Prospective Analysis of University Carbon Reduction Based on Photovoltaic Utilization - Taking Jinnan Campus of Nankai University as an Example

Rujie Liu [1,a], Xiao Wang [1], li Zhu [2,3], Fangfang Li [2,b*]

[1]Three Gorges Electric Energy Co, Ltd, Wuhan 430010, China
[2]School of Architecture, Tianjin University, Tianjin 300072, China
[3]APEC Sustainable Energy Center, Asia-Pacific Economic Cooperation (APEC)/ National Energy Administration (NEA) of China, Tianjin 300072, China

Abstract. In order to reduce campus carbon emissions, the accounting boundary and accounting list of carbon emissions of Nankai University's Jinnan Campus were set. On this basis, the carbon emissions of Nankai University Jinnan Campus were calculated using the emission factor method. Based on the PVsyst simulator, calculations were made to obtain the annual photovoltaic power generation and then to analyze its contribution to the carbon reduction of the campus. Conclusion: Between 2017 and 2020, the carbon emissions generated by buildings were the main influencing factor for campus carbon emissions. The net carbon emissions of Jinnan Campu were 50167.34 tons, 51848.27 tons, 50674.08 tons, and 42330.47 tonss from 2017 to 2020, respectively, reaching their peak in 2018. The total area of campus greenery, water bodies, and currently undeveloped areas is 602400m^2. It is possible to consider installing a photovoltaic power generation system in 50% of the area, which is 301200m^2. Using PVSyst to simulate the photovoltaic power generation system of Jinnan Campus, it was calculated that its annual power generation is about 28868000 kWh, replacing traditional electricity, which is equivalent to saving 108 tons of standard coal and reducing carbon emissions by 21073.64 tons per year. This can offset more than 40% of the net carbon emissions of the campus, which is very beneficial for the construction of low-carbon campuses. Campus photovoltaic construction relies on the huge roof resources of colleges and universities, and with the help of planning advantages, architectural advantages and energy-use advantages, it forms a photovoltaic power generation system suitable for the characteristics of schools. It not only reduces the initial investment cost, but also improves the economic efficiency and ecological benefits. The method proposed in this study can be applied to quickly and accurately evaluate the potential of campus photovoltaics. By combining more accurate hourly energy consumption data, it is possible to develop a reasonable photovoltaic utilization strategy for the entire campus and various functional clusters. Promoting to various campuses can promote the formation of more renewable energy substitution projects, reduce carbon emissions for campus communities and the entire society.

1 Introduction

Nowadays, energy shortage and environmental degradation are serious environmental problems that have long attracted the attention of people in various countries, and they are two serious challenges to global socio-economic development. Energy saving and emission reduction actions have been called for in all regions[1]. More than 190 countries have signed the Paris Agreement, which sets long-term targets for greenhouse gas emissions[2]. According to Energy&Climate, the carbon neutral target has covered 88% of global GHG emissions, 90% of the world's economic volume and 85% of the world's population[3].

Campus architecture is an important classification in public buildings. In July 2021, the Ministry of Education issued the "Action Plan for Carbon Neutrality and Technological Innovation in Higher Education Institutions", which put forward clear requirements for the national strategy of carbon peaking and carbon neutrality in university services. At the same time, universities are important building types and key energy consuming units in cities, with dense personnel and multiple composite functions such as teaching, research and development, production, and living. The consumption of energy resources and greenhouse gas emissions are far higher than the urban average[4]. How to coordinate the comfortable, livable, and reasonable layout of campus building complexes on the basis of achieving efficient energy use has gradually become a hot issue in university campuses[5].

[a]liu_rujie@ctg.com.cn , * Corresponding author: [b]lifangfangtju@outlook.com

With the advancement of science and technology, the efficiency of photovoltaic (PV) conversion has improved, the cost of related supporting facilities has decreased, energy storage technology has advanced, and the demand for electricity has increased. Especially with the deepening of green and ecological concepts, PV power generation will gradually change people's energy consumption structure. In order to achieve the goals of peaking carbon emissions and achieving carbon neutrality, it is urgent to explore methods and paths to reduce campus carbon emissions. Renewable energy, especially photovoltaic systems, have extremely low environmental impacts, with a power generation of only 0.043kg per kilowatt hour and greenhouse gas emissions, making them considered one of the most environmentally friendly systems. In recent years, a large number of newly built school buildings, especially the "University City" complex, are suitable for the development of photovoltaic power generation. The density of campus buildings is low, ranging from 20% to 30%, and the roofs of the buildings are basically unobstructed, with excellent solar radiation conditions. In addition, the buildings with various functions on campus are divided into different clusters, each with similar building forms and energy load characteristics, which is conducive to developing targeted photovoltaic deployment strategies based on the energy demand and consumption capacity of each cluster. Therefore, studying the rooftop photovoltaic power generation system on campus can not only reduce school expenses, but also leverage its power generation advantages of not emitting pollutants or greenhouse gases, providing strong support for the green and low-carbon transformation of campus energy and achieving regional carbon peak and carbon neutrality goals. The rooftop PV power plants in universities are an important component of promoting distributed PV power generation in China. Taking the construction of rooftop distributed PV in universities as a starting point, the entire campus can be built into a smart campus energy internet system in a planned and step-by-step manner. Currently, many scholars have conducted research on PV construction in universities. Ajiboye et al.'s sensitivity analysis of technology environment economy indicates that the PV diesel grid BESS renewable energy system is the optimal configuration[6]. Panicker et al. evaluated the feasibility of achieving a net zero energy campus in India by designing integrated grid connected roof and facade building integrated photovoltaics (BIPV)[7]. Obeng et al. explored the technical and economic feasibility of a 50MW grid connected PV power plant at Oregon State University[8]. However, there is currently a lack of specialized research on the impact of PV construction on carbon emissions in universities. Therefore, the paper first takes the Jinnan Campus of Nankai University (JCNKU) as an example to calculate its carbon emissions.

This study is organized as follows: First, basic information about JCNKU is presented, followed by a description of the data sources used for the study. Second, the relevant methods used for the study were described, including the assessment method for campus carbon emissions, the assessment method for campus carbon sinks, and the calculation method for PV potential. After the campus PV carbon reduction potential is analyzed, the study examines what aspects of the university are advantageous in contributing to campus carbon neutrality by setting up PV system.

2 Data sources and method

2.1 General Situation

JCNKU is located in the central area of Tianjin's central urban area and the Golden Corridor of Binhai New Area, covering an area of 2.4589 million square meters (Figure 1).

Fig. 1. JCNKU plane figure.

JCNKU has a good foundation of carbon peaking and carbon neutrality. At the beginning of its design, it conducted energy-saving design based on relevant national and local energy-saving standards and regulations, and utilized a large number of energy-saving building materials, equipment, and technical methods. Among the 50 individual buildings currently in use, 43 are star rated green buildings. The JCNKU energy system includes the Jinnan campus energy system, which mainly includes centralized energy stations, decentralized energy supply facilities, indoor and outdoor lighting systems, power transformation and distribution systems, power systems, indoor energy equipment, official vehicle fuel, and domestic water systems. The types of energy resources used mainly include electricity, natural gas, tap water, and fuel.

JCNKU originally used relatively less electricity compared to its own size. The cold and heat sources of each individual building in JCNKU are provided by centralized energy stations and heat exchange stations. The core area 1 # energy station area uses a ground source heat pump system, while the student dormitory area uses a gas boiler for direct heating and split air conditioning for cooling. The teaching area uses a GHP gas heat pump air conditioning system. Each area is equipped with equipment stations, which are equipped with equipment rooms for heating, air conditioning, water supply and drainage, and domestic hot water, responsible for energy supply within the area.

Geothermal energy is a clean energy source, and the combustion of natural gas produces less carbon emissions and other substances than traditional fuels.

2.2 Data sources

The data used in this article includes energy consumption data, water consumption data, transportation data, and solid waste emissions data. JCNKU's logistics support department provided campus electricity, water, and gas usage data and land use drawings for 2017, 2018, 2019, and 2020. The traffic flow data within the campus is obtained from on-site research records, and the fuel consumption is calculated based on the number of vehicles passing through and the average driving distance.

2.3 method

Corresponding campus carbon accounting inventories were created based on the campus carbon accounting boundaries (Table 1).

Table 1. Classification of campus carbon emissions.

classification	**content**	**Classification according to international standard system**
campus energy consumption	primary energy consumption (gas, fuel, coal)	Scope 1
	secondary energy consumption (electricity, heat)	Scope 2
campus resource consumption	water consumption	Scope 3
campus transportation carbon emissions	fuel powered motor vehicles	Scope 1
	campus shuttle bus	Scope 3

2.3.1 Accounting for annual net carbon emissions on campus.

The annual net carbon emissions of the campus are calculated according to equation (1):

$$C_{\text{net}} = C_e + C_r + C_t - RC\text{-}TC \qquad (1)$$

In the equation: C_{net} refers to annual net carbon emissions on campust; C_e refers to annual carbon emissions from campus energy consumption; C_r refers to annual carbon emissions of campus resource consumption; C_t refers to Annual carbon emissions from campus transportation; *RC* refers to Annual carbon reduction in PV and wind power generation; *TC* refers to annual carbon sink of campus greenery.

2.3.2 Accounting for campus carbon emissions.

The energy consumption involved in campus generally includes electricity, purchased heat (urban heating), purchased heating/cooling (regional centralized cooling and heating system), gas, fuel, and coal.

(1)Accounting for campus energy consumption should be based on energy consumption statistical data and calculated according to equation (2):

$$C_e = \sum_{i=1}^{n} AD_i \times EF_i \qquad (2)$$

In the equation: C_e refers to annual net carbon emissions on campust; AD_i refers to energy consumption (Table 2); EF_i refers to carbon emission coefficient per unit energy consumption.

(2) Accounting for campus resource consumption shall be based on tap water consumption statistics according to equation (3):

$$Cr = B \times WF \qquad (3)$$

In the equation: *Cr* refers to annual carbon emissions of campus resource consumption; *B* refers to water consumption (Table 2); *WF* refers to carbon emission factor per unit of water consumption.

(3) Accounting for campus transportation carbon emissions includes carbon emissions from vehicles such as inter-campus and intra-campus shuttles, official vehicles held or leased for use by the university, and fuel-fired motor vehicles entering the campus according to equation (4).

$$C_t = \sum_{j=1}^{n} AD_j \times EF_j \qquad (4)$$

In the equation: C_t refers to Campus transportation carbon emissions; AD_j refers to volume of activities in the transportation category (Table 2); EF_j refers to carbon emission factor per unit of activity.

Table 2. Carbon emission inventories and emission factors of JCNKU.

classification	**content**	**unit**	**carbon emission factors**	**factor dimension**
campus energy consumption	diesel	t	3.096	t CO_2/t
	electricity	kWh	0.73	kg CO_2/kWh
	coal	t	1.924	t CO_2/t
	gas	m^3	2.162	kg CO_2/m^3
	heat	GJ	0.11	t CO_2/GJ
campus resource consumption	water	t	0.168	kg CO_2/t
campus transportation carbon emissions	fuel powered motor vehicles	t	petrol: 2.203	t CO_2/t
	campus shuttle bus	t	petrol: 2.925 diesel: 3.096	t CO_2/t

The selection of emission factors mainly refers to the carbon emission factors in documents such as Guidelines for the Preparation of Provincial Greenhouse Gas Inventories[9], China energy statistical yearbook[10], and Standard for calculating carbon emissions from buildings GB/T 51366-2019[11].

2.3.3 Accounting for campus carbon reduction.

For the situation where the self consumption of renewable energy generation is not deducted in the electricity consumption statistics (campus photovoltaic, wind power self consumption), carbon emission reduction accounting for campus renewable energy utilization shall be conducted according to equation (5):

$$RC = P \times F \times 10^{-3} \tag{5}$$

In the equation: *RC* refers to annual carbon reduction in PV and wind power generation; *P* refers to The self use portion of campus PV and wind power generation; *F* refers to electricity carbon emission factor.

2.3.4 Accounting for campus carbon sink.

Plant carbon sinks on campus are simply accounted by the planting type-area method, i.e., based on the green space area with data on carbon sequestration by each type of plant, which should be calculated according to equation (6):

$$TC = \left(\sum A_i \times Cp_i\right) \times 10^{-3} \tag{6}$$

In the equation: *TC* refers to Average annual carbon sequestration by campus plant carbon sinks; A_i refers to area planted with vegetation type *i*; P_i refers to green planting method; Cp_i refers to total annual carbon sequestration by greening planting practices.

2.3.5 PV power generation calculation using pvsyst

PVSyst is a commonly used PV system simulation software, which calculates PV power generation based on a series of rules and algorithms.PVSyst PV power generation calculation rules are based on a large number of physical models and algorithms, which take into account the combined effects of a variety of factors, to accurately predict and estimate the power generation of the PV system[12]. Users can input the appropriate parameters and data to calculate and analyze the PV power generation according to the specific situation and needs.

The first year's electricity generation of the PV plant is calculated according to equation (7):

$$W = P \times t \times \eta \tag{7}$$

In the equation: *W* refers to power generation capacity of the power generation unit; *P* refers to installed capacity of power generation unit; *t* refers to annual peak sunshine hours; η refers to comprehensive efficiency of photovoltaic power stations; $t=Q/G$ refers to hours under standard test conditions; *Q* refers to Annual total solar radiation of photovoltaic array surface; *G* refers to standard solar radiation intensity.

3 Results

3.1 Net carbon emissions of JCNKU

According to the formula, calculate the total carbon emissions generated by JCNKU from 2017 to 2020 (Table 3, Figure 2). Among them, buildings generate the most carbon emissions each year, becoming the main influencing factor of campus carbon emissions.

Table 3. Carbon emission inventories and emission factors of JCNKU.

	2017	2018	2019	2020
building carbon emissions (t)	47728.49	49050.99	47695.75	39308.56
traffic carbon emissions (t)	25.84	25.23	20.67	9.73
personnel carbon emissions (t)	4259	4618.05	4803.66	4858.19
total (t)	52013.34	53694.27	52520.08	44176.47
number of users	12965	14058	14623	14789
per capita carbon emissions (t)	4.01	3.82	3.59	2.99

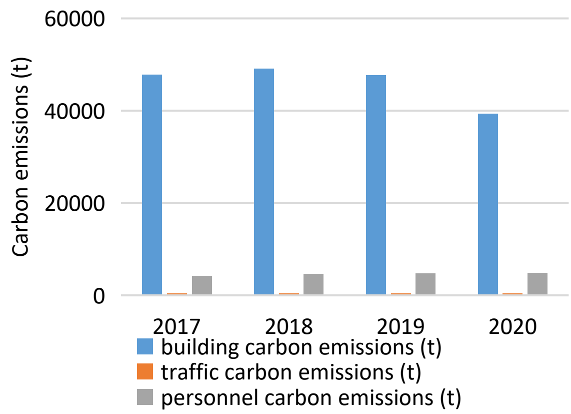

Fig. 2. Distribution of campus carbon emissions in JCNKU.

The forest coverage area of JCNKU is 34.15 hectares, and the calculated annual CO_2 absorption is 1607.95 tons. The grassland covers an area of 49.71 hectares, with an annual CO_2 absorption of 221.97 tons. The water area is 3.44 hectares, absorbing 16.09 tons of CO_2. The average annual carbon absorption of JCNKU campus is 1846 tons . JCNKU's campus net carbon emissions from 2017 to 2020 reached a peak of 51848.27 tons in 2018 (Figure 3).

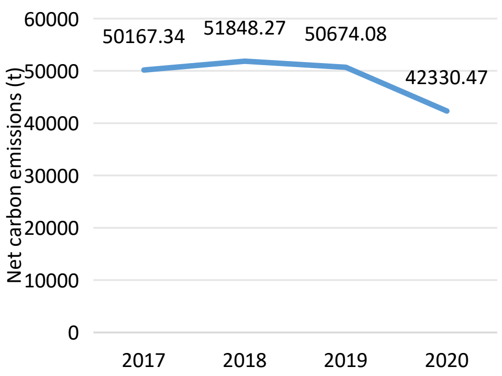

Fig. 3. Accounting of Net Carbon Emissions on JCNKU.

3.2 Analysis of campus PV carbon reduction potential

According to the building and energy system situation of Jinnan Campus and the analysis chart above, it can be seen that as a new type of university campus designed and constructed in an energy-saving manner, the carbon emissions of Jinnan Campus are basically at a relatively stable level (lower in 2020 due to the impact of the epidemic). Prior to the completion of the campus and the relocation of all teachers and students, as well as the normal operation of the campus's ground source heat pump and GHP gas air conditioning systems, coupled with the daily energy-saving renovation and promotional activities carried out by the energy conservation department, the annual carbon emissions did not fluctuate significantly. Therefore, we are considering introducing photovoltaics into the campus to advance towards the goal of carbon neutrality.

At present, in the completed area of Jinnan Campus, the total roof area is 184317 m^2, accounting for only 7.4% of the total campus area. Subtracting the area covered and installed with equipment, the available area of rooftop photovoltaic is 169200 m^2. In addition, the total area of greening and water bodies within the campus, combined with the currently undeveloped area, is 602400 m^2 (mainly unused vacant land in the eastern part of the campus). It is possible to consider installing a photovoltaic power generation system in an aesthetically pleasing manner with an area of 50%, or 301200 m^2, to increase the overall photovoltaic power generation of the campus.

The selection of photovoltaic panels for simulation is Yingli JSMGG144CELL, with dimensions of 2094 m (length) x 1038 mm (width) x 30 mm (thickness). The peak power of the photovoltaic panel is 455kWp, and the conversion efficiency is 21.12%. In actual operation, photovoltaic systems suffer from radiation level losses, temperature impact losses, module quality losses, transmission line losses, and inverter losses. Therefore, the actual operating efficiency converted by modules is 15.65%. The placement of photovoltaic modules determines the amount of light and radiation received throughout the year, and to some extent, also determines the annual power generation. Therefore, it is particularly important to arrange photovoltaic modules reasonably. This project adopts a fixed bracket installation method. In order to obtain the maximum light radiation, the installation angle of the components is due south, that is, the azimuth angle is 0 °. The optimal tilt angle is calculated to be 28 ° based on PVsyst software and the best power generation efficiency. Although the optimal inclination angle installation has high power generation efficiency, the spacing is too large. In the case of limited total area, according to the calculation results, the total power generation of horizontal installation is higher.

The power generation of grid connected photovoltaic power generation systems is related to factors such as local solar radiation energy, total power of solar cell modules, total efficiency of the system, and attenuation rate of photovoltaic modules. According to the warranty commitment of the solar cell modules, the expected power generation capacity degradation rate of this project is not less than 10% for 10 years and not less than 20% for 20 years. The actual design peak wattage of this project is 240kW. Based on the above data, the campus photovoltaic system is calculated based on a 25 year lifespan. Calculate the photovoltaic power generation potential of Jinnan Campus as shown in Table 4.

The PVSyst simulator calculates an annual photovoltaic power generation of 28868000kWh, which replaces traditional electricity and saves about 108 tons of standard coal. It reduces carbon emissions by 21073.64 tons per year and can offset over 40% of the current campus net carbon emissions.

Table 4. Table of Photovoltaic Power Generation Potential in JCNKU.

Installation method	**Calculation Items**	**Building roof**	**Green spaces and water area**	**Total**	Replacement ratio (%)
Horizontal installation	Annual photovoltaic power generation (kWh)	10796000	18072000	28868000	64.62%
Optimal inclination installation	Annual photovoltaic power generation (kWh)	6768000	12048000	18816000	42.12%

4 Disscussions: Advantages of PV assisted low carbon campus construction in JCNKU

4.1 Campus planning advantages

The Jinnan campus sites were chosen in suburban areas, avoiding sources of pollution such as exhaust gases, wastewater and dust, and seeking areas of good natural environment. The schools all occupy relatively large areas, and most of the roofs are flat, with plenty of usable area. Through field research, the total roof area in the built-up area of Jinnan Campus is currently 184,317m^2, accounting for only 7.4% of the total campus area. Subtracting the area covered by shading and equipment installation, the available area for rooftop photovoltaics is 169,200 m^2. In addition, the green and water areas of the campus, together with the area of the current uncompleted area, total 602,400 m^2 (with the unused open space in the eastern part of the campus as the main area).

The master plan of Jinnan Campus mostly adopts the principles of centralized layout and rational zoning, and reasonably allocates land resources. The functional areas in the university are arranged centrally, such as teaching area, living area, core area and office area are put together. Doing so reduces the waste of land resources. Reasonable zoning, on the other hand, is to link the various functional areas with each other, requiring both to meet the needs of teachers and students to use, but not to have an impact on and interfere with other use areas. For example, the physical activity area is required to be as close as possible to the living area and teaching area. This planning principle enables the PV power system to be used locally and reduces the long-distance distribution of power transmission. At the same time, the PV arrays are installed close to the control units and power loads, which reduces power losses and initial costs on the transmission lines.

4.2 Building design advantages

Most of the roofs of the buildings on the Jinnan Campus are of simple design, well lit, and are suitable for receiving sunlight as they are little affected by shadows created by building elements. In order to facilitate the demand for use, the campus buildings are controlled to be 6 floors and below, except for the library, which is 7 floors. The PV modules are mounted close to the roof, reducing the adverse effects of wind. In addition, the centralized arrangement of the PV roof power generation system can form a scale effect. The unit price of the system is reduced, which has higher economic benefits.

The life cycle of a PV power plant is generally about 20 years, while the service life of a campus building is more than 50 years, so it can be said that the service life of the building can include the full life operation cycle of the PV power plant system. In addition, GB50023-2008 "Classification Standard for Anti-community Defense of Building Engineering" stipulates that the seismic defense category of educational buildings should be no less than the key defense category. The service life and bearing capacity arrangement of the campus building structure are much higher than that of the local ordinary buildings, which relatively reduces the investment in structural safety reinforcement of the PV power generation system in the process of roof installation and improves the economy of the whole system.

4.3 Building energy advantages

The power generation peak of grid-connected photovoltaic power plants in colleges and universities occurs at the noon hour every day, which is also the peak energy consumption of many use spaces. Such as supermarkets, cafeterias, dormitory living areas, etc. need a lot of electricity. Photovoltaic power on-grid can to a certain extent alleviate the power demand of the peak power consumption on campus, which is conducive to improving the load balance of the power system and reducing line losses.

5 Conclusion

Between 2017 and 2020, buildings produce the most carbon emissions and become the most influential factor in campus carbon emissions. The net campus carbon emissions of Jinnan Campus are 50167.34t, 51848.27t, 50674.08t and 42330.47t from 2017 to 2020, respectively, and peak in 2018. The total area of campus greenery, water bodies, and currently undeveloped areas is 602400m^2. It is possible to consider installing a photovoltaic power generation system in 50% of the area, which is 301200m^2. Using pvsyst to simulate the PV power generation system of Jinnan campus, we calculate that its annual power generation is about 28,868,000 kWh. replacing traditional electricity, it is equivalent to saving 108 tons of standard coal, and reducing carbon emissions by 21,073.64t per year, which can offset more than 40% of the net carbon emissions of the campus, which is helpful for the construction of a low-carbon campus.

Relying on the huge roofing resources of universities, campus PV construction has formed a PV power generation system suitable for school characteristics with the help of planning advantages, architectural advantages and energy use advantages. It not only reduces the initial investment cost, but also improves the economic efficiency and ecological benefits. The method proposed in this study can be applied to quickly and accurately evaluate the potential of campus photovoltaics. By combining more accurate hourly energy consumption data, it is possible to develop a reasonable photovoltaic utilization strategy for the entire campus and various functional clusters. Promoting to various campuses can promote the formation of more renewable energy substitution projects, reduce carbon emissions for campus communities and the entire society.

At present, there are still many aspects that urgently need to be improved and improved in the combination of photovoltaics and campus. In order to better promote the application of campus photovoltaics and build low-carbon campuses, the following aspects can be improved. Firstly, governments at all levels should further enhance their understanding of the importance of developing campus photovoltaic power generation. Secondly, in energy planning, sufficient development space should be left for the development of renewable energy such as photovoltaics and low-carbon development, and clear development goals should be proposed. Thirdly, it is recommended that the government implement more lenient policies for the approval of photovoltaic power stations, stimulating and mobilizing the enthusiasm of various types of campus investments in photovoltaic power generation applications. It is important to support and assist the campus in initiating photovoltaic project construction to ensure that the project is implemented as soon as possible. Finally, in campus planning, architectural design, and renovation and expansion of buildings, the application of photovoltaic power generation should be considered comprehensively, and building design should be carried out according to different bearing types.

Acknowledgements

This work was sponsored by China Yangtze Power Co., Ltd. (No. Z152302009 / Z612302004).

References

1. Zou, C., Chen Y.., Xiong, B. (2010) Mission of new energy under carbon neutrality goal in China. Journal of the Chinese Academy of Sciences, **38**: 48-58.
2. Wang, L. (2022) Global carbon emissions will hit a new historical high this year. https://baijiahao.baidu.com/s?id=1750119260563777227&wfr=spider&for=pc
3. Ma, L., Luo, L., Luo, Q. (2022) China Pulp & Paper Industry, 4: 2-8.
4. Ministry of Education of the People's Republic of China. (2021) Notice of the Ministry of Education on Issuing the Action Plan for Carbon Neutrality Science and Technology Innovation in Higher Education Institutions. https://www.moe.gov.cn/srcsite/A16/moe_784/202107/t20210728_547451.htm .
5. Tan, H. (2010) Construction of energy-saving supervision system for campus buildings in universities. Construction Science and Technology, 02: 15-19.
6. Ajiboye, A.A., Popoola, S.I., Adewuyi, O.B., Atayero, A.A., Adebisi, B. (2022) Data-driven optimal planning for hybrid renewable energy system management in smart campus: A case study. Sustainable Energy Technologies and Assessments, 52.
7. Panicker K, Anand P, George A, Assessment of building energy performance integrated with solar PV: Towards a net zero energy residential campus in India[J]. Energy and Buildings, 2023, 281.
8. Obeng, M., Gyamfi, S., Derkyi, N.S., Kabo-bah, A.T., Peprah, F. (2020) Technical and economic feasibility of a 50 MW grid-connected solar PV at UENR Nsoatre Campus. Journal of Cleaner Production, 247.
9. General Office of the Development and Reform Commission. (2010) Guidelines for the Preparation of Provincial Greenhouse Gas Inventories (Trial). https://www.ndrc.gov.cn/fzggw/jgsj/bgt/wap_index.html
10. Energy Statistics Department of the National Bureau of Statistics. (2022) China energy statistical yearbook. China Statiscics Press, Beijing.
11. Ministry of Housing and Urban-Rural Development. (2019) Standard for calculating carbon emissions from buildings GB/T 51366-2019. https://baijiahao.baidu.com/s?id=1717889466000437482&wfr=spider&for=pc
12. Zhu, L., Jing, Y., Yin, B., Li F. (2023) Photovoltaic potential evaluation method based on parametric analysis and its application. Building Energy Efficiency, 51: 58-65