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Renewable Energy Application and Carbon Redution Study on the Campus Teaching Building

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Abstract. This work conducts carbon simulation and accounting of one public teaching building in South China. The calculation results show that the carbon emission of public teaching building is 2586.5 Tons of CO_2 per year. Based on the simulation, Solar Photovoltaic (PV) system can achieve carbon reduction of 595.5 TCO_2 per year, the total power of the PV system reaches 1201kWp, the average power generation of the system is 1025MWh/year, and the system efficiency is 68.1%. The PV system can reduce the carbon emissions of public teaching buildings by 23%. The utilization rate of the roof space of public teaching buildings reaches 64%. Based on the simulation results to analyse the models of colleges and universities participating in the carbon trading market, three models are proposed: unified integration into the national carbon trading market system, incomplete integration into the carbon trading market, and the establishment of a university carbon trading market.

Keywords: Photovoltaic System Design, Campus Carbon Reduction, Carbon Trading Market

1.Introduction

With the advent of environmental degradation and energy crisis, countries around the world have successively proposed carbon neutral plans [1]. Building energy efficiency is considered to be an important part of mitigating the climate crisis and energy structure revolution [2]. Buildings and infrastructure are fundamental components of economic and social development [3]. Relevant studies have shown that the direct or indirect energy-related carbon emissions of buildings account for about one-third of the total global carbon emissions [4]. In this context, the concept of zero-carbon buildings was proposed. Zero-carbon buildings use off-the-shelf, cost-effective technologies to reduce carbon emissions while providing economic benefits throughout the building's life cycle [5]. At present, most of the researches on carbon emission of buildings are aimed at social buildings, while universities are often ignored because of their special social status. As a special type of energy-intensive social institution, university campuses are more conducive to the study of “zero carbon buildings”. Each area in the university campus is clearly defined, and it is more controllable when conducting carbon accounting, and it is easier to carry out quantitative assessment.

In this paper, we take the public teaching building of Shenzhen Technology University (SZTU) as an example to investigate the impact of carbon reduction in universities and the feasible ways for them to join the carbon market.

2.Renewable Energy Design

2.1 Building Zoning

One giant public teaching building in SZTU was selected in the study. Sketchup Pro and PVsyst programs were utilized for building roof sketch and solar PV array layout, and the PV power generation simulation respectively. Meteorological Data such as solar radiation, wind speed, and temperature were obtained from Meteonorm8.0.

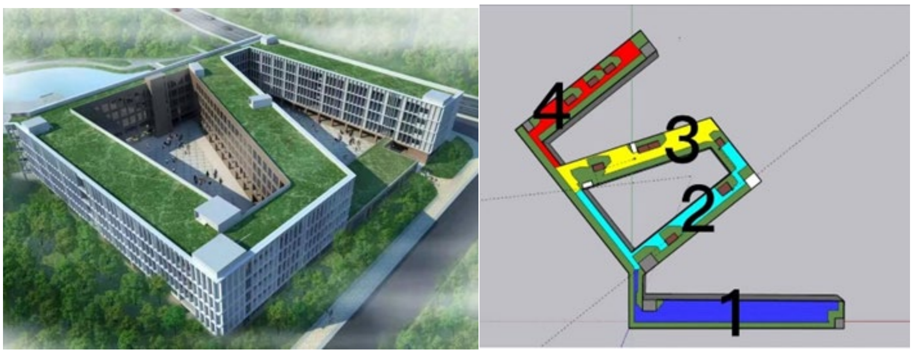

Figure 1. the model figure of the building (left) and the PV design on the roof (right), 4 areas with different PV design were noted by the colors.

The campus is located in 22.7° north latitude, where, it typical local climate is high temperature and humidity. The total roof area of the teaching building is $13650m^2$, and is divided into four parts for the PV system design, as indicated with numbers in Figure 1. A facade area facing south at (out all wall of the blue building in Figure.1) has a total area of $3440m^2$, where 80% of it could be integrated with transparent thin film solar cells. There is no obvious shading condition for both roof PV system and the facade PV panels.

Table 1. area of public teaching buildings.

Area	**Total area**	**Estimated Installed Capacity**
1	2721.37 m^2	451.4 kWp
2	1555.07 m^2	145.78 kWp
3	1556.63 m^2	186.11 kWp
4	1159.81 m^2	132.6 kWp

2.2 Photovoltaic Module Layout Design

On the concrete roof, the azimuth angle of the solar modules is adjusted according to the orientation of the building walls; the inclined angle of the solar modules was calculated by PVsyst to be 19° for all the 4 areas. Therefore, the inclined angle of area 1 is 19° and the azimuth angle is 0°. Area 2 chosen the same inclination, and facing -39°; Area 3 is placed with an azimuth angle of -18°. Area 4 is with azimuth angle of -39°. A thin film PV system (BIPV) installed vertically on the outall wall facing south in Area 1. According to PVsyst7.2 the radiation amount hitting on the roof modules can reach to $1423kWh/m^2$, when the inclined angle is 19° and the azimuth angle is 0°; comparably the panels can receive maximum radiation of $1403kWh/m^2$, if azimuth angle was set to -39°, which is 1.4% loss compared with the optimal value. When the azimuth angle was set to-18°, the radiation on the planes is $1418kWh/m^2$, that is a loss of 0.3%. Although these placements that mentioned above will lead to a decrease of solar radiation on the panels, the Skelion plug-in simulation shows that by this way more solar modules can be installed than the way with optimal azimuth (2199 for the former and 2195 for the latter). According to the characteristics of the four regions (Figure 1), different azimuth angles can be placed in the photovoltaic array to avoid resulting in difficulties in maintenance and complexity of cables wiring. For the BIPV system on the facade facing south, all thin film modules are installed vertically. The maximum radiation on the film panels is 792kWh/m2, which is 44.3% loss compared with optimal inclined angle installation.

The formula below is used to calculate the minimum distance between solar panel rows.

$$\sin\alpha = \sin\varphi \sin\sigma \cos\omega \qquad (1)$$

$$\sin\beta = \frac{\cos\sigma \sin\omega}{\cos\alpha} \qquad (2)$$

$$\beta_1 = \beta - \Theta \qquad (3)$$

$$D = \frac{\cos\beta_1 \times H}{\tan\alpha} \qquad (4)$$

α :solar altitude angle; β :Solar Azimuth; ω : hour angle; φ :Photovoltaic system construction site latitude; σ :solar declination; H :Vertical height of components; D :Component spacing; β_1 :Solar relative component azimuth; Θ : Component Azimuth

The PV modules are placed with an azimuth of 0°, and the distance between the photovoltaics is 0.472 m through the formula. Considering that the distance between the front and rear of the array is 1.55 m; when the PV modules are placed with an azimuth of -39°, the calculated distance between the photovoltaics is 0.679 m. Taking into consideration the distance before and after the array is 1.7 m; when the PV modules are placed with an azimuth angle of -18°, the calculated photovoltaics spacing is 0.608 m, and taking the distance before and after the array is 1.65 m. To verify the accuracy of the data, this work used PVsyst software to verify the minimum spacing conditions. Meanwhile, the force situation of photovoltaic components under wind loads was simulated using Fluent fluid simulation software. The wind loads on the components were analyzed for different wind speeds and wind directions. The results demonstrate that the distribution of wind loads does not affect the positioning of the components. The specific data is shown in Table.2

Table 2. components wind load.

	Left Entrance		Right Entrance	
Inlet Velocity	5m/s	10m/s	5m/s	10m/s
Vertical Force Situation	-224.78 N	-897.17 N	552.18 N	2222.10 N

The results show (Figure.2) that the components do not occlude each other in this case, and the spacing design between components meets the requirements. The total roof area of the teaching building is 13,650 m^2. After removing the shadow loss caused by the parapet, ventilation equipment and some buildings, the actual usable area of the roof is 6,993 m^2, and the utilization rate of the roof photovoltaic system reaches 64%.

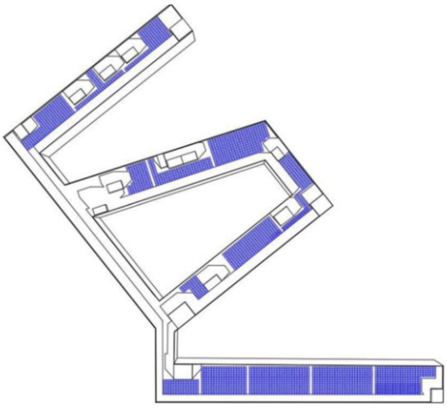

Figure 2. roof assembly layout with solar modules.

2.3 Photovoltaic Module Selection

The solar modules used in the rooftop of this project are LR4-60 HPB 370 M monocrystalline silicon modules produced by LONGI. The solar modules used in the facade are FS-4120-3 cadmium telluride (CdTe) thin film solar cell modules produced by FIRST SOLAR. Detailed parameters are shown in the Table.3

Table 3. photovoltaic module specifications.

Component Model	LR4-60HPH-370M	FS-4120-3
Maximum Power Voltage（V_{mp}/V）	34.4	70.8
Maximum Power Current（I_{mp}/A）	10.76	1.7
Maximum Power（P_{max}/W）	370	120
Open Circuit Voltage（V_{oc}/V）	40.9	88.7
Short Circuit Current（I_{sc}/A）	11.52	1.84
Efficiency（%）	20.3	16.7
Dimensions（mm）	1755×1038×35	1200×600×7

This project selects the SP-100K-L string inverter produced by SINENG. The total installation of the PV system is 1201kWp, including 2472 pieces of LR4-60HPH-370M and 2390 pieces of FS-4120A-3 CdTe solar modules, with 12 SP-100K-L inverters with a capacity ratio of 1.001. The average annual power generation of the system is 1025MWh/year, and the annual unit power generation is 854kWh/kWp/yr, the PV system average performance ratio is 68.1%. The power generation efficiency in winter is higher than that in summer. Although the irradiance of photovoltaic modules in summer is greater than that in winter, the power generation efficiency of photovoltaic modules will decrease with the increase of temperature. First of all, the high temperature and high humidity in summer in South China is prone to potential-induced degradation (PID), which leads to module performance degradation. Second, too high a local temperature will produce a hot spot effect, which will affect the life of the photovoltaic module. Third, inverter efficiency is also affected by temperature. Excessive temperature will reduce the efficiency of the inverter and even affect its life [6]. Detailed inverter parameters are shown in the Table.4

Table 4. photovoltaic inverter parameters.

Component Model	SP-100K-L
Maximum DC Input Power	100KW
Maximum DC Input Voltage	1100V

Input Voltage Range	200V-1000V
Input Current	26A
Rated AC Output Power	100KW
Nominal Output Voltage	380/400V
Maximum Efficiency	98.7%

Figure.3 (a) shows the monthly efficiency graph of the photovoltaic system. It can be seen from the figure that the power generation efficiency in winter is higher than that in summer. The reason is that the operating temperature of solar modules in summer is higher than that in winter. Excessively high temperatures lead to a drop in the output voltage of the modules, resulting in a decrease in system efficiency, which leads to a decrease in the power generation of photovoltaic modules. Figure.3 (b) shows the monthly unit power generation of the system, where the red part represents produced energy output by the inverter, the actual power generation of the system. The green part is the System loss of power generation including the inverter. The purple part is the collection loss by the photovoltaic power generation array. The data show that the high temperature in summer leads to higher power generation loss of solar array components, but the more abundant incident radiation in summer makes the power generation more than that in winter.

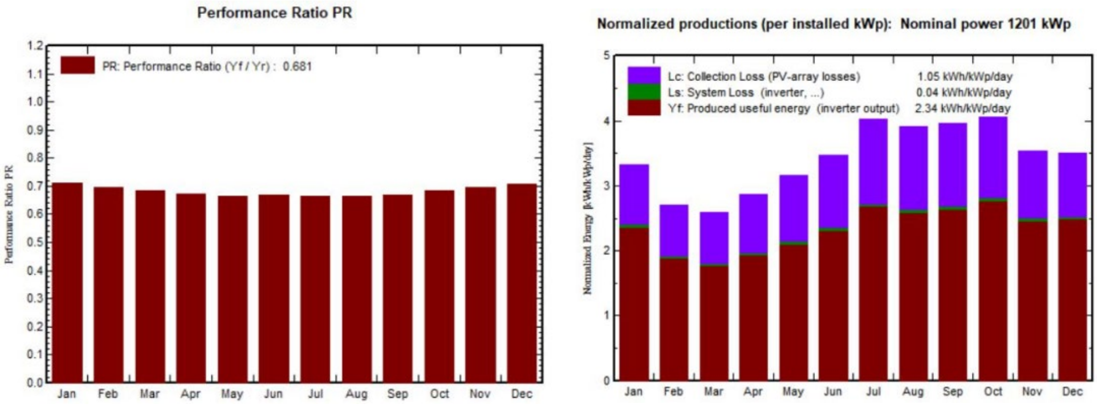

Figure 3. (a) year-round PR chart (b) unit power generation.

According to the loss analysis simulation, the total horizontal radiation is 1364kWh/m^2. The electricity loss due to non-optimized azimuth and inclined angle is 8.1%, and 3.8% due to near shading. Solar panels aging accounts for 13.5% reduction, and the degradation due to irradiance and temperature are 1.5% and 4.7% respectively. The loss due to solar modules mismatch is 7.0%, all these losses lead to the final annual output is 1025MWh(Figure.4).

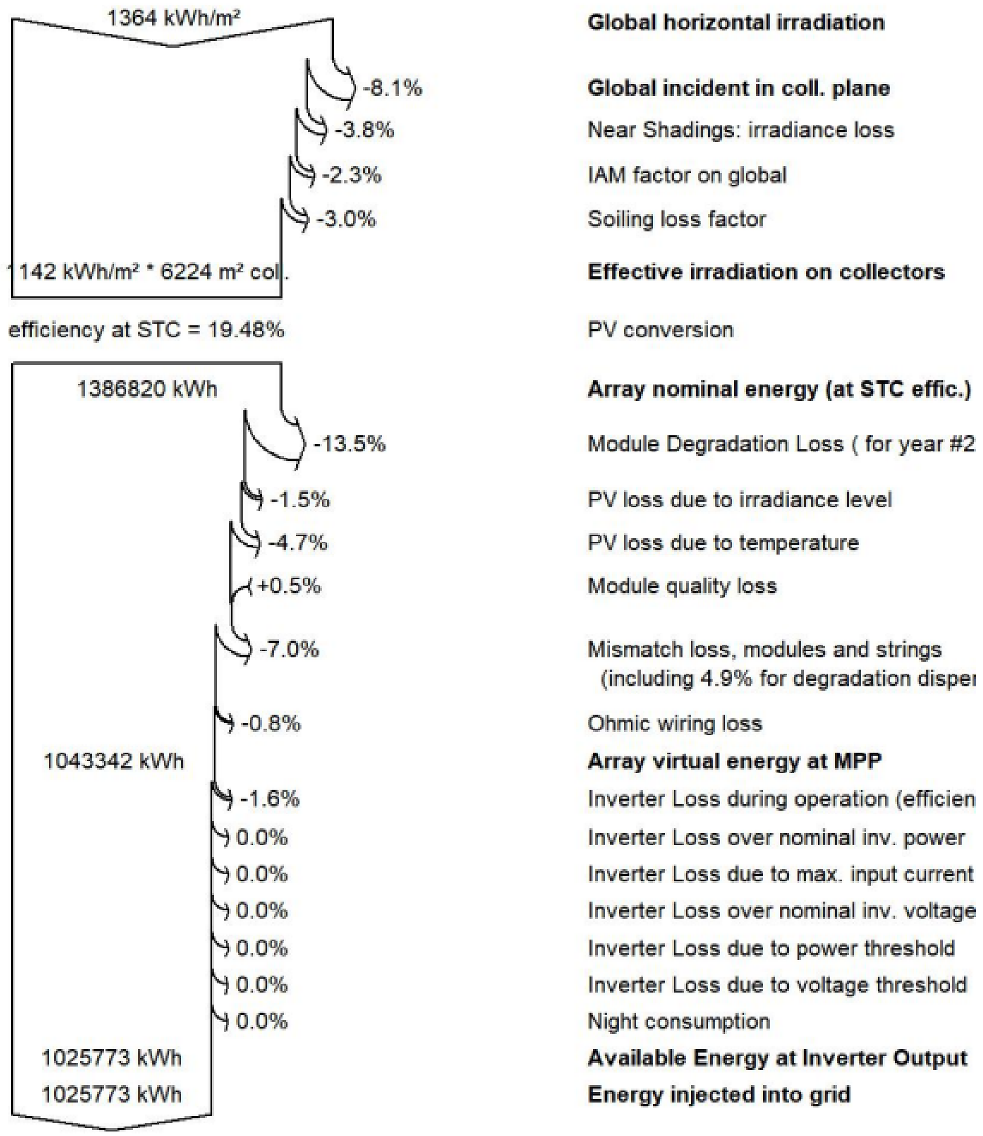

Figure 4. system annual loss.

3. Carbon Emission Results

For the research on carbon emissions in the campus, it is necessary to measure and calculate the various energy-consuming plates in the campus. The division of energy consumption for college campuses is: construction, transportation, water resources, waste, and carbon removal (Table 5). Among them, the sector that consumes the most energy and emits the most carbon is the building sector, and the carbon elimination sector mainly refers to the carbon sink of green vegetation in the campus and the negative carbon emissions of the renewable energy system. This work mainly studies the carbon emissions during the building operation phase in university campuses, without considering the carbon emissions during the building material production phase and the building construction phase. The reason is that the research on carbon emissions based on "zero-carbon" campuses mainly focuses on the dynamic balance of carbon emissions in the entire park during the operation phase of the campus, while other carbon emissions have little impact on the carbon emissions generated during the campus operation phase. In order to simplify the model, only the impact of building operation on campus carbon emissions is studied here. In terms of negative carbon emissions, there are mainly studies on the effect of solar photovoltaic power on carbon reduction.

Table 5. overview of campus carbon emission measurement panels.

Type	Content of the Visit	Carbon Emission Factors	Remarks
Architecture	Energy consumption during the operational phase of the building.	The carbon emission factor Kg of the national power grid is 0.5810 tCO_2/MWh.	This paper looks at electricity consumption in public teaching buildings.
Transportation	Energy consumption of campus vehicles.	The carbon emission factor of gasoline is $67.91tCO_2/TJ$.	Not examined in this paper.
Water	Water supply, sewage discharge.	Supply water carbon emission factor 0.168 $KgCO_2/t$	This paper looks at water use in public teaching buildings.
Waste	Amount of waste on campus and treatment.	The treatment varies from place to place and is not selected here.	Not examined in this paper.
Carbon Elimination	Campus Carbon Emission Reduction Means.	The carbon emission reduction coefficient of the photovoltaic system is taken from the national grid carbon emission coefficient K_g.	This paper looks at photovoltaic simulation systems for teaching buildings.

For public teaching buildings, the main energy consumption comes from the electricity consumption of teaching facilities, indoor lighting, indoor temperature control and the water supply consumption. Therefore, in this paper, in order to simplify the energy consumption analysis of the building, the calculation is mainly made from the annual electricity consumption and annual water consumption of the building.

The work focuses on the carbon emissions of campus buildings based on life cycle measurement. The life cycle measurement approach considers the whole life cycle of a product and, when applied to the study of the carbon footprint of buildings, examines the flow of carbon from operation and even disposal of the building. Life Cycle Measurement (LCM) is a common measurement method for measuring the carbon footprint of buildings.

The basic formula for the whole life cycle approach is:

$$C = \sum_i Q_i \times K_i \qquad (5)$$

C is the carbon footprint of the study as a whole, in this case as the sum of the carbon emissions over the whole life cycle of the study subject; Q_i is the quantity of substance i or the intensity of the behaviour in the study subject; K_i is the carbon emission factor of substance i or the behaviour in CO2/unit.

The carbon emissions of public teaching building are shown in Table 6.

Table 6. carbon emissions from public teaching buildings of SZTU.

Energy Category	Consumption	CO_2 Emissions
Electricity /MWh	4360	2533.5 t
Water /Mt	31.6	53 t
Photovoltaic Systems /MWh	-1025	-595.5 t
Total		1991 t

To simplify the carbon accounting model, this study only includes carbon emissions from water and electricity usage in operation of the public teaching buildings, while ignoring the carbon emissions from construction, transportation, maintenance, as well as the manufacturing, installation, and maintenance processes of photovoltaic systems.The carbon emissions result of the teaching building is 1991TCO_2. Although it is impossible to rely on the roof photovoltaic system to achieve zero carbon, the renewable energy design has reduced 23% carbon emissions for public teaching buildings.

4. Universities Join Carbon Market

At present, the research on the carbon market mainly focuses on the power industry, construction industry, transportation industry and chemical industry [7-9]. The idea of universities joining the carbon market has not attracted much attention. The following are the four assumptions of this work for universities to join the carbon trading market:

1. The carbon emission standards of some pilot areas or national universities are set by the competent department of the national carbon market, and universities exceeding the carbon emission standards will join the national unified carbon market. The competent department allocates carbon emission quotas according to the scale and historical carbon emission intensity of universities, and completes compliance once a year.
2. Universities are not fully integrated into the carbon market. Universities can carry out emission reduction projects as voluntary emission reduction units. Such emission reduction projects will receive emission reduction offset allowances allocated by the national authorities, and universities can trade the emission reduction offset allowances in the national carbon market with other units that need to purchase offset allowances to complete compliance to obtain funds. Such funds can reduce the cost of emission reduction projects or gain benefits through emission reduction projects
3. The carbon market authority establishes a national university carbon market. The colleges and universities that meet the market entry criteria will be unified into the college carbon market, and carbon emission accounting will be conducted for each college and university to derive the benchmark value of college carbon emission, and carbon quotas will be allocated to each college and university according to the benchmark value. Carbon trading among universities can only take place in the university carbon market.

5. Conclusions and Perspectives

This work conducts carbon sequestration accounting and designs renewable energy systems for a university in South China. Install a small solar photovoltaic power station in a public school teaching building. The roof photovoltaic system has a total of 1201kWp. The average annual power generation of the system is 1025MWh/year, and the annual unit power generation is 854kWh/kWp/year. The average efficiency of the photovoltaic system simulated in this work is 68.1%, and the utilization rate of the roof area of the teaching building reaches 64%, which can reduce carbon emissions by 23% every year. Compared with the 5-10% carbon emission reduction effect achieved by traditional university measures, the installation of renewable energy systems has a more direct and obvious effect. On the other hand, the BIPV system on the exterior wall can effectively block sunlight and reduce the indoor temperature in summer, and it can also play a role in heat preservation of the wall in winter, reducing the use of the air conditioning system in the teaching building. In addition to public teaching buildings, the school also has huge public buildings such as student apartments, libraries, and administrative buildings, which provide possible route guidance for the realization of a "zero-carbon campus". At present, most of the researches are focused on the reduction of carbon emissions on campus. We propose the possibility of university campuses joining the carbon trading market, which provides the possibility for the carbon trading market to gradually expand to various industries of social production.

Data availability statement

The data that support the finding of this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

Author contributions

Jinxing He[1]:Writing-original draft、Conceptualization、Software、Formal analysis

Yunfei Hu[1]:Writing-review & editing、Funding acquisition、Resources

Haihong Chen[1]:Software、Investigation

Yingjia Luo[1]:Software、Investigation

Competing interests

The authors declare no competing interests.

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