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Research

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A Study and Assessment of the Carbon Footprint of Tianjin University's Weijin Road and Peiyangyuan Campuses, China

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Abstract

Background: A living University campus is like a model city; its energy and carbon auditing can also model how energy and carbon can be studied and analyzed in a city. China's colleges and universities face grave problems, now and in the future - from declining quality of campus environments to deteriorating building performance, antiquated facilities, and inefficient energy and resources consumption. While research and discussion exists on improving existing university buildings' energy performance and evaluation standards - much of that research focuses on energy savings, rather than on greenhouse gas emissions reductions. Calculation of campus carbon emissions is the first step for transforming and planning each existing university to carbon neutral campus. Some researchers of campus carbon emissions in China have made calculations, which, although as yet unpublished, create an initial framework for carbon-neutral campus plan targets. The present research gives an overview of universities' drive towards sustainability in China and in other countries. The paper then details carbon footprint accounting steps, quantifying major carbon emission sources and carbon sequestration by vegetation inside the Tianjin University's Weijin Road and Peiyangyuan Campuses. Results from China's universities are compared with international results in the scientific literature. In this paper, based on this data, we suggest strategies and show preliminary target settings for how to transform Weijin Road into a carbon-neutral campus.

Results: Annual carbon emissions for 2019 of the Weijin Road campus were 58,172.68 tonnes, (2.60 tonnes per person), and Peiyangyuan campus, 55,213.75 tonnes (2.46 tonnes per person). The largest sources of the two campuses' greenhouse gas emissions were electricity and gas; Weijin Road campus; electricity = 61.42%, gas = 20.73%, and Peiyangyuan campus electricity = 69.32%, gas = 11.60%. Carbon sequestered in the two campuses by vegetation are 11,257.34 tonnes and 27,856.51 tonnes respectively. The renewable energy contribution to carbon reduction in Peiyangyuan campus is 50.85 tonnes.

Conclusion: Per person carbon emissions of Tianjin University's two campuses are below the average for some US campuses, but are also greater than some in European countries. Research may investigate methods used by successful campuses towards becoming carbon neutral.

Keywords: Carbon neutrality, Colleges and universities, Carbon footprint, Tianjin university, GHG accounting, Sustainable university, Zero-emission university, Carbon offsetting, University campus, Per capita carbon footprint

Paper Type: Research Paper

1 Introduction

Climate Change caused by daily human activity is threatening the sustainability of the earth and confronting Climate Change is critical for the sustainable development of the Earth (Edenhofer, 2015). In 1988 an intergovernmental UN body, the Intergovernmental Panel on Climate Change (IPCC) was established, 1990 IPCC completed its first report and concluded that the global mean surface air temperature has increased by 0.3 to 0.6 °C over the last 100 years (IPCC, 1990). The increase of greenhouse gases (GHG) in the atmosphere is the main reason for Climate Change, and water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone are considered to be the main parts of GHG total emissions and those gases are called carbon footprint, or CO_{2eq} when accounting for these gasses as the results are easy to compare.

To reduce GHG emissions, in 1997 the Kyoto protocol was adopted in Kyoto, Japan. The protocol requested countries to adopt necessary policies and measures to limit the GHG emissions and report their efforts periodically. Unfortunately, this failed mainly because some countries were not bound by the Kyoto Protocol, notably China and the United States, which together were responsible for approximately 40 percent of global carbon dioxide emissions (Rosen, 2015). In 2015, world leaders established the Paris Agreement, which pledged to control the temperature rise of 2^{o} compared with the Pre-industrial time (1850-1900). Although in recent years there have been pledges and other carbon reduction related policies implemented by countries, the most recent being the IPCC report which noted that the past five years have been the hottest on record since 1850. The 2021 report also suggests that human activity is changing the climate in an unprecedented and sometimes irreversible way (McGrath, 2021).

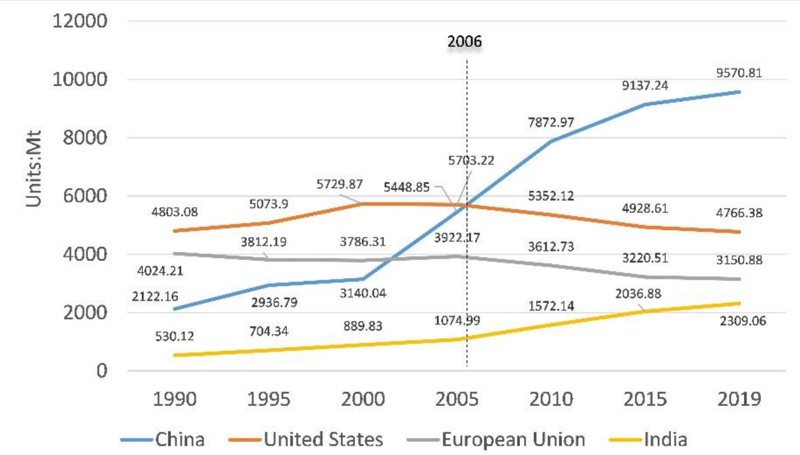


Fig. 1. World Major Countries and their CO_2 Emission
Source: International Energy Agency (IEA), author A.Zayit

China is now the world's largest carbon emission contributor since 2006 (**Fig. 1**), according to the International Energy Agency statistics, and by the end of 2019, total carbon emissions in China were 9.57Gt (Gigatonnes) of CO_2, which accounts for about 28% of total world carbon emission (IEA, 2021). Most recent studies and news reports suggest that China's GHG emission is critical to the world (Brown, 2021). With the growing attention to Climate Change, in the 75th UN meeting, China announced an ambitious 'Plan to reducing GHG Emissions' and set a target for the country, known as the "30-60" target, whereby 2030 will reach the peak value of the GHG emission and 2060 will reach carbon-neutral country (China Plus, 2020).

Climate Change is an important topic, and many organizations and universities have realized the importance of mitigating their carbon footprint, and some have completed their greenhouse gas inventories to determine their greenhouse potential, which is the first step towards a planned carbon emission target (Roche *et al.*, 2014). Colleges and Universities are seen as an important part of society with the main characteristic of a high density of population, and high energy consumption. Finding how to reduce colleges and universities carbon emissions is now an important reference and challenge for the whole of society.

Between 5-16 June 1972, the United Nations Conference on the Environment was held in Stockholm, Sweden, and for the first time mentioned ‘green school’, but that particular reference concerned environment-related teaching (NATIONS, 1972). In 1987, the World Commission on Environment and Development (WCED) published the Brundtland Report, also called ‘Our Common Future’, and introduced the concept of sustainable development (Lélé, 1991). In 1990, 350 universities from 40 countries around the world signed the Talloires Declaration (Butt *et al.*, 2009), and emphasized the role of universities in sustainable development, and agreed to the 10 action plans of sustainability (University, 1990), and as of February 2021, total signatory institutions reached 519 (Future, 2021). Universities began to pay attention to the sustainable problems, with the introduction of ‘COPERNICUS University Charter for Sustainable Development, which started to raise awareness of ‘Sustainability’ throughout Europe (UNECE, 2005). December 1991, 33 Higher Institutions from 10 countries on 5 continents signed the Halifax Declaration (Evangelinos *et al.*, 2009), emphasizing the role of Higher Institutions in education, research and the public service sector’s sustainable development. In December 2002, United Nations General Assembly proclaimed the ‘The United Nations Decade of Education for Sustainable Development’ (DESD, 2005-2014), its aims were to reorient education policy, practice and investment to address sustainability, bringing world focus to the important issues of education for sustainable development (UNESCO, 2022).

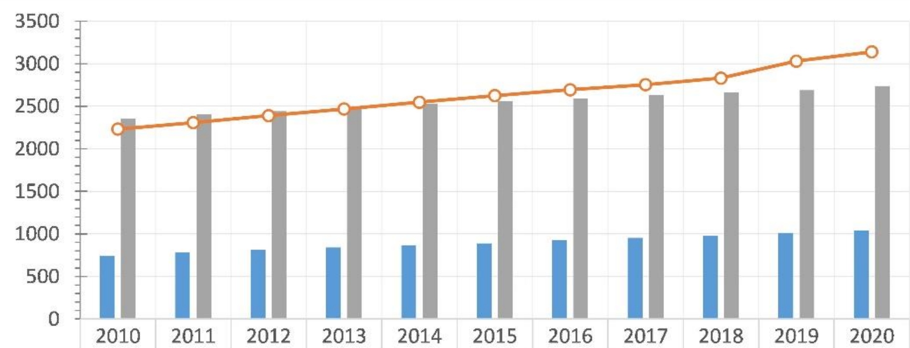
On April 22, 2010, Higher Education Institutions (HEIs) signed the American College and University Presidents’ Climate commitment (ACUPCC), amid increasing concerns for Climate Change. It premised the initiative for universities and colleges to be carbon neutral before 2030, as ACUPCC implored universities to change direction for carbon emission, and was applied to approximately 400 colleges and universities which signed the agreement (Denison, 2010). In summary, ‘green school’ initially started outside of China from a sustainability concept. This developed into environmental education and from there it developed to include higher education, colleges and universities holding various conferences, and signed declarations which ultimately pushed colleges and universities into a sustainable campus direction.

In 1996, The Chinese Ministry of Environmental Protection published the ‘National Action Plan’ for environmental publicity and education, demanding conduct of “Green School” activities throughout the country (China, 1996). In 1999, the Ministry published the ‘National Environmental Education and Promotion Plan for 2001-2005’, which proclaimed the ‘Green University’ (China, 2001). October 2009 Ministry of Housing and Urban-Rural Development published ‘Technical Guide for Colleges and Universities Building Energy Efficiency Supervision System’ (China, 2009) providing a guide for Chinese colleges and universities to establish ‘Conservation-Oriented Campuses’.

The Chinese government later published various guidelines and technical guides for building energy saving, ecological campus and more. Most recently, September 8, 2021, the Ministry of Housing and Urban-Rural Development of the People’s Republic of China (MOHURD) published the 'General standard for building energy conservation and renewable energy utilization'. It is the first mandatory standard in Chinese building history which requires all new and renovated buildings to meet the carbon emission reductions requirements (effective April 1, 2022) (China, 2021). The 'National

Assessment Standard' for 'Green Campus' (GB/T51356-2019) was officially launched in October 2019 (Ministry Of Housing And Urban-Rural Development, 2019). This standard was composed of five major parts, which are: 1. Planning and Ecology, 2. Energy and Resources, 3. Environment and Health, 4. Operation and Management, 5. Education and Spread. China's higher education campus construction developed from Energy-Saving Campus to Technical Standards and then to National Standards which concentrate mainly on 'Campus Energy Saving' (Zhu *et al.*, 2021) (Zhu and Dewancker, 2021), which ultimately led to the 'Green Campus' in China.

Although assessing a university's environmental impact is common, it is not common in Chinese colleges and universities to calculate the carbon footprint. This is mainly because there are few sustainable assessment tools for colleges and universities in China from the perspective of carbon emission evaluation. The assessment standard for the Green Campus in China included only a few points of the carbon assessment indicator which concentrated on-campus buildings, but the standards and technical guidelines were unable to measure and evaluate carbon emissions for the whole campus, which could not meet the current demand for creating a carbon-neutral campus.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
University building area （10×6m²）	746.04	780.76	810.60	841.55	863.11	891.41	926.71	954.00	977.14	1012.48	1040.34
Colleges and Universities	2358	2409	2442	2491	2529	2560	2596	2631	2663	2688	2738
Students（10K）	2231.79	2308.51	2391.32	2468.07	2547.7	2625.30	2695.84	2753.59	2831.03	3031.53	3139.60

Fig. 2 Statistics of colleges and universities in China，From 2010-2020
Source: Data from educational statistics yearbook of China, author A.Zayit

The higher education sector in China has a higher population than that of any country in the world. By the end of 2019, there were 2688 colleges and universities, with over 30.31 million students enrolled in mainland China (**Fig. 2**). The education system includes Bachelors, Masters and Doctoral degrees, as well as non-degree programs, and is also open to foreign students.

Colleges and universities' building area built before 2010 makes up 73.68% of total building area (**Fig. 3**), which means many campus buildings across China cannot meet "Green" building standards. Some of them have been renovated, although only a limited number.

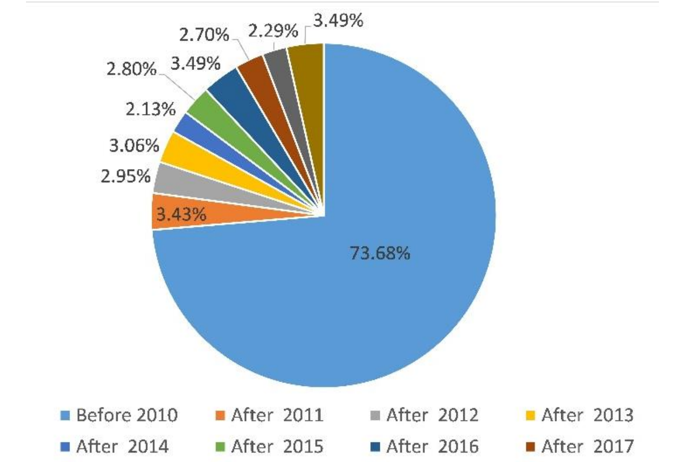


Fig. 3. University buildings year of construction

Source: Data from educational statistics yearbook of China, author A.Zayit

On 17-18 April 2021, China Carbon Neutral University Campus Forum, was held in Tongji University in Shanghai, PRC. 44 colleges and universities across China joined the global and national ambition for carbon neutrality and signed the Declaration on Carbon Neutrality of Chinese Colleges and Universities by 2050 (Development, 2021).

This paper assesses the GHG emissions of the first university in modern Chinese history. Firstly, it assesses and analyzes major carbon emission sources of the Weijin Road (Old) Campus and the Peiyangyuan (New) campus of Tianjin University (Fig. 4), Tianjin, China by selecting electricity, natural gas (used for heating and cooking), transportation, waste generation, human activity, and tap water, as the target research.

These areas have been selected by other researchers, where they also calculate the carbon footprint of universities (Yazdani *et al.*, 2013, Ridhosari and Rahman, 2020). Secondly, this paper also attempts to explain how the calculations are carried out, and finally, comparing two campuses' carbon emission results with other universities around the world, giving an explanation and strategies to help develop and transform.

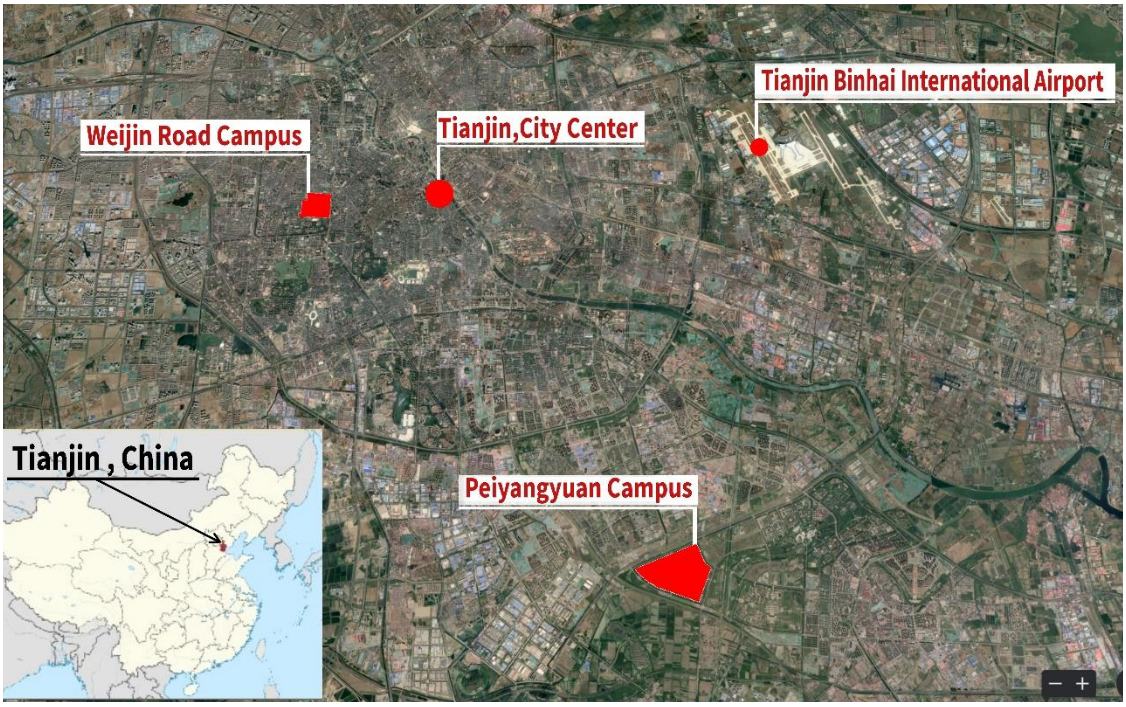


Fig. 4 Tianjin, China, and TJU two campuses relationship map, author A.Zayit

2 Review of carbon footprinting of colleges and universities

The first step for reducing GHG on campus is the calculation of carbon emissions that are emitted by campus activities, which is the basis for further development and implementation of carbon reduction strategies. To quantify carbon emission, the concept of carbon footprint emerged, with the carbon footprint concept coming from the ecological footprint. In 1990, Mathis Wackernagel and William Rees introduced the concept of Ecological Footprint'(Wackernagel and Rees, 1998), which according to the ecological footprint is the carbon footprint as an area of the earth that needs to absorb emission produced by one person's whole life. Although many articles and research have been done regarding carbon footprint, until 2007, not everything was clear. In 2007, Thomas Wiedmann and Jan Minx provided clearer definitions of the carbon footprint and introduced the calculation method of CO_2, which considers a full life-cycle approach (Wiedmann and Minx, 2008) and the ISO 14064 (Greenhouse Gas Validation and Verification https://www.lr.org/en/iso-14064) standards which also uses life cycle assessment methods (Sangwan *et al.*, 2018).

Calculating carbon emissions of university campuses is challenging, with the main obstacle being the lack of data for the calculations. Nunes, Catariono, Teixeria M R. put forward a framework for the inter-comparison of the ecological footprint of universities [J] entitled: ECOLOGICAL INDICATORS, but this method required repeated calculations with some inherent uncertainties (Nunes *et al.*, 2013).

In the academic field, calculating the environmental impacts of a university started to consider beyond a single building and it began to emphasize operational stage calculations. For example, Aly Abdelalim calculated 45 educational buildings carbon emissions in Canadian universities (Abdelalim *et al.*, 2015). Chia Chien Chang studied Nanyang Technological University's (NTU) 22 academic buildings, with a study showing that energy consumption in the operational stage is between 63% and 95%, while the remaining 5%-37% is from embodied energy. This suggested the necessity for expanding the research to the non-academic buildings to better understand overall campus' embodied carbon emissions, and it established a local database for major building materials to ensure higher accuracy for calculation of embodied energy(Chang *et al.*, 2019), meaning that the operational stage made the most emissions.

Results from further studies also suggest that transportation and carbon sequestration of green plants also contribute a large part to carbon emissions, for example: the University of Talca's carbon emissions results show the transportation of people produced the highest contribution of 0.41 tCO_2e per person (Yañez *et al.*, 2020a). The University Teknologi Malaysia (UTM) considered air transportation utilized by university students and employees contributed 34.74% and electricity usage contributed 19.37% (Naderipour *et al.*, 2021). Pusan National University campus carbon emissions calculated the movement of the campus' members which were 21.5% (Jung *et al.*, 2016), and the University of 'Lille 1' calculated the mobility users as 56% (Bouscayrol *et al.*, 2017).

Carbon absorption by vegetation also cannot be ignored. For example, studies show that the green belt in the SVNIT campus is absorbing 76.92 to 84.63% of CO_2 emission annually (Suresh *et al.*, 2021), Shandong Jianzhu University carbon sequestration of green spaces in 2015 was 11936 tonnes, which was equal to about 34.7% of the total carbon emissions (ZOURan, 2017).

In summary, studies have shown that campus carbon accounting emphasizes both special and temporal circumstances.

(1) Quantifying campus carbon footprint should emphasize the whole campus. It is necessary to move the carbon neutrality calculations beyond campus buildings and this should include buildings, mobility, carbon sequestration, and carbon reduction as a result of renewable resources.

(2) Studies related to the carbon emissions calculations of campuses mostly

emphasize the operational stage of a university campus.

(3) In the selection of carbon accounting objectives, due to their high percentages, studies have suggested including the importance of calculating carbon emission of mobility and the sequestration of green plants on campus (Bouscayrol et al., 2017, Suresh et al., 2021, ZOURan, 2017).

3 Study area and methodology of work

3.1 Case Study: Tianjin University

Tianjin University (TJU) was founded in 1895 as Peiyang University and is the first university in modern (1840-1919) Chinese history. In 1951, Peiyang University and Hebei Technical College combined under the name of TJU. The University has 3 campuses, and this research aims to calculate the carbon emission of TJU Weijin Road Campus (old campus) and Peiyangyuan Campus (new campus). The total numbers of domestic and foreign students, academic staff, and non-academic staff can be seen in **Table 1**.

Table 1 TJU'S Weijin Road and Peiyangyuan Campus's characteristics in 2019

	Weijin Road Campus	Peiyangyuan Campus	**Total**
Academic staff	2569	2500	5069
Undergraduates	10004	9784	19788
Postgraduates	8247	9080	17327
Foreign students	1243	824	2067
Non-academic staff	300	300	600
Total	22363	22488	44851

Source: TJU Office of Student Affairs & Office of Human Resources

3.1.1 Study area configuration

TJU Weijin Road campus enclosed areas is 1,362,000 m^2. TJU Peiyangyuan campus enclosed areas is 2,436,000m^2 (University, 2020a) . Weijin Road Campus is divided into two parts, Part A is the main campus area and it has three entry gates each marked with a number in the figure. Part B is the old and extended parts of TJU Weijin Road Campus and no longer part of the university, and therefore it can be excluded as it doesn't have any energy relationship with the study area (Fig. 5).

The object of this study is to include all the buildings and facilities (including teaching buildings, laboratories, libraries, logistics, all canteens, etc.) under the control of TJU, and all the carbon emissions and activities relating to the daily life of the two campuses. The research area includes a campus area illustrated below, which also has No.42 dormitory building that is used for guest accommodation, but due to the complexity of statistics for visitors, this study will not include the No.42 dormitory building.

Legend: (A)Weijin Road Campus 1.East Gate 2.West Gate 3.North Gate (B) Not forming part of campus	**Legend:** Peiyangyuan Campus 1.North Gate 4. East Gate 2.South Gate 5. Northeast Gate 3.Southeast Gate N

Fig. 5 TJU'S Weijin Road and Peiyangyuan Campus's study area

3.1.2 Scope and phases considered

Many universities around the world have considered the carbon footprint of the mobility of students and staff from outside the campus area where its impact is normally lower than that of electricity (Helmers *et al.*, 2021). The situation in China is not the same and is impractical to calculate due to the very high number of students and staff. Students and staff at TJU travel from various parts of China, and they have various modes of transport, making it difficult to predict or anticipate when and where mobility occurred. Some studies have suggested questionnaire-based calculations for the mobility of students and staff (Helmers et al., 2021), but due to the long distances covered and the mobility situation in China, 'questionnaires' for the thousand (two campuses with a combined population of approximately 45000 people in total) were beyond the scope of this study - but an estimate would be sufficient rather than attaining precise and reliable travel statistics from outside the campus.

The carbon footprint of a university should be intrinsically focused on emissions caused by activities within the campus, rather than the mobility of students and staff occurring outside of the campus boundary which cannot be controlled by the university. It is also supported by Isiaka Adeyemi Abdul-Azeez, who pointed out in his research that carbon emission assessment should be focused on the sources which a university authority has control over where carbon emission strategies could be applied (Adeyemi, 2018).

In this regard, this research considers electricity, natural gas (heating and canteen cooking), and mobility of cars within the campus, solid waste generation, tap water, and human activity are each quantified for carbon emission accounting. Data was collected to quantify the 'operational stage' of GHG emissions of the two campuses in 2019.

3.2 Selection of Carbon footprinting accounting method

There are several standards for quantifying greenhouse gas emissions; IPCC, GHG Protocol, PAS2050, and ISO14064. IPCC is mainly for countries around the world to assess their carbon emission inventories and calculation methods. Countries make their reports and submit to the UN about the emission status and plans of reduction (Arndt *et al.*, 2020). GHG Protocol is established by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (WRI, 2004), PAS2050 is established by the British Standards Institution (BSI) (García and Freire, 2014). These two carbon emission systems are mainly for quantifying product and product-related services. ISO14064 is established by the International Organization for Standardization (ISO), which is a standard to calculate Greenhouse Gas emissions and Carbon Footprints (Wintergreen and Delaney, 2007).

As discussed earlier, PAS 2050 is mainly for products and their service and is not suitable for colleges and universities carbon emission calculations. IPCC is the most recognized carbon emission calculation standard at a national level, however, it is not suitable for China's present energy structure status and development.

Quantification of GHG emission methods vary among universities, some use ISO 14064 standards and some universities around the world use a corporate accounting and reporting standard - GHG Protocol (WBCSD, 2004), but of this study, we established a carbon footprint calculation method, using both IPCC, ISO14064 and officially authenticated documents, standards, and regulations relevant to China. IPCC sets the target of carbon emission, the carbon absorption ISO14064 method, categorizing carbon emission sources, and finally, China’s national standard ‘General rules’ have been applied for calculating the comprehensive energy consumption, GB/T 2589-2020 (Information, 2020), ‘Provincial Guidelines for Greenhouse Gas Inventories(PGGGI)’ (Development, 2011), ‘China's Regional State Grid Average Carbon Dioxide Emission Factor for 2011-2012’ (China, 2014) were used to select the coefficients and form carbon accounting methods which are most suitable for Tianjin city regions of China.

Calculation of CO_2 emissions, equal to the energy consumption and coefficient;

$$E = \lambda \sum_{i=1}^{n} A_{D_i} \times E_i$$

Where E represents CO_2 emission due to energy consumption. i represents the corresponding energy coefficient, and E_i is the emission factor.

4 Carbon emissions accounting

4.1 University campus carbon emissions inventory

Fig. 6 identifies the carbon emissions inventory which can be classified based on the emission source. The most important source is the emission from the campus buildings. Carbon emissions of buildings are composed of: the product stage, construction stage, operational stage, and the end of the life, or recycling stage. The carbon emission from the ‘use’ stage is mainly from its operational stage, where we conducted carbon emissions calculations in our research.

The second source of emissions is mobility. A campus can be considered as a small city, where people move regularly across the two sites as well as different logistic vehicles which provide services. Based on the users, mobility can be divided into four main parts: support staff and teaching staff, students, visitors from outside and logistics.

The third source of emissions is campus life activities generating high levels of carbon emissions. The most carbon emissions can be observed from waste generation and people breathing inside the campus. The other factors are food and water usage inside the campus. Out of these emissions, food, waste and water could be controlled or managed more effectively. The carbon emission from people breathing inside the campus cannot be controlled, instead this could be replaced by carbon sequestration using more plantations.

In summary, the campus carbon emission inventory diagram can be used as a guide for calculating both campuses' carbon emissions. In this study, we calculated carbon emissions through their operational stage. In later sections of this paper we will examine embodied carbon, and the operational platform which will monitor, review, estimate, and most importantly, demonstrate - the carbon reduction paths for colleges and universities.

4.2 Campus carbon emissions inventory diagram

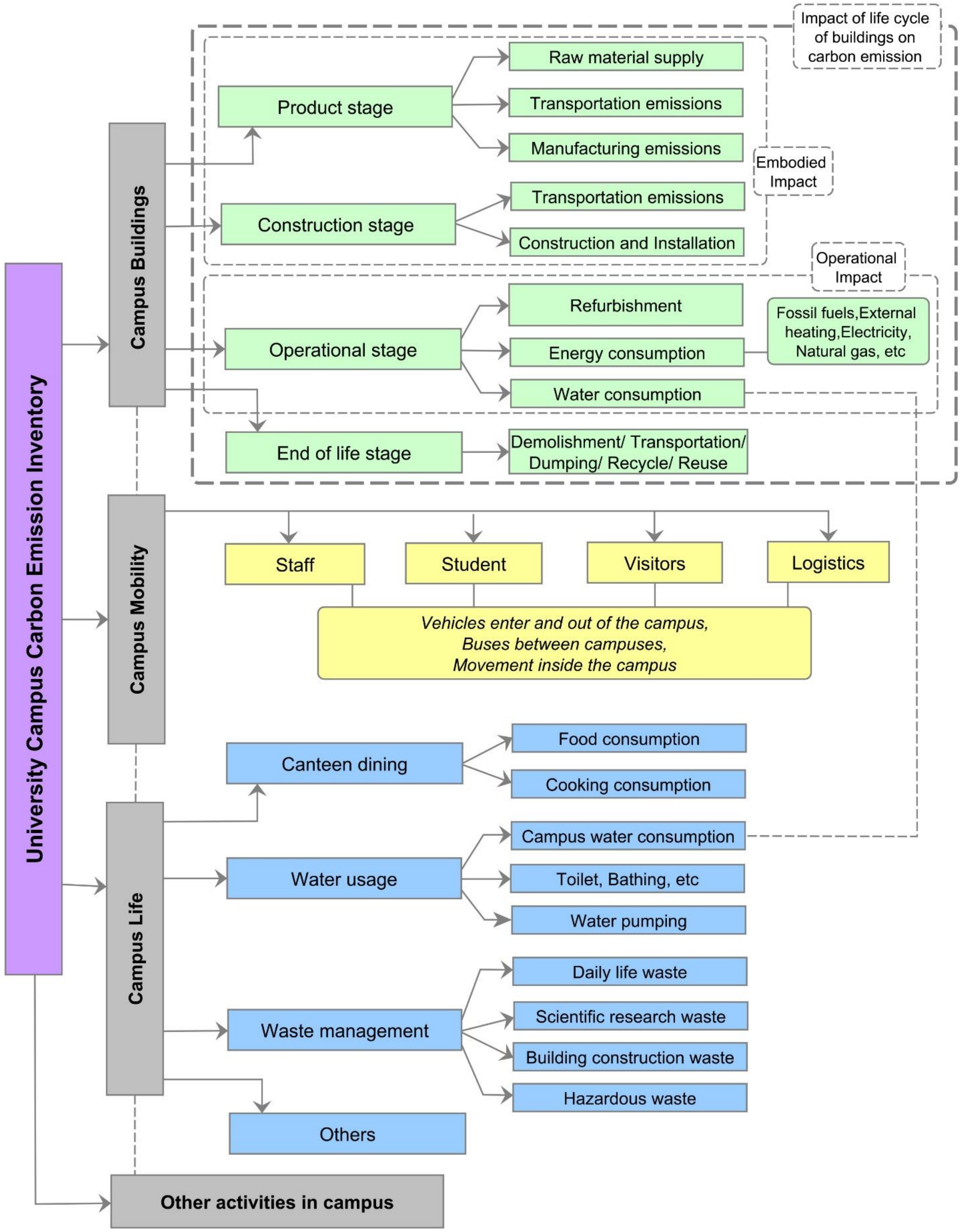


Fig. 6 Campus carbon emissions source system and classification

4.3 Carbon emission accounting of Tianjin University

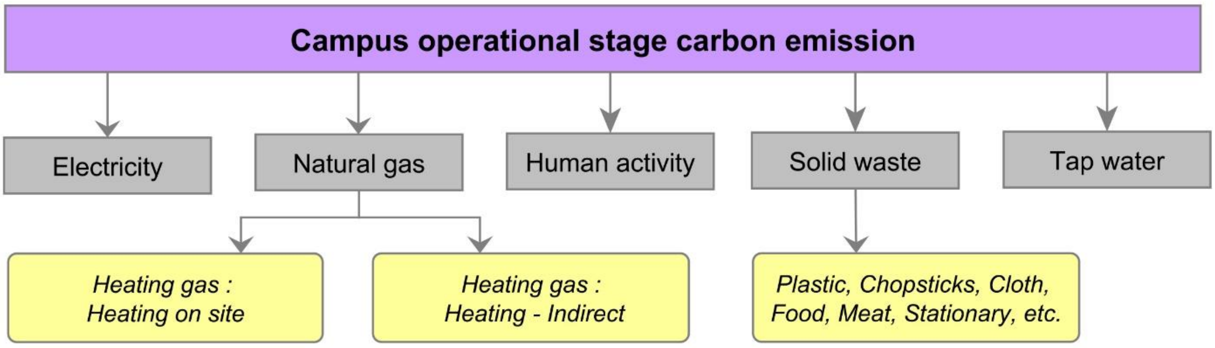


Fig. 7 Campus carbon emission calculation model based on the operational stage

4.4 Carbon emissions of electricity usage

The arithmetic terms of calculation are the following:

$$E_{electricity} = \sum_{i=1}^{n} S_i \times I_{electricity}$$

Where, S_i is the electricity consumed by i buildings (KWh), i represents the number of buildings. $I_{electricity}$ emission factor ($kgCO_2$/KWh).

The electricity used in both campuses is from the China State Grid, according to China's Regional State Grid average carbon dioxide emission factor for 2011-2012, published by the National Development and Reform Commission of the People's Republic of China, Tianjin belongs to the North China Branch of the State Grid. The standard emission factor for electricity is given as $I_{electricity}$=0.8843kgCO^2/kWh (China, 2014). There is no official data available for the standard emission factor for Tianjin in 2019, although the most recent research, published by academician Jiang yi, pointed out that the national average electricity carbon emission factor for 2019 is: $I_{electricity}$=0.577 kg CO_2/kwh (Yi and Shan, 2021). So for this purpose, we use the average electricity carbon emission factor of China in 2019.

Thus, the total carbon emission of Weijin Road Campus from electricity:

= 35729.77 tonnes CO_2

And, the total carbon emission of Peiyangyuan Campus from electricity:

= 38274.03 tonnesCO_2

Table 2 Carbon emissions of TJU's two campuses from electricity usage

Campus	CO_2 emission of electricity usage
Weijin Road Campus	35729.77 tonnes
Peiyangyuan Campus	38274.03 tonnes

4.5 Carbon emission by natural gas (consumption during heating)

Natural gas data for the Weijin Road Campus is used for combustion engines and gas-fired boilers for heating Teaching Buildings No.25 and partially for the Student Dormitory. In 2019, the total amount of natural gas consumed inside the campus is 158200m^3 (per annum).

Heating for the majority of buildings within Weijin Road campus is provided by the city municipality, using natural gas. Heating in Peiyangyuan campus is from heating appliances also using natural gas.

The arithmetic term of calculation is the following:

$$E_{natural\ gas} = \sum_{i=1}^{n} S_i \times I_{natural\ gas}$$

Where, S_i natural gas used in No. i building (m^3)

$I_{natural\ gas}$ is the carbon emission caused by burning 1 m^3 natural gas,

Natural gas measured (Tianjin area) has a calorific value of 33,486.8144KJ/m^3. Carbon content per unit of calorific value is 15.32 TC/TJ and carbon oxidation rate is 0.99

(2021), so the standard emission factor for natural gas is:

$I_{natural\ gas}$= (1 × 33,486.8144 KJ/m^3 × 15.32TC/TJ × 0.99 × 44/12)/1000000 = 1.862321kgCO_2/m^3.

Thus, the total carbon emission Weijin Road Campus from natural gas (for heating):

=12060.76 tonnes (per annum)

The total carbon emission for Peiyangyuan Campus from natural gas:

=6402.47 tonnes (per annum)

Table 3 Carbon emission of TJU's two campuses from natural gas usage

Campus	CO_2 emission of natural gas usage
Weijin Road Campus	12060.76 tonnes
Peiyangyuan Campus	6402.47 tonnes

4.6 Carbon emissions from mobility

The mobility of vehicles within TJU is complex, as the area of the university is large, densely populated, and generally very busy at peak times. To overcome this problem an average travelling distance inside the university was calculated based upon the entry points and parking bay locations. The travelling distance to each parking bay was calculated with the aid of Google Maps to measure optimum travel distances. Distances were carefully plotted and the average of these distances were assimilated. Entry points and parking bays for the TJU Weijin Road Campus are shown in **Fig. 8**. Weijin Road Campus has three main entry gates which are called East Gate, West Gate, and North Gate. All vehicles are allowed to enter from these gates.

The distance from each entry point to the most used parking bays is shown in Table Appendix A. It was observed from this calculation that the average travelling distance of any vehicle inside the Weijin Road campus is 1.594 km.

The entry points and parking bays for the TJU Peiyangyuan Campus are shown in Fig. 9. It was observed from this calculation that the average travelling distance of any vehicle inside the Peiyangyuan Campus is 2.720 km (Appendix B).

Data regarding vehicles entering and exiting the university campus was obtained from the Security Department of Weijin Road and Peiyangyuan Campus. Weijin Road campus during 2019 had a total count of cars entering and exiting amounting to 92964, whereas Peiyangyuan campus had 860359 cars entering and exiting the campus.

Overall average distance travelled inside the campus:

Weijin Road Campus: D = 929641÷ 2 × 1.594km = 740923.9km

Peiyangyuan Campus: D = 860359 ÷ 2 × 2.720km = 1170088km

The arithmetic term of CF calculation of transportation is the following:

$$E_{transportation} = \sum_{i=1}^{n} D_y \times Q_{fuel\ consumption} \times I_{fuel\ consumption} \div 100$$

Where: $E_{transportation}$ is carbon emission, D_y a car travel distance over a year (km/d. per car), $Q_{fuel\ consumption}$ (fuel consumption/100 km),$I_{fuel\ consumption}$ is the carbon dioxide emission coefficient of energy (kgCO_2/kg), and i is the energy consumed.

According to the 'Automobile Enterprises Corporation', the average fuel consumption published by the Ministry of Industry and Information Technology of the People's Republic of China, the corporate average fuel consumption is 5.56L/100km (China, 2020).

The standard emission factor for diesel oil is given as $I_{Diesel\ oil}$=3.096kgCO_2/kg, one liter of diesel is 0.9kg on average (2021).

Fig. 8. Entry, exit and parking spots inside the Weijin Road Campus

Weijin Road Campus:

$E_{transportation}$= 740923.9km × (5.56 × 0.9kg)/100km × 3.096kgCO_2/kg = 114.79 tonnes (per annum)

Peiyangyuan Campus:

$E_{transportation}$= 1170088km × (5.56 × 0.9kg)/100km × 3.096kgCO2/kg ÷ 100 = 181.27 tonnes (per annum)

Table 4 Annual vehicles entering and exiting the campus, Note: Data obtained from the Security Department of Weijin Road and Peiyangyuan Campus.

Campus	Total count of vehicles enter and exit	CO_2 emission of the vehicle
Weijin Road Campus	929641	114.79 tonnes
Peiyangyuan Campus	860359	181.27 tonnes

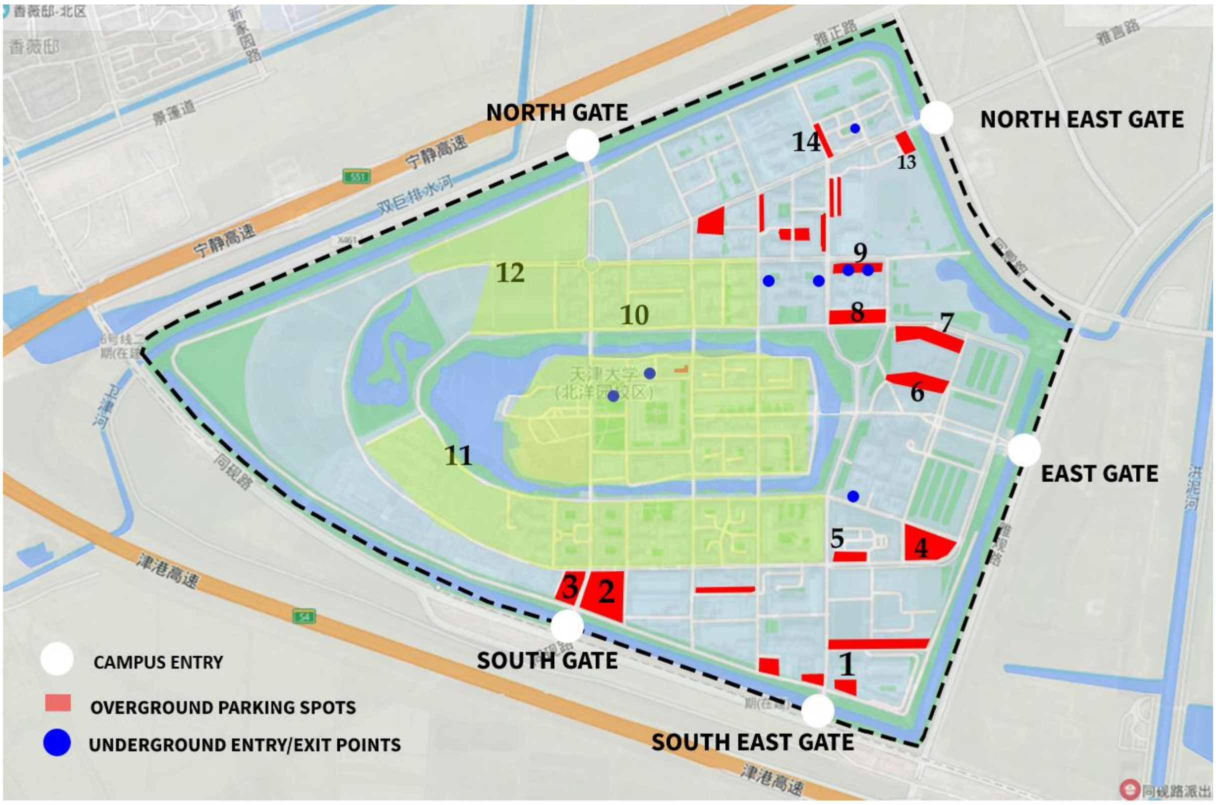


Fig. 9 Entry, exit and parking spots inside the Peiyangyuan Campus

4.7 Carbon emission by solid waste generation

Solid waste treatment in the Tianjin campus is by incineration. According to IPCC CO_2 emission of the total amount of waste combusted can be calculated by the equation:

$$CO_2\ \text{Emissions} = MSW \times \sum_{i=1} (WF_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times 44/12$$

Where: CO_2 Emissions in inventory year, tonnes/per annum;

MSW: the total amount of municipal solid waste as wet weight incinerated or open burned, tonnes/per annum,

WF_j: fraction of carbon in the dry matter (total carbon content),

dm_j: dry matter content in the component i of the MSW incinerated or open-burned, (fraction)

CF_j: fraction of carbon in the dry matter

FCF_j: fraction of waste type/material of component i in the MSW(as wet weight incinerated or open-burned)

OF_j: oxidation factor, (fraction)

44/12: conversion factor from C to CO_2

i: component of the MSW incinerated/open-burned (IPCC, 2016);

CF_j=20%; FCF_j=39%;OF_j=95% (Commission, 2013) (Zhao *et al.*, 1762)

During the 2019 academic year at TJU there were 292 school days and 73 days for winter and summer vacations (University, 2019), Vacations are calculated at 1/4 of waste generated.

Peiyangyuan Campus waste generation per day is about 35 tonnes (after dehydration). Therefore, the total waste during the year = during school day + during vacation (292 ×35t) + (73 × 35 × 1/4) = 10858.75 tonnes.

Therefore total $MSW_{peiyangyuan}$ = 10858.75 tonnes.

Peiyangyuan Campus: CO_2 emissions from solid waste=10858.75 × 0.20 × 0.39 × 0.95 × 44/12 = 2950.32 tonnes.

Weijin Road campus solid waste is managed by the Tianjin City Municipality and it is not clear how much waste is generated on campus each day or per annum. An average per capita solid waste generation for Peiyangyuan Campus was estimated and used to calculate the Weijin Road Campus carbon emission from solid waste.

Total waste generated during the year in Weijin Road campus = (Total waste in Peiyangyuan Campus/Total population in Peiyangyuan) × Total population in Weijin Road Campus = (10858.75/22488) × 22363=10798.39 tonnes.

Weijin Road Campus: CO_2 emissions from solid waste= 10798.39 × 0.95 × 0.20 × 0.39 × 44/12 = 2933.92 tonnes.

4.8 Faculties and students' daily life consumption

The emission caused by faculties, students, and other nonacademic staff on campus is difficult to assess, so approximate values were derived from similar situations. The most recent study on carbon emission caused by human activity is from Peking University. In this study, it was estimated that daily consumption of plastic, chopsticks, cloth, food, meat, buying a book, and paper, etc. created an average of 0.53 tonnes/per person per annum, so during the academic year of 292 days, the average was 0.39 tonnes/per person per academic year (Y Zheng, 2011).

$$E_{daily\ life} = C_{DAY} \times R \times t$$

Where, C_i per capita carbon emission per day, R total population of campus, t number of days for calculation.

Weijin Road Campus = 6977.26 tonnes;

Peiyangyuan Campus = 7016.26 tonnes

Table 5 Carbon emission of TJU's two campuses from human activity

Campus	Total population	CO_2 emission of human activity
Weijin Road Campus	22363	6977.26 tonnes
Peiyangyuan Campus	22488	7016.26 tonnes

4.9 Carbon emission by tap water

The arithmetic term of Carbon footprint calculation of tap water is the following:

$$E_{water} = \sum_{i=1}^{n} S_i \times I_{water}$$

Where S_i is water used by i buildings (m^3), i represents the number of buildings.

I_{water} emission factor ($kgCO_2/m^3$)

Tap water consumption is considered with a conversion factor of $0.194 kgCO_2/m^3$ (Com, 2015).

Weijin Road Campus: E_{water}= 356.18 tonnes

Peiyangyuan Campus: E_{water}= 389.40 tonnes

Table 6 Carbon emission caused by using tap water for consumption

Campus	CO_2 emission of tap water usage
Weijin Road Campus	356.18 tonnes
Peiyangyuan Campus	389.40 tonnes

4.10 Total Carbon emission

The total Weijin Road Campus emission for 2019

E(Total) = E(electricity) + E(natural gas) + E(transportation) + E(solid waste) + E(tap water) + E(human activity)

Table 7 TJU Weijin Road Campus - Fiscal Year 2019 emissions and percentages

Item	Emissions (tonnes CO_2)	Percentage %
Purchased electricity	35729.77	61.42
Natural gas for heating	12060.76	20.73
Human activity	6977.26	11.99
Solid waste	2933.92	5.04
Tap water	356.18	0.61
Transportation	114.79	0.20
Total Carbon emission	**58172.68**	**100%**

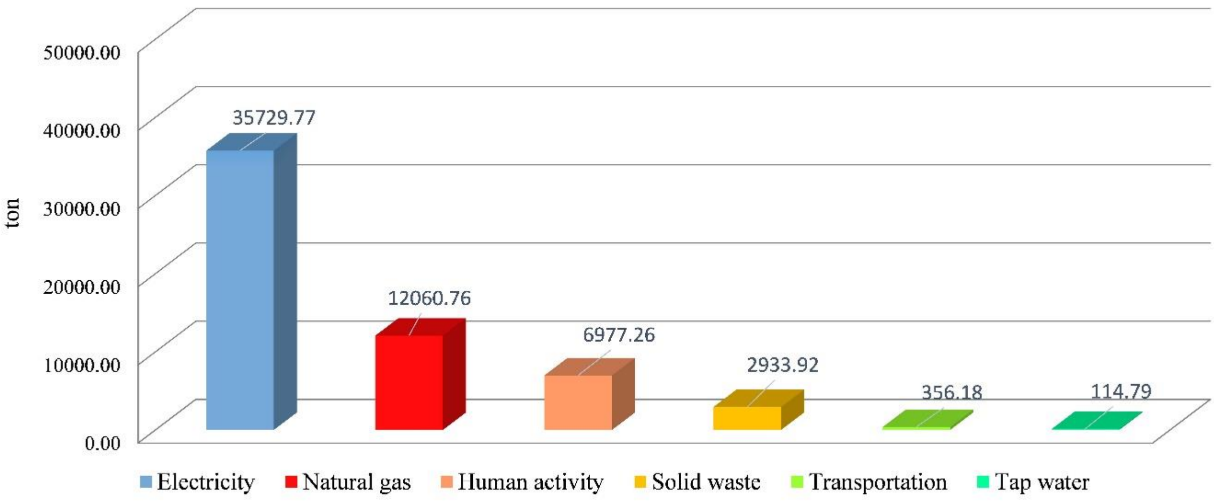


Fig. 11 Carbon footprint by source at Weijin Road Campus

Table 8 TJU Peiyangyuan Campus's– the Fiscal Year 2019 emissions and percentages

Item	Emissions (tonnes CO_2)	Percentage %
Purchased electricity	38274.03	69.32
Natural gas for heating	6402.47	11.60
Human activity	7016.26	12.71
Solid waste	2950.32	5.34
Tap water	389.40	0.71
Transportation	181.27	0.33
Total	**55213.75**	**100%**

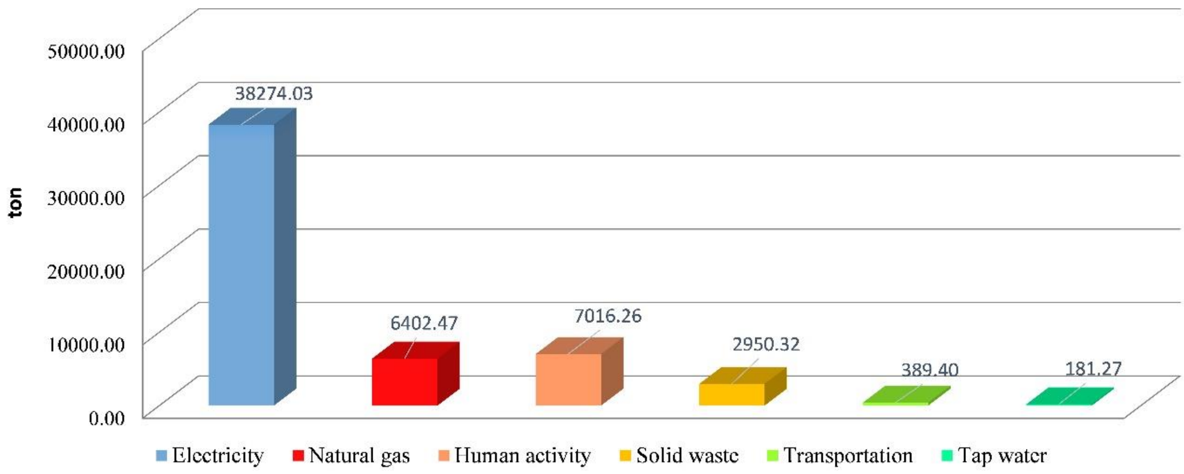


Fig. 10 Carbon footprint by source at Peiyangyuan Campus

4.11 Total carbon sequestered amount by trees and green areas

The intensity of green plant photosynthesis and the plant's leaf area is critical for carbon sequestration. To account for the carbon sequestration of green plants on campus, the green-lands type structure on campus is divided into four types: tree-shrub-herb type, shrub-herb type, lawn type, and grassland.

The arithmetic term of carbon sequestration amount is the following:

$$C_{\text{sequestration}} = \sum_{i=1}^{n} T_i \times S_i \times D$$

Where T_i is i are green-lands with daily carbon sequestration ($g \cdot m^{-2} \cdot d^{-1}$)

S_i and i area green-lands area (m^2); D number of days for calculation, generally D=365.

Weijin Road Campus: the lawn area is approximately 153700m^2 and there are 15,000 trees and shrubs.

C_{lawn}=153700$m^2 \times 55.42 g \cdot m^{-2} \cdot d^{-1} \times 365$ = 3109.09 tonnes

The available published report regarding Weijin Road campus's carbon sequestration suggests that 1,950m^2area with 50 tree-shrub-herb types or shrub-herb, have total average carbon sequestration of approximately 27.16 tonnes (Garden, 2021);

$C_{\text{trees and bush}}$ = (Total tree – shrub - herb type shrub - herb)/unite carbon sample area total tree-shrub-herb × 27.16 tonnes = 8148.25 tonnes

Therefore, the total carbon sequestration of the Weijin Road Campus is:

C_{lawn}+ C_{trees} and bushes = 11257.34 tonnes

Peiyangyuan Campus: the lawn area is about 808,750m^2, there are 110 types of trees making a total of 59,740 trees inside the campus.

C_{lawn}=（808,750m^2/2 × 55.42g·m-2·d-1 × 365）+（808,750m^2/2 × 23.38g·m-

2·d-1 × 365） = 11630.63 tonnes

$C_{\text{trees and bushes}}$ = (Totaltree-shrub-herb type shrub-herb)/Unite carbon sample area total tree-shrub-herb × 27.16/2 tonnes = 16225.88 tonnes

The total carbon sequestration of Peiyangyuan Campus is: C_{lawn}+$C_{\text{trees and bushes}}$ = 27856.51 tonnes.

Table 9 Different kinds of green-lands and types of plant structure per unit area for daily carbon sequestration amount ($g \cdot m^{-2} \cdot d^{-1}$) (GUO Xinxiang, 2010)

Type	tree	bush	lawn	Total
tree-shrub-herb type	35.67	20.95	23.38	79.99
shrub-herb	15.29	33.52	23.38	72.18
lawn	15.29	16.67	23.38	55.42
grassland	0.00	0.00	23.38	23.38

4.12 Carbon emissions reduction by renewable energy

4.12.1 Solar water heater

Weijin Road Campus has no renewable energy at the moment, whereas, on Peiyangyuan Campus there are solar water heaters, ground source heat pumps and air source heat pumps in use.

According to the design specification, Peiyangyuan Campus solar water heater system's design terms are: water temperature should be considered 60°C, and the winter temperature of tap water set at 10°C. Total water consumed during 2019 at 3387.20 tonnes = (11.69 tons per day × 292 school day), with solar fraction factor being 60%.

Total heat absorbed: $Q = C_p m \Delta T = 4.18 \times 3387200 \times (60 - 10) = 0.71 \times 10^{12}$J.

Where: Q is heat absorbed, C_p is the specific heat capacity of liquid water (C_p=4.18KJ/kg·°C), m is mass of water, ΔT is the change in temperature, defined as the difference between the final temperature and the initial temperature.

$$Q' = Q \times 60\% = 0.71 \times 10^{12}J \times 60\% = 0.43 \times 10^{12}J$$

Carbon emission coefficient of standard coal 94.60t/TJ, and the efficiency of η boiler=80%. So the amount of carbon reduction by the solar water heater, BE= $(0.43 \times 10^{12} \div 80\%) \times 94.60t/TJ \times 10^{-12} = 50.85$ tonnes

Therefore, the total avoided greenhouse gas emission due to using a solar water heater system is 50.85 tonnes.

4.13 Carbon neutrality assessment

$$E_{net} = E(total) - E(sequestered) - \text{carbon reduction by renewable energy}$$

Table 10 Carbon neutrality assessment

Campus	Total carbon emission (tonnes)	Total carbon Sequester (tonnes)	Carbon reduction by renewable energy (tonnes)	Net carbon emission (tonnes)
Weijin Road Campus	58172.68	11257.34	—	46915.34
Peiyangyuan Campus	55213.75	27856.51	50.85	27357.23

5 Results comparison analysis

5.1 Comparison of the two campuses

According to the 2019 inventory, Tianjin University's two campuses emitted 113,386.42 metric tons of carbon dioxide equivalent. Fig. 10 shows that, at Tianjin University's both campuses, electricity was the greatest source of emission, producing 65.27 % of total carbon emission followed by natural gas for heating, producing 16.28%, human activity producing 12.34%, solid waste generation producing 5.19%, tap water and transportation producing 0.66% and 0.26% respectively (Fig. 12).

Table 11 Carbon emission by sector

Item	Emissions (tonnes CO_2)	Percentage %
Purchased electricity	74003.80	65.27
Natural gas for heating	18463.23	16.28
Human activity	13993.51	12.34
Solid waste	5884.25	5.19
Tap water	745.58	0.66
Transportation	296.06	0.26
Total Carbon emission	**113386.42**	**100.00**

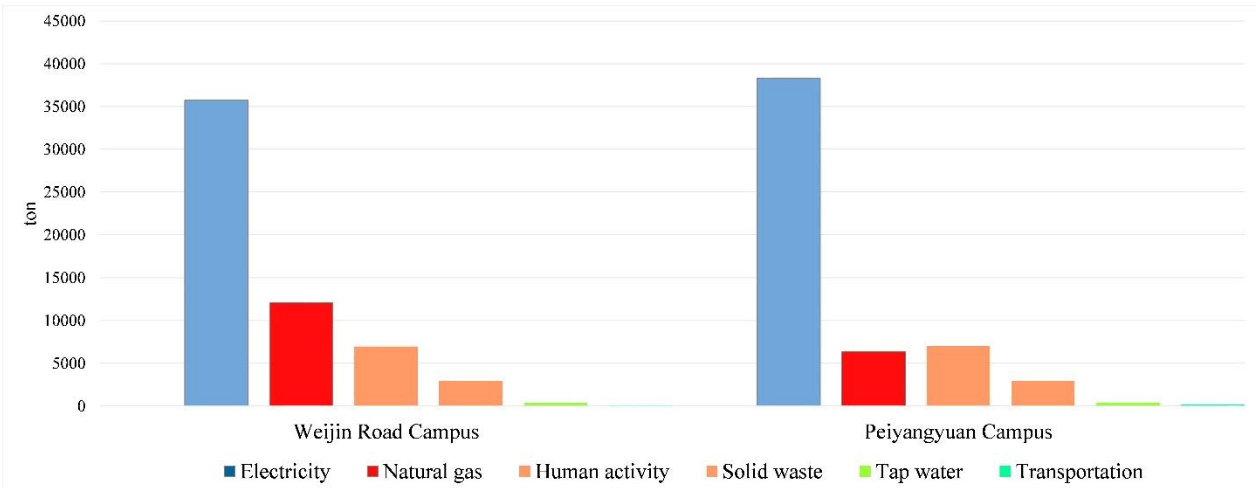


Fig. 12. Carbon emissions percentage by sector

Results show that the campus's emissions are mostly concentrated on a daily 'operational stage'. Most of the energy use is heating related to the winter season, followed by air conditioning, lighting, and canteen cooking, affecting CO_2 campus emissions. The majority of energy consumed on both campuses is electricity, and natural gas, constituting 81.55% (Fig. 13) of total carbon emission with electricity usage being highest on both campuses. The main difference in carbon emissions is natural gas usage. Weijin Road Campus uses heat provided by the Municipal Corporation of Tianjin, whereas Peiyangyuan Campus produces heating on its own. Carbon emissions from transportation in both campuses are very low and this could be reduced in the future by using electric vehicles. The most important factor to be considered in reducing carbon emissions is the reduction of national grid electricity and natural gas usage. These two energy sources are indirectly related and both could change through improvements and renovations to all buildings with a view to upgrading heating, lighting, and ventilation equipment and appliances that require less energy input. A carbon emission reduction program should begin as soon as possible to ensure the best overall outcome.

5.2 General comparison with other campuses around the world

This section outlines the comparison between carbon emissions from different

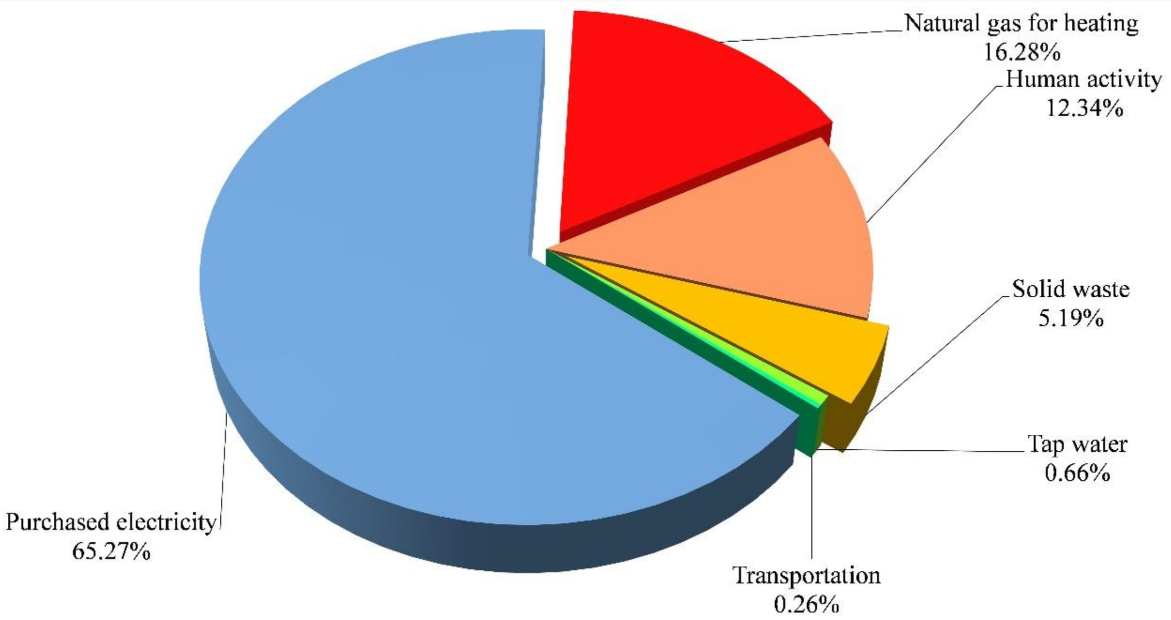


Fig. 13 Carbon emission percentage by sector

universities around the world using at least two universities from each continent. There were many universities from Europe and USA but only one university from Africa and South America, where current research data was available. In total, 13 Universities were selected as shown in **Table 12** , together with Tianjin University. For this comparison, both campuses were combined to represent Tianjin University as a whole.

The survey started with analyzing published research papers regarding the carbon emissions of universities around the world. Only specific data was used for each university so that all universities can be compared within the same parameters together with scientific papers and university reports. It wasn't possible to collate data for the same year as each university had research or publications carried out in different years and therefore data is presented from universities not older than 2013. The total number of students and staff was directly adopted with CO_2 emissions taken from existing research papers and university reports. The carbon footprint of each university is further evaluated based upon two main factors, per capita and per build-up area. The term 'Build Up Enclosure Area' is used as a common term to describe the different areas under consideration while calculating carbon emissions. These areas differ between universities as they use alternative units such as: measuring internal net floor areas, deducting lift shafts, vertical service shafts, stairs, etc. In this study, it is assumed under the same collective term for general comparison.

Table 12 Universities around the world and their carbon emissions (Note: data a & b taken from 2017 Zhejiang university yearbook)

NO	University (Or campus)	Country	Research period	Total No. of students and staff	Build up enclosure areas (m_2)	Tonnes CO_2e emitted / per annum	Ref
1	Tianjin University	China	2019	46269	3,798,000	113,386.42	(University, 2020b)
2	Tongji University	China	2014	53000	1,600,000	180,480	(Li *et al.*, 2015)
3	Zhejiang University	China	2016	57185[a]	4,265,653[b]	76,649.99(Zhu *et al.*, 2021)	
4	Shandong Jianzhu University	China	2015	27622	1,600,000	36798	(Chen Yue, 2016)
5	NTU Singapore	Singapore	2017	40750	1,382,388	138,402	(NTU, 2017)
6	Yale University	USA	2016	28642	1,342,297	234,024	(University, 2016)
7	Minnesota State University	USA	2017	15567	157,930	44,831	(UNIVERSITY, 2019)
8	Monash University	Australia	2015	70924	728,193	188,416	(University, 2016)
9	University of Queensland	Australia	2015	57621	747,523	214,249	(QUEENSLAND, 2015)
10	Leuphana University	Germany	2015	10339	83,300	7,593	(Opel *et al.*, 2017, Lüneburg
11	Kings College, London	Great Britain	2018	39877	251,154	50,556	(London, 2020)
12	University of Cape Town	RSA	2013	31041	668,165	88,752	(TOWN, 2013, Rippon and Design
13	University of Talca	Chile	2016	7869	98,000	32,869	(Yañez *et al.*, 2020b)

Intercorrelations of carbon footprints were investigated between all the universities based upon per square meter of carbon emissions and carbon emissions per person. Based on the data from the previous table these two factors were calculated and placed in the chart shown in Fig14 .. It can be seen that TJU carbon emissions are lower in comparison to most of the selected universities around the world. As the campus area of TJU is very large, it accounts for less carbon emission per square meter, but unfortunately, TJU carbon emissions are higher than many European Universities. Monash University (Australia) has almost the same carbon emission per person and capita as TJU, and it intends to reach carbon neutrality in 2030 by implementing energy-efficient retrofitting into the buildings, reducing energy consumption, and establishing renewable electricity plants. In this comparison, data presented here suggest that TJU could have zero carbon emissions possibly sooner.

Moreover, in 2019, the total expenditure of TJU was 5411567300 Rmb (University, 2020c), which is equal to 838768.61 USD (Buying Rate=645.18, BOC Exchange Rate 2021.09.24 15:06:58). Thus the carbon footprint per USD1000 is 134.25kgCO_2e.

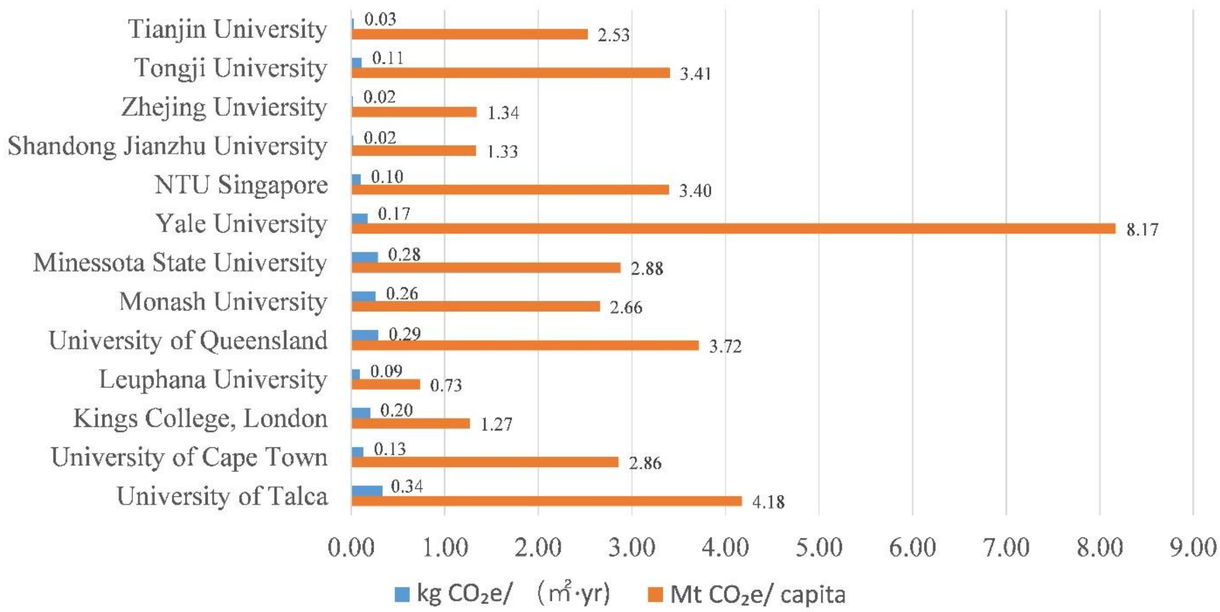


Fig .14Carbon footprints comparing universities around the world

6 Carbon neutrality 'Road Map' for Weijin Road and Peiyangyuan Campus

A hypothetical carbon reduction 'Road Map' can now be proposed. The first proposal is a carbon reduction plan for every each year until the total emission is zero.

The second proposal, as an alternative, is a 5-year plan giving a carbon reduction target for the next five years until the total emission is zero.

6.1 Time planning of carbon reduction target

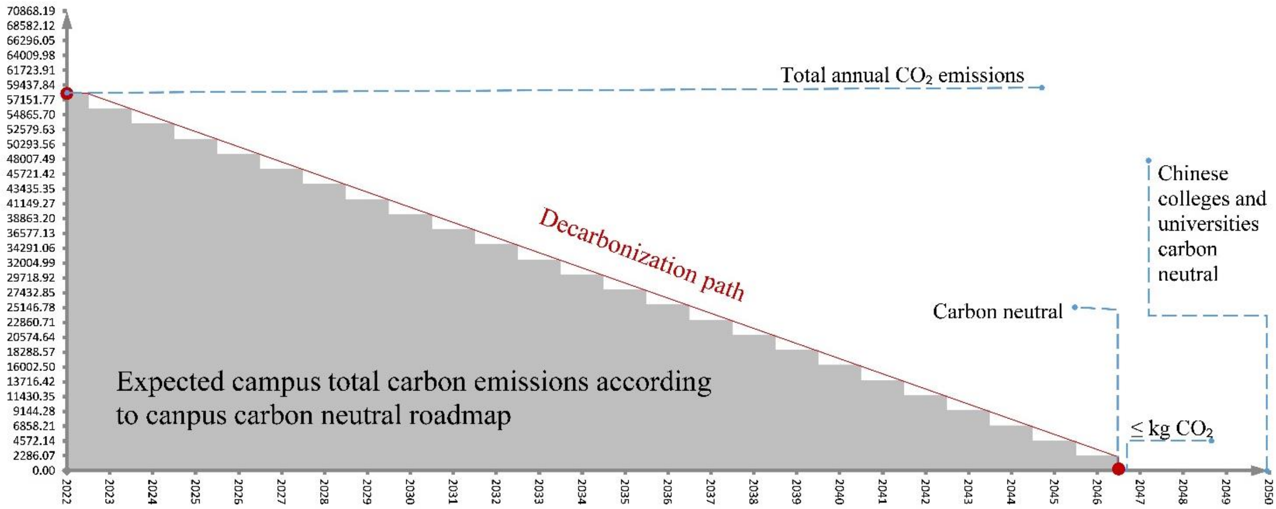


Fig. 15 Decarbonisation path for Weijin Road campus on a yearly based plan

Yearly Carbon Reduction Plan: Fig. 15 shows a carbon reduction strategy up to the year 2050. This path explains one possible direction for carbon reduction over a long period of time, 2326.91 tonnesCO_2 should be reduced each and every year to achieve carbon neutrality in 2047.

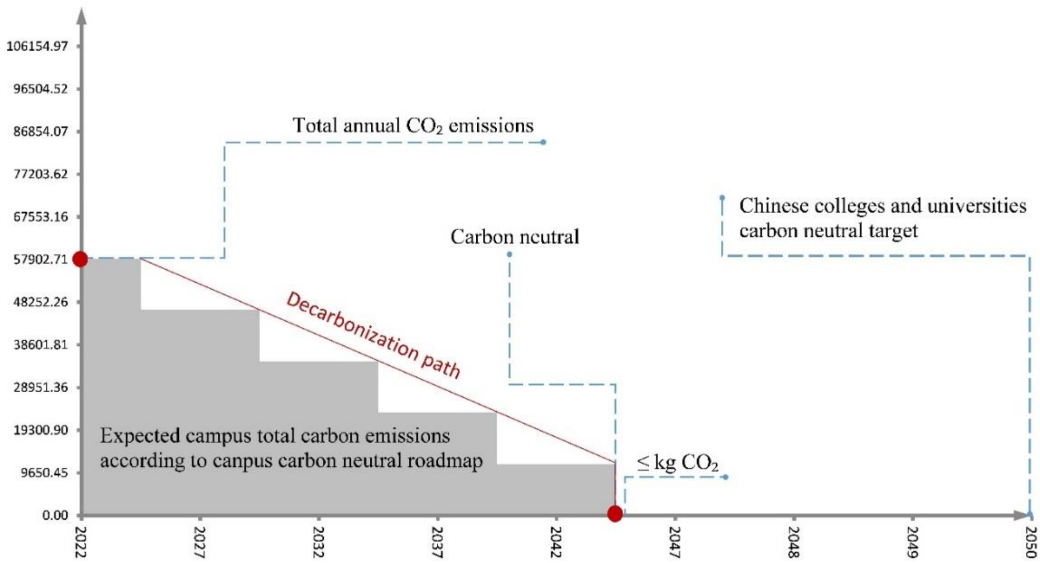


Fig. 16 Decarbonisation path for Weijin Road Campus five-yearly based plan

Five Year carbon reduction plan: Fig. 16 shows how a series of targets need to be achieved in successive five yearly stages to achieve zero carbon emission in the target year of 11634.54 tonnes CO_2 should be reduced each and every five years to achieve carbon neutrality in 2047. The carbon reduction roadmap formulas are listed as below:

B2= (AN-A2)*ABS(SLOPE($D$2:$D$3,$C$2:$C$3)) (formula reference for Excel based Table 13)

X— Initial total carbon emission;

N— Final net zero carbon target year;

T— Target year of net-zero carbon emission;

E— Annual carbon reduction amount

Table 13 Campus annual carbon emission reduction amount calculating tool

	A	B	C	D	E
1	Year	Carbon emission in the corresponding year	Year	Initial total carbon emission	Annual carbon reduction amount
2	2022		2022	X	?
3	2023		T	0	
…	…				
N	T				

7. Limitations of this research

• Eating routines of students and staff are variable, throughout the year, where up to three meals per day are consumed on the premises per person. Eating off-site is an unknown variable and therefore not included in this study.

• Sequestration of trees and green spaces lacks detailed onsite information where there are no standards currently available to accurately calculate sequestration of trees and green spaces. This study has therefore taken an average minimum, which in the future needs to be calculated more precisely and objectively.

- Since $Q_{fuel\ consumption}$ (fuel consumption/100 km) is closely related to vehicles type, model (such as Audi, BMW...etc.), and age. We don't have this specific and detailed information regarding vehicle types, models and age for carrying out emission calculations for transportation, but there is official data on the total number of cars entering and leaving the site. Therefore in this study for $Q_{fuel\ consumption}$ (fuel consumption/100 km), we have taken a corporate average for fuel consumption, which is 5.56L/100km but in reality, $Q_{fuel\ consumption}$ (fuel consumption/100 km) could be higher than 5.56L/100km.

- Studies have shown that university carbon footprint from food is large, as a study from the campus cafeteria in Peking University shows. There is a necessity for further studies in the future on how best to reduce canteen carbon / ecological footprints and their emissions from daily food consumption and canteen practices (HUANG Bowei, 2016).

Conclusions

China has set a "30-60" target (China Plus, 2020), but there are still no official standards or technical guides for colleges and universities to plan for 'carbon emissions accounting and evaluation standards' (Zhu and Dewancker, 2021). The Assessment Standard for the green campus-GB/T 51356-2019' in China lacks comprehensive carbon assessment indicators, which in turn, currently constrains colleges' and universities' plans toward achieving carbon-neutral campuses. This study has laid out detailed accounting steps for a carbon footprint calculation methodology and outlined a scope of carbon accounting in an attempt to bring assessment theory and practice much closer together. This methodology may be used as a guide or framework for other Chinese colleges and universities to establish their carbon inventory and to assist in their future planning for a roadmap towards a carbon-neutral campus.

At present, fossil fuels still supply 84% of world energy (Plc, 2021). Carbon neutrality is a huge challenge for everyone. It is ultimately in everyone's best interest, and colleges and universities must set an example and should lead this new era of evolution.

Abbreviations

Tianjin University: TJU;

Ethics approval and consent to participate

Not applicable

Consent for publication

All the authors have approved the contents of this manuscript and have all agreed to submit it to Environmental Sciences Europe. All the authors confirm that the work described has not been published by any academic papers or in any form of a thesis and also is not under consideration for publication in any other Journals.

Availability of data and material

Datasets supporting the research included area in Appendix.

Competing interests

The authors declare no conflicts of interest.

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Author Contributions

Conceived the original idea, conceptualization, writing original draft preparation, investigation collected all the data and analyzed the data A.Z; Methodology—review and editing by A.Z.; Formal analysis by A.Z.; writing-review, editing and visualization, A.Z. and A.B.G; project administration, A.Z.; K.S. supervised and reviewed all work and manuscripts. Funding acquisition, A.Z. and K.S. All authors have read and agreed to the published version of the manuscript.

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Appendix A: Average distance travelled inside Weijin Road Campus

Destination	From the west gate in(km)	From the east gate in(km)	From the east gate in(km)
1	2.440	2.000	0.360
2	1.860	2.020	0.600
3	2.500	1.582	0.440
4	2.000	1.560	1.600
5	2.000	1.560	1.600
6	1.720	1.280	1.320
7	1.200	0.820	1.360
8	1.080	1.080	1.400
9	1.560	0.980	0.960
10	1.340	1.320	1.220
11	0.980	1.840	1.500
12	0.800	2.000	1.740
13	0.820	2.400	1.680
14	0.720	2.400	1.840
15	0.700	1.440	1.760
16	0.460	1.700	2.200
17	0.160	2.080	2.660
18	0.600	1.460	2.200
19	1.160	0.940	1.700
20	1.360	0.760	1.520
21	1.480	0.560	1.560
Average	1.282	1.513	1.486
Average			**1.427**
East Gate to West Gate (Return)		1.940	
North Gate to West Gate (Return)		2.500	
North Gate to East Gate (Return)		1.940	
North Gate to South Gate (Return)		1.746	
East Gate to South Gate (Return)		0.940	
West Gate to South Gate (Return)		1.500	
Average		**1.761km**	
Overall average distance travelled inside the campus		**1.594km**	

Appendix B: Average distance travelled inside Peiyangyuan Campus

Destination	From the north gate in(km)	From the northeast Gate in (km)	From the east gate in (km)	From the southeast gate(km)	From the south gate(km)
1	4.08	3.36	2.02	0.20	2.20
2	3.8	3.56	2.26	1.00	1.64
3	3.8	3.16	1.80	0.40	2.00
4	1.4	3.48	2.12	1.40	0.4
5	2.3	4.18	2.74	2.06	0.2
6	3.68	3.36	0.96	1.26	2.04
7	3.6	2.86	1.40	0.82	1.60
8	3.36	2.6	1.24	1.32	2.06
9	3.24	2.6	0.60	3.00	3.96
10	2.8	2.12	1.04	2.40	3.34
11	2.32	1.58	1.48	2.26	2.92
12	1.98	1.26	1.86	2.62	3.38
13	1.66	1.30	2.24	2.72	3.42
14	2.00	0.84	2.40	2.86	3.52
15	1.68	0.96	3.00	3.00	3.24
16	2.76	0.20	3.00	3.40	3.80
17	2.4	0.64	2.66	3.10	3.60
18	1.2	1.54	3.40	4.00	2.60
19	1.2	1.98	3.00	4.20	2.24
20	1.36	3.12	3.40	3.16	1.44
21	1.9	3.66	3.36	2.60	1.00
Average	2.50	2.30	2.19	2.28	2.40
Average			**2.33 km**		
North Gate to Northeast Gate (Return)		2.8			
North Gate to East Gate (Return)		3.8			
North Gate to Southeast Gate (Return)		4.2			
North Gate to South Gate (Return)		2.4			
Northeast Gate to East Gate (Return)		3			
Northeast Gate to Southeast gate (Return)		3.6			
Northeast Gate to South Gate (Return)		4.2			
East Gate to Southeast Gate (Return)		2.06			
East Gate to South Gate (Return)		2.86			
Southeast Gate to South Gate(Return)		2.2			
Average		**3.11 km**			
Overall average distance travelled inside the campus		**2.72 km**			

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