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Research Paper

Research on indicator system and carbon emissions of low-carbon eco-city - A case study in Hangzhou, China

J. Ge[1], M.Y. Lu [2], J. Lu[3], X.Y. Luo [4] and Y. Zhu [5]

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ABSTRACT

Based on an extensive review of 31 international and domestic indicator systems, a system, which consists of 6 primary categories, 19 secondary categories, and 39 indicators is proposed for Transfer Science and Technical Park in Hangzhou city, covering sustainable development in environment, urban space and green building, transportation, energy and resource, governance and infrastructure, and economy aspects. Then all indicators are classified into three implementation stages (e.g. regional control indicators, park management indicators, and block control indicators) to ensure the fully accomplishment of low-carbon targets, which are always neglected by researchers, planners, governments and city managers. In the end, two scenarios are adopted, while the former is developing in traditional way and the latter is under the circumstance that all indicators are accomplished, to calculate the carbon reduction in order to quantitatively evaluate the effect of the indicator system. The results reveal that the policy makers should give the priority to indicators related to green buildings (e.g. ratio of green buildings), utilization of renewable energy, green transportation (e.g. mixed land use, green travel, green vehicles, etc.), greenery (green coverage ratio, multi-coat landscaping planting system etc.) while establishing policies and guidance towards a low-carbon eco-city.

1. Introduction

Climate change as a global issue is drawing close attention from the international community, as well as some energy and environment issues. Nowhere are the issues more pressing than in China, where urban areas and their economies are expected to grow rapidly over the next few decades and where resource use and environmental quality are already raising grave concerns. Under this background, national and local leaders have responded to the challenge by marking sustainable development a high priority.

Cities, as a rule, are regarded as economic powerhouses, major energy consumers, and key contributors to environmental degradation. China's 35 largest cities representing account 18% of the population, for instance, account for 40% of the country's energy use and carbon dioxide (CO_2) emissons (Dhakal, 2009). Hence, the low-carbon eco-city, a term that combines low-carbon development and eco-city concepts, jumps

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[1] Professor & IALT member, Department of Civil Engineering and Architecture, Zhejiang University, Hangzhou, CHINA, gejian1@zju.edu.cn
[2] Department of Civil Engineering and Architecture, Zhejiang University, Hangzhou, CHINA, 709953403@qq.com
[3] IALT member, Zhejiang University of Science and Technology, Hangzhou, CHINA, 13858019381@139.com
[4] Department of Civil Engineering and Architecture, Zhejiang University, Hangzhou, CHINA, teacher_xiaoyu@126.com
[5] Department of Civil Engineering and Architecture, Zhejiang University, Hangzhou, CHINA, 17902884@qq.com
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into popularity once it was put forward by Qiu in 2008 (Qiu, 2009). According to statistics, by February of 2011, 230 prefecture-and-above level cities have proposed to establish themselves as “eco-cities”, accounting for 80.1% of 287 such cities nationally. 133 (46%) have set targets to develop as “low-carbon cities” (CSUS, 2011).

Then three questions should be addressed: “What is a low-carbon eco-city?”, “How can we assess our attainment of a low-carbon eco-city?”, and “How can we effectively develop a low-carbon eco-city?” By conducting city-wide low-carbon planning and accomplishing city-level emissions targets, a growing number of experts recognize that it is important to firstly explore the efficient measures and approaches for developing low-carbon eco-cities at the small scale, i.e. at the level of metropolitan regions or districts. More and more demonstration projects at district level are practiced by local governments, for example, the Sino/Singapore eco city in Tianjing and Caofeidian eco-city in Tangshan.

Meanwhile, numerous indicator systems have been developed to assess the attainment of a low-carbon eco-city and provide decision basis for urban sustainable development (Zhao et al., 2009). The indexes constructed by United Nations Commission on Sustainable Development (UNCSD) (ACCA21, 2004), Organization for Economic Co-operation and Development (OECD, 2001) and United Nations Statistics Division (UNSD, 2002) are relatively dynamic and influential in foreign countries. All of them are structured in society, economy, system, resource and environment (or ecology) aspects, which is consistent with the framework of sustainable development. Several national and local indicator systems have been explored by many organizations and research institutions, partnering with government and other stakeholders, to establish best practices of low-carbon eco-cities in China. For instance, Chinese Society for Urban Studies (CSUS) developed 45 indicators pertaining to support for the living, resource, industry, environment, society and culture. The Tianjin Sino/Singapore eco-city indicator system has 26 indicators related to coordination with regional policy, the natural ecosystem, society and culture, and regional economic. The indicator system for Caofeidian eco-city contains 141 indicators related to city function, building and building industry, traffic and transportation, energy, waste, water, landscape and public spaces, which is put forwarded by Sweden’s Sweco in cooperation with Tsinghua Urban Planning Institute.

However, a lack of consensus not only on the conceptual framework and the approach favoured, but also on the selection and optimal number of indicators is revealed by Tanguay et al. (2010), which results in the difficulty of comparison between municipal jurisdictions of the same stature. And because of the miscellaneous composition of indicator system and lack of effective means and measures, few are accomplished successfully in the end (Tongji Univerisity, 2013). Hence, relevant supporting strategies, which are always neglected by researchers, planners, governments and city managers, should be complied at the same time to ensure the implementation of indicator system.

In this paper, the commonality and limitations of indicator systems, along with the frequency of indicators, are interpreted based on an extensive review of 11 international indicator systems and 20 domestic Chinese indicator systems in session 2. In the following session, the indictors for Transfer Science and Technology Park in Hangzhou city were chosen in accordance with the previous analysis, as well as the relevant implementation strategies. In session 4, two scenarios are adopted, while the former is developing in traditional way and the latter is under the circumstance that all indicators are accomplished, to calculate the carbon reduction in order to quantitatively evaluate the effect of the indicator system. Then the most efficient measures, as well as corresponding indicators, to develop a low carbon city are discussed in session 5 according to the results of carbon emissions. The conclusion follows.

2. Characterization of reviewed indicator systems

We initially compiled several studies that apply indicators related to the terms “eco-city”, “sustainable city”, “liveable city”, “garden city” and similar concepts at neighbourhood, city or province level . 11 international systems at sub-national level (3 neighbourhood level, 8 city level) and 20 Chinese systems (8 national-level city assessments, 4 individual city level systems, and 8 research systems of pilot projects) were chosen to find the most common indicators used by experts when evaluating city performance towards low-carbon eco-city.

All of those systems cover the indicators in society, economy, system, resource and environment (or ecology) aspects, which is consistent with the framework of sustainable development. In addition, it is noted that the systems aiming at national-city level pay more attention on the indicators in economy (e.g. GDP per capita, value of service sector in GDP), population (e.g. crude growth rate), education (e.g. gross intake ratio in first grade of primary education) (ACCA21, 2004; OECD, 2001; UNSD, 2002) while those aiming at individual city level or neighbourhood level are more concerned about the indicators in the sectors, such as buildings (e.g. the ratio of green buildings), transport (green travel, the ratio of public transportation, etc.), water (water quality, water treatment), energy (renewable energy utilization) and solid waste (waste collecting and recycling) (Zhou et al., 2015; IBR, 2013). The indicators vary partly due to the fact that sustainable goals at different levels are diverse; the time period in which goals were established; and the ability of the city to implement programs and policies.

On the other hand, the reviewed studies use between 19 and 141 indicators, which reveal a lack of consensus on indicators resulting in the difficulty of comparison between municipal jurisdictions of the same statue. In order to be found to be common, an indicator would have the similar name or functionally the similar numerator and denominator-for instance, an indicator defined as “tap water quality” and “surface water quality” would be treated the same as “water quality”. In this way, more agreements are found among indicators. The most frequently used indicators in reviewed systems include free accessible facilities within 500 meters’ walking distance of residential area, ratio of green building, renewable energy utilization, waste water treatment, water quality, utilization of non-traditional water sources, waste harmless treatment rate, and green coverage, which can be classified into 6 categories, as shown in **Fig. 1**. These indicators can directly reflect the goals and the path of planning and construction of a green, ecological and low-carbon city.

However, because of the miscellaneous composition of indicator systems and lack of hierarchical and effective measures, few are accomplished successfully in the end (Williams et al., 2012), especially some indicator systems developed in pilot projects. The relevant supporting strategies and policies are necessary at the same time to ensure the implementation of indicators.

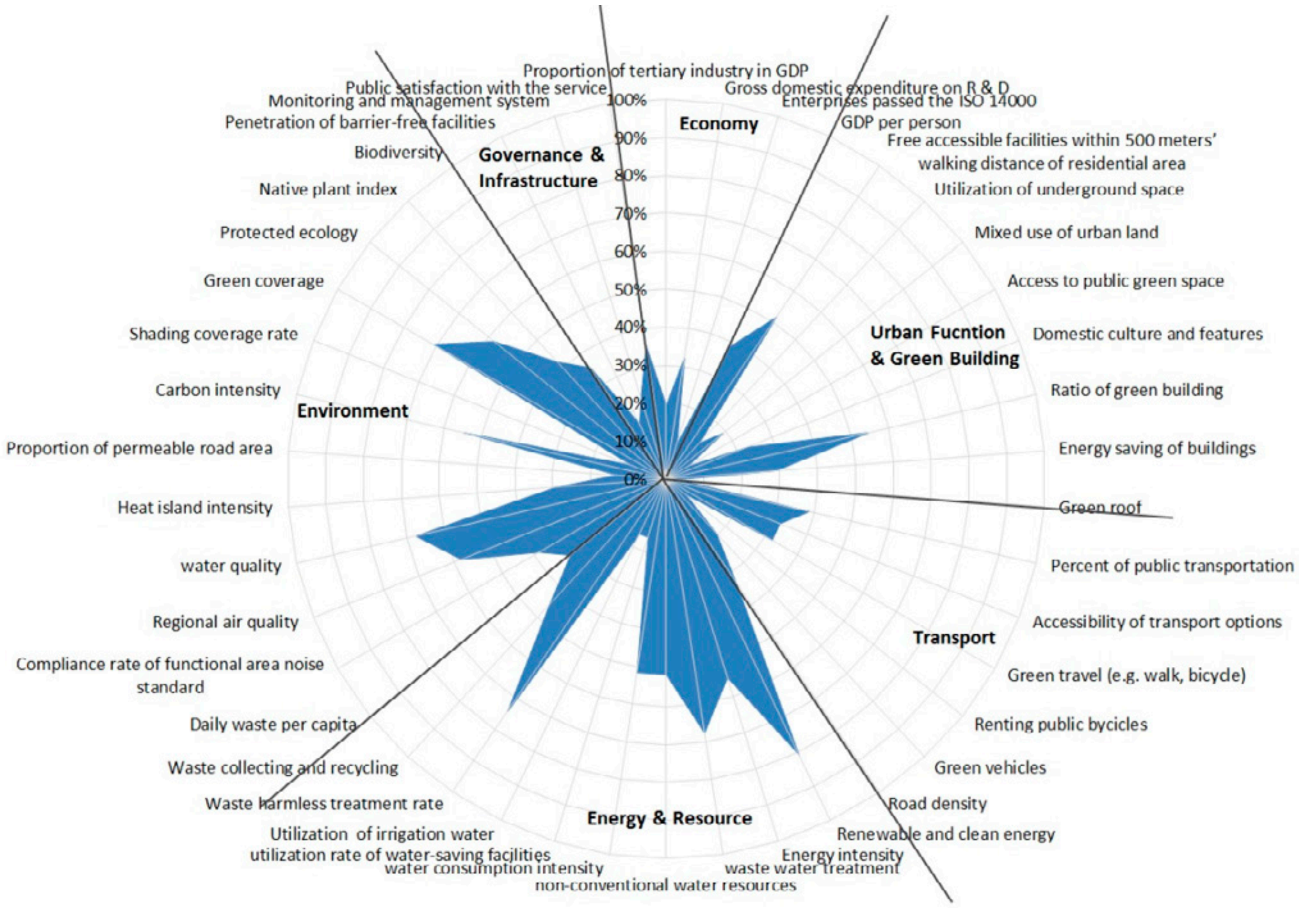

Fig. 1. The frequency of indicators.

3. Indicator system of Transfer Science and Technical Park

Based on these observations, an indicator system for Transfer Science and Technical Park in Hangzhou city has been proposed, as well as the relevant implementation strategies.

3.1 Transfer Science and Technical Park

The Transfer Science and Technical Park is located in Hangzhou City, Zhejiang Province. The park, formerly known as “Zhejiang high-tech agricultural garden”, is currently the largest demonstration project in this province, which has the goal of demonstrating the low-carbon mode in Hangzhou in order to tackle climate change, save resources and energy, protect the environment and achieve social harmony. The development plan targets an area of 0.6 square kilometres (km^2) having abundant water resources, convenient traffic system and natural environment.

3.2 Selection criteria and indicator system

Great differences in how indicators were selected have been revealed by Williams et al. (2012) that “relevance”, “data availability”, and “comparability” were more common among 16 indicator systems. Tanguay (2010) found that 68 different selection criteria were used by 17 reviewed indicator systems, 6 of which were frequently used: credibility, universality, data availability, comprehensibility, links with management, and spatial and temporal scales of applicability. A particularly widespread approach is worth mentioning that an indicator must be SMART, namely “specific”, “measureable”, “achievable”, “relevant”, and “time-related-completed” (SIAP, 2007). Therefore, in accordance with the common criteria from the 31 reviewed systems in this paper, 3 criteria are proposed while selecting the indicators, namely: “credibility and operability”, “universality and characteristic”, “accessibility and perspectiveness”.

Then, an indicator system including 6 primary categories, 19 secondary categories and 39 indicators is proposed based on the selecting criteria and characterization of reviewed indicator systems (as shown in **Table 1**). The primary categories common to all systems are identified as follows: environment, urban space and green building, transportation, energy and resource, governance and infrastructure, and economy. The secondary category refers to a more specific means of measuring or evaluating the state of the primary category issue. And the indicators reveal several measurement methods and precise units for each secondary category. The most common indicators observed in previous studies are selected in this system, such as water quality, green coverage ratio, ratio of green buildings, leading to the comparability of low-carbon development within cities and a better coordination of actions for cities within a given region. In this way, cities with the same size can have a common grid to share and apply successful tools and measures (Tanguary et al., 2010). Besides, some indicators reflect the features of the park are also involved, for instance, proportion of tertiary industry in GDP and the proportion of enterprises passed ISO 14000 certification.

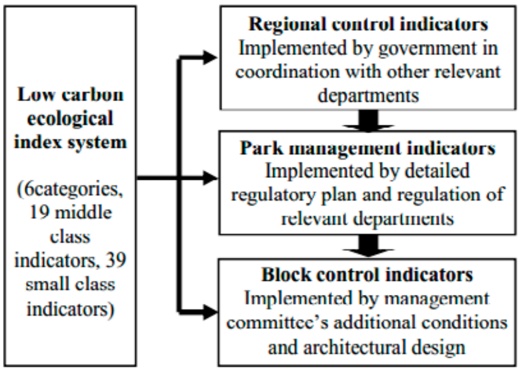

Fig. 2. The implementation phases of indicators.

The target value for each indicator is established in accordance with the national Chinese targets, city-level targets set by progressive Chinese cities, actual performance levels of Chinese cities, international and domestic best-practice standards established by credible and well-respected agencies, and corresponding standards in environment, energy, building, transport, etc.

3.3 Three implementation stages of indicator system

In order to ensure the full accomplishment of each indicator, three implementation stages are constructed as those indicators should be conducted at different levels. **Figure 2** reveals that the stages are regional control indicators, park management indicators and block control indicators. The regional control indicators refer to the indicator which only can be achieved at urban scale with the help of local departments relating to planning, land, environment and transport, etc. For example, the park could satisfy the functional area noise standard only under the circumstance that the whole district adopts the noise-control measures. And some indicators require the management from the whole park and implemented during the regulatory plan, e.g. the green coverage rate and underground space intensity. In the end, block

Table 1. Indicator system.

Primary category (6)	Secondary category (19)	Indicator(39)	Target Value	Implementation level		
				Regional	Park	Block
Environment	Noise-control	Compliance rate of functional area noise standard	100%	●		
	Water quality	Surface water quality	Reaching the water quality of class III	●		
	Biodiversity	Native plant index (the proportion of native plants among the total plants in the park)	≥80%			●
		Species richness	≥25 types			●
	Rural feature	Proportion of ornamental fruit tree	≥50%			●
		Proportion of food crops	≥50%			●
	Ecology protection	Construction of ecological corridor along the river	—		●	
	Waste treatment	Rate of waste collecting and recycling	100%	●		
Urban space & Green building	Urban design	Green coverage ratio	≥45%		●	
		Accessibility of green space in residential area	—		●	
		Number of trees per 100 square meters	≥3 trees			●
	Green buildings	Rate of green roof among new buildings	≥25%			●
		Proportion of green buildings among new buildings	100%			●
	Outdoor environment	Proportion of permeable road area	≥45％			●
		Heat-land intensity	≤1.5			●
		Shading coverage rate	Venue ≥45%； Pavement≥50%； Parking lot≥60%			●
	Intensive land use	Underground space intensity (the underground floor area divide the above ground area)	≥0.25		●	
Transportation	The accessibility of transport facilities	Accessible distance to bus stops	≤400 m		●	
		Accessibility of rental stations of public bikes	≤400 m		●	
		Intensity of transit network	3 km/km^2		●	
	Non-motorized travel	Intensity of low traffic network	3.7 km/km^2		●	
		Parking system	—			●
	New energy transportation	Application of green vehicles	—		●	
		Proporetion of solar bus shelters	80%	●		
Energy & Resource	Water saving and utilization of water resource	Penetration of water-efficient appliances	100%			●
		Collection and recycling use of rainwater	100%			●
		Water-saving irrigation	—			●
	Energy saving and utilization of energy	Building energy saving rate	≥65%			●
		Utilization of renewable energy	≥10%		●	
		Green lighting	—		●	
Governance & Infrastructure	Infrastructure and supporting facilities	Penetration of barrier-free facilities	100%		●	
		Supporting recreation facilities	—		●	
		Commercial service radius	≤500 m		●	
	Governance	Intelligent management	—		●	
		Social participation	—		●	
Economy	Industrial structure	Proportion of enterprises with the characteristic of agricultural science and high-tech	≥80%	●		
		Proportion of tertiary industry in GDP	≥50％	●		
	Enterprises' sustainable development	The proportion of funds for R&D in GDP	≥5%	●		
		Proportion of enterprises passed ISO1400 certification	100%	●		

control indicators are related to the development of blocks and low-carbon design of buildings, like the proportion of energy-saving facilities and green roof. Detailed classification is shown in **Table 1.**

4. Carbon emission

4.1 Scope of the emission inventory

In order to quantitatively assess the effect of indicator system and find out the most effective measures to develop a low-carbon eco-city, the carbon emissions of the Transfer Science and Technical Park have been calculated.

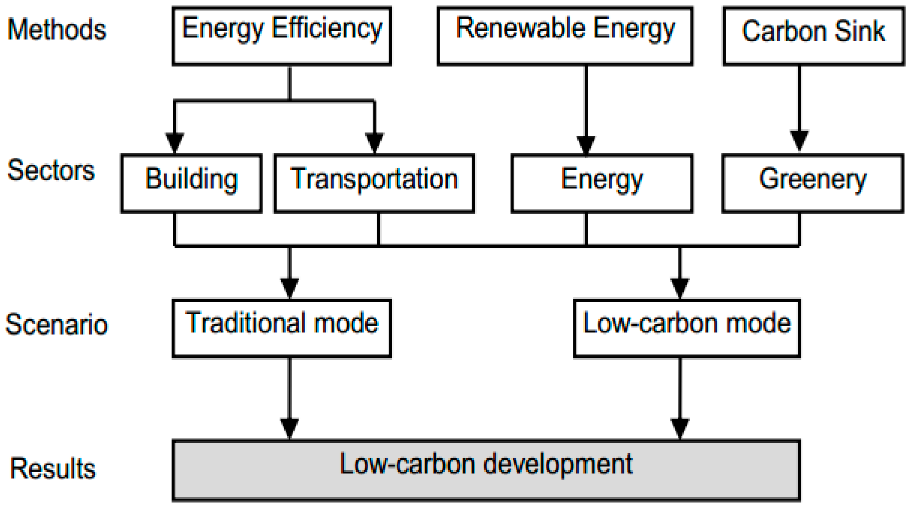

Fig. 3. The composition of park carbon emissions.

The scope of a carbon emissions inventory should be defined clearly to ensure that the results are comparable. By referring to Low Carbon City Development Guidance (MLIT, 2012), the research of the low carbon city should be carried out in the following four fields: buildings, transportation, energy and greenery. In these fields, there are three main courses for low-carbon development mode, which involves the use of energy efficiency, renewable energy and carbon sink (see **Fig. 3**).

Otherwise, a convenient and applicable assessment system must be devised to determine whether the park is developing on a low-carbon basis. Two scenarios are adopted which are known as traditional scenario and low-carbon scenario. Firstly, traditional scenario is the traditional way of developing, which is embodied in the form of urban development and economic advancement both at the same pace as the current and historical trend (2005~2010), as well as the carbon emissions. On the other hand, low-carbon scenario is the sustainable development mode adapting the indicator system mentioned before.

4.2 Accounting methods for various sectors

4.2.1 Building sector

Carbon emissions in the usage and construction phase of all buildings accounts for more than 20% of the total CO_2 emissions in China (Building Energy Research Centre of Tsinghua University, 2008), which occupies 80% to 90% of the CO_2 emissions in the buildings life circle. Carbon emissions due to electricity use for residential and commercial energy consumption sector were calculated as:

$$E_B = \sum_i [A_i \times EUI_i \times EF] \times 10^{-3} \qquad [1]$$

where E_B is the carbon emissions from the building energy consumption sector, t-CO_2; i is the building sub-sectors (e.g. residential buildings and commercial buildings); A_i is the gross floor area of different types of buildings i, m^2; EUI_i is the energy use intensity of types i, kWh/m^2; and EF is the carbon emission factor of electricity, kg-CO_2 per unit.

The energy consumption data were obtained from 2010 Annual Report on China Building Energy Efficiency (CSUS, 2010), and CO_2 carbon emission factor for electricity were calculated as 0.82 kg-CO_2/kWh based on the information from the East China Power Grid (ECPC) (NSB, 2009).

4.2.2 Transportation sector

The carbon emissions due to road transport were calculated for each vehicle fleet, such as private car, taxi, and bus, which were summed to obtain the total emissions:

$$E_T = \sum_i [TV_i \times TD_i \times EI_i] \times 10^{-6} \quad [2]$$

where E_T is the carbon emissions from the road transportation sector, t-CO2; TV_i is the traffic volume of vehicle fleets i, vehicle/year; TD_i is the average travel distance of the vehicle fleets i, km/vehicle/year; and EI_i is the carbon emission intensity of the vehicle fleets i, g-CO2 /km/vehicle.

The information on traffic volume of vehicle fleets and their correspondent travel distance were obtained from the China Academy of Urban Planning and Design (CAUPD) et al. (2009), EI was acquired from National Institute for Land and Infrastructure Management (NILIM), Japan (2003).

4.2.3 *Energy sector*

Full use of renewable energies is emphasized in the low-carbon city construction. Up to 2020 in China, hydroelectricity will account for 321 million tons of coal equivalent, nuclear energy will account for 163-186 million tons of coal equivalent, wind power and solar power account for 96.6-132.2 million tons of coal equivalent, according to the research of Chinese Academy of Engineering (2011) (Chen and Zhu, 2013).

Hence, there are two main parts in this sector. One is the carbon emissions produced by consuming water and emissions reduced by recycling water and making full use of rainwater. The method is as follows:

$$E_W = Q_S \times W_1 + Q_D \times (W_2 + C_2) + Q_R \times (W_3 + C_3) \quad [3]$$

where E_W is the carbon emissions from the water consumption, t-CO2; Q_S, Q_D and Q_R are values of domestic water consumption, gross sewage volume discharged to waste pipe network and recycling water volume by the wastewater treatment plant, respectively (unit: m^3/year). W_1, W_2 and W_3 are carbon emissions generated by power supply consumption of feed water system, sewage disposal system and plant of water disposal in the district, separately (kg/m^3). C_2 is CO2 converted by carbon source of sewage disposal system and C_3 is CO2 generated by the sewage water treatment station. The water consumption data were calculated in accordance with The Standard of Water Quantity for City's Residential Use (MOHURD, 2002), W and C were acquired from China Real Estate Chamber of Commerce et al. (Sheng, 2013).

On the other hand, the renewable energy (such as solar power, wind power and marsh gas) was used to supply energy load in buildings. The carbon reduction was calculated using the following equation:

$$E_R = -E_B \times r \quad [4]$$

where E_R is the carbon reduction caused by renewable energy, which is considered as zero-carbon energy without generating CO2 when used, and it is negative (t-CO2). E_B is the carbon emissions from the building energy consumption sector, t-CO2; and r is the utilization ratio of renewable energy (default is 0). The green energy should account for above 10% of the buildings energy consumption according to the Evaluation Standard for Green Building (MOHURD, 2014). Hence, the value of r is 10% to achieve the sustainable development goals in low-carbon scenario.

4.2.4 *Greenery sector*

From the viewpoint of the low-carbon city development, the greenery is expected to play significant role in realizing a compact urban structure, reducing CO2 in the air, and mitigating heat island effect through the improvement of ground surface covering. The formula for

calculation CO2 fixation and sink in the greenery sector is:

$$E_G = -\sum_i \left[V_i \times SC_i \right] \times 10^{-3} \quad [5]$$

where E_G is the carbon fixation and sink in the greenery sector, and is always negative, t-CO2; V_i is the volume of plant species i, m^2. SC is the sink coefficient (kg-CO2 /m^2/year), which can be acquired form Chen et al. (1998).

4.3 *Results*

4.3.1 *Building sector*

Figure 1 suggests that the total carbon emissions in building sector every year are 101.39 thousand tons and 63.89 thousand tons in traditional scenario and low-carbon scenario, respectively. And commercial building consumption takes up a predominant proportion in the gross CO2 emissions, due to the relatively larger floor areas and higher EUI than residential building. In order to reduce CO2 emission attributable to energy consumption in this park, it is advisable to give first priority to considering measures to reduce energy load of buildings, e.g. adapting ecological technologies to develop green buildings, without decreasing the indoor environmental quality. The requirements of energy savings are enhanced from 50% in traditional scenario to 65% in low-carbon mode, compared to the reference buildings in 1980 (which did not have any energy saving measures). Under this circumstance, the annual CO2 emissions from commercial electricity consumption decrease from 94.99 thousand tons in traditional scenario to 66.5 thousand tons in low-carbon one. The carbon reduction is 1.92 thousand tons in residential buildings, as shown in **Fig. 4.** **Figure 5** reveals increasing energy saving rate in commercial building and residential building can reduce 76% and 5% divided to the total carbon reduction.

Otherwise, natural ventilation plays an irreplaceable role in improving indoor environmental quality in this area, as well as reducing energy load of buildings by about 10% (Qin, 2009). Hence, it could reduce 7.1 thousand tons of CO_2 in the building sector every year.

4.3.2 *Transportation sector*

The percentage of carbon emissions caused by transportation as compared to the total emissions varies with cities. And the major source of CO_2 emission in this sector is automobiles. Therefore, low-carbon measures contribute to "shift away from automobiles", "shortening of travel distance" and "improvement of travelling performance" (MLIT, 2012). Many of correspondent measures, such as realizing mixed-use land, improving public transportation facilities, advocating green travel (e.g. walking, bicycle), and promoting utilization of green vehicles, have been carried out in the low-carbon scenario to reduce carbon emissions. **Figure 6** reveals that 905 tons of CO_2 emissions can be reduced, which occupies 67.3% of the overall emissions in the traditional mode. Otherwise, the percentage of passenger car used in the low-carbon mode, including private car and taxi, decreases to 54%, which is 63.6% in the traditional one.

4.3.3 *Energy sector*

Figure 7 indicates that 2.25 thousand tons of annual CO_2 emission in energy sector is reduced in low-carbon scenario compared to that in traditional one. In view of a balance between water quantity and water quality in the water consumption sector, the aquatic environment system's low-carbon assessment is divided into two aspects: The first are highly efficient use of water resources to achieve reduction of CO_2 emissions generated in production and transport processes; and reducing CO_2 emissions by using green water-treatment technologies. Secondly, CO_2 emission reduction can be accomplished through conversion at the carbon source while getting rid of the pollutants (CRECC). Hence, after facilitating the water-saving instruments, full utilization of rainwater and recycling waste water in the development of low-carbon eco-park, 229 tons of carbon emissions can be reduced. And the total CO_2 emissions in the traditional scenario without any water-saving measures would reach 696 tons every year, as shown in **Fig. 7.**

Otherwise, it is evident that the utilization of renewable energy to supply the energy demand of buildings can rapidly decrease the eco-park's carbon emissions, approximately 3549 tons/year. With the broader penetration of renewable energy in the cities required by Chinese government, its effect on reducing carbon emissions can skyrocket in the future.

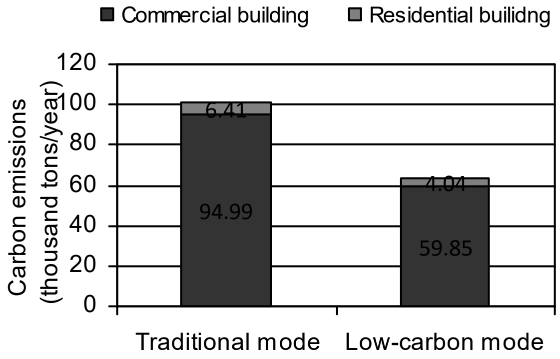

Fig. 4. Carbon emissions in building energy consumption sector.

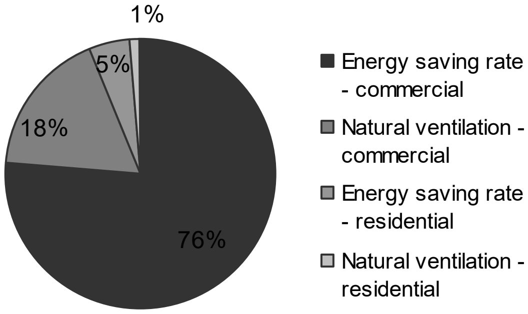

Fig. 5. The compositions of reduction carbon in building sector.

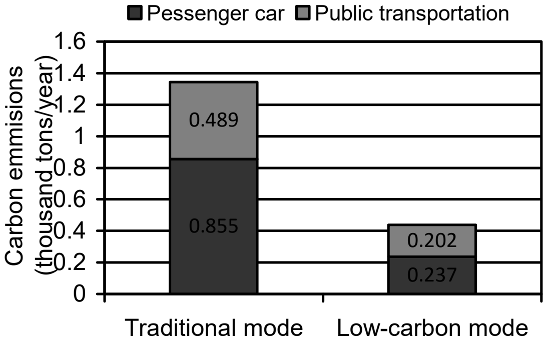

Fig. 6. Carbon emissions in transportation sector.

4.3.4 *Greenery sector*

As the amount of CO_2 fixed and absorbed varies depending on the form of greenery (type of plants, conditions of ground surface covering, maintenance status etc.) as well as on the area, a multi-coat landscaping planting system is regarded to greatly elevate the fixed amount of CO_2. Meanwhile, the effect on fixing and sinking CO_2 of big arbor and shrub is much better than the low flowerbed or low-grass weed. The density of tall trees is increased to enhance the low-carbon effects. Except the greenery in public area, greenery on building roofs not only can absorb the CO_2 in the air, but also can advance the insolation effect of roof to reduce the buildings' energy consumption. Hence, over 15% of the total roof area is covered with vegetation due to partly space is needed for building equipment and PV systems. The carbon absorption increases from 4.41 thousand tons in traditional scenario to 6.75 thousand tons in low-carbon scenario (seen in **Fig. 8**). Among the amount of carbon fixation in the low-carbon eco-park, 34.7 percent is absorbed by low grass and brushwood and above 50 percent attributes to the big arbor and shrub.

4.3.5 Total carbon emissions

The overall carbon emissions in Science and Technical Park in two scenarios are illustrated in **Table 2.** The amounts of carbon emissions related to building energy consumption, transportation, and water consumption are (101.39, 1.34 and 0.69) thousand tons/year, respectively, in the traditional scenario. The building energy consumption sector is the largest contributor to carbon emissions in this park due to the huge gross area, contributing 98% of the emissions. As 4.4 thousand tons of CO_2 is fixed and absorbed by the urban greenery, the final carbon emissions of the park is 99.02 thousand tons every year under the circumstance that none low-carbon measures are implemented. Meanwhile, the carbon emissions sharply decrease to 54.49 thousand tons in the low-carbon scenario, accounting for 55% of the emissions in traditional mode. It means that 45% carbon emissions can be reduced after executing the evaluation system in the park. Carbon reduction related to building sector, transportation sector, energy sector and greenery sector account for 84%, 2%, 9% and 5% of the overall reduction **(Fig. 9)**, which indicates that reducing the energy load of buildings and utilizing renewable energy in the district play the dominant roles in carbon reduction. Although the amount of reduction in transportation sector is limited compared to other sectors, the proportion of carbon reduction is highest in low-carbon scenario (67.3%).

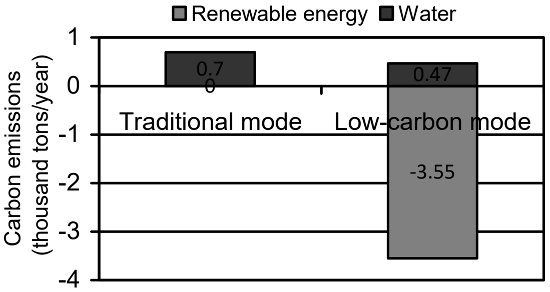

Fig. 7. Carbon emissions and reduction in energy sector.

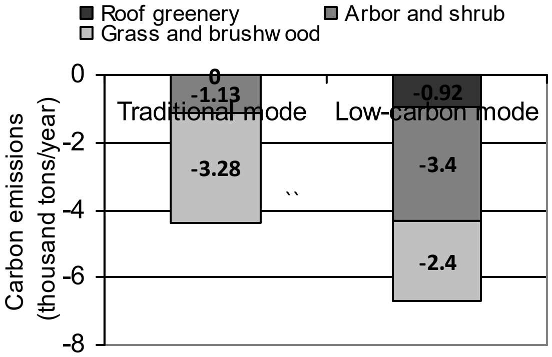

Fig. 8. Carbon emissions in greenery sector.

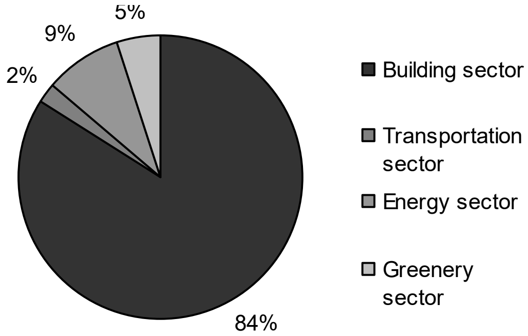

Fig. 9. The compositions of carbon reduction.

5. Discussions

Based on the characteristics of international and domestic indicator systems towards a low-carbon eco-city and results of carbon reduction caused by the implementation of indicator system in the demonstration project in Hangzhou City, several main measures should paid more attentions, as well as corresponding indicators.

Firstly, as the Transfer Science and Technical Park is an area of 0.6 square kilometres covering 109 square kilometres area of commercial buildings, office buildings residential buildings and hotels. Therefore, the carbon emissions in building sector attribute approximately 98% of the total emissions from building sector, transport sector and energy sector. Under this circumstance, the measures related to buildings energy saving rate and green buildings make the most contribution to the carbon reduction, occupying 84% of the total reduction (as shown in **Fig. 9**). Commonly, carbon emissions in the usage and construction phase of all buildings accounts for more than 20% of the cities' total CO_2 emissions. Hence, these measures would still reduce the carbon emissions effectively at regional levels.

Table 2. The carbon emissions of Science and Technical Park.

Sectors		Traditional scenario	Low-carbon scenario	Compared to traditional scenario	
				Carbon reduction	The ratio of reduction
Building (t/a)		101391	63889	37502	37.0%
Transportation (t/a)		1344.5	439.4	905.1	67.3%
Energy (t/a)	Renewable energy	-	-3549	3549	-
	Water	696	467.2	228.8	33%
Greenery (t/a)	Green land	-4410	-5832	1422	32.2%
	Roof greening	-	-920.5	920.5	-
Total (t/a)		99021.5	54494.1	44527.4	45.0%

Secondly, the **Fig. 9** illustrates that the frequently used indicators in energy and resource category, such as utilization rate of renewable energy, also to a large extent reduce carbon emissions, following the carbon reduction effect in building sector. With the broader penetration of renewable energy in the cities required by Chinese government, its effect on reducing carbon emissions can skyrocket in the future.

In addition, the greenery plays a significant role in realizing a compact urban structure, reducing CO_2 in the air, and mitigating heat island effect through the improvement of ground surface covering. 5% of the carbon reduction in this park is caused by adopting a multi-coat landscaping planting system, increasing the green coverage rate, and planting of big arbor and shrub, etc. It is obvious that those related indicators are indispensable to seek a low-carbon eco-city.

Fourth, because of the limited transport demand in this small district, transportation only contributes 1.4% to the total carbon emissions. The rate of contribution is well below the China's national average level of 6%-11% (He et al. 2005), as well as the level of 20%-50% in global cities (Kennedyet al., 2010). It is foreseeable that the proportion of transportation emissions will grow rapidly due to transportation policies and vehicle demands in Chinese cities (Wang et al., 2011). However, the policy makers and researcher should recognize that the effect of measures, e.g. mixed land use, green travel, green vehicles, and promoting public transportation, can be dramatic on reducing cities' carbon emissions caused by transportation sector. For instance, 67% of carbon emissions reduced in low-carbon scenario compared that in traditional mode (as shown in **Table 2**) in this demonstration project.

6. Conclusion and policy implications

An indicator system of Transfer Science and Technical Park in Hangzhou city, which consists of 6 primary categories, 19 secondary categories and 39 indicators, has been proposed based on the extensive review of 31 international and domestic indicator systems. The primary categories common to all systems are identified as follows: environment, urban space and green building, transportation, energy and resource, governance and infrastructure, and economy. Meanwhile, those frequently used indicators are adopted in this system to ensure the universality and comparability of other cities with the same size, as well as some specific indicators to reflect the project's features related to culture, economy, ecology, etc. All of the indicators are classified into three implementation stages to achieve the completely accomplishment of low-carbon targets, which may be neglected by researchers, planners, governments and city managers.

Then a methodology, which classified carbon emissions into 4 sectors including building energy consumption, transportation, energy and greenery, was used in this study to account for carbon reduction in two different developing ways in this park. The carbon emissions in the low-carbon scenario under the circumstance that all indicators are fully implemented are 54.4 thousand tons every year, accounting for approximately 55% of the total emissions in the traditional scenario. It reveals that the effect of indicator system is quite foreseeable in this project. Also, those measures related to the frequently used indicators, for instance, the green building, utilization of renewable energy, green coverage rate, etc., play the dominant roles in reducing the carbon emissions and absorbing the CO_2. Hence, the policy maker should pay more attention on the measures mentioned in session 5 while proposing national and local policies to develop low-carbon eco-cities.

In the end, there is no carbon emissions caused by industries in this project because of its small scale. However, the methodology of proposing an indicator system and the relevant implementation strategies of developing a low-carbon eco-city, as well as the calculation method of carbon emissions, can provide a reference for other cities.

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