in the Wanshan Island area was tested using the M-K method, and the results are shown in **Figure 2**.



**Figure 2.** M-K statistics test value of global solar irradiance at different periods in Wanshan Islands area.

From **Figure 2**, it can be seen that the M-K test value of total solar radiation in the Wanshan Island area in recent decades is greater than zero, indicating that the total radiation in the region is on the rise, but it has not passed the significance confidence test. The M-K test value for January-6-September-October is less than zero, indicating that the total radiation in these four months is on a downward trend. The total radiation series in June passed the 90% significance confidence test, and the September total radiation series passed the 95%

significance confidence test; The M-K test for the remaining months of total radiation is greater than zero, showing an upward trend, with the February total radiation series passing the 90% significance confidence test and the remaining months total radiation series failing the significance test.

### 3.2 Analysis of intra-year changes

Figure 3 shows the characteristics of the annual change in the multi-year average total solar radiation in the Wanshan Island area from 1986 to 2011.

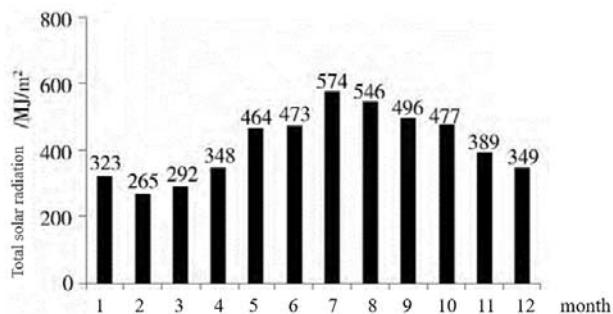


Figure 3. Monthly variations of global solar irradiance in Wanshan Islands area.

From Figure 3, it can be seen that the intra-year change of total solar radiation is monomodal, with the highest in July and the second highest in August; February low, March second low; The highest value reaches 574.47 MJ/m<sup>2</sup> with a minimum value of just 265.16 MJ/m<sup>2</sup>. This is related to the inter-month differences in astronomical radiation and precipitation characteristics in the Wanshan Island Area<sup>[7]</sup>: the maximum total astronomical radiation in this area occurs in June and the minimum value occurs at February 1<sup>st</sup>; However, due to the large number of rainy days in June, the total radiation reaching the ground is weakened, and July is controlled by subtropical high pressure, the number of rainy days is less than that of June, but the total astronomical radiation in July is second only to June in the whole year, so the total solar radiation in July is the highest throughout the year; Similarly, although the total astronomical radiation in February is less than that in February, because February is in the winter-spring transition season, the cold air in the north that frequently moves south and the warm and humid air flow of the ocean actively up the north confronts the region, resulting in

a high number of days of low temperature and rainy weather and less sunshine time, so that the total solar radiation from February to the ground is the lowest in the whole year.

## 4. Characteristics of changes in sunshine hours

### 4.1 Analysis of inter-annual changes

Statistical analysis of the sunshine hours in the Wanshan Island area from 1981 to 2011 shows that the average annual sunshine hours in the Wanshan Island area in the past 31 years have been as long as 1,766.5 h; The maximum number of sunshine hours for the year appeared in 1986 and was 2,081.4 h, the minimum value appeared in 2006, it is 1,542.8 h. The interannual variation in sunshine hours in the Wanshan Island area is shown in Figure 4.

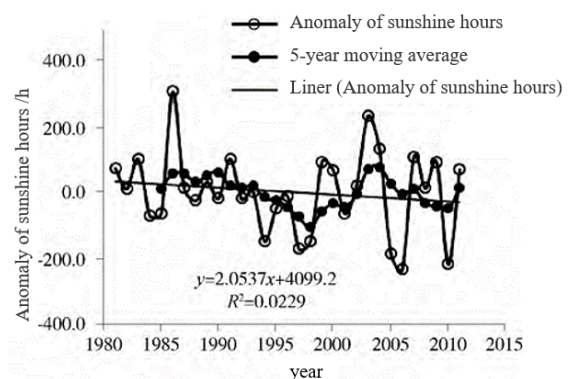


Figure 4. Annual variations of sunshine duration in Wanshan Islands area.

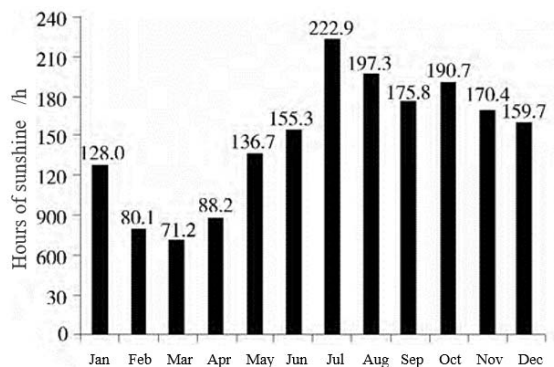
It can be seen from the figure: (1) The trend of sunshine hours in the Wanshan Island area is opposite to the total radiation change trend, showing a downward trend, with a decrease of 20 h/10 a; (2) From the perspective of the 5-year sliding average of the sunshine hours in previous years, before the end of the 1990s, the annual sunshine hours in the Wanshan Island area generally showed a large downward trend; Since the end of the 1990s, the number of sunshine hours has shown a short-lived, large upward trend; Since the beginning of this century, the annual sunshine hours have shown an upward and downward fluctuation state, but the amplitude is large; (3) Judging from the number of sunshine hours in different years, the end of the 1980s was a high value area of sunshine hours, which was higher than the multi-year average; The

1990s were low in sunshine hours, below the multi-year average; Since the beginning of this century, the average annual sunshine hours have been slightly lower than the average sunshine hours for many years. This is basically consistent with the results of the literature<sup>[9-13]</sup> of domestic scholars.

The M-K method test for the number of annual sunshine hours and the number of sunshine hours for each month in the Wanshan Island area is shown in **Figure 5**. It can be seen from the figure that the M-K test value of the number of sunshine hours in recent decades in the Wanshan Island area is less than zero, indicating that the trend of sunshine hours is decreasing, but it has not passed the significance confidence test. However, the change trend of each month is different, and the M-K test value from February to May and August is greater than zero, indicating that the trend of the number of sunshine hours in these 5 months is rising; The M-K test values for the remaining months are less than zero, indicating that the trend in the number of hours of sunshine for the remaining 7 months is decreasing. In terms of significance confidence tests, only 95% of the significance confidence tests passed in February and June, and none of the remaining 10 months passed the significance tests.

#### 4.2 Analysis of intra-year changes

**Figure 5** shows the characteristics of the multi-year average sunshine hours and years of change in the Wanshan Island area from 1981 to 2011.



**Figure 5.** Monthly variations of sunshine duration in Wanshan Islands area.

It can be seen from the figure that the variation of the number of insolation hours in the Wanshan Island area during the year is large, showing a bimodal distribution, with two peaks appearing in

July and October, and two valley values appearing in March and September, respectively. The longest number of hours of sunshine is in July, with hours of sunshine at 222.9 h, followed by August with sunshine hours of 197.3 h; The shortest number of sunshine hours is in March, with 71 hours of sunshine. 2 h, followed by February, with sunshine hours of 80.1 h. The difference between the longest and shortest months of sunshine hours is 157.1 h.

### 5. Solar resource assessment

The richness and stability of solar energy resources are used to evaluate solar energy resources at different levels.

#### 5.1 Solar resource richness assessment

The abundance of solar energy resources is measured by the total annual solar radiation<sup>[14]</sup>, which is divided into four levels according to the resource situation, as shown in **Table 1**.

**Table 1.** Richness grade of solar energy resources

Total annual solar radiation MJ/m <sup>2</sup> /a	Richness
T1 ≥ 6,300	Most resourceful
5,040 ≤ T1 ≤ 6,300	Very resourceful
3,780 ≤ T1 ≤ 5,040	Resourceful
T1 < 3,780	Resources in general

Note: T1—Annual solar radiation per year.

According to the statistics of the total solar radiation data of the Wanshan Island area for many years, the annual average annual average of total solar radiation in the area is 4,996.25 MJ/m<sup>2</sup>, which belongs to the resource-rich area.

#### 5.2 Solar resource stability assessment

The stability of solar resources is expressed in K, the ratio of the maximum to a minimum number of days greater than 6 h per month<sup>[14]</sup>, and its rank is shown in **Table 2**.

**Table 2.** Steady grade of solar energy resources.

Stability indicator	Degree of stability
<2	Stable resources
2—4	Resources are relatively stable
>4	Resource instability

From the statistics of the monthly sunshine hours greater than 6 h days in the Wanshan Island area over the years: the average number of days with more than 6 h in the region for many years is 160 d, accounting for 43.8%; Among them, July has

the most servings, reaching 19.7 d; March minimum, only 5.5 d; The difference between the two reaches 12.2 d. The multi-year average K value in the Wanshan Island area is 3.6, according to the stability level classification in **Table 2**, this area belongs to the area with more stable resources.

## 6. Conclusion

1) The total solar radiation in the Wanshan Island area showed a weak interannual upward trend, but failed the significance confidence test, and the increase was only 1.711 MJ/m<sup>2</sup>/10 a; Total solar radiation varies undrilled during the year, peaking in July and lowest in February.

2) The number of sunshine hours in the Wanshan Island area showed a slight interannual downward trend, but failed the significance confidence test, and the decrease was 20 h/10 a; Sunshine hours vary bimodal over several years, with the largest in July and the smallest in March.

3) The solar energy resources in the Wanshan Island area are abundant and stable, and the total solar radiation has risen in recent years, which is beneficial to the development and utilization of solar energy in the region.

4) Similar to the previous research results, the trend of sunshine hours in the Wanshan Island area is decreasing; The trend of total solar radiation change in the Wanshan Island area is rising. It is generally believed that the factors that affect the total solar radiation and sunshine hours are mainly meteorological factors (such as cloud cover, precipitation, etc.) and environmental factors (such as aerosols, etc.). Especially since the beginning of the 21<sup>st</sup> century, the phenomenon of haze across the country has become increasingly serious, and the transparency of the atmosphere has continued to decline, resulting in a decrease in the number of sunshine hours, which should also affect the total solar radiation that is closely related to it. The author's analysis believes that this result is closely related to aerosol particulate matter, aerosol particulate matter may reduce direct solar radiation, but at the same time may increase scattered radiation, resulting in the total solar radiation composed of the sum of the above two parts is not significantly reduced. However, the degree and mechanism of the

influence of various factors on the total solar radiation are not very clear at present, and relevant analysis and calculations need to be carried out in future studies.

## Conflict of interest

The authors declared that they have no conflict of interest.

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