Suggestions for development of solar photovoltaic power generation projects in Guangdong Province

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Abstract. In this paper, the solar energy resources in Guangdong Province are divided into three categories according to the development and utilization value, and the development and evaluation of distributed photovoltaic projects and grid-connected photovoltaic projects are carried out for each region. According to the calculation results and sensitivity analysis, the development and evaluation suggestions for photovoltaic power generation projects in Guangdong Province are obtain.

1. Introduction
Guangdong Province is located between 20°13'~25°31' north latitude and 109°39′~117°19' east longitude, the solar energy resources are relatively rich in China. The annual irradiation hours are about 2000 hours, and the total annual radiation amount is 3760-5100MJ/m².¹ Guangdong Province is a pioneer in photovoltaic power generation in China. In 2004, a demonstration system of 1 MW grid-connected roof photovoltaic power generation with the largest installed capacity in Asia was built in Shenzhen. But in recent years, compared with other provinces, the development is relatively lagging behind. Based on the analysis of solar energy resources in different regions of Guangdong Province and the calculation of the power generation projects, this paper gives suggestions for the development of photovoltaic power generation projects in different regions of Guangdong Province.

2. Division of Light Resources in Guangdong Province
In terms of geographical distribution, the solar energy resources in Guangdong Province are higher in the South and lower in the north. The southern part belongs to the third type of solar energy resources in China,² mainly in the coastal areas of eastern and Western Guangdong, mainly in Shanwei, Jieyang, Shantou, Chaohou, Zhanjiang and Yangjiang. The annual sunshine hours are 2200-3000 hours, and the annual solar radiation is 4600-5300MJ/m² per square metre. The other parts of Guangdong Province belong to the fourth type of solar energy resources, mainly in the Pearl River Delta and northern mountainous areas, with the annual sunshine hours. The number is 1400-2200 hours, and the solar radiation is 4200-5000MJ/m² per square meter per year.³ The spatial distribution of annual total solar radiation in Guangdong Province is shown in Fig. 1.

According to the value of utilization, the solar energy resources in Guangdong Province are divided into three categories: I -level available area, II -level available area and III-level available area.
Fig 1  Distribution Map of Solar Energy Annual Total Radiation in Guangdong Province

I-level available area. In the southern part of Guangdong Province, the coastal areas of eastern and Western Guangdong are dominant. The cities are Shanwei and Yangjiang. The solar radiation is 4800-5100 MJ/m².

II-level available Area. It covers most parts of Guangdong Province. The main cities are Maoming, Zhanjiang, Shenzhen, Chaozhou, Jieyang, Shantou, Jiangmen, Zhongshan, Zhuhai, Yunfu, Heyuan, Huizhou, Meizhou, Qingyuan, Foshan, Guangzhou, Dongguan and Zhaoqing. The solar radiation is 4300-4700MJ/m².

III-level available Area. The main mountainous area in northern Guangdong is Shaoguan City. The solar radiation is only about 4000MJ/m².

3. Evaluation of Solar Photovoltaic Power Projects

3.1. Calculating method of photovoltaic project

In photovoltaic power generation system, the annual equivalent utilization hours of the system h is calculated as follows:

\[
h = \frac{M \times \eta}{3.6 \times e}\tag{1}
\]

In the formula (1), M represents the annual solar radiation intensity under the optimal dip angle, calculated by RETScreen; \( \eta \) represents System comprehensive utilization efficiency; \( e \) represents the Standard irradiance, the value is 1000W / m².

The annual power generation amount of the system \( W \) is calculated as:

\[
W = D \times e \times h \times \eta_s\tag{2}
\]

In the formula (2), D represents the installed capacity of the system; \( \eta_s \) represents the System attenuation coefficient.

3.2. Evaluation of Solar Photovoltaic Power Projects in I-level available area

Divided from the administrative area of Guangdong Province, the major cities in the I-level available area include Shanwei and Yangjiang City. Taking Yangjiang City as the representative city, the boundary conditions are as follows:

1) The overall efficiency of the fixed polycrystalline silicon battery array system is 81%;
2) The operation period of the photovoltaic power generation system is 20 years;
3) 20-year system output attenuation of 15.2%;
4) Taking 10 MWp photovoltaic power plant as an example.

The calculation of photovoltaic system in Yangjiang City is shown in Table 1.

Table 1 Calculating Table of Power Generation for I-level Available Regional Photovoltaic System

| Year | Emutation Coefficient | Yangjiang Annual power generation | Annual Equivalent Utilization Hours |
|------|-----------------------|-----------------------------------|-----------------------------------|
| 1    | 0.996                 | 1122.81                           | 1118.32                           |
| 2    | 0.988                 | 1109.33                           | 1109.33                           |
| 3    | 0.98                  | 1100.35                           | 1100.35                           |
| 4    | 0.972                 | 1091.37                           | 1091.37                           |
| 5    | 0.964                 | 1082.39                           | 1082.39                           |
| 6    | 0.956                 | 1073.40                           | 1073.40                           |
| 7    | 0.948                 | 1064.42                           | 1064.42                           |
| 8    | 0.94                  | 1055.44                           | 1055.44                           |
| 9    | 0.932                 | 1046.46                           | 1046.46                           |
| 10   | 0.924                 | 1037.47                           | 1037.47                           |
| 11   | 0.916                 | 1028.49                           | 1028.49                           |
| 12   | 0.908                 | 1019.51                           | 1019.51                           |
| 13   | 0.9                   | 1010.53                           | 1010.53                           |
| 14   | 0.892                 | 1001.54                           | 1001.54                           |
| 15   | 0.884                 | 992.56                            | 992.56                            |
| 16   | 0.876                 | 983.58                            | 983.58                            |
| 17   | 0.868                 | 974.60                            | 974.60                            |
| 18   | 0.86                  | 965.61                            | 965.61                            |
| 19   | 0.852                 | 956.63                            | 956.63                            |
| 20   | 0.844                 | 947.65                            | 947.65                            |
| Total|                       | 20664.13                          | 20659.64                          |
| Average|                     | 1033.21                           | 1032.98                           |

For distributed photovoltaic power plants with 10 MWp installed capacity, the static investment of the project is based on 80 million yuan, and the boundary conditions are as follows:[4]

1) Self-use of electricity is the main method. The proportion of self-use is 70% when calculating, and the remaining 30% of electricity is connected to the internet.
2) User's electricity price is 0.819 yuan/kWh.
3) The local desulfurization benchmark price is 0.453 yuan/kWh.
4) State financial subsidy of 0.42 yuan/kWh for 20 years

For the 10 MWp installed capacity grid-connected photovoltaic power station, the static investment of the project is based on 82 million yuan, and all the electricity is connected to the grid.

The financial evaluation results of the I-level photovoltaic power generation projects that can be developed on behalf of the cities in the region are shown in Table 2.

From the calculation, it can be seen that under the current electricity price policy, the rate of return of the 1-level regional development of distributed photovoltaic power generation projects is higher, and the internal rate of return of the project's own capital is 10.82%, but the rate of return on investment of the development of grid-connected photovoltaic projects is lower. Distributed photovoltaic power generation projects which has a higher ability to cope with the increase of cost and the reduction of electricity price, can be developed in the 1-level available area. To develop grid-connected distributed photovoltaic power generation, it is necessary to optimize the design of the project, or further reduce the cost and reduce the development cost of the project.
### Table 2: Financial Evaluation Table for Photovoltaic Projects of I-level Available Area

| Number | Project Name (Unit) | Yangjiang Distributed Photovoltaic Project | Grid-connected Photovoltaic Project |
|--------|---------------------|-------------------------------------------|-------------------------------------|
| 1      | Installation capacity (MW) | 10 | 10 |
| 2      | Total investment (million) | 8614.7 | 8861.1 |
| 3      | Interest during construction period (million) | 211.39 | 216.91 |
| 4      | Liquidity (million) | 403.31 | 444.19 |
| 5      | Total sales revenue (excluding VAT) (million) | 19106.09 | 17657.85 |
| 6      | Total cost (million) | 14229.42 | 15432.39 |
| 7      | Total Sales Tax Added (million) | 237.62 | 210.82 |
| 8      | Total profit of power generation (million) | 4639.05 | 2014.64 |
| 9      | Average Electricity Price in Business Period (excluding VAT) (RMB/kWh) | 0.9248 | 0.8547 |
| 10     | Average Electricity Price in Business Period (Including VAT) (RMB/kWh) | 1.082 | 1 |
| 11     | Payback period of investment (before income tax) (year) | 9.89 | 11.84 |
| 12     | Payback period (year after income tax) | 11.59 | 13.57 |
| 13     | Internal Return Rate of Owned Funds (%) | 10.32 | 3.88 |

### Table 3: Calculating Table of Power Generation for II-level Available Regional Photovoltaic System

| Year | Emulation Coefficient | Zhanjiang | Guangzhou |
|------|-----------------------|-----------|-----------|
|      |                       | Annual power generation | Annual Equivalent Utilization Hours | Annual power generation | Annual Equivalent Utilization Hours |
| 1    | 0.996                 | 1066.11   | 1061.84   | 1015.68   | 1011.62   |
| 2    | 0.988                 | 1053.31   | 1053.31   | 1003.49   | 1003.49   |
| 3    | 0.98                  | 1044.79   | 1044.79   | 995.37    | 995.37    |
| 4    | 0.972                 | 1036.26   | 1036.26   | 987.24    | 987.24    |
| 5    | 0.964                 | 1027.73   | 1027.73   | 979.12    | 979.12    |
| 6    | 0.956                 | 1019.20   | 1019.20   | 970.99    | 970.99    |
| 7    | 0.948                 | 1010.67   | 1010.67   | 962.87    | 962.87    |
| 8    | 0.94                  | 1002.14   | 1002.14   | 954.74    | 954.74    |
| 9    | 0.932                 | 993.61    | 993.61    | 946.61    | 946.61    |
| 10   | 0.924                 | 985.08    | 985.08    | 938.49    | 938.49    |
| 11   | 0.916                 | 976.55    | 976.55    | 930.36    | 930.36    |
| 12   | 0.908                 | 968.03    | 968.03    | 922.24    | 922.24    |
| 13   | 0.9                   | 959.50    | 959.50    | 914.11    | 914.11    |
| 14   | 0.892                 | 950.97    | 950.97    | 905.99    | 905.99    |
| 15   | 0.884                 | 942.44    | 942.44    | 897.86    | 897.86    |
| 16   | 0.876                 | 933.91    | 933.91    | 889.74    | 889.74    |
| 17   | 0.868                 | 925.38    | 925.38    | 881.61    | 881.61    |

3.3. Evaluation of Solar Photovoltaic Power Projects in II-level available area

According to the administrative division of Guangdong Province, the second level available areas mainly include Maoming, Zhanjiang, Shenzhen, Chaozhou, Jieyang, Shantou, Jiangmen, Zhongshan, Zhuhai, Yunfu, Heyuan, Huizhou, Meizhou, Qingyuan, Foshan, Guangzhou, Dongguan and Zhaoqing. Taking Zhanjiang and Guangzhou as representative cities, the boundary conditions are the same as 3.2, and the calculation of photovoltaic system in II-level available area is shown in Table 3.
Because of the poor economy of the development of grid-connected photovoltaic projects in I-level available area, the economic performance of grid-connected photovoltaic projects in II-level available area is bound to be worse than that I-level available area. The development of distributed photovoltaic power generation projects is mainly measured in II-level available area. The boundary conditions are the same as 3.2. The results of financial evaluation are shown in table 4.

### Table 4 Financial Evaluation for distributed Photovoltaic Projects of II-level Available Area

| Number | Project Name (Unit) | Zhanjiang | Guangzhou |
|--------|---------------------|-----------|------------|
| 1      | Installation capacity (MW) | 10        | 10         |
| 2      | Total investment (million) | 8594.14   | 8620.31    |
| 3      | Interest during construction period (million) | 211.23    | 211.43     |
| 4      | Liquidity (million) | 382.91    | 408.88     |
| 5      | Total sales revenue (excluding VAT) (million) | 18139.14  | 19081.48   |
| 6      | Total cost (million) | 14225.37  | 14228.14   |
| 7      | Total Sales Tax Added (million) | 221.19    | 237.21     |
| 8      | Total profit of power generation (million) | 3692.59   | 4616.13    |
| 9      | Average Electricity Price in Business Period (excluding VAT) (RMB/kWh) | 0.9247    | 1.021      |
| 10     | Average Electricity Price in Business Period (Including VAT) (RMB/kWh) | 1.0819    | 1.1946     |
| 11     | Payback period of investment (before income tax) (year) | 10.49     | 9.48       |
| 12     | Payback period (year after income tax) | 12.2      | 11.16      |
| 13     | Internal Return Rate of Owned Funds (%) | 7.9       | 11.42      |

It can be seen that under the existing electricity price policy conditions, Guangzhou, Dongguan, Foshan, Zhuhai and Shenzhen are more developed and have higher electricity prices in the second-level region of Guangdong Province. According to the calculation, these cities in Guangdong Province have a higher rate of return for developing distributed photovoltaic power generation projects, which can be used to develop distributed photovoltaic power generation projects; however, in Shantou, Chaozhou, Jieyang and Yangjiang, the development of distributed photovoltaic power generation projects can be carried out. Zhanjiang, Maoming, Zhaoqing and other cities have lower electricity prices. According to the calculation, the yield of developing distributed photovoltaic projects in this city is relatively low, and the ability to resist risks is poor, so the project can be reserved according to the actual situation. In Yunfu, Heyuan, Meizhou, Qingyuan and other cities where the electricity price is lower, the development of distributed photovoltaic has poor returns and is not yet ready for development. [5]

### 3.4. Evaluation of Solar Photovoltaic Power Projects in III-level available area

The III-level available area solar energy utilization areas in Guangdong Province are mainly mountainous areas in the north of Guangdong Province, Shaoguan, with a longitude of 24.8 and latitude of 113.59. Because the level of light resources in these areas is the worst, the income of developing photovoltaic projects is necessarily worse than that in II-level available area, so no detailed calculation is made here. It is not recommended to develop photovoltaic power generation projects in the solar energy resource-poor areas of Guangdong Province.
4. Conclusions
The calculation and analysis in this paper show that under the existing conditions, Guangdong Province is not suitable for the development of grid-connected photovoltaic projects, but if it can further reduce development costs and improve efficiency, grid-connected photovoltaic projects can be developed in areas with better solar resources and higher electricity prices. For distributed photovoltaic projects, the Ⅰ-level of solar energy resources available area and the Ⅱ-level of high electricity price available area in Guangdong Province have higher benefits for developing photovoltaic projects. It is suggested that priority should be given to developing photovoltaic projects where conditions are ripe in the region. For other Ⅱ-level available areas and areas where solar energy resources are poor, the conditions for developing photovoltaic power projects are not available at this stage. The photovoltaic power generation project can be developed when the conditions are ripe. It is not recommended to develop photovoltaic power generation projects in the solar energy resource-poor areas of Guangdong Province.

References
[1] Department of Science and Education, Guangdong Provinical Department of Construction. Investigation Report on Development and Utilization of Solar Energy in Guangdong Province [J]. Construction Supervision, Inspection and Cost, 2008,1(2): 64-66.
[2] Wu Zhenxia, Li Peng. Thoughts on the Development and Utilization of Solar Energy in the Construction Field of South Guangdong Province [J]. Residential Science and Technology, 2008, 04:13-16.
[3] Guangdong Development and Reform Commission. Guangdong Solar Photovoltaic Power Development Plan (2014-2020) [EB/OL]. http://www.gddrc.gov.cn/zwgk/zcwj/gfxwj/201501/t20150128_422441.shtml, 2014-8-20.
[4] Ministry of Construction, National Development and Reform Commission. Economic Evaluation Method and Parameters of Construction Projects [M]. China Planning Publishing House: Beijing, 2006:10.
[5] Liu Shijun. Research on Industrial Strategy of Solar Energy Development and Utilization in Guangdong Province [D]. Changsha, Hunan: Central South University, 2002.