Delivering a low carbon community in China: Technology vs. Strategy?

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Abstract:

Delivering low carbon communities requires an understanding of community practices and technologies, strategies and constraints associated with and accessed by communities. However, little research to date has investigated the application of green technologies as well as green strategies in achieving low carbon communities. This paper first reviewed low-carbon technologies and strategies in the previous literatures and then examines how these technologies and strategies are addressed in two ongoing low carbon communities. By comparing the differences of adopting various low carbon technologies and strategies in the two cases, it is found that green strategies are not as valued as green technologies in the current stage of low carbon communities in China. The ten One Planet Living principles are not fully considered and comprehensively implemented, and there is also lack of a clear and harmonious inter-sector working mechanism within and between energy, transport, waste management and water management sectors. Recommendations are proposed to provide a vehicle for a more effective and efficient use of green technologies as well

as green strategies to reduce carbon emissions in low carbon communities. Research findings in the study may therefore provide valuable references to guide low carbon community development.

Keywords: Low carbon community; green technology; green strategy

1 Introduction

No country in the world is outside the challenge of climate change and its effects and risks are increasingly clear. Since the British Government issued a White Paper “Our energy future, creating a low carbon economy in 2003”, the concept of ‘low carbon economy’ brought about a new economic development trend which aims to generate more economic output at the cost of less natural resource consumption and less environmental pollution. The concept of ‘low carbon economy’ then develops into ‘low carbon society/city/community’ in Japan and other developed countries (“Japan 2050 Low-Carbon Society” scenario team, 2008). Despite its widespread use in practitioner, policy and academic circles, researchers have yet to reach a consensus on the definition of ‘low carbon community’.

There are many different understanding and definitions for low carbon city/community (WWF, 2006; DFID, 2009). The most updated definition is given by the Climate Group, which is “to help cities develop and implement low carbon technologies and strategies to cut global greenhouse gas emissions and accelerate a

prosperous low carbon economy" (The Climate Group, 2010). It is obvious that these definitions have emphasized the importance of 'technologies' and 'strategies'. Technology can be termed as the application of knowledge for practical purposes. The "green technology" is a broad term for environmentally friendly solutions (United Nations, 2008). In this context, technology allows people to become more efficient or to do things that were not possible before. The term "green strategy" is considered as important means to implement sustainable development principles in the built environment (Zhang *et al*., 2011). Voluntary green strategies play a central role in the discussion of non-mandatory approaches to foster corporate environmental performance (Khanna, 2001). On one hand, green technology is the basis which may become in-efficient without the guidance of green strategies. On the other hand, green strategies alone do not guarantee an improvement in environmental performance, for example, with regard to pollution abatement.

Many countries in the World have initiated a range of low carbon practices. A significant sector is low carbon city/community, which focus on either strategies or technologies. Berlin has rolled out numerous climate change mitigation and adaptation programs largely focused on promoting energy awareness, encouraging energy efficiency in housing and public buildings, and greening the transport system. The Greater London Authority firstly addressed the problem of rising energy consumption in the 2004 London Plan and Mayor's Energy Strategy. Since 2004, these policies have helped avoid approximately 251,880 tonnes CO_2 per year (Day

and Jones, 2009). By 2009, there are 79 cities and towns that have started low carbon community planning or construction, which spread across all over the world. Most of these cities located in Europe, including Denmark, Norway, Iceland, Finland, UK, France and Germany. There are also many low carbon communities in USA and Canada. It is expected that the next region that take the leading initiatives would be Asia and South Pacific area, such as China, Australia and New Zealand (Flynn *et al*., 2011).

China is going through a rapid urbanized process, which goes from 45% (urbanization rate) in 2010 to an expected 75% by 2050. A massive source of embodied energy producing carbon emissions will be generated from large infrastructures, buildings, transportation systems and daily urban household life. Then how to deliver an appropriate low carbon community mode forces a challenging question from China? It is important to develop a set of strategy and technology toolkit that fit into China's conditions. By relying on international experiences, on one hand, green technologies have been promoted for many countries and regions, for example, ground source heat pump technology (Doherty *et al* ., 2004) and efficient equipment and appliances for natural ventilation technology (U.S Department of Energy, 2009) are considered as effective means to reduce energy consumption and carbon emissions in operation. On the other hand, green strategies act as another approach to achieve low carbon emission goal. Strategies, such as the Energy-efficient urban transport (APEC Energy Working Group, 2011), Carbon pricing for transport (Greater London Authority, 2007) are regarded as efficient methods to be adopted in the low carbon communities. It can

be identified that green strategies and green technologies have their indispensable merits in delivering low carbon community. Although green technologies have better applicability in different countries, it is rather difficult for China due to its 1.3 billion population and its per capita GDP being 4500 USD. In this context, Chinese cities need to provide a clear and explicit low carbon community strategy which fit into their local conditions when acting as one of the main battlefields for combating low carbon emissions. However, most of the discussion on low carbon communities centers on local communities in different geographical places in the World and few literatures have discussed the different role between green strategies and green technologies. We therefore introduce into the discussion on technologies and strategies of low carbon community by using cases in China. The purpose is not to argue that they are better than other communities, but rather to explore the progress, merits, and challenges of low carbon community between green technologies and green strategies among the rapid urbanization process in China. By analyzing various types of low-carbon community, problems of individual practices and solutions that they have adopted and in which ways are examined.

This article is structured as follows. Special attention is paid to the presentation of low-carbon technologies and strategies as a solution to achieve low carbon community. We then examine how these technologies and strategies are addressed in practical application of case studies, drawing on a dataset collected in two ongoing low carbon communities. By comparing the differences of adopting various low

carbon technologies and strategies in the two cases, avenues and suggestions for further research and low carbon community development are presented in the end.

Research methods

The research data in this study was searched and collected using a combination of content analysis on literatures and existing research reports, case-study and structured face-to-face interviews with planners, project managers, developers and governors. Content analysis on existing literatures and research reports are adopted to examine the green technologies as well as green strategies applicable in implementing low carbon communities, which has been presented in the previous section. Case-study and interviews are employed to demonstrate the differences of adopting various green technologies as well as green strategies during implementation in the process of developing low carbon communities.

Identification of green technologies and strategies in the existing low carbon community initiatives

Previous studies have addressed and documented a lot of green technologies and green strategies. For example, according to GRHCC (2003),Zhang *et al* (2011a) and Zhang *et al* (2012), the green roof system can help lower temperatures inside the building in warm climates and thus reduce the demand for the use of air-conditioning systems. 'Dynamic CO_2 emissions monitoring and evaluation systems' is considered by Qiu (2010) that it is efficient system to reduce carbon emissions. Other researchers, communities, and organizations have introduced various lists of green strategies. For

example, it is proposed that the ‘cooperative energy efficiency design for sustainability’ (APEC Energy Working Group, 2011) and ‘invest in transport systems and infrastructure that reduce dependence on fossil fuel use’ (WWF, 2006) are effective strategies to meet the low carbon goal.

In UK, BedZED is the largest mixed use zero carbon community until now, which was initiated by Bio-regional and ZED factory, and developed by the Peabody Trust. It was completed and occupied in 2002. They have developed the 10 One Planet Living Principles, which can be presented as follows (Corbey, 2005; Bio-Regional Development Group, 2011):

- **OPL1-Zero carbon (ZC)**
- **OPL2-Zero waste (ZW)**
- **OPL3-Sustainable transport (ST)**
- **OPL4-Local and sustainable materials (LSM)**
- **OPL5-Local and sustainable food (LSF)**
- **OPL6-Sustainable water use (SWU)**
- **OPL7-Natural habitats and wildlife (NHW)**
- **OPL8-Culture and heritage (CH)**
- **OPL9-Equity and fair trade (EFT)**
- **OPL10-Health and happiness (HH)**

Generally, two groups of green initiatives are documented and described into green

technologies (GT) and green strategies (GS) according to the 10 One Planet Living Principles, as shown in Table 1 and Table 2.

Table 1 Typical green technologies/systems in low carbon community

Code	Green technologies
GT_1	Exterior and interior Extruded Polystyrene (XPS) wall insulation technology
GT_2	Bio-fuelled combined heat and power; Heat recovery ventilator
GT_3	Radiant Thermal Slab
GT_4	Dynamic CO2 emissions monitoring and evaluation systems
GT_5	Vehicle sunshine deflector and fixed shading appliance
GT_6	Biogas micro digester for waste water treatment
GT_7	Green landscape design
GT_8	Green roof technology, e.g. sedum transformation of eco-roof
GT_9	Solar energy power generating system
GT_{10}	Efficient equipment and appliances for natural ventilation technology
GT_{11}	Use of environmental friendly materials for HVAC systems
GT_{12}	Deep Green Materials (recycled/ locally produced/ durable
GT_{13}	Wetland technology
GT_{14}	Integrative use of natural lighting with electric lighting technology
GT_{15}	Ample ventilation for pollutant and thermal control
GT_{16}	Waste management technology; Waste classification and recycling technologies
GT_{17}	Minimizing the construction disruption to living environment technology
GT_{18}	Aluminium Low-E energy-saving insulation window; Insulating glass blinds and double window
GT_{19}	Decentralized rainwater technology and water-saving appliances
GT_{20}	Ground source heat pump technology
GT_{21}	Gray water systems; Water reclamation and reuse projects;
GT_{22}	Prefabricated concrete technology
GT_{23}	Green technology monitor and maintenance system
GT_{24}	System for green facility management
GT_{25}	“Drop-in” residential heat pump water heater
GT_{26}	Radiant floor and electric radiant heating (gas) technology
GT_{27}	Voice-activated light perception technology
GT_{28}	Elevator shaft, Floor insulation technology
GT_{29}	Smart home technology
GT_{30}	Ecological data collection technology

(Note: GTs are mainly cited from BedZED, 2003; zHome, 2011; Qiu,2010; GRHCC, 2003; U.S Department of Energy, 2009; Doherty et al., 2004; UNEP, 2003; Noguchi, 2003)

Table 2 Typical green strategies in low carbon community

Code	Green strategies
GS_1	Increase energy efficiency
GS_2	Encourage sustainable design
GS_3	Energy-efficient urban transport (TOD / BRT)
GS_4	Energy-efficient freight transport / logistical
GS_5	Alternative transport fuels (Biofuel/ Electric)
GS_6	Street and Outdoor LED Lighting
GS_7	Energy-Saving Windows Programs
GS_8	Cooperative Energy Efficiency Design for Sustainability
GS_9	Encourage re-use, recycling and composting thus generating energy
GS_{10}	Invest in transport systems and infrastructure that reduce dependence on fossil fuel use
GS_{11}	Reduce the energy consumption for tap water production
GS_{12}	Raise the ratio of non-tap water usage
GS_{13}	Using equipment and furniture that needs less resource consumption and results in less environmental impact
GS_{14}	Encouraging residents to choose means for carbon-balance and for curtailing carbon-sink
GS_{15}	Preserving and remediating the natural environment
GS_{16}	Utilizing traditional assets, cultural assets and local resources
GS_{17}	Facilitate participation and encourage green lifestyle
GS_{18}	Alternative transportation to improve opportunities to utilize public transit
GS_{19}	Reduce urban heat island impact
GS_{20}	Provide increased shade for parking lots, pedestrian paths, building entrances and windows
GS_{21}	Incorporate energy-efficient design into the site layout and building design
GS_{22}	Neutralize carbon emissions from unavoidable travel
GS_{23}	Use local, reclaimed, renewable and recycled materials if possible
GS_{24}	Support local and low impact food production
GS_{25}	Promote low-impact packaging, processing and disposal
GS_{26}	Implement water use efficiency measures, re-use and recycling;
GS_{27}	Protect or regenerate existing natural environments and the habitats
GS_{28}	Celebrate and revive cultural heritage and the sense of local and regional identity
GS_{29}	Promote healthy lifestyles and physical, mental & spiritual well-being
GS_{30}	Less harmful chemical products for construction and maintenance of the building
GS_{31}	Offer homeowners with heavily subsidized loft and cavity wall insulation
GS_{32}	Improving energy-efficiency of housing stock
GS_{33}	Pursuing large-scale renewable power generation
GS_{34}	Supporting carbon sequestration
GS_{35}	Carbon pricing for transport
GS_{36}	Developing non-motorized and human-oriented transportation system and road design
GS_{37}	Providing bespoke energy audits and project management of installation of energy efficiency improvements

(Note: GSs are mainly cited from APEC Energy Working Group, 2011; WWF, 2006; Greater

London Authority, 2007; CRECC & CEREA working paper, 2010; Kim, 2009; Long Range Planning, 2008)

Case study

In China, a dramatic shift toward scalable low carbon provincial and urban development has been occurring in the rapid urbanization process. This can be evidenced by the long and sustaining governmental policy efforts in the past 8 years. By 2010, 27 low carbon pilot cities/towns/communities have been introduced in China. There are generally four types of low carbon community initiatives which have been promoted by Chinese government (Ye, 2011): National Low‐carbon Ecological Demonstration City, National Experimental Low‐carbon City, National Comprehensive Supporting Reform Trial Areas to Build a "Two‐oriented Society" and the International Cooperative Low‐carbon Eco‐community.

In line with these demonstration projects, the Chinese government has promulgated a series of policies as well as document to promote low carbon communities. By initiating the Green Eco-housing Sample Projects Program since 2002, 23 eco-housing sample projects were established in 20 cities across 14 provinces in 2007, (Nie 2007; Zhang *et al*., 2011b). These sample projects have embodied various green features such as solar energy application and prefabrication concrete technology. China's NDRC introduced its low carbon pilot provinces and cities program in 2010. Considering these statistics, it can be clearly seen that low carbon practices have received positive effects. According to the results by Asian Development Bank,

Chinese cities have maintained good growth momentum in the livability index in recent years. Beijing, Guangzhou, Shanghai and Lanzhou saw a growth of over 15% from 2000 to 2007 (China Daily, 2010).

Case studies can be used for explorative, descriptive, explanatory or illustrative research (Yin, 1993). In China, low carbon community practices can be illustrated and described into different types depending on the project objectives, different green technologies and green strategies used and the specific obstacles encountered in the implementation process. Currently, 'low carbon' has become the critics of debate due to its rather empty and conceptual 'wording'. In order to combat the misunderstanding, green technologies and green strategies are considered as effective approaches to bridge the gap between 'conceptual idea' and 'low carbon community practices'. Among those example projects, two cases are selected, as shown in Table 3, which briefly summarizes the profiles of the two cases (namely, Case 1 and Case 2) selected for the study. Case 1 is selected as it is initiated and driven by government (public sector), which reflects governments' strong determination in combating climate change, saving resources and energy. While Case 2 is selected as it is developed by commercial real estate developers (private sector), which demonstrate their social responsibility to improving community environment.

The findings from the case study are constructed based on the content analysis on relevant technical report and feasibility report, interviews and discussions with professionals and managerial staff undertaking the referenced projects. In the course

of interviews, a number of questions are designed as follows:

- What are the objectives to be achieved in each of the green technologies?
- What are the practical operations conducted in each of the green strategies?
- In order to meet the ten One Planet Living Principles, what specific green elements are adopted to help achieve the goal?
- What are the major constraints for applying green elements in the low carbon communities?

Table 3 A summary of the profiles of cases under study

Project	Project description	Type	Location
Case 1: Sino-Singapore Tianjin Eco city (Phase I)	This low carbon community covers total construction area of 4 square kilometre, started from July 2007, and was finished on 2010.	New low carbon community development which is based on international Cooperative scheme	Tianjin
Case 2: Vanke Four season Garden Community	This project is a residential building with a total construction area of 126000 m^2, started from June 1, 2005, and was finished on October 2, 2009.	New low carbon residential community which is developed by real estate developers	Shenzhen

Findings

This section analyses the major findings revealed by the case studies. First, the identification on green technologies and green strategies from the case studies is conducted, followed by the comparison on the major green technologies and green strategies applied in the two case studies through content analysis and several face to face interview discussions. The ten One Planet Living Principles is used as the 'yardstick' to measure whether or to what extent these green elements have achieved

the low carbon goal.

(1) Case 1: New low carbon community development which is based on international Cooperative scheme

The 30 square kilometre Tianjin Eco-City is to serve as an experiment model as low carbon communities for Chinese cities. By engaging several interview discussions with some of their managerial staff and investigating the feasibility reports of Tianjin Eco-city, the application of green technologies and green strategies are summarized in the appendix 1 and appendix 2.

(2) Case 2: New low carbon residential community which is developed by real estate developers

Since 2000s, a lot of low carbon communities have been developed by real estate developers in many cities in China. The case of Vanke Four season Garden in Shenzhen is selected in this study. The residential communities are characterized with many green technologies and green strategies, which act as the early low carbon experiment field in China. By engaging a series of interview discussions with their managerial staff and investigating the feasibility reports, the application of green technologies and green strategies are summarized in the appendix 3 and appendix 4.

It is important to note that both of the two Cases' focus includes important areas critical for the future of Chinese low carbon communities: energy, transport, waste management and water management sectors. These initiatives and measures illustrate how Chinese low carbon communities are focusing on these areas for the immediate

future. By corresponding to Table 4, the following sections provide each of these findings by comparing the two cases in this study.

Table 4 Comparison on the case studies

Case1 / Case2		I (Number of obs.=0)		II (1<=Number of obs.<=3)		III (Number of obs. >=4)	
I (Number of obs.=0)	GT	LSF-Energy, SWU-Energy, EFT-Energy, SWU-Transport, EFT-Transport, EFT-Waste, LSF-Water, EFT-Water	CH-Energy, ZW-Transport, CH-Transport, CH-Waste, LSM-Water, CH-Water				
	GS		ST-Energy, ST-Waste, ZW-Water, ST-Water		LSF-Transport, LSF-Waste, SWU-Waste		
II (1<=Number of obs.<=3)	GT			NHW-Energy, ZC-Transport, ZW-Transport, ST-Transport, ZC-Waste, HH-Water	ST-Energy, LSF-Transport, HH-Transport, ST-Waste, LSF-Waste, SWU-Waste, ZW-Water, ST-Water	NHW-Waste	LSM-Energy, HH-Energy, LSM-Waste, ZC-Water

	GS				ZW-Energy, LSM-Energy, CH-Energy, HH-Energy, LSM-Transport, NHW-Transport, CH-Transport, HH-Transport, ZW-Waste, LSM-Waste, CH-Waste, ZC-Water, LSM-Water, SWU-Water, CH-Water		HH-Energy, NHW-Water
III (Number of obs. >=4)	GT					ZC-Energy, HH-Waste	ZW-Energy, NHW-Transport, ZW-Waste, SWU-Water, NHW-Water
	GS						

Note: CH: Culture and heritage; EFT: Equity and fair trade; HH: Health and happiness; LSF: Local and sustainable food; LSM: Local and sustainable materials; NHW: Natural habitats and wildlife; ST: Sustainable transport; SWU: Sustainable water use; ZC: Zero Carbon; ZW: Zero waste.

OPL Principles

In Table 4, it can be summarized from regions I-I and II-I that there are 'no action' undertaken to achieve the principles of 'local and sustainable food', 'sustainable water use', 'equity and fair trade' in the two cases. Though there are a few actions that have been undertaken in the waste management sector in achieving the principles of 'local and sustainable food' and 'sustainable water use' in Case 1, the outcomes are still not satisfactory. It is also noted that 'no action' has been taken in meeting the principle of 'sustainable transport' in the energy sector and waste management sector. Meanwhile, it can be seen from III-III region that many GTs and GSs have been implemented in

meeting the principle of ‘zero carbon’ in the energy sectors of the two cases. This can be evidenced and echoed by the recent large-scale low carbon initiatives in many Chinese cities. Similarly, in region III-III, GTs and GSs are adopted to achieve the principle of ‘natural habitats and wildlife principle’ in both ‘transport’ sector and ‘water management’ sector. It can be summarized that the ten OPL principles are not fully considered and comprehensively implemented, which is due to various constraints.

Green technology vs. green strategies

It can also be concluded from regions III-II and III-III in Table 4 that green strategies are not as valued as green technologies in the current stage of low carbon communities. For example, Zero carbon principle have been implemented by adopting many green technologies in case 1 and 2, while Sustainable transport principle remains ‘no action’ in the sector of green strategies, as shown in Table 4. It is obvious that green technologies are more than ever focused after a long period of development in China. It is due to the effective and proactive application of ‘green strategies’, low carbon community remains as a skin-deep ‘hype concept’ for real estate developers rather than an integration system that involves energy, transport, waste and water management. It is also believed that better green strategies can make sure that green technologies are better promoted to a large scale in China.

Four Sectors

It is worth noting that no GT/GSs have been adopted in the sectors of ‘energy sector’, ‘transport sector’ and ‘waste management sector’ when implementing the principles

of ‘local and sustainable food’, ‘sustainable water use’, ‘culture and heritage’ and ‘equity and fair trade’. Similarly, no actions were taken in ‘water management’ sector when it was performed the principles of ‘local and sustainable food’, ‘culture and heritage’ and ‘equity and fair trade’.

Sustainable transport is generally considered as one of the most effective low carbon approaches according to the global guideline. However, in the two cases, no ‘green strategies’ actions were undertaken in both energy and waste management sectors, though a number of ‘green technologies’ have been implemented. As it is identified in III-III region, there are very few GTs and GSs that are applied in the transport, waste management and water management sectors in achieving the principle of ‘Zero carbon’. In particular, it is very significant to reduce carbon emissions in the transport sector, while in reality these sectors are not well recognized. It is therefore noted that many OPL principles that are directly relevant to each of the four sectors have not received due attention and there is also lack of a clear and harmonious inter-sector working mechanism in coordination and cooperation.

Discussion

As it can be indicated from Table 4, I, II, and III regions are classified depending on the number of green technologies and green strategies that have been adopted. Studied both horizontally and vertically, Cases 1 and 2 both have demonstrated different distributions on their GTs as well as GSs in different regions. Generally speaking,

there are many empty sectors in I-I region (GT and GS are both zero), for example, Local and sustainable food -Energy, Sustainable water use -Energy, Culture and heritage -Energy, Equity and fair trade -Energy, which indicates that some of the ten OPL principles are not implemented in the energy sector for both Case 1 and 2. These areas are considered to be further improved in the future. Meanwhile, II-II region has demonstrated a good number of GT/GSs, showing that relevant sectors have started to take actions in these areas, but still they are not satisfactory. It is worth noting that III-III region has shown several GT/GSs that have been focused area, for example, Zero carbon -Energy, Health and happiness -Waste, indicating that 'zero carbon' and 'Health and happiness' principles are implemented by adopting several GT/GSs in the two cases in practice. Compared with Cases 1 and 2, it can be found that Case 1 did much better than Case 2 in the III-III region, which demonstrates that comprehensive low carbon community is more advanced in providing showcases of GT/GSs than that of developer led communities.

There are also several constraints that may hinder the low carbon community development. It can be concluded from the case studies that there are a list of constraints in government policy, public behavior and private real estate developers' cost-benefit sectors that hinder the application of GT/GSs, which can be shown as follows:

- Government policy sector

  According to the cases surveyed, green technologies have been adopted to a large

extent while green strategies are limited due to many reasons. Currently, there is a lack of government legislation and tax regulations to adopt low carbon energy and materials compulsively. In this context, many organizations fail to initiate low carbon communities. In fact, many high-carbon technologies are also linked to broader systems of supporting knowledge structures, supply chains, commercial interests and conventions (Guy and Shove, 2000), which becomes the fatal constraints for the low carbon community development in China.

- Public behavior sector

The public attitude and behavior is very important in implementing low carbon communities. In order to investigate the cognitive and behavior of residents in the low carbon community, a short questionnaire survey is conducted in the context of two case projects. Respondents to survey were asked to report how they were aware of low carbon practices. It is not surprising that almost half of the sample (46.5%) indicated that they ‘just heard of the concept but do not know any details’. Only 18% of the sample indicated their strong intention as well as actions and have attempted to behave in a low carbon way. Take the waste classification as an example; it is impossible for them to take any actions if the public do not know the classification between those harmful waste and recycled type. It is therefore noted that there is urgent necessity to educate the public to raise their awareness of low carbon concept.

- Private real estate developers’ cost-benefit sector

In the practical implementation of low carbon community, the cost-benefit issue has become the top concern for real estate developers. High cost for green technologies is

considered as the biggest constraint for implementing low carbon communities in the cases particularly in China. Many real estate developers are in pursuit of maximizing short-term economic interests. While the development cycle of the low carbon community is relatively long, which also requires more upfront cost but relatively slow investment recovery, therefore, the developers would choose commercial residential community rather than low carbon communities. This is also echoed with the findings from Global Green Building Trends study, released in 2008, reports that of the over 700 construction professionals who responded to the survey, 80% cited “higher first costs” as an obstacle to green building (Kats, 2010; Zhang et al., 2011). In addition, many real estate developers do not pay to be really ‘green’. Some of the developers attach the label of ‘ecological/ green /low carbon community’ but in essence it is used to cater to buyers who value the quality of living environment. However, these residential communities are often staying in the sectors of green buildings, landscape or green technologies, which can not be efficient to reduce carbon emissions.

It can be noted that low-carbon community projects that are focusing on local developmental effects faced higher constraints than traditional property projects. The high cost of green technologies is perceived to have high risk of investment return for those local investors and local real estate developers. In this context, it is highly recommended that local governments play the roles of both project implementer and facilitator for low carbon community project. Besides, the OPL principles have

provided a guideline for government, private sectors, and the public to implement green technologies and green strategies proactively.

Recommendations for improving low carbon communities

The findings and discussions above have revealed many constraints for low carbon communities in China. It is therefore significant to find out useful recommendations for policy makers in combating with these problems. By summarizing from case studies, a few suggestions are recommended as follows:

- Governance

It is suggested that governance plays key role in building low carbon communities, which may transcend the traditional way of urban community planning and construction. Incentive policies and proactive supporting financial strategies for low carbon community and behavioural lifestyle changes among local residents should be promoted. As a developing country, the level of public participation is low in China. Building low carbon communities is also an opportunity for improving the awareness of public participation. The public participation should be started at the beginning of the community planning and throughout the implementation process. In this context, the efficient application of GT/GSs can be maintained by involving energy, transport, waste management and water management sectors overall. Moreover, green technologies should be guided by effective and efficient green strategies in promoting low carbon communities. In the process, in order to more effectively improve

governance in terms of low carbon community's construction, it is rather significant to strengthen the public and private partnership.

- Implementation of OPL Principles

The implementation of the ten OPL principles should be comprehensive and all-round. Whilst it can be summarized from cases that the principles of 'sustainable water use', 'natural habitats and wildlife' and 'equity and fair trade' are not well considered, which may not fully achieve the low carbon community goal. Take water resources management as an example, the lack of water resources in china lie in its quality rather than quantity. The Cyanobacteria event in Taihu Lake made the city of Wuxi out of water supply for a long time, which indicates that the water management should be systematically considered to achieve zero carbon emissions rather than neglect one of the aspects. In this context, it is high necessary to increase water price gradually as well as tax all effluent discharges. Even there is a frequent worry about carbon taxes that they will hurt business and the economy, it might be an appropriate to push the low carbon community to the right track for many developing countries such as China.

- Effective and efficient use of green technologies and green strategies

In order to promote the low carbon communities to a large scale, it is considered cost efficient to lower the cost of green technologies by applying different green strategies. For example, in the transport sector, it is highly recommended that TOD strategy

should be proactively promoted in the low carbon communities in China. TOD community has many designed centers, fusion boundary; multiple types of residential function buildings (parks, plazas and municipal buildings) within the community which can satisfy mixed functional use. The network-like road system and interconnected pedestrian street can avoid traffic congestion and at the same time encourage the needs for walk, which can reduce carbon emissions to a large extent.

On the other hand, in order to achieve the efficient implementation of green strategies, a technical team including senior managers, planning, engineering and technical sector, financial and facilities management sector should be coordinated to develop the institutionalised framework to promote GT/GSs to make sure that they are implemented from the very initial stage. In the developing countries, such as China, it is important to implement appropriate GT/GSs that can fit into local conditions. In this way, the low carbon communities can be efficiently implemented to maximize the social, economic and environmental benefits.

Conclusion

Global climate change has greatly affected human living environment, while China's carbon emissions is ranked second in the world. In this regard, low carbon communities in China are of great significance to the world due to its rapid urbanization, which may continue until the next 20 years. This study identified the commonly referred green technologies and green strategies applied in the low carbon

communities, followed by the comparison of the two case studies. It is concluded that the ten OPL principles are not comprehensively implemented, and there is also lack of a clear and harmonious inter-sector working mechanism between energy, transport, waste and water management sectors. In particular, the principles of ‘sustainable water use’, ‘natural habitats and wildlife’ and ‘equity and fair trade’ are not well implemented, which may affect the achievement of low carbon community goal. Comparing the four sectors investigated from case studies, many green technologies as well as green strategies in the energy and transport sectors have been implemented, while the waste management and water management sectors are not given sufficient emphasis, which needs further improvement in the future. The findings from the case studies also demonstrate that green strategies are not as valued as green technologies in the current stage of low carbon communities. After the new millennium, the dissemination of technology becomes faster, green technologies have taken their initiatives in some of the low-carbon communities in China, however, green strategies is highly recommended to guide the use of green technologies, which may greatly improve the future low-carbon communities.

The implementation of green technologies and green strategies for the low carbon communities have to combat with various constraints which conventional communities do not, such as ‘government’s lack of relevant supporting measures to promote low carbon strategies’, ‘behavior change from the public’, ‘developers’ seeking for short-term profits and using “low carbon” as their speculation means’ and

‘high cost of green technologies as well as green strategies’.

Consequentially, suggestions are recommended which may help improve the implementation of green technologies and green strategies in low carbon community. The suggestions from the aspects of governance, OPL Principles and efficient and effective use of green technologies and green strategies, provide references for achieving the low carbon communities in China.

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Appendix 1 The application of green technologies for Case 1

OPL	Energy sector	Transport sector	Waste sector	Water sector
Zero carbon	GT_1, GT_2, GT_8, GT_9, GT_{10}, GT_{11}, GT_{12}, GT_{14}, GT_{20}, GT_{24}, GT_{25}, GT_{26}, GT_{27}, GT_{28}, GT_{29},	GT_{23}, GT_{24},	GT_4, GT_{10}, GT_{11},GT_{12}, GT_{16}, GT_{18}, GT_{23}, GT_{24}, GT_{29},	GT_9, GT_{23}, GT_{24}, GT_{29},
Zero waste	GT_2, GT_{11}, GT_{12}, GT_{23}, GT_{24}, GT_{25}, GT_{26}, GT_{28},	GT_{17}, GT_{23}, GT_{24},	GT_6, GT_{11}, GT_{12}, GT_{15}, GT_{16}, GT_{17}, GT_{23}, GT_{24},	GT_6,GT_{17}, GT_{24},
Sustainable transport	GT_{23}, GT_{24},	GT_{23}, GT_{24},	GT_{23}, GT_{24},	GT_{23}
Local and sustainable materials	GT_1, GT_3, GT_{11}, GT_{12},	N.A.	GT_{11}, GT_{12}, GT_{22}, GT_{23}, GT_{24},	N.A.
Local and sustainable food	N.A.	GT_{23}, GT_{24},	GT_{23}, GT_{24},	N.A.
Sustainable water use	N.A.		GT_6,	GT_6, GT_{19}, GT_{21}, GT_{23}, GT_{29},
Natural habitats and wildlife	GT_7, GT_{23},	GT_7, GT_{13}, GT_{23}, GT_{30}	GT_7, GT_{13}, GT_{23}, GT_{30}	GT_7, GT_{13}, GT_{23}, GT_{30}
Culture and heritage	N.A.	N.A.	N.A.	N.A.
Equity and fair trade	N.A.	N.A.	N.A.	N.A.
Health and happiness	GT_{10}, GT_{11}, GT_{12}, GT_{14}, GT_{26}, GT_{29},	GT_{23},	GT_{10}, GT_{11}, GT_{12}, GT_{15}, GT_{17}, GT_{23}, GT_{29},	GT_{17}, GT_{23}, GT_{29},

Appendix 2 The application of green strategies for Case 1

OPL	Energy sector	Transport sector	Waste sector	Water sector
Zero carbon	GS_1, GS_3, GS_4, GS_5, GS_6, GS_7, GS_8, GS_{17}, GS_{19}, GS_{21},	GS_2, GS_3, GS_4, GS_5, GS_{10}, GS_{17}, GS_{18},GS_{20}, GS_{23}, GS_{35},	GS_2, GS_9, GS_{17}, GS_{23}	GS_2, GS_{17}, GS_{26},
Zero waste	GS_1, GS_8, GS_{21},	GS_{10}, GS_{35},	GS_2, GS_9, GS_{13},	
Sustainable transport	N,A.	GS_2, GS_{18}, GS_{35},		
Local and sustainable materials	GS_2, GS_{16},	GS_{16}, GS_{23}	GS_2, GS_{16},	GS_2, GS_{16},
Local and sustainable food		GS_2,	GS_2, GS_{23}	

Sustainable water use				GS_2, GS_{12}, GS_{26},
Natural habitats and wildlife	GS_{13},	GS_{15},	GS_{15},	GS_2, GS_{15}, GS_{26}, GS_{27},
Culture and heritage	GS_{16}, GS_{28},	GS_{16}, GS_{28},	GS_{16}, GS_{28},	GS_{16}, GS_{28},
Equity and fair trade				
Health and happiness	GS_2, GS_{17}, GS_{29},	GS_2,GS_{17}, GS_{20}, GS_{29}, GS_{36},	GS_2,GS_{17}, GS_{29}, GS_{30},	GS_2,GS_{17}, GS_{29},

Appendix 3 The application of green technologies for Case 2

OPL	Energy sector	Transport sector	Waste sector	Water sector
Zero carbon	GT_1, GT_2, GT_9, GT_{12}, GT_{14}, GT_{24}, GT_{27}, GT_{28}, GT_{29},	GT_{23}, GT_{24}, GT_{10}	GT_{10}, GT_{12}, GT_{16}, GT_{18}, GT_{23}, GT_{24}, GT_{29},	GT_3, GT_9, GT_{23}, GT_{24}, GT_{29},
Zero waste	GT_2, GT_{12}, GT_{23}, GT_{24}, GT_{28},	GT_{17}, GT_{23}, GT_{24},	GT_6, GT_{12}, GT_{15}, GT_{16}, GT_{17}, GT_{23}, GT_{24},	GT_6, GT_{17}, GT_{24},
Sustainable transport	GT_{23}, GT_{24},	GT_{23}, GT_{24},	GT_{23}, GT_{24},	GT_{23},
Local and sustainable materials	GT_1, GT_{12},		GT_{12}, GT_{22}, GT_{23}, GT_{24},	
Local and sustainable food	N.A.	GT_{23}, GT_{24},	GT_{23}, GT_{24},	N.A.
Sustainable water use	N.A.	N.A.	GT_6,	GT_6,GT_{19}, GT_{21},GT_{23}, GT_{29},
Natural habitats and wildlife	GT_7, GT_{23},	GT_7, GT_{13}, GT_{23}, GT_{30}	GT_7, GT_{13}, GT_{23}, GT_{30}	GT_7,GT_{13}, GT_{23}, GT_{30}
Culture and heritage	N.A.	N.A.	N.A.	N.A.
Equity and fair trade	N.A.	N.A.	N.A.	N.A.
Health and happiness	GT_{12}, GT_{14}, GT_{29},	GT_{23}, GT_{10}	GT_{10}, GT_{12}, GT_{15}, GT_{17}, GT_{23}, GT_{29},	GT_{17}, GT_{23}, GT_{29},

Appendix 4 The application of green strategies for Case 2

OPL	Energy sector	Transport sector	Waste sector	Water sector
Zero carbon	GS_1, GS_7, GS_{17}, GS_{19}, GS_{21}	GS_{17}, GS_{20}, GS_{35}, GS_{23}	GS_9, GS_{17}, GS_{23}	GS_{17}, GS_{26}
Zero waste	GS_1, GS_{21}	GS_{35}	GS_9, GS_{13}	N.A.
Sustainable transport	N.A.	GS_{35},	N.A.	N.A.
Local and sustainable materials	GS_{16},	GS_{16}, GS_{23}	GS_{16}, GS_{23}	GS_{16},
Local and sustainable food	N.A.	N.A.	N.A.	N.A.
Sustainable water use	N.A.	N.A.	N.A.	GS_{12}, GS_{26},
Natural habitats and wildlife	GS_{13}	GS_{15}	GS_{15},	GS_{15}, GS_{26}, GS_{27}
Culture and heritage	GS_{16}	GS_{16}	GS_{16}, GS_{28},	GS_{16}, GS_{28}
Equity and fair trade	N.A.	N.A.	N.A.	N.A.
Health and happiness	GS_{17}, GS_{29}	GS_{17}, GS_{20}, GS_{29}	GS_2, GS_{17}, GS_{29}, GS_{30}	GS_{17}, GS_{29}