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To cite this article: Dong Huang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **227** 022019

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Analysis of solar energy potentials at Nansha Guangzhou

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Abstract. The increasing energy supply is believed to exceed the capacity of three existing thermal power plants at Nansha Guangzhou for the rapid development. Thus constructing an eco-friendly energy structure will be one of the main themes during the region planning in near future. In this study, solar energy resources were assessed theoretically and simulated by PVsyst, PVGIS, Global Solar Atlas, RETScreen and SSE Release 6.0 as well. It drew a conclusion that from 2010 to 2014, sun exposure hour percentage averaged at 41.28% and demonstrated prominent higher from June to November, solar radiation was extremely stable and extremely abundant in this area. Furthermore, simulation results of horizontal irradiation carried out by SSE Release 6.0, PVsyst (based on NASA-SSE) and Global Solar Atlas were much similar, averaged at 3.93 kWh/m²/day; results provided by Global Solar Atlas (4.01 kWh/m²/day) were more visualized and representative if thinking about the latest database. For another, results calculated by PVGIS (4.22 kWh/m²/day) were relatively higher, and that of Meteornorm 6.1 (3.50 kWh/m²/day) were relatively conservative. In conclusion, it's feasible to offer stable solar energy supply at Nansha Guangzhou especially in summer and autumn.

1. Research background and significance

Nansha(NS) is planned as China(Guangdong) Pilot Free Trade Zone since Dec.28th, 2014, covering an area of 783.86 km²[1]. The GDP growth at NS caused an average annual total electricity consumption growth rate of 22.44% from 2005 to 2014 [2], which was believed to exceed the capacity of three existing thermal power plants in the near future.

So constructing a more proper and eco-friendly energy structure would be one of the main themes during the region planning in this area. According to the research based on 50 years' statistics (1961 to 2011) of total solar radiation and sun exposure hours at Guangzhou Meteorological Station from LIU Aijun [3], solar energy was extremely abundant at Guangzhou (at an average of 4279.58 MJ/m² per year). In this study, solar energy resources were assessed more accurately at NS(22.8016°N, 113.5252°E, in the southernmost of Guangzhou), which was likely to show more potentials in this district, aiming to help the local exploitation and utilization of renewable energy.

2. Methodologies

Solar energy can be assessed by Table 1 and Table 2 [4]. Simplified diagram of solar energy measurement is shown in Figure 1 [1].

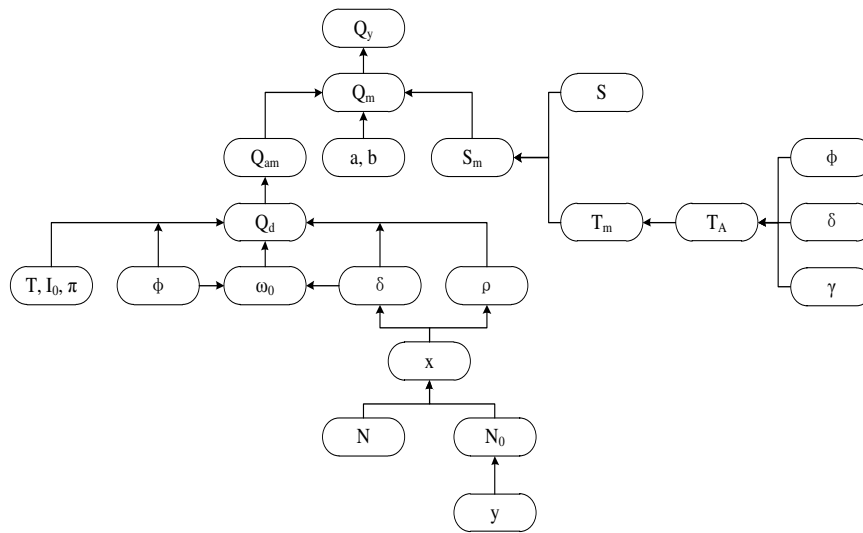


Table 1. Solar energy abundance level.

Amount of Solar Radiation Q_y (MJ/m ² per year)	Level
≥ 6300	Extremely abundant
$5040 \leq Q_y < 6300$	Abundant
$3780 \leq Q_y < 5040$	Available
< 3780	General

Table 2. Solar energy stability level.

K	Level
< 2	Extremely stable
$2 < K < 4$	Stable
> 4	Unstable

**Figure 1.** Simplified diagram of solar energy measurement.

Q_y can be assessed by:

$$Q_y = \sum_{m=1}^{12} Q_m \quad (1)$$

where,

Q_y : annual solar radiation (MJ/m²).

Q_m : monthly solar radiation (MJ/m²), can be figured by:

$$Q_m = Q_{am}(a + bS_m) \quad (2)$$

where,

a, b: empirical coefficients, were valued as 0.1963 and 0.5345 respectively in this study [5].

S_m : monthly sun exposure percentage, can be calculated by equation (9).

Q_{am} : astronomical monthly solar radiation (MJ/m²), can be superposed by Q_d (MJ/m²), which is the daily astronomical solar radiation, can be calculated by:

$$Q_d = \frac{TI_0}{\pi\rho^2} (\omega_0 \sin \phi \sin \delta + \cos \phi \cos \delta \sin \omega_0) \quad (3)$$

where,

T: 1440 mins per day.

I_0 : solar constant, 0.0820 MJ/(m²·min).

ρ : constant of earth-sun distance, can be figured out by equation (7).

ϕ : latitude, is valued as 0.397963 rad at NS.

δ : solar declination(rad), can be figured out by equation (4).

ω_0 : sunset angle(rad), can be figured out by equation (8).

$$\delta = 0.0174533 \times (-0.1712 \sin 3x + 0.1149 \sin 2x + 23.2567 \sin x + 0.3723 + 0.0201 \cos 3x + 0.3656 \cos 2x - 0.7580 \cos x) \quad (4)$$

where,

x: procedure parameter which can be figured out by:

$$x = 2\pi \times (N - N_0) / 365.2422 \quad (5)$$

where,

N: Range from 1 to 365 or 366. For instance, N of Jan. 1st is 1.

N₀: procedure parameter which can be figured out by:

$$N_0 = 79.6764 + 0.2422(y - 1985) - \text{int}[0.25 \times (y - 1985)] \quad (6)$$

where,

y: target year of the assessment, such as 2014.

int: integer conversion.

Constant of earth-sun distance ρ can be calculated by:

$$\rho^2 = 1.000423 + 0.032359 \sin x + 0.000086 \sin 2x - 0.008349 \cos x + 0.000115 \cos 2x \quad (7)$$

ω_0 can be calculated by [6]:

$$\omega_0 = \arccos(-\tan \phi \tan \delta) \quad (8)$$

Monthly sun exposure percentage can be calculated by:

$$S_m = \text{int}\left(\frac{S}{T_m}\right) \times 100\% \quad (9)$$

where,

S: monthly sun exposure hours practically.

T_m: available monthly sun exposure hours, can be figured out by:

$$T_m = \sum_{A=1}^B T_A \quad (10)$$

where,

B: number of days in the appointed month for calculation.

T_A: available daily sun exposure hours, can be figured out by:

$$\sin \frac{T_A}{4} = \sqrt{\frac{\sin(45^\circ + \frac{\phi - \delta + \gamma}{2}) \sin(45^\circ - \frac{\phi - \delta - \gamma}{2})}{\cos \phi \cos \delta}} \quad (11)$$

where,

γ : astronomical refraction, is valued as 0.0098902 rad in this study[1].

Besides, K can be calculated by the following equation:

$$K = \frac{\max(D_1, D_2, \dots, D_{12})}{\min(D_1, D_2, \dots, D_{12})} \quad (12)$$

where,

D₁, D₂, ...D₁₂: number of days with more than six hours sun exposure practically in each month.

3. Assessment results

The assessment was based on practical monthly sun exposure hours from 2010 to 2014 provided by National Bureau of Statistics of China. As presented in Figure 2, sun exposure hours percentage averaged at 41.28% in these five years and demonstrated prominent higher in summer and autumn (526.06 hrs and 519.58 hrs on average respectively, from June to November). Similarly, according to the assessment results demonstrated in Figure 3, solar radiation showed more potential in these six

months (averaged at 2789.90 MJ/m^2) and the annual one amounted to $8089.65 \text{ MJ/m}^2/\text{year}$ from 2010 to 2014. Otherwise, solar energy stability index was averaged at 1.17 as shown in Table 3. With respect to Table 1 and Table 2, solar energy was extremely stable and extremely abundant at NS. In conclusion, it's feasible to offer stable solar energy supply in the whole year especially from June to November at Nansha Guangzhou.

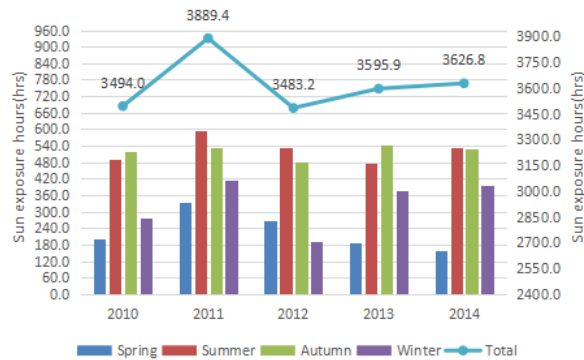


Figure 2. Sun exposure hours from 2010 to 2014.

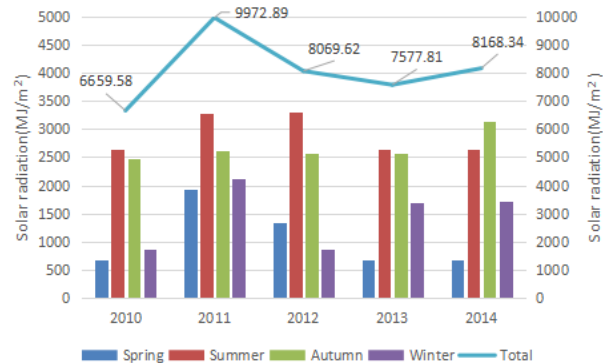


Figure 3. Solar radiation from 2010 to 2014.

Table 3. Monthly solar radiation and stability of solar energy from 2010 to 2014.

		2010	2011	2012	2013	2014	Average
Amount of Solar Radiation (MJ/m^2)	Jan.	155.27	577.49	154.97	578.66	1000.92	493.46
	Feb.	162.31	603.45	168.13	162.55	162.33	251.75
	Mar.	208.02	207.81	208.47	208.26	208.05	208.12
	Apr.	222.58	828.17	222.85	222.72	222.60	343.78
	May	241.05	897.21	897.79	241.11	241.06	503.64
	June	236.07	878.87	878.87	878.88	878.87	750.31
	July	899.27	899.42	1556.44	899.10	899.25	1030.70
	Aug.	1500.52	1501.18	865.84	866.23	866.61	1120.08
	Sept.	774.82	1342.64	773.44	774.09	1341.37	1001.27
	Oct.	702.63	703.47	1213.40	1214.86	1216.33	1010.14
	Nov.	1008.41	583.09	581.03	581.69	582.34	667.31
	Dec.	548.63	950.09	548.39	949.66	548.61	709.08
K		1.10	1.26	1.20	1.15	1.13	1.17

Nevertheless, above theoretical assessment results were based on total astronomical irradiation, which were incapable of reflecting the actual irradiation arrived on the ground surface due to the effect of air mass. Then PVGIS, PVsyst, RETScreen and other tools were utilized to simulate amount of irradiation based on five different databases for higher accuracy compared with theoretical results. Crucial parameters in different softwares and tools were defined in Table 4.

According to Table 5, results simulated by SSE Release 6.0, PVsyst (based on NASA-SSE) and Global Solar Atlas were demonstrated high similarity. If thinking about the latest database, results figured out by Global Solar Atlas were more representative and visualized as shown in Figure 4. For another, Meteonorm 6.1 could provide records of wider period, which were relatively more complete and accurate, being utilized extensively in the pre-sizing steps of preliminary design of photovoltaic systems. Simulation based on Meteonorm 6.1 showed conservative results like that carried out by RETScreen, but relatively more convincing for the reason that RETScreen was more suitable for economic analysis rather than doing resource potentials assessment. Nevertheless, PVGIS could provide assessment reports quickly but roughly, containing summaries listed in Figure 5, Figure 6 and

Table 6, which were helpful at the beginning of preliminary siting. In conclusion, it's possible to offer stable solar power supply during the whole year especially from June to November in this area.

Table 4. Crucial parameters definition of PV systems in different softwares/ tools.

Software/ Tool	System Specification	Module Efficiency	Nominal Power	Tilt (optimized)	Azimuth (optimized)
PVsyst	Standard, polycrystalline, flat roof, fixed, ventilated	13.0%	1.0 kWp	21°	South
NASA Surface Meteorology	-----	-----	-----	22°	-----
PVGIS	Crystalline silicon, fixed, building integrated	14.0%	1.0 kWp	21°	South
Global Solar Atlas (Owned by the World Bank Group)	Small residential, fixed	-----	1.0 kWp	19°	South

Table 5. Results of solar energy assessment carried out by different softwares/ tools.

Software/ Tool	Database	Periods of the Records	Horizontal Irradiation (kWh/m ² /day)	Irradiation on Tilted Plane (kWh/m ² /day)
PVsyst	Meteonorm 6.1	1981 to 1990 1991 to 2010	3.50	3.70
PVsyst	NASA-SSE	1983 to 2005	3.90	4.20
RETScreen	Ground stations and NASA's satellite/----- analysis data		3.13	-----
SSE Release 6.0	NASA-SSE	1983 to 2005	3.87	4.12
PVGIS	Climate-SAF PVGIS	1996 to 2005(30%) 2007 to 2013(70%)	4.22	4.41
Global Solar Atlas (Owned by The World Bank Group)	Solargis	2007 to 2015	4.01	4.17

Table 6. Results of utilizing different PV systems in PVGIS.

Type of the System	Orientation	Inclination	Annual Average of Daily Electricity Production from the Given System (kWh/m ² /day)	Annual Average of Global Irradiation Amount Received by the Modules of the Given System (kWh/m ² /day)
Fixed System	0	21°	3.03	4.41
Vertical Axis Tracking System		1°	2.94	4.26
Inclined Axis Tracking System	---	21°	3.57	5.14
Two-axis Tracking System		---	3.65	5.40

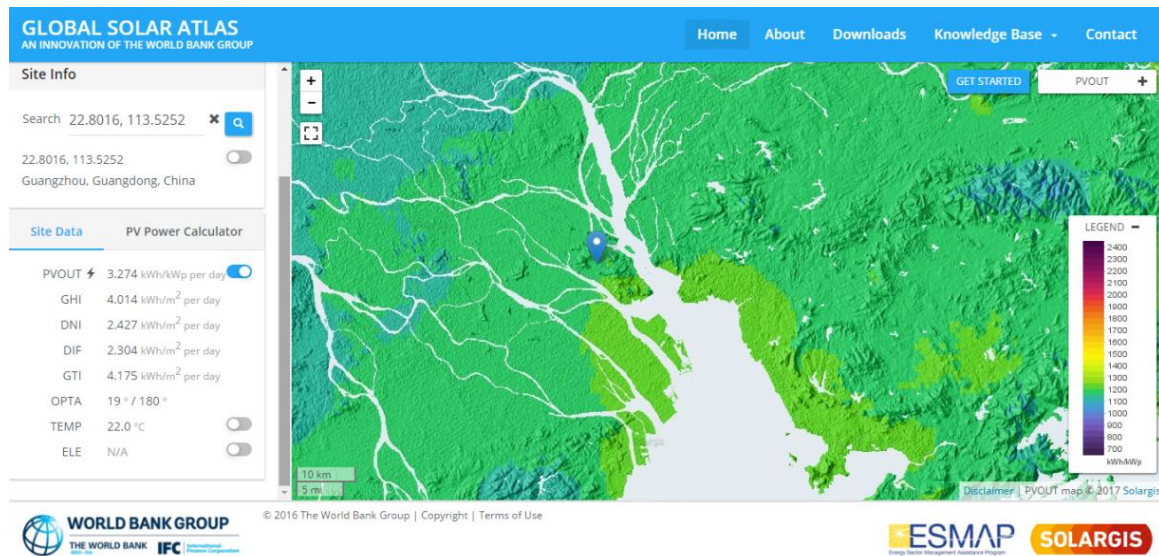


Figure 4. Simulation results carried out by Global Solar Atlas.

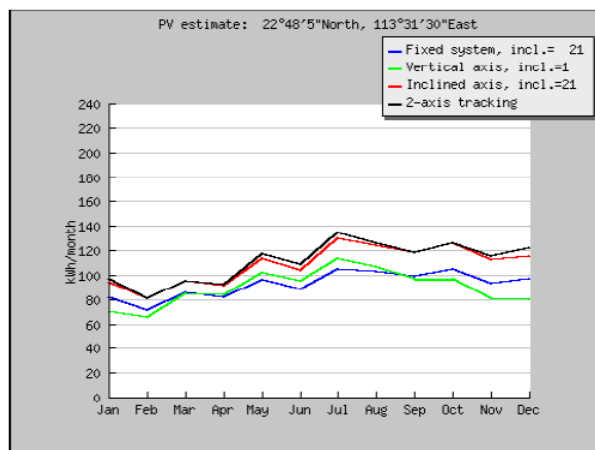


Figure 5. Monthly energy output from fixed angle PV system carried out by PVGIS.

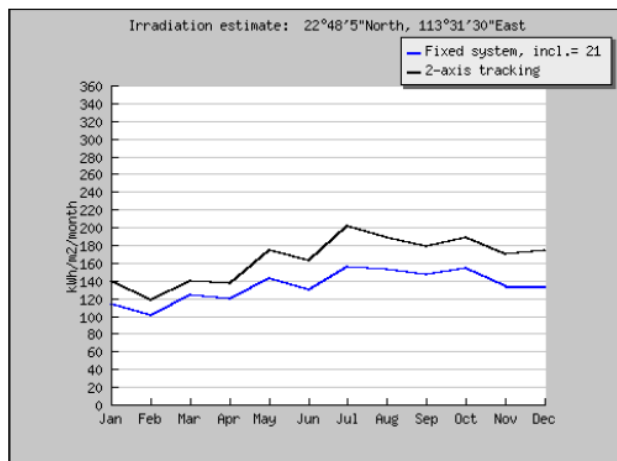


Figure 6. Monthly in-plane irradiation for fixed angle carried out by PVGIS.

4. Deviation analysis

In the theoretical assessment process:

- 1) The above mean sea level of NS was valued as 11 m.
- 2) Due to the limited data source, empirical coefficient a and b were valued as 0.1963 and 0.5345 respectively according to the related research [5], which was based on the meteorological data from 2007 to 2011.
- 3) Practical monthly sun exposure hours were referred to the data of Guangzhou from China Statistical Yearbook instead of the statistics of NS because there was no local record.
- 4) Solar energy stability index was calculated by equation (13) instead of equation (12) for the limited data source:

$$K = \frac{\max(M_1, M_2, \dots, M_{12})}{\min(M_1, M_2, \dots, M_{12})} \quad (13)$$

where,

$M_1, M_2, \dots, M_{12}$: number of months with practical sun exposure more than 180 hours.

5. Conclusions

1) From 2010 to 2014, theoretical assessment results showed that sun exposure hours percentage averaged at 41.28% and demonstrated prominent higher from June to November, solar radiation was extremely stable and extremely abundant in this area. Hence it's possible to offer stable solar power supply in the whole year especially in summer and autumn at Nansha Guangzhou.

2) Simulation results of horizontal irradiation provided by SSE Release 6.0, PVsyst (based on NASA-SSE) and Global Solar Atlas were much similar, averaged at 3.93 kWh/m²/day. Results figured out by Global Solar Atlas (4.01 kWh/m²/day) were more representative and visualized if thinking about the latest database. Simulation based on Meteonorm 6.1 (3.50 kWh/m²/day) was relatively conservative, and that of PVGIS (4.22 kWh/m²/day) was relatively higher. In addition, RETScreen was more suitable for economic analysis rather than doing resource potentials assessment.

3) Preliminary design showed that optimized tilt of solar panels ranged from 19° to 22°, facing the south. Under the crucial parameters defined in Table 4, irradiation on tilted solar panel averaged at 4.16 kWh/m²/day carried out by SSE Release 6.0, PVsyst(based on NASA-SSE) and Global Solar Atlas. And that simulated by PVGIS and PVsyst (based on Meteonorm 6.1) were 4.41 kWh/m²/day and 3.70 kWh/m²/day respectively.

4) In the light of the simulation results figured out by PVGIS, annual global irradiation received by the two-axis tracking system/inclined axis tracking system/vertical axis tracking system/fixed system were averaged at 5.40/5.14/4.26/4.41 kWh/m²/day, and the electricity production were averaged at 3.65/3.57/2.94/3.03 kWh/m²/day.

Acknowledgement

This project was supervised by Dr. Wilton W.T. FOK from the University of Hong Kong and supported by Shantou Polytechnic(No. SZK2018Q01). In the meantime, thanks for National Bureau of Statistics of China to provide the practical monthly sun exposure hours from 2010 to 2014 at Guangzhou.

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